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A. B. WOOD, O.B.E., D.Sc.

Vol. 20 ★ JULY, 1965 ★ No. 4

MEMORIAL NUMBER

THE A. B. WOOD MEMORIAL FUND

An Invitation from the Appeal Committee

This July 1965 issue of the Journal of the Royal Naval Scientific Service which appears on the first anniversary of his death is dedicated to the memory of Dr. Albert B. Wood, who was the archetype of the Naval Scientist of today. In this Memorial are recorded many aspects of his distinguished career in Naval Science over a period of nearly 50 years.

Many of his colleagues, on both sides of the Atlantic, consider that some further memorial to Dr. Wood should now be established. It has therefore been decided to open a special fund for this purpose, and an Appeal Committee under the Chairmanship of the Chief of the Royal Naval Scientific Service, Dr. R. H. Purcell, has been set up with members from Canada and the U.S.A.

It is envisaged that the Memorial might take the form, for example, of a Memorial Lecture to be delivered, alternately, in the U.K. and North America; but the final choice will, of course, be determined by the response to the Appeal Fund.

The purpose of this present leaflet is to invite contributions to the A. B. WOOD MEMORIAL FUND. The appeal is addressed to all former colleagues of A. B. Wood, to the younger scientists whose work today may to some extent have derived from the pioneer work of Wood and his contemporaries, and indeed to all scientists and engineers who are concerned with Naval Science.

Contributions should be sent as follows:—

CANADA to—

D. A. Keys, D.Sc., Ph.D., F.R.S.C.,
Scientific Adviser to the President,
Atomic Energy of Canada Ltd.,
Chalk River, Ontario.

U.K. to—

R. H. Purcell, C.B., Ph.D.,
Chief of the Royal Naval Scientific Service,
Ministry of Defence, Main Building, Whitehall, S.W.1.

U.S.A. to—

George W. Wood, M.S.,
Associate Editor of the Journal of the Acoustical Society of America,
2813 Woodley Road, N.W., Washington, D.C.

Cheques should be made payable to the A. B. Wood Memorial Fund.

Journal of the Royal Naval Scientific Service

Vol. 20 **JULY, 1965** **No. 4**

ALBERT BEAUMONT WOOD, O.B.E., D.Sc.
MEMORIAL NUMBER

ALBERT BEAUMONT WOOD, O.B.E., D.Sc.
1890 - 1964

Foreword

This special issue of the Journal of the Royal Naval Scientific Service commemorates the life and work of Albert Beaumont Wood, O.B.E., D.Sc.

His career in Naval science covered a period of nearly fifty years, embracing two major wars, in both of which the survival of his country depended crucially upon the mobilization of the physical sciences to the many problems special to Naval operations.

He was involved in Naval science, not only over a long period of time, but also over a variety of disciplines, frequently as an originator of concepts, which he and his colleagues carried forward to the point where the value of their widespread application could be clearly seen. In brief, he was the archetype of the Naval scientist of today.

Some idea of the nature of the man, and of his long and broad experience of the many processes involved in ensuring that science is applied effectively to Naval affairs, can be gained from this Memorial.

Chief Scientist, Royal Navy

Chief, Royal Naval Scientific Service

APPRECIATIONS BY FORMER COLLEAGUES

W. L. BORROWS

B.Sc., D.I.C., R.N.S.S.

SUPERINTENDENT, ADMIRALTY RESEARCH LABORATORY

DR. ALBERT BEAUMONT WOOD died suddenly on 19th July, 1964, whilst on holiday and, with his passing, an era in Naval Scientific Research came to an end. Born at Uppermill in the West Riding of Yorkshire in 1890, A. B. Wood received his education at Huddersfield Technical College and at Manchester University where he graduated with 1st class honours in Physics in 1912. Staying on at the University he joined Sir Ernest (later Lord) Rutherford's team of exceptionally brilliant scientists carrying out research in atomic physics. Amongst his colleagues were H. G. J. Moseley, C. G. Darwin, Hans Geiger, Niels Bohr, Ernest Marsden, J. Chadwick, E. N. da C. Andrade, Fritz Paneth, G. von Hevesy and others whose names are now household words. Two years afterwards in 1914 he was appointed Oliver Lodge Research Fellow at the University of Liverpool, later becoming University Lecturer in Physics, but throughout kept in close contact with Rutherford at Manchester.

All the omens predicted for A. B. Wood an academic career of high distinction but, like many young men of his time, he became dissatisfied with the apparent calm of the academic world when the nation was plunging deeper and deeper into war and in the summer of 1915 he asked Rutherford to sign papers recommending him for a commission in the Air Force. About this time, however, the Admiralty, seriously concerned about the German Naval threat, was forming the "Board of Invention and Research" under the presidency of Admiral of the Fleet Lord Fisher. Rutherford, whose laboratory was already carrying out experiments on underwater sound, suggested to A. B. Wood that his talents might more usefully be employed in this field than in the air and shortly afterwards "A.B." became one of the first two physicists to receive an official appointment to the Admiralty under the B.I.R. This event may properly be regarded as the birth of the R.N.S.S.

Of the trials, vicissitudes and successes which followed over the next 45 years and more, "A.B." has himself written in a series of articles published in *J.R.N.S.S.* In the first of these he apologises for making his account of the growth of science in the Admiralty something of an autobiography, but in fact the progress of research in underwater warfare was so linked with his own work that any history of one must be largely a biography of the other. It is interesting to reflect that when A. B. Wood joined the Admiralty, knowledge of underwater sound propagation consisted of little more than one series of velocity measurements in a Swiss lake and one on the propagation of explosion waves in the sea, whereas in the last few years of his life his shallow water sound propagation experiments—although marked by characteristic elegance and simplicity—required the services of an advanced electronic computer to analyse the results and confirm the theory.

Space does not permit the recording here of more than a few of his technical achievements, and any selection must be a matter of personal choice, but mention must be made of his very accurate measurements of sound velocity in sea water, the development of the first cathode ray oscillograph for recording underwater explosion pressure-time curves, a directional hydrophone and the magnetostriction echo depth recorder. The original model of the latter is still in good working order to-day. Its accuracy was clearly demonstrated during the original proving trials in the Clyde. "A.B." was in the cabin of the trials boat watching the depth recorder and thought it advisable to warn the coxswain that he was getting very short of water under the keel. The coxswain assured him that there was at least another 200 yards to go before there was any need to worry—and at that moment the boat gently ran aground !

Dr. Wood served the Admiralty in many places and capacities: Aberdour, Parkeston Quay, Shandon, the Admiralty Research Laboratory, Teddington (on its formation in 1921 and later as Deputy Superintendent), H.M. Signal School, Portsmouth, H.M. Mining School (as Chief Scientist) and at R.N.S.S. Headquarters as Deputy Director of Physical Research. He formally retired from the Deputy Directorship in 1950 and immediately returned to Teddington to take up again his researches in underwater sound. He was always happiest when working in a laboratory and had returned to this country after a year at the U.S. Naval Electronics Laboratory, San Diego, only a very short time before his death.

He had many publications to his credit and his *Text Book of Sound,* first published in 1930, was and still is the standard work on the subject. He was awarded the D.Sc. degree of his University in 1919, became a Fellow of the Physical Society in 1920 and was a Founder Fellow of the Institute of Physics. In 1952 he was awarded the Duddell Medal of the Physical Society and in 1961 received the " Pioneer of Underwater Acoustics " award of the Acoustical Society of America. The latest addition to the fleet of research vessels operated by Marine Acoustical Services Inc. of Miami has been named the "A. B. Wood " in his honour. For his services to his country and in particular recognition of his part in dismantling the first German magnetic mine recovered in 1939, he was, the following year made an Officer of the Order of the British Empire.

Notwithstanding his remarkable achievements, he was a man of singular modesty and very great kindliness. He was always ready to help in any way he could and his younger colleagues in particular owe much to his wisdom, patience and inspiration. This did not mean that he could not be severe when he felt the situation demanded it. The story is told that on one occasion after reasoned argument had failed to convince a young man that certain rather extraordinary values the latter had obtained for the internal tension of water should not be explained by an equally extraordinary theory, "A.B." finally closed the discussion by saying: " Well, Mr. X, if you are right, then everyone who has ever measured the velocity of sound in water is wrong ! "

All who have known A. B. Wood have deemed it a great privilege and it has been a considerable honour for the Admiralty Research Laboratory to have had him on its staff so long and a matter of great regret that he has not lived that little longer to have completed 50 years in Naval Service.

His work was his life and he was sustained in it by the devoted support of his wife Ethel, born in his native village, whom he married in 1916. His work will survive and others will build on it; "A.B." would not have asked for more.

LAURENCE BATCHELDER

A.B., M.S.

RAYTHEON COMPANY, U.S.A.

To have known Dr. Wood even briefly is a privilege. My own association with him was particularly happy because of the glad circumstance that brought it about. In November 1961 he was awarded the Pioneer of Underwater Acoustics Medal by the Acoustical Society of America and it was my pleasant duty to make the presentation.

Our friendship began in England the previous June when I asked if I might call to discuss the plans for the award. I had feared he might think Cincinnati too far for him and Mrs. Wood to travel for just a medal. My request for an appointment was answered by a cordial invitation to my wife and me to lunch at Chamfer, in Hampton-on-Thames. My fear had been unfounded. There was no need of urging for the Woods were eager for the trip. They gave us a delightful meal and a cheerful visit in the garden.

The Woods came to Cincinnati where their warm and genial personalities won many friends at the Acoustical Society Meeting. Dr. Wood gave a formal talk about the history of asdics, and contributed actively and most usefully to the discussions of many current problems of underwater acoustics. As a climax, his delightful and gracious speech of acceptance of his award was a pleasure never to be forgotten.

Before flying back to England, the Woods made a series of visits in the United States and Canada, culminating with four days at our home in Cambridge, Massachusetts. These days included a drive to New London to see Dr. J. W. Horton, another to Woods Hole Oceanographic Institution, a luncheon with Dr. and Mrs. H. C. Hayes, and dinner with the Leo Beraneks and the F. V. Hunts. The untiring Woods withstood the unrelenting pace and left a trail of happy memories with their American friends, both old and new.

The next time I saw Dr. Wood was the occasion of another pleasant visit to Chamfer. I was there to ask if he would consider spending a year as Consultant at the U.S. Navy Electronics Laboratory in San Diego. This required considerable urging, not because he was hesitant to undertake a new venture in another country, but because he was reluctant to interrupt his research at Teddington. Eventually he accepted, much to the good fortune of the U.S.A. This happy and beneficial year was an ideal culmination of his creative and inspiring life.

Our last meeting was in London in June 1964, where my wife and I, returning from the Continent, spent one night before flying the Atlantic. As we lacked the time to go to Chamfer, the Woods came to meet us at our hotel. Our flight arrived so late that we almost missed them altogether, but before the last bus to Hampton-on-Thames we did have a few minutes of hurried conversation. They told us of their joy in San Diego, of the new boat in Miami to be named the *A. B. Wood*, of the friends they had left behind, and the welcome of their friends in England.

Then it was time to go. We said goodbye and watched them step out briskly, almost running, into the traffic and a drenching summer shower. Once safely across Oxford Street, and barely visible in the rain, Albert turned and waved farewell.

SIR FREDERICK BRUNDRETT

K.C.B., K.B.E., M.A.

CIVIL SERVICE COMMISSIONER

Although, of course, I knew Albert Wood by reputation as one of the best scientists in the Admiralty Scientific Pool, I did not actually meet him until I came up to the Admiralty to join S.R.E. Department in 1937. From then until I went to the Ministry of Defence in 1950, I saw a lot of him.

In his special field of underwater acoustics he had, of course, an international reputation but he was worth consulting and indeed was frequently consulted on many scientific problems. He was, too, an excellent leader of a scientific team and first class at bringing out the best in the young aspirant.

He was not at his best in an administrative capacity. I remember early in the war when he was Superintending Scientist at M.D.D. trying to help him by providing him with a first-class secretary, but this gesture can hardly be said to have been successful.

In a more civilised age, Albert would, of course, have been in the Special Merit class and we should have been able to reward him adequately without inflicting on him an unsuitable load, which prevented him doing the work at which he was so good.

One could not have met a nicer or more modest person. He had great personal courage as was evidenced by the part he played in dealing with the first German magnetic mine recovered on 23rd November 1939.

He served the Admiralty well and we who were associated with him will always be the better for having known him.

SIR EDWARD BULLARD

M.A., Sc.D., Ph.D., F.R.S.

FELLOW OF CHURCHILL COLLEGE, CAMBRIDGE

I first met A. B. Wood when I joined H.M.S. *Vernon* in November 1939 at the start of the work on degaussing and on the sweeping of magnetic and acoustic mines. During the eighteen months that I worked on these things I did not see a great deal of Wood since he was mainly concerned with the design of our own mines. When I did, it was always a pleasure; he was friendly, gentle, quietly humorous, delightfully intelligent and deeply knowledgeable about underwater warfare. He had foreseen so many things and done so much during and since the 1914-1918 war. He had devised an acoustic mine, was largely responsible for the design of our magnetic mine and had played a large part in the work on the magnetic field of ships during the 'thirties.

He and Butterworth seemed to me among the best physicists I had met and it surprised me to find that they were both so doubtful about their powers of influencing policy and getting their ideas effectively used. It is a real tragedy that the Navy made relatively ineffective use of their talents when they were at their most productive. It seemed to me that it was not only that money for the Navy was short between the wars, but that there was a real lack of appreciation of how to run an effective research and development organisation and how to keep scientists happy. I am sure that we really do know better now.

GEORGE E. R. DEACON

C.B.E., D.Sc., F.R.S.

DIRECTOR, NATIONAL INSTITUTE OF OCEANOGRAPHY

Dr. Wood's keen interest in the sea and his feeling for a systematic approach to scientific problems were a great help to the wave group set up in the Admiralty Research Laboratory in 1944. There was some urgency about the work which sought more precise understanding of variations in wave characteristics in relation to the wind, and of their effect on offshore submarine bars and beaches, as well as requiring instruments that would make forecasting and reconnaissance easier, but it was not easy to fit such new work into the already over-extended facilities and crowded accommodation of a war-time laboratory working at full stretch. Nor could quick results be promised. The groups of high and low waves and other readily observed variations in a complex wave pattern had long been attributed to interference between underlying component wave trains travelling with different velocities, but in devising rules for forecasting, the complex pattern had to be treated as if it could be represented adequately by a single dominant wavelength. No one had been bold enough to attempt a frequency analyses of a wave record, and although this seems an obvious thing to do it was quite a large undertaking at the time, and rather an act of faith.

The work had to be done in a cellar below the gun laboratory but it led upwards to the conception of the wave spectrum, and triggered off the revolutionary advances made in the study of waves during the past 20 years. The first frequency analyses of ship motion were made at the same time to see if ships could be used as wave-recorders, and they did much to stimulate the study of the motion of ships in complex wave patterns as well as the development of a shipborne wave recorder. Frequency analyses were also made of the ground movement at Kew. These led to the identification of microseismic oscillations with regions of sea-wave interference near the coast and in the open ocean, work which still has some practical possibilities as well as being an exciting example of interaction between atmosphere, ocean and the solid earth. One of the 24-hour records from Kew showed 125 signatures of flying bombs, and N. F. Barber, now Professor at Wellington, N.Z., was seen holding a long and highly-technical telephone conversation while sitting underneath his desk instead of at it.

There was other work on electric currents induced by the action of water in tidal streams and waves and the associated magnetic effects. Dr. Wood was always there to help and encourage: it was a very exciting time and he wrote enthusiastically about it in his series of articles in the *Journal*. He kept in touch with the subsequent work and was a frequent visitor at the National Institute of Oceanography. The last time I saw him was at the meetings of the International Association of Physical Oceanography held at Berkeley in 1963 in conjunction with a general assembly of the International Union of Geodesy and Geophysics. There he was really in his element. He knew most of the men who had pioneered such research and had worked with many of them. He was excited about the new discoveries and was able to add to many people's appreciation of them.

He was always a welcome visitor. There seemed to be no major or minor difficulty in which he could not give some help or encouragement. He was particularly kind to beginners and for this will be specially remembered.

SIR CHARLES F. GOODEVE

O.B.E., D.Sc., F.R.S.

DIRECTOR, BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The first few weeks of September, 1939, were rather an anti-climax after the "Munich" weeks a year before. On the occasion of the 1938 call-up of Naval Reserves, we, led by Dr. A. B. Wood, exhaustively discussed what would be the chain of events if war really came. Their Lordships' policy was quite clear: the almost unsweepable mine which the Mine Design Department had designed with such loving care over the years of peace would not be used until we had our counter-measures ready, except in dire necessity, for fear it fell in to the enemy's hands. This, of course, was because we as a sea power were much more vulnerable to mining than were the Germans. Sweep the unsweepable or at least develop counter-measures was the order.

The outbreak of war found the Navy's scientists with no answer. The years of frustration experienced by the small team engaged on counter-measures was hardly conducive to the solving of a problem of this magnitude. And in any case no one really knew what the problem would turn out to be. This situation led to criticism, unjustified as it turned out, by the Naval personnel and the setting up by the latter of their own organisations. This, together with the move of Mine Design Department away from H.M.S. *Vernon,* could have led to a difficult situation in those trying first weeks, but fortunately Wood's imperturbable personality and universal popularity prevented a deterioration.

The brilliant analysis by Wood and his assistants under very difficult conditions of the first magnetic mine found in late November at Southend restored completely everybody's confidence in the Mine Design Department. I will long remember the excitement of that night, when two of us from *Vernon* after waiting until past mid-night, heard Wood's report on his return to his home outside Portsmouth. The improbable had happened. The German magnetic mine was found to be actuated solely by the change in the vertical component and was simply a refinement of the mine the Royal Navy had laid in enemy waters at the end of the Kaiser war twenty-one years before!

Wood had measured precisely the critical firing magnetism, the time constants and the anti-sweeping characteristics. He had missed nothing. Gone was all the uncertainty about counter-measures. No longer had we to attempt the almost impossible. Schemes rejected before could now be brought out and the elaborate ones being worked on could go into the limbo.

Many hours and many cups of coffee and sandwiches produced by Mrs. Wood went their way before Wood's official written report was completed. Then followed an act of generosity, which I was to learn was typical of him, and one which led me into the thick of this technical battle. Wood invited me to take his report to the Admiralty on the first train that morning.

From then on I saw much of Wood. His technical knowledge was encyclopaedic and he became the technical centre around which all the many teams working on counter-measures revolved. His fertile imagination often produced key pieces to the jig-saw puzzles of the many technical developments which followed. For example, he pointed out that a floating cable carrying a current gave zero vertical magnetism on the sea bottom underneath and thus would not explode a mine in a position close enough to destroy the cable. This and his calculations of the optimum over-lapping of the fields of the two cables proposed in the rather impracticable scheme put forward by Professor Hague, led rapidly to the development of the double-L sweep.

To my regret after six months of working in close association with him, my move to other spheres meant that I saw less and less of A. B. Wood. I shall always remember him as a gentle person, unless provoked to anger, and one who was always ready to help the many people who came into association with him.

CURTIS R. HAUPT

M.A., Ph.D.

UNITED STATES NAVY ELECTRONICS LABORATORY

The Navy Electronics Laboratory appreciates the opportunity to add its contribution to those being written by other activities and individuals concerning the accomplishments of, and benefits derived from association with, Dr. A. B. Wood. Such comments are particularly appropriate for Dr. Wood spent most of the last year of his life at the U.S. Navy Electronics Laboratory in San Diego, California, as a consultant in underwater acoustics.

His activities while here encompassed a wide range of subject matter in underwater technology ranging from oceanographic considerations through the physical acoustics of the medium to the implications of such knowledge in guiding the design of equipment and systems for naval use. This wide spectrum of interest, taken together with the depth of his abilities and experience in finding solutions to difficult acoustic problems, made his stay at the Navy Electronics Laboratory a particularly fruitful one.

In these brief notes, it is impossible to describe the contributions made by Dr. Wood to many projects of the Laboratory. However, a few examples of his work while here can be mentioned. Dr. Wood's interest in modelling techniques is well known as is the fact that he has made some of his most outstanding contributions to the understanding of underwater acoustic phenomena through his brilliantly conceived and executed experiments using models. At NEL, Dr. Wood continued his active participation in underwater acoustic experiments employing models in a large tank. He was interested in the interpretation of echo structure and the possibilities for improved classification and recognition of targets. Measurements on pairs of simple targets rotated about the centrepoint of a connecting supporting rod were examined with careful interpretation of the echo patterns generated, as when one target partially shielded the other so as to modify the interference pattern. Other similar studies were in progress, and the Laboratory's potential for improved measurements was carefully evaluated in each case. Dr. Wood took an interest in the detection of the multiple echoes, such as those from an extended target or a rough bottom reflected path, and proposed more optimal processing for these echoes. He was very interested in a new project in hypersound and made many suggestions for other types of observations. In the field of ASW, much experimental work is necessary to investigate the acoustic properties of submarines and it is always difficult to schedule as much test time as needed with actual operating submarines. This is particularly true for the newest types. The decision of the Laboratory to build a model submarine was made during Dr. Wood's stay at the Laboratory and he provided invaluable help in design factors which would ensure that the model would be an accurate acoustical representation of the real submarine. He also assisted Laboratory scientists in planning a series of experiments to be carried out with the model, together with the necessary instrumentation and looked forward with keen anticipation to participating in early tests in which it would be used. Unfortunately, the model could not be completed in the Laboratory's shops before Dr. Wood departed so that this desire was not realized.

While in California, Dr. Wood graciously consented to give a series of illustrated lectures, some at the Laboratory and some before other audiences such as local chapters of the Acoustical Society. Because of Dr. Wood's pre-eminence in the field of acoustics, these lectures drew very large attendances. The presentations which were to a considerable degree autobiographical were divided into two principal periods, the first covering his earliest experiments and experiences in acoustics and extending through and beyond World War II. This lecture was in the more popular vein arranged to appeal to both technical and non-technical listeners. The second lecture, designed primarily for underwater acousticians, dealt with Dr. Wood's experiments in more recent years.

Both lectures proved to be highly stimulating. The generous use of anecdotes, many coloured with humorous episodes, and the introduction of his listeners to various personalities of world renown in science whom Dr. Wood had known intimately made these talks outstanding in their appeal and value to his audiences.

The Laboratory feels very fortunate in having had Dr. Wood as a member of its staff, not only for his technical contributions but also for the enrichment of the lives of its scientific personnel who had the privilege of associating with him.

DAVID A. KEYS

D.Sc., Ph.D., F.R.S.C.

SCIENTIFIC ADVISER TO THE PRESIDENT, ATOMIC ENERGY CONTROL BOARD, CANADA

It is a pleasure to be able to take part in a tribute to my old friend and one-time colleague, Dr. Albert B. Wood. I first met Wood when he came to Shandon in 1919 following the close of the antisubmarine work at Harwich. I was one of the Canadians whom Professor (late Sir John) McLennan gathered together when he joined the Board of Invention and Research of the Admiralty. I went up to Shandon on the Gareloch when that station was opened in late May, 1918 to test out a method of measuring time-pressure curves of explosions suggested by Sir J. J. Thomson, using a cathode ray to record on a photographic plate in a vacuum, the variation in charge produced by pressure on a piezoelectric crystal. By August 1919 preliminary results had been obtained using small charges of a few pounds of explosives. I had been offered a fellowship by Harvard and had to leave in early September and Albert Wood agreed to take over the experiment and carry it on to larger charges, the apparatus being placed on a trawler, *Robert Barton*, just before I left.

Dr. Wood not only improved the cathode ray tube but also the vacuum plate holder so that the vacuum did not need to be broken every time an exposure was made. He carried on the work to obtain records of a thousand pound explosion and sent me one or two photographs a few years later when he had fulfilled his promise and had developed the method to a successful conclusion.

Albert Wood was a devoted experimental scientist, modest and painstaking in all he did during the many years he remained with the Admiralty Research Division. His book, *A Textbook of Sound*, is a veritable source of theory and useful applications of sound to many problems in which he himself made outstanding contributions. In the few months at Shandon when we both worked there, he was occupied like Dr. Drysdale, Joseph Ford and others, on underwater type of detectors and acoustical methods of locating moving objects. He and Mrs. Wood lived in Helensburgh, if I remember correctly, so we didn't see as much of him as we did of the unmarried men who were moved to Shandon with the closing of the other stations. Several of the Canadians remained with the Admiralty, including C. S. Wright (later Sir Charles) and J. A. Craig.

During recent years we have seen more of Albert and Ethel Wood, due in part to both of us having passed the normal retiring age but still being occupied with our respective spheres of work, which took us to London for several months and brought them to visit us in Canada. I learned much about the various problems he had worked on and the important contributions he had made. His work has been recognized both in the United States and in the United Kingdom—perhaps more appreciated by his admirers in the former than by his colleagues in the latter. Both scientists and Government in the United States have paid him well deserved honours which his friends have greatly appreciated.

Both Albert Wood and the writer knew the late Lord Rutherford very well which often resulted in many reminiscences being discussed in our evening chats. Albert Wood had a good memory and both he and his devoted wife amused us with many interesting accounts of their early experiences before and during the First World War. We shall miss their congenial company and hospitality as I am sure those who knew him at the Admiralty Research Laboratory in Teddington will also. We retain many happy memories of this modest, able and devoted scientist who lived for his science, never seeking any reward for himself, and of his loving wife who took such pride in the good work her husband did.

ROBERT B. LINDSAY

M.Sc., Ph.D.

BROWN UNIVERSITY, U.S.A.

The high point in Dr. A. B. Wood's association with acoustics in the United States was probably the occasion of the award to him of the Pioneers of Underwater Acoustics Medal at the sixty-second meeting of the Acoustical Society of America in Cincinnati, Ohio on November 10, 1961. This award of the Society is " presented not oftener than once every two years to any individual, irrespective of nationality, age, or society affiliations, who has made an outstanding contribution to the science of underwater acoustics, as evidenced by publication of research results in professional journals or by other accomplishments in the field. The award was named in honor of five pioneers in the field: H. J. W. Fay, R. A. Fessenden, H. C. Hayes, G. W. Pierce and P. Langevin."

On the occasion in question the writer of this note had the privilege of presenting Dr. Wood for the award. The following account is taken largely from what was said at that time. Those present at the banquet at which the award was made had in their hands a rather substantial biographical sketch of the recipient by Dr. G. E. R. Deacon of the British National Institute of Oceanography. On that I felt I could not improve. Hence I concentrated attention on the impressions which Dr. Wood and his work had made on me personally over the years. One of these was his great contribution to education in acoustics through his book, *A Textbook of Sound*, first published in 1930. Many physicists had come to believe that there was no more physics in acoustics, and that in fact Lord Rayleigh in 1878 had more or less exhausted the subject, so far as fundamentals were concerned. Dr. Wood helped to dispel this illusion and showed clearly in his book that acoustics was and is a lively subject indeed. It is worth noting that the book has gone through three editions, the latest appearing in 1955. There has been a disposition in certain quarters to look down the nose at the writing of textbooks. This is an unfortunate and unreasonable attitude. When all is said, textbooks still have a vital rôle to play in the education of the young, who cannot be expected to learn physics in the first instance from the pages of the Physical Review or acoustics from the Journal of the Acoustical Society of America. Evidently, Dr. Wood agreed with this point of view, or he would not have written *A Textbook of Sound*. It is a clear and elegant presentation of the physical significance of acoustical concepts without letting the reader get lost in abstract analysis. At the same time its pages reflect the author's complete mastery of the details of the subject. It has helped many a student over the hump, and the world of acoustics owes a great debt to the author.

Any scientist who examines Dr. Wood's published papers cannot fail to be impressed by their variety and originality. This is particularly evident in those involving the design and development of acoustic instruments of high precison. Here Dr. Wood showed an uncanny ability to squeeze high accuracy out of methods that ordinary practitioners would be inclined to give up as impracticable. Take for instance his development of the humble tuning fork as a precision time standard and his pioneer work on magnetostriction oscillators for depth finding. Another and more striking example is to be found in the celebrated acoustic version of the Michelson-Morley experiment, in which the attempt was made to detect the change in frequency of a vibrating quartz rod, when rotating in a horizontal plane. According to pre-relativity physics, one would have expected a change as large as 5 parts in 10^9, which the experiment was designed to pick up easily. However, no change as great as 4 parts in 10^{11} was actually found, thus providing another experimental verification of the Einstein principle of special relativity. Too few people are aware of this fascinating connection between acoustics and one of the great principles of contemporary physics. In conclusion a more personal note may be in order. I, of course, knew Dr. Wood in a professional sense for a very long time, but it was only some 15 years ago that I had the privilege of getting acquainted with him personally and learning the charm of his personality. At that time he had just surrendered his administrative duties at the Admiralty and had returned to research work at the A.R.L. in Teddington. It was a delight to note the infectious enthusiasm with which he was taking up again studies in sound propagation. Unless my memory fails completely, the most conspicuous object in his laboratory then was a barrel of mud. Most people would hardly consider this as a promising prop for acoustics research, but if anyone could get good acoustics out of a barrel of mud, it would be A. B. Wood !

Dr. Wood was a delightful raconteur, and much enjoyed reminiscing about his experiences in the early days of underwater sound. It was a great source of satisfaction to me that I succeeded in persuading him to allow some of these recollections to appear in "Sound—Its Uses and Control," 1 (May-June, 1962) where they met with appreciative attention.

Dr. Wood's many friends in acoustical circles in the United States are happy to salute his memory.

SIR FRANK E. SMITH
G.C.B., G.B.E., D.Sc. F.R.S.

I first met Dr. Wood about fifty years ago when he was working with Professor William Bragg (later Sir William Bragg) at an Admiralty Station at Harwich for the detection of submarines by acoustical methods. It was, I estimate, some time in 1915-16 that Wood and Bragg came to the National Physical Laboratory, at the time I was in charge of Electrical Standards. I recall the impression I got of Wood; a charming personality, no superiority complex, indeed he was exceedingly modest, always ready to listen to others while giving his own ideas on a problem with some hesitation but a desire to help. So it was during his whole life time. At this "first time of meeting" I was attempting to produce a magnetic mine depending on the change of direction of the earth's horizontal magnetic field; one which would work irrespective of any countermeasures produced by a ship such as were effective with the German "Vertical Field" mine in the Second World War. I succeeded in doing so but the mine was a triumph of skill of the instrument maker and the petrol used to keep the system light contained many higher hydrocarbons which deposited on the electrical contact pieces and needed a cutting force to pierce them. However a number of German submarines were sunk and I received an award of £2,000 from the Admiralty. Wood and Bragg were interested but Wood was acoustically minded and electrical things did not interest him very much. When the war was over the work at Harwich and all physical research for the Admiralty was transferred to Shandon on the Gareloch where a large number of ships and naval personnel were housed. I was made the Director of Scientific Research and after some "unpleasant" as well as some pleasant experiences I concluded a scheme to "teach Naval Officers their job" was a mistake and I recommended the closure of Shandon and the transfer of all staff to a new research station at Teddington. In this were Wood, Dr. Drysdale, Sir Charles Wright and others and they were given plenty of liberty. Dr. Wood was the expert on all acoustic problems and the first acoustic tank was due to him. Echo sounding attracted him and his "phonic" chronometer — better known as the

" chronic " photometer—was a great achievement, and led to King George V becoming very intimate with echo sounding at sea. Wood's chronometer recorded thousandths of a second, it enabled the interval between the clapping of hands to start the clock and a similar clapping to stop it to be measured to a thousandth of a second. Wood made an echo sounder which recorded the time when a " sound " impulse left a ship and again when the " echo " from the ocean bed was received. Knowing the velocity of sound in sea water, the depth of the sea bed could be automatically recorded. Error at small depths were not more than one foot. H.M. King George V wished to attend a lecture at the Royal Society and I had the honour of giving it. I chose to " demonstrate " Wood's method of echo sounding by raising and lowering a large horizontal board over a high frequency source of sound and a spot of light moved over a scale and gave the depth direct. The King was enthusiastic and some days afterwards he asked to see me and tell him more. I can assure everyone I paid tribute to that charming but modest personality A. B. Wood. I am glad American societies studying acoustics have recognised Wood's genius.

JOHN G. D. OUVRY

D.S.O., Cdr., R.N. (Retd.)

It was my duty during the Second World War to take charge of the Enemy Mining Section of the Mining Department, H.M.S. *Vernon*, Portsmouth, and provide specimens of German and Italian underwater weapons for Dr. Wood (Mine Design Department) and his assistants to examine and to probe into their secrets. The Germans never failed to provide plenty of problems of this sort, and we were pleased to keep Dr. Wood busy.

We had a good start with the arrival of Hitler's first " Secret Weapon," the Magnetic Mine. On this occasion Dr. Wood arrived on the scene at Shoeburyness when we were stripping the weapon of its external fittings. After it had been conveyed to H.M.S. *Vernon* the following day a personal message was received from the First Lord of the Admiralty, Mr. Winston Churchill (as he then was), to state that investigation was to proceed without ceasing until the answer was produced. This Dr. Wood was able to give in detail within twelve hours of the reception of the mine in H.M.S. *Vernon*.

We, in H.M.S. *Vernon*, found Dr. Wood a most capable, charming and modest man and very easy to work with. He certainly rendered great service to his country and over a long period.

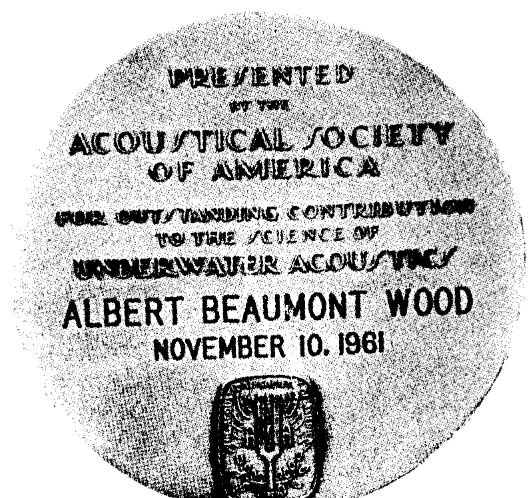
SIR CHARLES S. WRIGHT

K.C.B., O.B.E., M.C., M.A.

When I blew into the Admiralty—the day I was demobilised in January 1919—Wood was busy putting the finishing touches on his report on underwater rangefinding using a Cathode Ray timing system which used photo plates *inside* the C.R.O. But this was after all his activities at Parkeston Quay and other places during the first war. One could always rely on " A.B. " to contribute something quite new, whatever job he took on. I think the happiest and simplest contribution was the small boat minesweeping depth sounder for Hydrographer while I was at the Admiralty Research Laboratory. If my memory serves me properly, this was licked in about one month.

What will always stick in my memory is Churchill's meeting in the Admiralty (late at night, as usual) to receive the report by Ouvry and Wood on the recovery and opening of the first magnetic mine we recovered.

He was a great man, but very self effacing.


PRESENTED
BY THE
ACOUSTICAL SOCIETY
OF AMERICA
FOR OUTSTANDING CONTRIBUTION
TO THE SCIENCE OF
UNDERWATER ACOUSTICS
ALBERT BEAUMONT WOOD
NOVEMBER 10, 1961

FROM BOARD OF INVENTION AND RESEARCH TO RO

By A. B. Wood, O.B.E., D.Sc.

HAWKCRAIG, ABERDOUR, 1915-1917

Introduction

Having been invited by the Editor of *J.R.N.S.S.* to write an account, from personal recollections, of the growth of scientific research and development in the Navy, I have encountered considerable difficulty in deciding not only 'where to begin' but 'how to proceed' and 'where to stop.' It must be obvious to everyone, that almost any account by a single author cannot be expected to be a complete factual history. Such an account, even if attempted, would require several volumes to complete, covering as it does a period of 46 years, *i.e.*, from 1915 onwards.

In what I have to write I shall try to compromise between such a lengthy 'history' and a very brief and possibly rather uninteresting summary. So I wish to make it clear at the outset that this is not a history of science in the Navy, but merely an impression, almost an autobiography, based mainly on personal recollections and a few papers and diaries, of a somewhat reminiscent and superficial character, during the years subsequent to 1915 when I made my first close contact with the Navy. During this period the growth of a civilian scientific service in the Navy, so far as I was personally concerned, can be conveniently divided between four research establishments following each other in geographical and chronological order as follows: (1) Hawkcraig, Aberdour, 1915–17; (2) Parkeston Quay, Harwich, 1917–19; (3) Shandon, Gareloch, 1919–21; and (4) A.R.L., Teddington, 1921 to date. At the outbreak of war in 1914 there already existed such establishments as H.M.S. *Vernon*, A. E. W. Haslar 'Signal School,' primarily concerned with instruction of Naval officers, and with trials and modifications of Service equipment—mainly of an engineering character. Soon after the war began their staffs were augmented by civilian engineers converted into R.N.V.R. officers. As the war progressed, contacts between our civilian research establishments and the purely Naval establishments increased until, as we now know well, civilian research staffs of the R.N.S.S. can be found in almost all Naval establishments concerned with the application of research in the service of the Navy.

At the risk of turning my remarks into an autobiography, I should like to explain briefly the situation so far as I was personally concerned a few years preceding the first world war, and how I unexpectedly came to be involved in the affairs of the Navy. During this period (1909–14) I graduated in honours physics and was doing research in Prof. Sir Ernest Rutherford's laboratory at Manchester University. I was fortunate to be learning physics—atomic physics—in very good company. Working in the physics research laboratories at that time under Rutherford's direction were such (now) well-known figures as H. G. J. Moseley, C. G. Darwin, Hans Geiger, Niels Bohr, Ernest Marsden, H. Bateman, J. Chadwick, E. N. da C. Andrade, R. W. Boyle, Prof. Boltwood, Fritz Paneth, G. von Hevesy, H. Robinson, J. M. Nuttall, H. Stansfield, E. J. Evans, Margaret White, W. Makower, H. Richardson and others. It would be difficult

EARCH TO ROYAL NAVAL SCIENTIFIC SERVICE

to find anywhere such a galaxy of scientific talent, either before or since, working together in the same physics laboratory at the same time. Much could be written about all these men who reached eminence in the scientific world in later life. Moseley, one of the best research physicists of his day, joined the army and was shot by a sniper in the Dardenelles campaign. Hans Geiger, who taught me glass-blowing, some physics and a little German, died a few years ago, but his name will long survive him as the inventor of the Geiger tube (so well known now as to be spelt with a little 'g')—I saw it being 'developed' as the almost inevitable consequence of a course of lectures he gave us on 'Ionisation by Collision.' Ernest Marsden worked with Geiger in counting the large-angle scattering of α particles which, with the theoretical work of Rutherford and Bohr, provided the foundations of the nuclear theory of the atom. The work of Darwin and Moseley on the X-ray spectra of the elements formed the basis of our knowledge of atomic number. Hevesy and Paneth's work of the uses of isotopes as tracers, Chadwick's work on γ-rays and his later discovery of the neutron; Niels Bohr's theoretical work on atomic structure—and more such major developments in atomic physics could be mentioned. Sir Arthur Schuster (Professor Emeritus) also came to the laboratory, and H. P. Walmsley and I did some work for him during the 'long night watches' (when no trams were running) on a problem relating to the origin of the earth's magnetism—due possibly, in Schuster's opinion, to the earth's rotation. I was also working on a determination of the range of recoil atoms from radio-active substances (in the Ra, Th and Ac series emitting α particles (helium/atoms) — the heavy atom (at wt. of order 230) on emission of a light helium atom (at wt. 4), recoiling like a gun when it fires a shell. At this time Ernest Marsden and I conjointly made a determination of the atomic weight of actinium emanation by a diffusion method suggested to us by Niels Bohr. It was an inspiration, albeit a chastening one, to be working alongside so many brilliant scientists, and such an experience can never be forgotten. I could write much about their personalities and the work they were doing and have since done, but this would be outside the scope of my present purpose. After leaving Manchester University, I continued my research in atomic physics at Liverpool University, where I was Oliver Lodge Fellow and Lecturer in Physics (L. R. Wilberforce was Professor and J. Rice Senior Lecturer), whilst still co-operating in research and discussions with members of Rutherford's laboratory in Manchester.

In August, 1914, the war broke upon us. I was considered 'indispensable' until July, 1915, when a close friend of mine was considering applying for a commission in the Air Force. I had similar ideas and approached Rutherford with the object of signing the necessary papers. It was then the unexpected occurred. The Admiralty Board of Invention and Research (B.I.R.) was being formed, and Rutherford suggested that research for the Navy (in particular, detection and location of submarines) might be more in my line than learning to fly. I didn't require much persuasion and from then on I paid frequent visits to Rutherford's laboratory to do experiments on underwater sound. Harold Gerrard, lecturer in electrical engineering in the adjoining laboratory, was also appointed with me to work with Rutherford. In the preliminary stages we were experimenting in a small water-filled tank with various possible sound-receivers for use under water, *e.g.*, Broca tubes (aneroid barometer capsules, single and multiple) with stethoscope tube attached, carbon granule microphones (A.T.M. and S. G. Brown types), single-contact microphones, and magnetophones (telephone earpieces). We used a bell-type buzzer and a C.W. diaphragm sounder as sound sources in these tank experiments. At this time, too, Rutherford was hopefully, if not very optimistically, scratching small pieces of quartz crystal (with a telephone headpiece connected), to discover if the piezo-electric effect of quartz was likely to prove useful. The result of this was inevitably disappointing as no means of amplification was available at that time. This preliminary work went on until Gerrard and I received our 'official' appointments as physicists to the B.I.R. in October, 1915, at the then remarkable salary of £1 per day! We continued work in the Manchester laboratory with Rutherford until 17th November, when Gerrard and I, with F. W. Pye (a mechanic from Liverpool University), left for 'Hawkcraig,' Aberdour, Fife, N.B., a naval experimental establishment under the command of Cdr. C. P. Ryan, R.N.

The Board of Invention and Research (B.I.R.)

At this juncture it seems opportune to refer to the formation of this organisation in 1915. It consisted of a Central Committee whose function was 'to initiate, investigate, and advise generally upon proposals in respect to the application of science and engineering to naval warfare'; a consulting panel of scientific and engineering experts; and an advisory and secretarial staff 'to deal with the preliminary sifting of proposals from inventors and others, and such other secretarial and recording work as may be found necessary.'

In May, 1916, the Central Committee consisted of: President, Admiral of the Fleet Lord Fisher; Professor Sir Joseph J. Thomson, O.M., F.R.S.; The Hon. Sir Charles A. Parsons, K.C.B., F.R.S.; Dr. G. T. Beilby, F.R.S. (The name of Vice-Admiral Sir Richard H. Pierse was added at a later date).

The Panel: Prof. H. B. Baker, F.R.S.; Prof. W. H. Bragg, F.R.S.; Prof. H. C. H. Carpenter; Prof. Sir Wm. Crookes, O.M., F.R.S.; Mr. W. Duddell, F.R.S.; Prof. Percy F. Frankland, F.R.S.; Prof. Bertram Hopkinson, F.R.S.; Prof. W. J. Pope, F.R.S.; Prof. Sir Ernest Rutherford, F.R.S.; Mr. G. Gerald Storey, F.R.S.; Prof. the Hon. R. J. Strutt, F.R.S. Note: At a later date the name of Mr. (later Sir) Richard Threlfall, F.R.S., was added to the Panel.

Secretariat: Capt. T. E. Crease, R.N., Secretary. Assistant Secretaries: Cdr. Cyprian D. C. Bridge, R.N.; Flt. Cdr. Lord Ed. Grosvenor, R.N.; Engr. Lt. Cdr. C. J. Hawkes, R.N.; Mr. T. H. Hoste; Lt. the Hon. Walter J. James, R.N.V.R.; Sir Richard A. S. Paget, Bart.; Mr. J. F. Phillips.

The work of the Panel was divided into Sections I to VI and their respective sub-committees, which dealt with all aspects of science and engineering likely to be applicable to Naval Service problems at that time. The full list of members of these six sections contains many famous names in science and engineering. It may be sufficient to quote here the names of those particularly concerned with Section II—'Submarines, mines, searchlights, wireless telegraphy and general electrical, electro-magnetic, optical and acoustic subjects.'

Sub-Committee: The Duke of Buccleuch; Prof. W. H. Bragg, F.R.S.; Mr. W. Duddell, F.R.S.; Prof. Sir Ernest Rutherford, F.R.S.; Dr. R. T. Glazebrook, C.B., F.R.S.; Mr. C. H. Merz.

Secretaries: Sir Richard A. S. Paget, Bart., and Lt. the Hon. Walter J. James, R.N.V.R.

(Members of the Panel and the committees of other sections were sometimes involved in the work of Section II. Associated with the Central Committee and/or the sub-Committee were also certain officials of the various Admiralty departments concerned). Prior to the formation of the B.I.R., the Navy had not been very successful in their efforts to counter enemy submarines, and it became one of the primary objects of Section II Sub-Committee to deal with the anti-submarine problem, *i.e.*, the detection, location and destruction of enemy submarines.

It is important to note that the formation of the B.I.R. represents a landmark in the history of the Navy (and of the R.N.S.S.) in that it officially encouraged co-operation between the Navy and civilian scientists and engineers.

The Admiralty Experimental Station at 'Hawkcraig,' Aberdour, Fife

In the introduction to these notes I concluded by remarking that H. Gerrard and I, with F. W. Pye (as mechanical assistant), left Manchester on 17th November, 1915, for Aberdour. A drifter met us at Granton, Edinburgh, and took us across the Forth direct to Hawkcraig, a rocky promontory on the north side of the Forth and adjoining

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Fig. 1(a). Portable non-directional hydrophone (Drifter set).

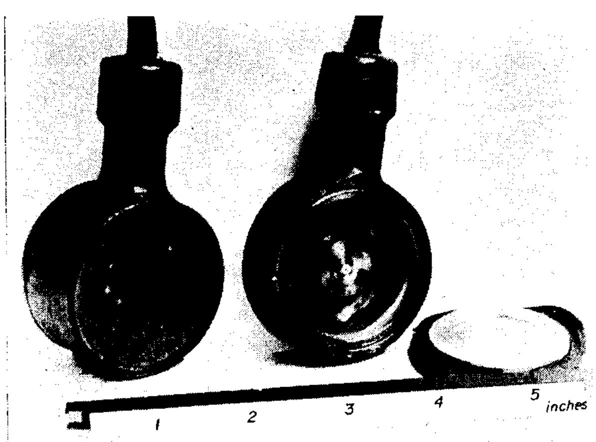


Fig. 1(b). Submarine Signalling Company's non-directional hydrophone.

the little sea-side village of Aberdour (Fifeshire), about five miles east of Rosyth. Here we met Cdr. C. P. Ryan, R.N., his secretary, Lt. Cdr. Ashley A. Froude, R.N.V.R., and other R.N.V.R. officers of his staff, to whom I will refer later. A few days later Sir Ernest Rutherford visited Hawkcraig and just before his arrival, in conversation with Cdr. Ryan, I was amazed to discover that he had never heard of Rutherford ! Such was the state of 'science in the Navy' in 1915 ! When Rutherford arrived we talked with Ryan, who demonstrated his hydrophones (underwater microphone receivers), and we went out in H.M. Drifter *Hiedra*. This vessel was nominally allocated for Gerrard and myself to use for B.I.R. experiments, although still under the command of Ryan, who was Naval Officer-in-Charge at Hawkcraig. Soon afterwards, Sir Ernest Rutherford came up again, this time with Sir Richard Paget and a Mr. Gordon, who was totally blind but had developed a sense of 'absolute pitch.' He listened to moving ships, using Ryan's moored hydrophones and some portable ones lowered over the gunwhale of *Hiedra*.

At the time of our arrival at Hawkcraig the state of our knowledge of underwater sound propagation in the sea was very primitive indeed. All we could gather from Rayleigh, Lamb and Barton on sound underwater was the measurement of velocity of sound by Colladon and Sturm in Lake Geneva in 1827, and the velocity of explosion waves in the sea by Threlfall and Adair in 1889. Any information likely to be useful in detecting submarines seemed to be lacking. I was impressed by Ryan's achievements in designing and making successful moored hydrophones, portable hydrophones, Figs. 1(a) and 1(b), and hull-fitted hydrophones on ships. These were already in existence when we were first 'initiated.' Large ships of Beatty's Rosyth Battle Squadron could be heard, under favourable weather conditions, at distances up to 10 or 12 miles in the Firth of Forth when proceeding out to sea. Most of his work was empirical but he had made valuable initial progress in the art of listening underwater. He knew little or nothing about the theory of sound or the possibilities of designing equipment which would indicate direction of sound. He had, however, gone so far as to fit submarines with pairs of hydrophones—one 'port' and the other 'starboard'—which would indicate to a reasonably intelligent operator the approximate bearing of another ship—utilising the sound-screening property of the hull of the submarine. In selecting hydrophone-pairs for this purpose he made use of the musical ability of one of the most famous musicians in the country—Lt. Hamilton-Harty, R.N.V.R. (later Sir Hamilton Harty and conductor of the Hallé Orchestra). It seems a little bizarre to recall Lt.

Hamilton Harty sitting amongst a pile of hydrophones using a little hammer to tap the steel diaphragms and arranging them in pairs as 'port-low' and 'starboard-high' pitch. (Lt. Hamilton-Harty and his wife, Agnes Nicholls (a famous soprano singer), lived in a flat above mine in Aberdour.) It was fairly clear, when listening to moving ships with Ryan's hydrophones, that the sound came mainly from the propellers, the modulation of the sound depending on the type of power drive of the ship. Thus trawlers, drifters and other ships fitted with reciprocating engines had a characteristic 'beat' due to the engines, whilst destroyers and larger ships fitted with turbines emitted a more or less continuous 'rushing' sound. All the ships' sounds, however, appeared to have a predominant frequency (or frequencies) but as this frequency changed from one hydrophone to another, it was fairly obvious that it was characteristic of the hydrophone diaphragm (and/or microphone) rather than of the vessel emitting the sound. As I have said, Ryan's observations were empirical. He made no measurements. In comparing sensitivities of hydrophones and ranges at which sounds could be heard in the sea he relied on his mental impressions, in spite of the fact that these impressions were dependent on water noise conditions and other factors out of his control.

Whilst referring to Cdr. Ryan's work at Hawkcraig, it may be of some interest to mention also some of his staff. This consisted mainly of R.N.V.R. officers, one or two ratings and a few seamen. I have mentioned his secretary, Lt. Cdr. Ashley A. Froude. He was an elderly man, the son of J. A. Froude (1818-94) the celebrated historian, author of *Froude's History of England* and biographer of Thomas Carlyle. Lt. Hamilton-Harty I have already mentioned; there were also Lt. Brett, a famous violinist, and Lt. Rose, a London theatre manager, and one or two more whose names I forget. (Lts. Hamilton-Harty, Brett and Rose, with Mrs. Hamilton-Harty (Agnes Nicholls), gave a concert in the village hall in Aberdour to entertain the staff and the villagers. First-class London talent—front seats 2s. 6d.!) Cdr. Ryan's brother, who had held, just previous to joining the Navy, a responsible colonial post in Africa, showed me a letter received by him at Hawkcraig from one of his native servants, which included the striking remark: "The great white chief who now sits in your chair is not a very cruel man." To complete the list, mention should also be made of Cdr. Ryan's two dogs, which were great favourites of everyone. These were a white cairn terrier and a red water spaniel. The terrier was a 'rover' which, Ryan told me, had once been shot and buried by a gamekeeper, but dug itself out and returned home to Hawkcraig! The water spaniel was stone deaf and on one occasion which I witnessed stood over the lighted fuse of a charge due to explode when blasting rock for a new jetty at Hawkcraig. We threw stones at it, waved and shouted without avail and, luckily, the fuse failed and all was well. This water spaniel was in the habit of stealing Ryan's lunch from the table in his private hut, until one day the beef-steak was connected to a high voltage circuit—the dog emerged from the door of the hut at great speed with all four legs off the ground and its tail between its legs!

It was at Aberdour that I became acquainted with Sir Richard Paget's remarkable musical talents. On one occasion Rutherford, Paget and I were dining together after a day's experiments at sea. After dinner he entertained us by his delightful singing and playing of the piano. He improvised 'on the spot' in grand opera style the song and accompaniment of one of Edward Lear's nonsense rhymes. 'The Dom with the Luminous Nose.' On a later occasion, at Dartmouth, he gave a similar performance, this time improvising on an extract from the current number of *Engineering*, relating to the Cooper Hewitt lamp! It was at Aberdour that I first heard him sing a duet (without words) whilst playing his own accompaniment on the piano. Some time later I remember him, with his daughter, singing a quartet during a lecture on 'speech synthesis' which he gave at the National Physical Laboratory. His work on human speech is now well known. Using plasticine models, or by careful cupping of his hands, and blowing through an 'artificial' larynx he could produce artificial speech, to the delight of his audiences.

There were several experimental ships attached to the station at Hawkcraig: H.M. Submarine B3, H.M.D. *Tarlair*, H.M.D. *Hiedra*, and *Nyker*. The last named was a small steam yacht used by Cdr. Ryan in his experiments on radio-control —hence the name, which indicated 'No Yachting Knowledge Required.' In view of the fact that no valve amplifiers or valve-rectifiers were available at that time. Ryan was very successful in his early efforts at radio control (steering, engine speed, *etc.*) of the navigation of a ship.

The early experiments which Gerrard and I made at Hawkcraig were concerned with various forms of sound-receivers for use in the sea, *e.g.*, 'Broca' tubes, microphones and magnetophones mounted on diaphragms, and in testing out equipment sent to us by Sir Ernest Rutherford from Manchester. We used Campbell and Duddell turnable vibration galvanometers in an attempt to analyse the predominant frequencies in the sounds of ships — our drifters and the Submarine B3.

The result of all this was, as I have already indicated, that we found the predominant frequencies were those of the hydrophone used to receive the complex sounds of the ships. Early in the year 1916 Sir Richard Paget, on being informed of our failure to obtain a reliable frequency analysis of a submarine's propeller noise due to resonances in hydrophone diaphragms and microphones, suggested listening direct with the two ears under water. Meeting with little enthusiasm from Gerrard and myself, he went out with a sailor in a small boat and a submarine circled round at a moderate distance. Sir Richard, who had a 'skull note' G sharp when he tapped his head, leaned over the side of the boat, with the sailor sitting on his legs, put his head under the water, came up, tapped his head and ran up the scale to the required note, which the sailor duly wrote down. Then down again to fish up another note, and so on. I am not sure that the notes he obtained in this way were very reliable—but at any rate he didn't develop pneumonia!

No electronic amplifiers were available in those days, until we were fortunate in receiving a three-electrode valve designed by H. J. Round of Marconi's. This valve was about two inches in diameter and five inches high with a glass 'pip' at the top about one inch long. The 'pip' contained asbestos and was used, in conjunction with a small heating coil (a few turns of wire wound outside the glass 'pip' in series with the valve filament), to control the degree of 'softness' of the vacuum. When in correct adjustment this valve was a very efficient amplifier and at its best was as good as two or three 'hard' valves with which we were supplied towards the end of the war (in 1917 and 1918).

Based on Rayleigh's theory of concentration of sound by conical and exponential horns, we were supplied by S. G. Brown, for the B.I.R., with several long, solid horns made of wood or of paraffin wax, tapering from a diameter of 12 or 15 inches at the base to about ½ inch at the tip in a length of several feet. These were tested at sea but for various reasons were unsatisfactory. Similarly, two 'sound insulated' tanks were fitted on the port and starboard sides of *Hiedra*. Holes were cut in the hull and the tanks, exposed to the sea, were insulated from it by air-filled rubber tubes. Although these pneumatically insulated tanks cut out a good deal of 'local' ship's noise, the sound of the propeller was still very strong, as this was conveyed to the tanks by the water outside, the rubber tubes being acoustically short-circuited by the sea water. We also explored the sound field in the water around a stationary submarine, the source of sound being a sub-marine-signal company's bell some distance away. The observations were somewhat qualitative but served to show the extent of the sound shadow, as modified by diffraction, due to the hull of the submarine.

Observations were also made of the frequencies of the propeller blades of a submarine when tapped by an iron bar. The various frequencies of the notes heard inside the submarine when the motors were running at different speeds were also observed, their relation to the speed, number of brushes and commutator segments being proved. In a similar manner, but listening outside the hull of the submarine, an attempt was made to determine the principal frequencies when charging batteries.

Experiments were made to devise a portable directional hydrophone. The first promising attempt to achieve this was made by Sir Ernest Rutherford, who sent us for a test a thick-walled open-ended cast-iron cylinder about eight inches external diameter and length about one foot (with removable extensions at each end to make it about two feet long, if required), Mounted rigidly inside it at the mid point was a steel diaphragm of about four inches diameter with a microphone enclosed in a small watertight box at the centre, the whole arrangement being symmetrical about an axis at right angles to the length of the cylinder, the diaphragm being exposed to water on both sides. This arrangement gave good results when the box containing the microphone was made very small and a similar 'dummy' box was mounted symmetrically on the opposite side of the diaphragm. The long iron cylinder was, however, found to be unnecessary to achieve the directional properties. It was eventually replaced by a heavy metal ring and the diaphragm had a symmetrical boss turned at the centre to contain the microphone. This device, shown in Figs. 2 and 3 had good bi-directional properties showing a figure of eight characteristic with a good maximum when either face of the diaphragm was broadside-on and an almost silent minimum when the diaphragm was edge-on to the source of sound. Some time later, in May, 1916, after the arrival of Professor Bragg, tests were made of a directional hydrophone, similar in basic principles, but having two metal diaphragms tied together at the centre by a stiff metal rod, which carried the microphone, the whole being mounted in a massive metal ring. (Fig. 4). This was designed and brought to Hawkcraig for test by Prof. J. T. McGregor Morris and Mr. Sykes (of East London College). These two directional hydrophones, the 'single' and 'double' diaphragm types, gave equally good results as regards sensitivity and directional accuracy (within 1 or 2°), but the single-diaphragm type was much lighter and more portable and, as

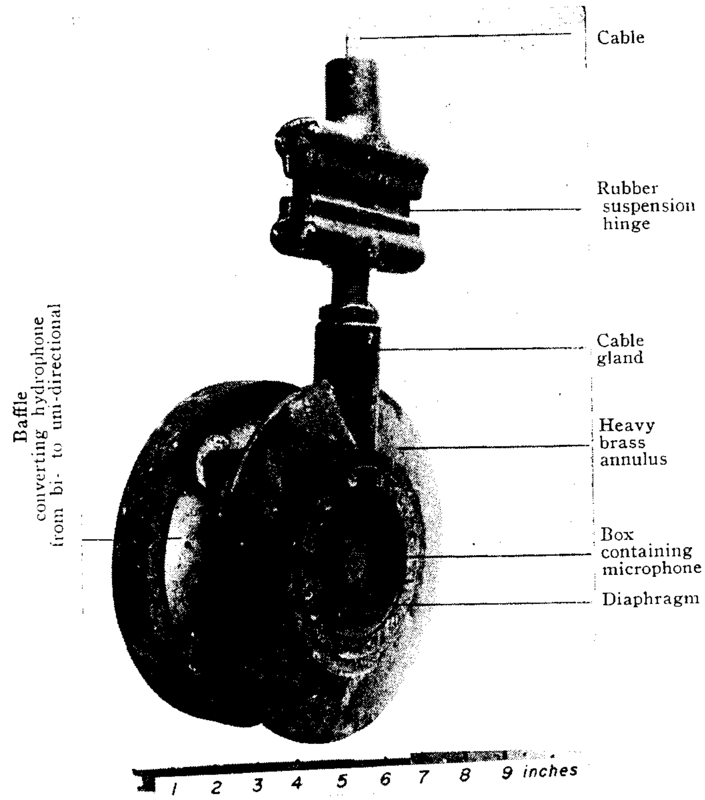


Fig. 2. Single diaphragm type bi- or uni-directional hydrophone.

will be seen later, was easily converted from a bi-directional to a uni-directional hydrophone.

In addition to the frequent visits of Sir Ernest Rutherford and Sir Richard Paget during this early period, Admiral Sir David Beatty and Lady Beatty (who lived at Aberdour House) and their son David were fairly regular visitors, always showing a lively interest in the hydrophones and in any attractive laboratory experiments. On one occasion, in February, 1916, Prince Louis of Battenberg came with them. The Duke of Buccleuch, who was chairman of B.I.R. Section II, also visited us frequently. In May, 1916, Prof. William H. Bragg, who had previously visited Hawkcraig with Sir Ernest Rutherford and Sir Richard Paget, came as Resident Director of Research, bringing additional scientific staff—T. C. Sutton (from Australia), and Prof. F. Ll. Hopwood (from St. Bartholomew's Hospital, London), and Prof. Bragg's secretary, Miss Winifred Callis. He also brought additional mechanics, C. Menkens (from Australia) and J. Elliott (from Leeds), followed soon afterwards by T. P. Rigby and G. B. Burnside, F. B. Young (Bristol) and R. S. H. Boulding (W. Duddell's assistant) joined the scientific staff at Hawkcraig in August, 1916, and October, 1916, respectively. Dr. A. O. Rankine now became a frequent visitor and introduced the 'photophone' to our programme of investigations. The day after the arrival of Prof. Bragg as R.D.R., Prof. le Duc de Broglie visited Hawkcraig. He came later (in August, 1916) with M. Perrin, and again in December, 1916.

We had often watched and listened to Admiral Beatty's Battle Squadron as they went out to the North Sea from Rosyth, but our feelings on 1st and 2nd June, 1916, were very different from normal when the stragglers returned to Rosyth after the Battle of Jutland. Only two weeks earlier both Admiral Jellicoe and Admiral Beatty were at Hawkcraig and now we were hearing the reports of some of their fine ships sunk and large numbers of men lost. Shortly afterwards, on 17th June, 1916, His Majesty King George V was at Aberdour visiting Admiral Beatty, and the day previously Mr. Asquith was at Rosyth. These events impressed us all more than ever before of the very serious issued involved in war.

After the arrival of Prof. W. H. Bragg and the increased scientific staff at Hawkcraig in May, 1916, research was concentrated on further improvements of the single-diaphragm bi-directional hydrophone and methods of making it uni-directional. Baffle-plates of slightly smaller diameter than the hydrophone were mounted facing one side of the diaphragm (see Figs. 2 and 3). These baffle-plates were of various kinds, lead-covered cones of wood or lead-covered flat discs of wood, and later F. L. Hopwood used hollow discs of *Xylonite* partly filled with lead shot. The baffle was only effective at a certain critical distance of separation (about two inches) from the hydrophone diaphragm. The effect of the baffle was to convert the bi-directional 'figure of eight' polar diaphragm into a uni-directional figure having a broad maximum and a not-so-good minimum. I have a note on some experiments in August, 1916, using this hydrophone that we located the submarine G.4 at a range of four miles (weather conditions not stated). Considerable numbers of uni-directional single-diaphragm portable direction-finders were used, mainly by drifters and other small craft, and a few on submarines (see Fig. 3) in their search for enemy submarines during the war.

A. O. Rankine's photophone[1] was fitted up with the transmitting mirror at Hawkcraig and the receiving mirror on the island of Inchcolm(2), 1½ miles away. Briefly, the photophone operates on a speech-modulated beam of light, transmitted by a large diameter convex lens (or mirror). The light from a point light source is focussed by the lens on a small concave mirror attached to a gramophone sound box or to the reed of a telephone earpiece. The light diverges and passes through a similar lens which projects the beam to the distant station. Two similar grids are mounted — one in front of each lens. An image of the first grid is superimposed on the second by reflection in the small concave mirror. When the latter oscillates under the vibrations of speech the dark spaces of the image-grid move over the openings of the second grid, thus producing fluctuations of intensity of the light beam. This fluctuating light is collected at the receiving end by a mirror or a lens and focussed on a photo-electric cell (actually one of Fourrier d'Albe's selenium cells) in circuit with a battery and telephones. The resistance changes of the selenium result in the reproduction of the original sounds in the telephones. *(Note:* There was then no amplifier at the receiving end.) If, and when, the light-beam was picked up by a large searchlight mirror at the receiving end on Inchcolm (1½ miles away) the speech was easily audible and of good quality. But it was very exasperating to the operators at both ends when the beam was not accurately directed and there was no alternative means of communication between Hawkcraig and Inchcolm. Eventually, Prof. Bragg persuaded Cdr. Ryan to lay a spare length of hydrophone cable to be used as a telephone line between the two photophone stations, and this resulted in a marked improvement. But, alas, about two weeks afterwards, when Prof. Bragg was attending a meeting in London, the cable was picked up again without apology or explanation, just 'orders,' by one of Cdr. Ryan's officers. On another occasion, when Prof. Bragg was out on H.M.D. *Hiedra,* he asked the skipper of the ship to perform a certain manoeuvre. On the ship returning to Hawkcraig, Cdr. Ryan sent for the skipper and gave him 14 days C.B. (in the ship) for disobeying his orders. Prof. Bragg went to see Ryan and apologised for having asked the man to do what Ryan had previously told him not to do and accepted all the blame, but the C.B. sentence had to stand. I mention these incidents in illustration of a 'state of strain' which was beginning to develop at Hawkcraig at this period, and shall have to refer to this later. I could tell of a number of amusing incidents which occurred during the photophone experiments, but one must suffice! On one occasion when I was out in a small boat, maybe 50 or 100 yards, from the transmitting end of the photophone on Hawkcraig, I could clearly hear the operator saying "I am speaking softly now," and I wondered what was the advantage of using the photophone! The photophone was designed for use as a short-range station-keeping device between ships of a fleet, but so far as I know it was never used for that purpose.

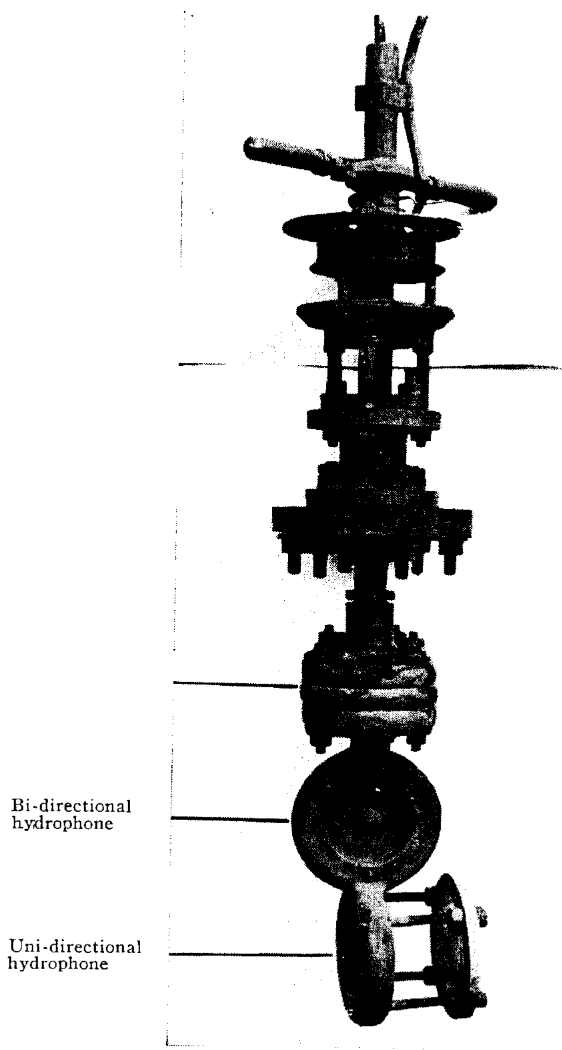


Fig. 3. Bi- and uni-directional hydrophones fitted to submarines.

(1) *Proc. Phys. Soc.*, **31,** (1919), 242; **32,** (1920), 78 and "Sound", A. B. Wood, G. Bell and Sons Ltd., 1930.

(2) On which stand the remains of an ancient monastery and a hermits' cell. At this time the monastery was being used by a company of submarine miners (in command of Brigadier Bose). Some of us were made members of the Officers' Mess on Inchcolm.

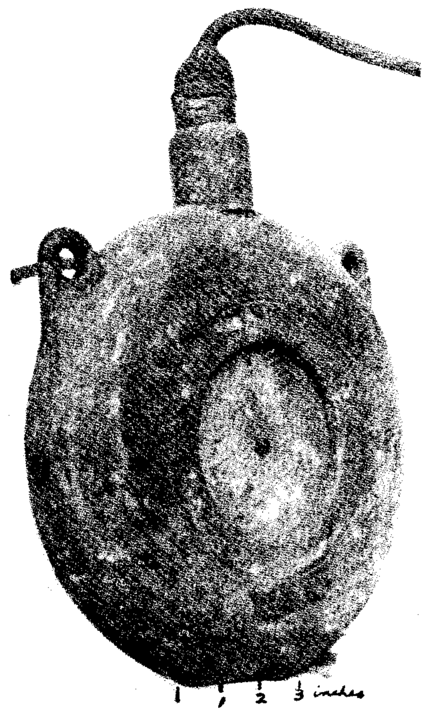


Fig. 4. Double diaphragm type bi-directional hydrophone.

The photophone method of modulating a beam of light by speech was, however, used after the war by Rankine for recording speech on film in connection with the development of 'talking' films, a process then in its infancy.

After his arrival at Hawkcraig in August, 1916, F. B. Young and I became interested in a number of new developments. In one of these it had been suggested that a simple elongated ellipsoid of light but rigid construction in which was mounted a carbon granule 'button' microphone might serve as a directional receiver in water. Such a body lighter than the medium it displaces, should have a displacement or velocity-amplitude greater than that of the surrounding medium, depending on the shape of the body. For example, an ellipsoidal body would have the greatest amplitude when the long axis coincides with the direction of the sound-waves. The response of the enclosed microphone would therefore vary with the orientation of the ellipsoid. Preliminary tests with a hollow glass ellipsoid indicated a direction ratio of 20 or 40/1, whereas the theory (developed by Prof. H. Lamb) indicated only 2/1. By means of a specially constructed ebonite ellipsoid in which the microphone could be rotated relative to the axis of the ellipsoid, we showed that the observed high direction ratios were mainly due to the microphone itself[3]. Hence it appeared that there was little to be gained by adhering to the ellipsoidal form, a microphone being mounted in a small, light sphere being equally effective and possessing the advantages of greater compactness and rigidity. Although this type of hydrophone was not used under Service conditions, it proved very valuable as a research tool. We used such a hydrophone (one inch in diameter) in exploring the sound distribution, direction and amplitude, around various bodies submerged in water. It was in these experiments we discovered that the baffle effect in the uni-directional hydrophone described above was due primarily to the air film enclosed in it and *not* to the solid materials which enclosed the air film! The 'displacement' or 'velocity' hydrophone as it was called is less sensitive than a 'pressure' (diaphragm) hydrophone of comparable dimensions, but it serves not only as a detector but also as a direction indicator. We also used these small 'velocity' and 'pressure' hydrophones to explore the sound distribution in shallow water, and observed Lloyd's mirror interference effects due to interference between 'direct' sound and sound reflected from the water surface and the bottom.

In connection with the above-mentioned experiments, F. B. Young and I devised a system of intensity-loudness calibration, using a resistance shunt in the microphone circuit calibrated to an intensity scale by means of a vibration galvanometer at frequencies between 500 and 1,600 c/s. Sounds in the 'unknown' region of the sound field were adjusted by means of the resistance shunt to equal loudness with the sound in the 'free' undisturbed sound field. We found also, in conformity with the Weber Fechner law, that "the increase of stimulus δE to produce the minimum perceptible increase of sensation is proportional to the pre-existing stimulus E." In the case of our measurements of sound intensity under water it was found that $\delta E/E$ was approximately 0·1 in the absence of extraneous noises. This observation has often been confirmed since by other experimenters in this country and the U.S.A. We had no means, at that time of course, of measuring sound pressures in dynes/cm^2, or in decibels—the db had yet to be 'invented.' Measurements were also made of the frequency sensitivity of the ear, at various frequencies.

Some experiments were made with towed hydrophones both by Cdr. Ryan and the B.I.R. contingent, but very little progress was made due

[3] See Proc. Roy. Soc., **100** (1921), 252 and 261. See also "Sound," A. B. Wood, G. Bell and Sons Ltd., 1930.

to excessive water noise and vibration of the towing rope. G. H. Nash, of the Western Electric Company, Woolwich, was also interested in towed hydrophones and visited Hawkcraig in 1916 for advice and discussions. He eventually produced a 'fish' containing our directional hydrophone (electrically controlled from the ship), for which he claimed a large award at the end of the war.

Preliminary tests were also made of a depth-sounding bomb sent up to Hawkcraig by Sir Richard Paget. The depth was to be determined from the time of fall of the bomb from the water surface to the bottom, the impact on the bottom being indicated by an explosion of a small charge. A recorder designed by W. Duddell indicated the instants of release and impact, and by calibration in known depths of water its depth as a function of time was found. The suggested alternative acoustic method of taking soundings by means of echoes from the bottom was then considered impracticable owing to the short time intervals involved and to the faintness of the echoes which a Fessenden oscillator had been found to produce from a hard sandy bottom. The trials of the bomb were a history of failures[4]. It was hoped that this D.S. bomb could be used to take soundings at speed and D. of N. attached the highest importance to the work. The price quoted in 1916 for its manufacture in quantity was 30s. each. We know now that echoes are much cheaper !

During the early tests of the D.S. bomb and recorder. William Duddell visited us at Hawkcraig. We talked with him about our sound analysis experiments using his vibration galvanometer. He did not seem physically strong at that time (1916) and he died soon afterwards, in 1917. In 1915 he wrote a B.I.R. report on 'The general question of detecting submarines by electrical and electromagnetic means'— an excellent summary of the subject with the facilities available at that time. It was, however, not until the experimental station moved to Harwich (Parkeston Quay) that investigations of electrical, electromagnetic, and magnetic methods of submarine detection were taken up seriously. Other visitors to Hawkcraig late in 1916 were Vice-Admiral Sir Richard H. Pierse (who was a member of the B.I.R. Central Committee), Admiral Commander-in-Chief, Rosyth, and Lady Hamilton and their daughter; Prof. J. E. Petaval (Professor of Engineering at Manchester University, and later Sir Joseph, Director of the National Physical Laboratory, Teddington); and Mr. Richard Threlfall, who later invented the 'sticky' (phosphorous) bullets which spelt the fate of the hydrogen-filled Zeppelins: he was later knighted for this, and it required some effort on the part of Lady Bragg to dissuade him from appearing at Buckingham Palace for the ceremony in soft trilby hat, tweed coat and brown shoes !

I first met Captain W. L. Bragg, Prof. W. H. Bragg's son, at Aberdour in 1916, on one of his home leave visits from France where he was serving in the Army Sound Ranging Corps, and several times subsequently at Parkeston Quay (1917-19). It was shortly before this that they were awarded the Nobel Prize (Physics) for their work on X-rays and crystal structure.

Towards the end of 1916 it was becoming clear that if we were to make more rapid progress we should have to part company with Cdr. Ryan's small establishment at Hawkcraig. When Prof. Bragg explained the situation to Lord (A. J.) Balfour, the latter suggested that Cdr. Ryan should be moved, but Prof. Bragg said it would be better if the civilian staff should move as Ryan was there first. So on 26th December, 1916 Prof. W. H. Bragg and his family, with all the staff, except F. B. Young, myself and G. B. Burnside (who was then a mechanic), left Hawkcraig, Aberdour, to start a new Admiralty Experimental Station at Parkeston Quay, Harwich. F. B. Young and I stayed behind to complete our experiments, to which I have already referred, on Cullaloe Reservoir. We finally left Aberdour and re-joined our staff at Parkeston Quay in March, 1917. Besides completing our sound-field experiments with the direction-finder and baffle, we had one or two other interesting experiences. In connection with depth-sounding bombs, we had occasion to visit the navigating officer on H.M.S. *Lion* at Rosyth. He proved to be Capt. the Hon. A. C. Strutt, R.N., the son of Lord Rayleigh. He told us that in the Jutland battle, and luckily whilst he was on the bridge, a shell passed through his cabin, exploding further inside the ship. The heat from the shell had burnt up everything in his cabin except his iron bedstead and the ends of his golf clubs! A short time after this I visited the battleship *Emperor of India*—also at Rosyth—to have a look at the port and starboard hydrophones. After being told they were all right, I examined them and found they were full of water !

Perhaps one of the most colourful, if not the most profitable (from a Naval point of view), of our experiences in this period was my contact with 'Captain' Woodward of Hengler's Circus in Glasgow. It had been suggested to the B.I.R. that sealions might be trained to hunt enemy submarines, instead of fish, and to betray their position to our M.L's or destroyers. Captain

[4] A Report on the history and demise of the Depth Sounding Bomb was written by F. B. Young and A. B. Wood in a Shandon A.E.S. Report dated 22nd January, 1919.

Woodward, a famous sealion trainer, had been asked to experiment with his animals to see what were the possibilities of doing this. After he had made some preliminary experiments, I was asked by the B.I.R. Section II secretary (Sir Richard Paget) to arrange a visit to see what progress Captain Woodward had made. Consequently, on 6th January, 1917, I travelled from Aberdour to Glasgow and met him at Hengler's Circus, where I had a front row complimentary seat and saw the whole performance, which included the wonderful balancing feats of his sealions. After the show I was introduced to the sealions and some of his assistants. The next day, Sunday, 7th January, experiments were made with two sealions. In the first test one of the sealions, which was muzzled (with a small trap-door in the muzzle), was released into a swimming pool (56 feet long) in which were half-a-dozen live trout and a bell which could be operated from the edge of the pool. With one flap of its tail the sealion chased the trout from one end of the pool to the other, the tails of the trout operating at very high frequency (ultrasonic!). This continued, the sealion disregarding all appeals from the bell, until the trout could swim no longer and they lay huddled together on the bottom of the pool. In this condition the sealion had its muzzled nose centred on the trout and its tail out of the water and body describing a conical path above them. At this stage, the bell tinkled again and the sealion responded at once and came up to be fed with dead fish. Subsequently, realising the futility of chasing trout, it became more and more attentive to the bell signals. Further experiments were made with the second sealion in an open-air swimming pool (48 yards long) in a park. Here it was demonstrated that the animal could easily be trained, in the absence of fish, to respond to very faint underwater sounds (the tinkle of a pony's harness bell) even when swimming under water at high speed (about eight knots); under these conditions its hearing compared favourably with that of a sensitive, stationary hydrophone. It was interesting to note that no sound could be heard when the sealion was passing close to the hydrophone at speed, although the water noise could easily be heard by the hydrophone when the animal broke surface. (The report on these experiments was issued in B.I.R. 2228/17). In a later series of experiments, in which I was not involved, the sealions gave demonstrations in the sea off the south coast of Wales. A full report of these experiments, supervised by an Admiral and several high-ranking naval officers, concluded with the succinct remark: "It is recommended that these animals should now be allowed to return to their legitimate business." As a sequel to all this, I was shown at Parkeston Quay, sometime in 1917 or 1918, a cutting from a German paper showing an illustration of a British destroyer being led by a sealion towards a German submarine! How the 'secret' got out during the war I never discovered—my report was issued by the B.I.R. as 'secret' and 'subject to the provisions of the Official Secrets Act.'

Whilst we were at Hawkcraig other civilian scientists were working in various universities on B.I.R. problems dealing with underwater acoustics. For example, G. Barlow and H. B. Keene were working with Sir Oliver Lodge at Birmingham University on methods of sound-analysis. They devised a variable speed interrupter method using a d.c. galvanometer to indicate tuning to a frequency component present in a complex a.c. (such as might be due to submarine noise in a hydrophone). This method was stated to be more sensitive than the vibration galvanometer methods which we had tested at Hawkcraig. So far as I am aware, however, it was only tested on laboratory a.c. supplies, but not on hydrophone currents generated by ships' noise. J. H. Powell and J. H. T. Roberts, working in Rutherford's laboratory at Manchester, did a lot of work on the experimental determination of the frequency and damping of metal diaphragms when vibrating in air and in contact with water. Their observations mainly confirmed the theoretical work by Prof. Horace Lamb (then Professor of Mathematics at Manchester University). Lord Rayleigh and Prof. Lamb both did some theoretical work on underwater acoustics, *e.g.*, 'sound waves in water as modified by reflection at the surface'—discussing the reversal of phase which occurs when sound is reflected from a water-air interface.

In conclusion, the relatively short period of our stay, November, 1915, to March, 1917, at Hawkcraig. Aberdour, was in a number of ways very fruitful. We learnt a great deal about the sea and the propagation of sound in it. We soon appreciated the implications of the fact that the velocity of sound in the sea was about 4½ times that in air and that wavelengths were increased in the same proportion. We learnt a lot about hydrophones, microphones and magnetophones, and were in due course surprised to find what long distances sounds could travel through water, notably that the propeller noise of a large ship could be heard at 10 or 12 miles. We discovered ways of obtaining sound direction under water, using devices considerably smaller in linear dimensions than the wavelength of the incident sound.

I think we derived a very real benefit also from our association with such a strange mixture of men working with the same purpose in view.

R.N. and R.N.V.R. officers (a very mixed lot). engineers and university scientists, we found, had much in common and had much to learn from one another.

When F. B. Young and I finally left Aberdour in March, 1917, to join our new B.I.R. Admiralty Experimental Station at Parkeston Quay, Harwich, we felt in a much better shape to tackle anti-submarine problems than in the early days at Aberdour. At Parkeston Quay, where Admiral Tyrwhitt's destroyer and submarine flotillas were based, we had better sea and laboratory facilities, increased staff, and altogether much better scope for developing new ideas into 'hardware.'

ADMIRALTY EXPERIMENTAL STATION, PARKESTON QUAY (HARWICH) 1917 to 1919

The Resident Director of Research, Professor W. H. Bragg, and staff left Hawkcraig, Aberdour, at the end of 1916 "to reopen on new premises" at Parkeston Quay, Harwich, at the beginning of 1917. F. B. Young and I followed them from Aberdour in March, after the completion of some experiments to which I have previously referred. At Parkeston Quay the conditions for sea research were in many ways a great improvement on those at Aberdour. A greater number and variety of ships were available, workshop and laboratory facilities were considerably better and a large increase of scientific, clerical and workshop staff was provided. The workshops and laboratories were situated between the railway and the quay-side at Parkeston in the area which is normally used by the Harwich Hook of Holland shipping lines. Alongside the quay was moored H.M.S. *Maidstone* (Capt. Waistell, R.N.), a clipper built about 1905 used as a depot ship, officers' quarters, and mess for submarines (mainly 'E' class) based on Harwich. (H.M.S's *Pandora* and *Forth*, moored at the quay near *Maidstone*, served a similar purpose for the 'C' class submarines.) The scientific staff were also made members of the *Maidstone* officers' mess. Some of *Maidstone's* senior officers were very helpful to us in discussions of problems relating to submarine detection. Of these, the names of R.N. Commanders Brooke-Booth, Ham, and Wilkinson come to mind. In addition to advice, they frequently provided us, on request and at short notice, with submarines for experimental purposes. At that time most of the submarines were of the 'E' and 'C' class (800 and 320 tons submerged displacement) fitted with Ryan's service hydrophones, port and starboard near the bows, and frequent use was made of these in the course of our experiments.

Harwich is situated at the confluence of the rivers Stour and Orwell and the entrance to the harbour is partially 'screened' from the North Sea by the peninsula ending in Landguard Point and upon which Felixstowe stands. Parkeston Quay, a little to the west of Harwich, is on the south side of the Stour, so that vessels leaving or approaching Parkeston Quay have to negotiate a buoyed channel. At the period of which I am writing a picturesque feature of the Stour, viewed from Parkeston Quay, was the old *Ganges*, used as a depot ship, moored just off Shotley. It was said that at dusk the singing of the nightingales near the Shotley Naval Hospital could be heard from the *Ganges*. The submarines and destroyers of Tyrwhitt's squadron were moored in the Stour near Parkeston Quay and Harwich.

In a short time after our arrival at Parkeston Quay from Aberdour, our scientific staff grew from the 'Aberdour Six' to well over 30; the number of mechanics increasing from five in an even greater proportion, to about 50. As no group photographs of the scientific staff were ever taken, either at Aberdour or Parkeston Quay, I think it might prove of some interest if I gave a list of their names with a 'shorthand' indication of their main occupations at A.E.S., Parkeston Quay:

Professor W. H. Bragg, F.R.S.
Resident Director of Research.

Professor (Major) A. S. Eve, F.R.S.
Deputy R.D.R.
Succeeded Prof. Bragg as Resident Director of Research when he went to the A.S. Dept., Admiralty, about the end of 1917.

Dr. A. O. Rankine — Chief Research Assistant, and later R.D.R's deputy.

Dr. R. W. Boyle	Asdics.
R. H. S. Boulding	Sound ranging (underwater).
G. B. Burnside	Microphones.
Dr. C. V. Drysdale	A.C. unit and leader gear.
H. Gerrard	Hydrophones. Loops.
F.Ll. Hopwood	Hydrophones (D.F's and 'bias').
A. L. Hughes	Hydrophones (rubber types), towed 'binaural' and 'sum and difference' methods.
J. T. Irwin	Sound recording. Instruments.
J. H. Powell	Hydrophones—all kinds.
J. H. T. Roberts	Hydrophones.
H. R. Rivers Moore	Leader gear.
B. S. Smith	Microphones and magnetophones.
A. B. Wood	P.D.Hs., loops, 'A' mines, sound measurements.
F. B. Young	Electrode 'search gear'.
L. Hartshorn	A.C. unit. Relays.
R. S. J. Spilsbury	A.C. unit.
F. D. Smith	Electrolytic condensers.
R. E. Gibbs	Relays.
W. Jevons	Electrode search gear.
W. F. Rawlinson	Asdics.
J. Anderson	Asdics.
J. A. Craig	Instruments. Electrode gear.
T. C. Sutton	Hydrophones (towed from aircraft).
G. Williamson	Hydrophones. Parson's siren.
F. P. Burch	Electrode search gear.
– – Place	Electrode search gear.
– – Brookes	Electrode search gear. Asdics.

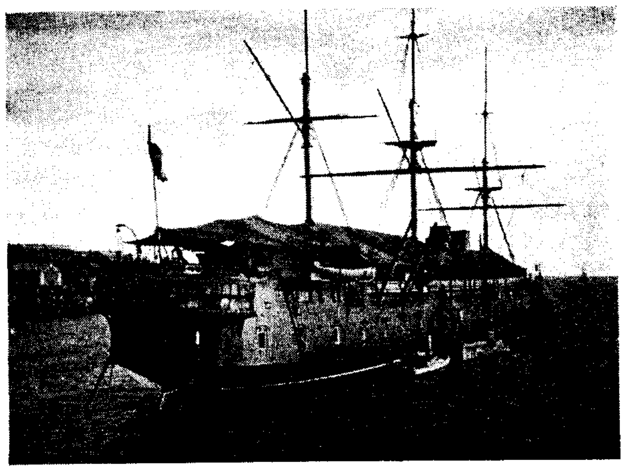
The following lieutenants R.N.V.R. also formed part of the scientific staff and assisted in sea trials in connection with the items mentioned above:

G. F. Partridge, Bieler, Ionides, Wells, H. Hamilton (N.Z.), Saville, Wylie, and Capt. A. J. Roberts, R.A.F.(N.Z.).

Professor J. C. McLennan and Kenneth Kingdon (both from Canada), working on magnetic mines ('M' sinkers), divided their time between Parkeston Quay and Mining School, Portsmouth. It should be understood, of course, that the scientists in the list given above also frequently worked on other research items in addition to those I have indicated.

On the engineering design and drawing office side we had Major J. H. W. Gill, R.E., Mr. D. V. Hotchkiss, Lieutenant R. Lucas, R.N.V.R., Messrs. M. W. Burgess, J. L. Orchard, and O. le M. Knight; Miss W. W. Callis (Professor Bragg's secretary) with Misses E. Gerrard and M. Milsom, took care of the clerical work, and Messrs. O. H. Dyke, Staddon and C. M. Hubbard the stores. I can remember the names of some of the workshop staff: C. Menkens (manager), T. P. Rigby (foreman), J. Elliott, D. Bradbury, E. W. Dowsett, V. Allerton, H. M. Jackson, G. H. Jessop, E. Wood, L. S. Pogson, three brothers James, George and Edgar Stephenson; two brothers, W. D. Vick and A. E. Vick (the father and uncle of F. A. Vick, who is now Director of A.E.R.E., Harwell), F. Stokes, T. Dare, J. Robinson, H. Marvel, and H. Coulson.

On our first arrival at Parkeston Quay, work continued on the lines developed at Hawkcraig, but with the improved facilities it became possible to investigate new lines of research. With an almost phenomenal increase of new ideas, the staff, workshop, and the 'B.I.R. Fleet' grew rapidly, as illustrated in the list of scientific staff indicated above. In addition to submarines, patrol boats (' P ' boats) and destroyers available ' on the doorstep', we had our own vessels: M.L. 14, H.M.T. *Nellie Dodds*, H.M.D. *Hiedra* (from Hawkcraig), H.M.Y. *Dotter* (a large steam yacht), *Ebro, Ivy,* the barge *Excelsior* (moored up the River Stour), and possibly one or two more vessels whose names I forget. With Admiral Caley's permission we were also enabled to make good use of the two large gateships *(Hautpur* on the Landguard side, and another on the Harwich side). These two ships, each of length 200 ft., moored about 180 yards apart, formed very stable platforms with plenty of free deck space and deck cabins available for experimental equipment. All ships entering or leaving the harbour were compelled to pass between them, so we had a plentiful



H.M.S. Ganges

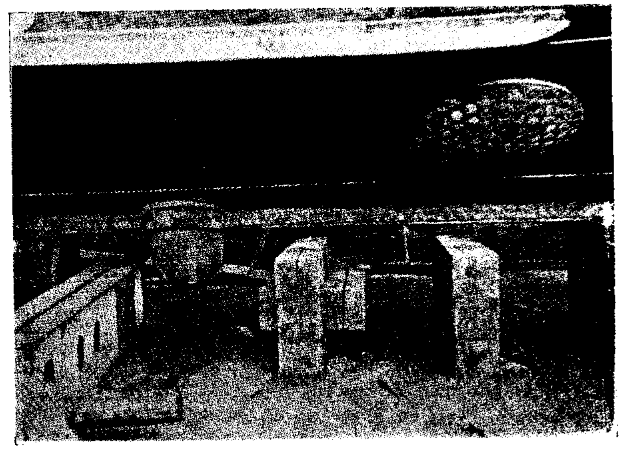
supply of ship targets of various kinds — submarines, destroyers, cruisers and small craft—on which we could test our experimental equipment.

The list of staff and research items shown on page 28 gives an over-simplified impression of the numerous research items with which we were concerned. If I were to try to enumerate them all it would certainly appear that at Parkeston Quay we 'skimmed the cream' off many of the submarine detection, location and destruction methods which have been used in the two major wars! Some of these methods have been much improved and are still in 'potential' use today. In addition to the development of 'hardware', useful in time of war, new knowledge was obtained on fundamental principles relating to the propagation of sound and electro-magnetic signals in the the sea, and in terrestrial magnetism as it affects the magnetisation of ships and the detection and destruction of submarines below the surface of the sea. In what follows, I propose to refer briefly to some of the more important problems with which we were immediately concerned at Parkeston Quay.

Workshop Staff at A.E.S. Parkeston Quay, Harwich, 1918

At Hawkcraig we had laid down the basic principles in the design of a portable directional hydrophone (P.D.H.) and had made the first successful model. The work of making a reliable 'service type' P.D.H., either bi- or uni-directional, and to get these hydrophones into service as quickly as possible was therefore a high priority item. Much of the work of testing P.D.Hs was done in the relatively quiet waters of the Stour, using the barge *Excelsior* as a floating laboratory, and one or other of our 'fleet' of ships to circle around and provide the source of sound. Alternatively, a source of 'white noise' (analogous to 'white light', as including all frequencies in a wide range) was provided by a 'rattler'—a thick steel plate struck by a hammer about 20 times a second, and a 'rumbler'—a motor-driven drum containing miscellaneous pieces of metal and which 'rumbled' or 'rattled' around inside. Range tests of the hydrophones were generally made out at sea in the neighbourhood of the *Cork* lightship. A new reproducible baffle (or 'bias), to make the hydrophone uni-directional, was developed. In its final form this baffle consisted of a lenticular disc of xylonite with an air cavity containing lead shot as damping material. This is shown in Fig. 2. Much effort also went into the standardisation of sensitivity and frequency range of both granular button microphones and hydrophone diaphragms. Both 'single' and 'double' diaphragm hydrophones were used in considerable numbers by small craft from mid-1917 to the end of the war in November, 1918. In a drifting ship, under average weather conditions, they could detect and give the bearing within a few degrees, of a ship's propeller at several miles, the range depending, of course, on the horsepower and speed of the ship. These directional hydrophones were sometimes fitted on the superstructure of submarines, and others were used in towed streamlined bodies astern of the aerated wake of the towing vessel, the orientation of the hydrophone being motor-controlled via a multi-core cable to the ship.

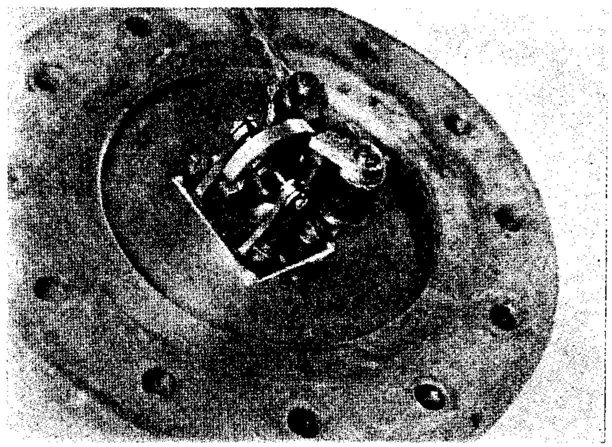
Reference has already been made to the use of Commander Ryan's 'port and starboard pairs' of hydrophones in submarines and surface ships. Ryan also controlled a series of about 20 hydrophone stations at suitable situations around the coast. These were fitted with a number of fixed non-directional hydrophones, on moorings or mounted on tripods, connected by cables to a listening post ashore. They kept a constant watch on all vessels approaching estuaries and harbour entrances. Numerous other forms of hydrophones were designed for various purposes. Instead of using resonant metal diaphragms to receive the sound, some of these hydrophones were constructed entirely of thick rubber enclosing a small air space containing the microphone (which also had a rubber annular diaphragm to replace the more usual micra annulus). These non-resonant hydrophones were designed to give a less distorted impression of the characteristic sound of a ship. Some were spherical in shape, three or four inches in diameter, others cylindrical (length equal to diameter)—known as 'chunks.' Many forms of towed hydrophones (fishes), 'Eels,' 'Porpoises,' etc. were tested, some carrying a single hydrophone, others having several. Pairs of hydrophones were often used binaurally, with suitable spacing, to obtain directionality, an American 'binaural compensator' being employed as an alternative to mechanical rotation of the line of hydrophones. Pairs of electrical receivers (hydrophones) were also used either binaurally or by the 'sum and difference' method to obtain directionality. My own impression of towed hydrophones in general use at this time was not very favourable. At speeds above three or four knots extraneous noise due to towing rope vibration, water noise and own ship's propeller noise tended to mask the 'wanted' noise of a distant ship or submerged submarine, and ranges of detection were consequently rather small. Attempts were made to tow hydrophones from a low-flying seaplane off Felixtowe, but the results were not very encouraging. A novel form of directional hydrophone system fitted to the hull of a ship was suggested by Lieutenant Walser of the French Navy. This consisted of a pair of 'blisters' on port and starboard sides of the hull. These blisters, 3 or 4 ft. in diameter, were spherical steel surfaces covered with a large number of small diaphragms (apparently like a magnified fly's eye). The sound from an external source was brought to a focus inside the ship and the direction determined by the position of this focus, the operator listening to the airborne sound picked up by two (port and starboard) collecting cones. I never actually listened to the 'Walser Gear,' as it was called, but I remember meeting Lieutenant Walser when he visited Parkeston Quay. His 'blisters' were fitted to ships in the French Navy but, so far as I am aware, we never used them in our own ships. I often went out with our own 'E' class submarines, listening on the hull-fitted hydrophones to other ships. When travelling at two or three knots on motors submerged there was hardly any background noise and destroyers could be heard many miles away. When the submarine was at rest on the bottom of the North Sea the silence was impressive and the ranges of passing vessels considerable. On some of these submarine expeditions I was frequently accompanied by a young submarine officer, Lieutenant Leslie, R.N., who was experimenting with towed W/T aerials using a box-kite to keep them above the water. In his first attempt he lost the kite, the first 'dot' having burnt the bit of string which tied it to the aerial! Not long after this he was reported missing in a submarine which failed to return.



The Walser Blister gear, 1918. Asdic or hydrophone dome on left.

Contradictory reports of the relative sensitivities of hydrophones of the same or different types were making it increasingly clear that some form of objective measurement of relative sound intensities was urgently required. Earlier I referred to sound measurements made at Hawkcraig and at Cullaloe Reservoir, but I felt that the requirement now was for a portable direct-reading instrument. I first used a hot-wire indicating instrument in the secondary circuit of a microphone, but this was far too insensitive. Eventually, I tried a carborundum-steel rectifier, as used in W/T on ships, and, to my surprise, found that ordinary hydrophone sounds gave rectified currents which were easily measurable on a D.C. micro-ammeter. After experimenting with various types of rectifying contacts, *e.g.*, carborundum-steel, zincite-bornite, zincite, platinum, silicon-steel, tellurium-zincite, and different transformers, I found that currents of the order 100 to 1,000 micro-amps were easily obtainable when ships passed a hydrophone at short ranges of 100 yards or so. I used crystal rectifiers, calibrated by means of an A.C. potentiometer, to compare sound intensities (or rather, pressure amplitudes) in a large number of underwater acoustic applications, *e.g.*, (1) directional characteristics of bi- and uni-directional hydrophones; (2) variation of water-noise with speed of ship (using service hull-hydrophones on surface ships and submarines); (3) noise of auxiliary machinery on a patrol boat with the object of sound-insulating the machines (an experiment which was never completed—I only did the 'before' measurements !); (4) rise and fall of sound intensity as a ship approached towards and receded from a hydrophone; (5) the variation of sound output with speed of a motor driven cavitating propeller; (6) water noise in towed hydrophones, variation with speed, and so on. It was clear from such observations as those in (4) that there was enough rectified current available to operate a D.C. relay of the Weston moving coil type. Consequently, I laid a hydrophone on the bottom between the gateships at Harwich and arranged a ' crystal ' circuit to operate two relays, one the more sensitive which gave warning of an approaching ship, and the other less sensitive which indicated when the ship was passing over the hydrophone. Destroyers, submarines on diesels, and minelayers rang the warning bell when 200 or 300 yards away, the current subsequently rising to a peak of several hundred micro-amps and falling again after the vessel had passed over or near the hydrophone. Of course, the obvious application of this was an *acoustic non-contact mine*. We had many visitors to see these demonstrations at the gateships. In May, 1917, soon after the proposal for an acoustic mine had been submitted to the Admiralty, Mr. Richard Threlfall was at Parkeston Quay and told me that Admiral Lord Fisher (Chairman of the B.I.R. Central Committee) was very keen about it and that its development was a matter of high priority. Professor Bragg also showed me a letter from Vice-Admiral Pierse re the urgency and secrecy of the crystal acoustic mine experiments. A short time afterwards, in June, we had other visitors: Sir J. J. Thomson, Vice-Admiral Pierse, Sir Charles A. Purvis, Sir Alfred Yarrow, Professor O. W. Richardson and Professor C. G. Barkla. As at Aberdour, Sir Ernest Rutherford and Sir Richard Paget were frequent visitors to Parkeston Quay, staying at the Alexandra Hotel in Dovercourt. R. W. Paul was also in and out of the laboratories at Parkeston Quay at this time (mid 1917) making tests of a magnetic system which he was developing for a non-contact magnetic mine. There was the occasion when he borrowed a slop-pail from the Alexandra Hotel and carried it undisguised to Parkeston Quay from Dovercourt ! He used it to contain his magnet system, to be tested, submerged, with a ship running past. Unfortunately, on the first test the watertight joint under the lid of the slop-pail failed and his lovely pivoted magnet system was put out of action. About this time also Rankine and I were testing a new *Evinrude* outboard motor fitted to a small boat. We started off gaily from Parkeston Quay to go to the gateships, but as we were passing Harwich pier we were caught by a fast tide, well in excess of the maximum speed of the *Evinrude*, and were being rapidly carried out to sea towards Kiel ! Fortunately we were able to steer close to one of the gateships where a rope was thrown to us by a friendly and observant sailor.

Although the practicability of the acoustic mine ('A' attachment crystal unit) was demonstrated at Parkeston Quay in May, 1917, the development trials did not commence until October, 1917, and continued until April, 1918. During most of this period I was in Portsmouth, at ' Mining School ' Gunwharf. Some of the staff here were Captain Napier, R.N.; Commander Gwynne, R.N.; Lieut.-Commander Murray, R.N.; Lieutenant Budgen, R.N.; and R.N.V.R. Lieutenants Lamb, Henderson, Anthony and Pickford. (Lieutenant Lamb was the son of Professor Horace Lamb of Manchester University and was himself Professor of Electrical Engineering at East London College). F. E. Smith's magnetic mine, ' M sinker ' or ' M destructor,' as it was called, was also being developed at Mining School at the same time. The 'A' attachment was to be fitted to a standard HII buoyant mine, which sways in a tideway, whereas the ' M ' unit was fitted in a hemispherical ground mine (known as the ' M sinker '), which was motionless after laying. It seems advisable at this point to continue my remarks on the development of these two mines rather than to break the continuity by referring here to other important work at Parkeston Quay started prior to the Mining School trials. The development of the acoustic mine was considered sufficiently important for Professor W. H. Bragg (then Resident Director of Research at Parkeston Quay and soon afterwards Scientific Adviser to the Director of the Anti-Submarine Department, Admiralty) to take part personally at Mining School in the development and trials—extending as they did over a period of about seven months. These trials involved the plotting of what we called ' iso-sonic lines ' around various ships (destroyers, submarines and mine-laying trawlers) using the crystal rectifier system to measure the microphonic currents from a hydrophone fitted on the cover of a buoyant mine, the ships running past on a series of parallel courses in Spithead. The charts of such observations showed clearly the sound distribution round a moving ship, and indicated that there was plenty of mine actuation sensitivity ' in hand,' as the Parkeston Quay observations had previously shown. Then came the countermining trials which gave the first severe setback to the scheme. The violence of the shock from a nearby countermining charge dished the steel diaphragm and smashed the carbon granule microphone. For more distant countermining explosions, the reverberation due to bottom and surface reflections, a very loud sound lasting about 30 seconds, was also sufficient to fire the mine. After much effort these difficulties were surmounted; a thicker steel diaphragm and protecting plate was used, a single vibrating ('chattering') contact was substituted for the rather delicate carbon granule microphone and a clockwork delay was introduced which operated on the initial shock of an explosion pulse to cut out the mine firing circuit for any desired period (usually about a minute). Several thousands of these mines were ready for laying when the end of the war came in November, 1918.



Shock contact (hold-off type) for sound ranging, 1917 - 18.

Whilst the 'A' attachment trials were in progress, Professor J. C. McLennan (McGill, Montreal) and Kenneth Kingdom were working on F. E. Smith's magnetic mine. In principle, this mine used a magnetic system of two bar magnets, one having a large moment of inertia and the other relatively small. These were pivoted vertically above one another and when at rest pointed N-S. One magnet carried a pair of contact wires and the other a single wire, mounted in such a way that a small deflection of one magnet relative to the other would bring the wires into contact and fire the mine. The mine was not allowed to come into operation for some time after laying in order to permit the two magnets to settle down in the natural N-S position. The subsequent passage of a steel ship over the magnetic system would then deflect the small magnet more quickly than the larger one and consequently cause firing. I well remember Professor McLennan and F. E. Smith condoling with me when my acoustic mine was so easily countermined, pointing out, of course, that such a thing was not possible with a magnetic mine. But I also remember a little later when the 'purely formal' countermining trials of the magnetic mine took place in Spithead. The hemispherical ground mine (the 'M sinker') was laid and a firing lead from it brought to the 'observing' ship and connected to an indicating bell circuit. The countermining charge, about half a ton of T.N.T., was laid about 100 yards away, also on the sea bed, like the 'M' mine. When the countermining charge was fired the bell rang and continued to ring for at least a minute; the cause, no doubt, being due to the ground shock of the explosion violently shaking both magnets which, in their undamped condition, continued to close the firing contacts intermittently for so long a period. Needless to say, the A.C.M. (anti-countermining) mechanism, shock contact and clock, of my acoustic mine now became a matter of more urgent interest for the magnetic mine! The clockwork delay mechanism finally chosen for this purpose was a modified Ingersoll watch mechanism which could in 1918 be bought very cheaply in large numbers. The magnetic mines were ultimately laid before the war ended, but I have no reliable information as to their effectiveness.

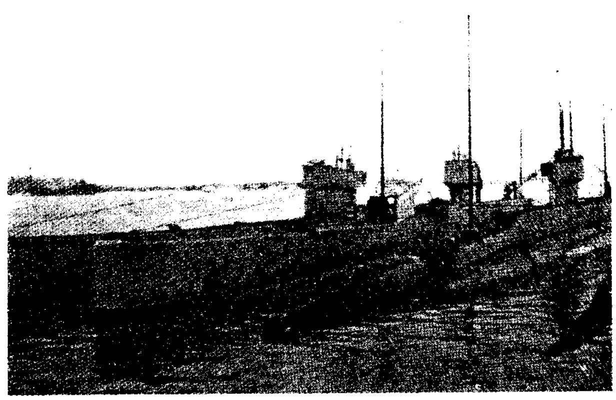
Whilst still at Mining School, in December, 1917, I devised an acoustic firing system known as the 'shunt-relay unit,' which was considerably simpler than the crystal unit, requiring much less current and having a much longer 'life.' In this new system the 'chattering' contact short-circuits a relay, when not in vibration, but allows intermittent direct current (without rectifier) to flow through the relay when the chatterer vibrates (effectively changing its 'shunt' resistance from zero to a high value). This shunt-relay acoustic mine was used extensively and with success during the 1939-45 War.

Soon after returning to Parkeston Quay at the end of April, 1918, I had the good fortune to meet Professor C. V. Boys (who was visiting A.E.S. Admiralty). Whilst discussing with him the 'frequency of chatter' of chattering contacts (used in acoustic mines) and the question of the hardness required in the contact surfaces, he related his experiences with 'a handfull of diamonds.' Pressure of the hand on these, the hardest of materials, caused a piercing squeal, the frequency rising from a comparatively low value to somewhere above the upper audible limit. With the object of making an acoustic mine which required no microphone or chatterer current and consequently would have a very long life after laying. I experimented with what we called 'vibration integrators.' Several forms of these were designed on the principle that the friction between two surfaces in contact is reduced when one (or both) of the surfaces is in vibration. The continued vibrations of a diaphragm have an 'additive' effect on a spring-controlled moving arm which closes a 'local' contact. A simple resetting device was fitted so that the integrator was continuous in action so long as the vibrations were maintained. Such a device in an acoustic mine takes current from the (limited) battery supply only when the diaphragm is in vibration. As a simple alternative to this, for use with the shunt-relay mine mentioned above, I used non-polarising sea-water cells, *e.g.*, carbon-cast iron or carbon-zinc with sea-water electrolyte, capable of supplying a small current (of the order of a few milli-amps) for an almost indefinite period. A 'horn' battery of iron-carbon was all that was required to energise a shunt-relay unit for a very long period (at least equal to the ordinary life of a mine).

This brings me back to May, 1917, when I was using a crystal rectifier as a means of indicating visually the small alternating currents from hydrophones, and as a means of actuating an acoustic mine. About that time also I had several other urgent interests and the day-to-day work was divided between them as circumstances, availability of ships and workshop staff, *etc.*, allowed. I have mentioned previously that we had tested a Marconi 'Round' valve at Aberdour in 1916. A few other types of valve became available in 1917, soon after our arrival at Parkeston Quay. A *Pliotron* valve from G.P.O., a valve amplifier (using small 'Round' valves) from Dr. W. H. Eccles, a 3-valve French Army type amplifier, some 'White' valves (from G.E.C. I think) and one or two more kinds. In July, 1917, the Marconi Co. supplied us with a wireless telephone equipment for use between Parkeston Quay and our ships doing trials a few miles away. I remember the thrill we had when talking from *Hiedra* at the gateships to *Orion* up the River Stour. This equipment contained valve amplifiers, and Captain H. J. Round of Marconi's came to Parkeston Quay to make tests of its satisfactory operation. As may be expected, these valve amplifiers were soon in great demand and proved useful in many ways, to which I shall refer later.

We had several aeroplane raids over Harwich, Parkeston Quay and Dovercourt in which only a few enemy planes took part and not much damage was done. The craters formed by exploding bombs in the mud flats near Parkeston remained water-filled, but exposed at low tide, till the end of the war. A Zeppelin raid over Felixstowe and Essex on the night of June 16th, 1917, provided quite a spectacle. Firing started from Harwich at about 2 a.m. and we could see the Zepp. held in the searchlights and could hear our own planes attacking. At 3.30 a.m. it burst into flames and fell near Saxmundham, a few miles to the north. It had been brought down by Threlfall's 'sticky' (phosphorus) bullets which ignited the escaping hydrogen. (*Note*—At the suggestion of Threlfall, the B.I.R. had formed a committee to consider using helium, obtainable in considerable quantities from natural gas in wells in Canada, to inflate our own airships. This, of course, is non-inflammable but much more expensive than hydrogen.)

In July, 1917, H. Gerrard and I started a series of experiments to explore the stray magnetic field from the electric motors of submarines. At first we took portable multi-turn coils and telephones *inside* 'E' class submarines, and by listening with telephones connected to the coil we could pick up the hum of the motors and other 'noises' which we then ascribed to sparking at the brushes. We also used large multi-turn coils on the drifter *Hiedra*—both horizontal coils around the deck and vertical coils suspended from the rigging. Approaching a submarine with its motors running we could pick up the stray field at distances up to 40 or 50 feet (using a 2-valve amplifier), the vertical coil giving better results than the horizontal. Eventually we laid a 24-turn loop on the seabed between the gateships and listened to submarines, destroyers and other ships passing over it. To our surprise the motor hum was much less noticeable than an irregular noise, of indefinite frequency, which was always associated with the propellers of the ship. Using a valve amplifier, a crystal rectifier and a Brown microphone relay it was found possible to ring a bell as a submarine or destroyer crossed the cable loop. Experiments were made on varying the number of cores of the cable, the width of the loop, and on the effect of armouring. The cause of this variable field ('V.F.' effect as we



'E' class submarines at Parkeston Quay, 1918.

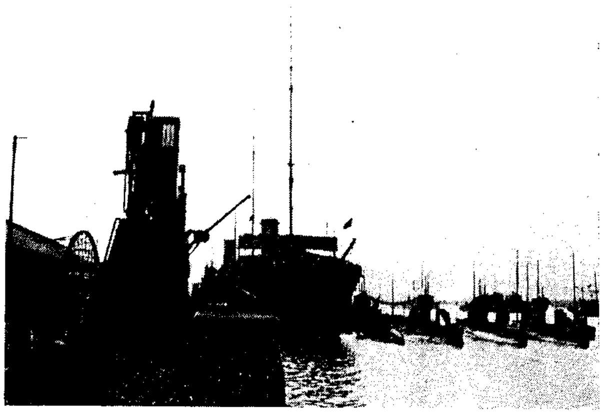
called it) was at first ascribed to transverse and torsional vibration of the propeller shaft and other magnetic structures of the steel ships, but as will be seen later, this was not a sufficient explanation. With this 'magnetic theory' in mind, however, I made some experiments on different lines, based on the assumption that there must be a slowly varying field (or 'C.F.' effect) in a loop of cable as a vessel passed or crossed over it. A simple means of testing this was to use a revolving commutator to convert the slowly varying currents into intermittent current of audio frequency. I tried a 24-coil on *Heidra* but the rolling of the ship in the earth's field induced large currents. These were much reduced by using a crossed 'figure of 8' loop, but there was still considerable effect due to rolling and pitching. Nevertheless, it was still possible to detect an iron ship at 50 yards or so. I next tried the commutator method on a loop laid on the seabed at the gateships. Very strong signals with or without amplifier were observed in the phones when submarines, destroyers and minesweepers crossed the loop. It was found that the sound was at least ten times as loud as the 'V.F.' effect and had three definite maxima as the ships crossed the loop. Inserting a microammeter in series with the loop, I found, on the average, that submarines and destroyers produced a rise of voltage of the order of 14 millivolts in a 250 ohm circuit (*i.e.*, a current of about 50 or 60 micro-amps).

It was soon after this I heard that the loop method of submarine detection had been suggested in November, 1915, by Professor Crichton Mitchell of Edinburgh, who had found that large ships passing over a loop laid in the deep water of the Firth of Forth produced deflections of a sensitive reflecting galvanometer. In my experiments at the gateships, where the water was comparatively shallow, I found that submarines developed currents very much greater than this, *i.e.*, of the order of 50 or 60 micro-amps in a 250 ohms circuit. These observations led to a revival of the 'loop' idea of submarine detection. Both 'indicator loops' and 'controlled mine loops' were rapidly developed. Loops were laid at Dungeness and at Hardelot (near Boulogne) and in the Clyde near Wemyss Bay. But with these much larger loops in deeper water troubles arose which were unforseen at Harwich (with its very small loop between the gateships in very shallow water). Magnetic disturbances due to local tramway systems, magnetic storms, *etc.*, produced galvanometer deflections at times when no surface ships or submarines could possibly be crossing the loops. In these very early days of loops a report came through from Dumpton Gap that the German Fleet was out! But no one else had noticed it.

Eventually, after much painstaking research, using balancing land loops, crossed seabed loops, *etc.*, the system became a standard method of harbour defence. Professor J. C. McLennan, to whom I have referred in connection with magnetic mines, also did some useful theoretical work to determine the most suitable galvonometers for use with loops. He also analysed loop records to determine the magnetic moments of the ships passing over them—information which was useful in the design of magnetic mines.

Whilst this 'loop' work was in progress, F. B. Young had been independently experimenting on electrode signalling with alternating currents of audio frequency in the sea, using silver chloride non-polarising electrodes on towed cables. With a pair of these electrodes towed about 50 yards apart in line astern near a moving submarine, he obtained the so-called V.F. effect much more strongly than Gerrard and I had observed it by the coil or 'loop' method. Young was definitely of the opinion that the observed effects arose from the fact that a submarine (or destroyer) acted as a battery with sea-water as electrolyte, bronze propeller and steel (or zinc-coated) hull as the positive and negative 'plates', and the propeller shaft (connecting propeller and hull) as the 'return' lead. The crackling noise, of indefinite frequency, heard when the shaft revolves being due to irregular electrical contact between the shaft and its bearings. F. B. Young, with the assistance of W. Jevons, Captain Ionides, R.A.F., and Messrs. Brookes and Place, developed this V.F. electrode search gear into a service method for short-range (about 100 yards) detection of submarines. It met with considerable success in 1918 and has also been used extensively during the 1939-45 war—when it was re-named 'U.E.P.' (underwater electric potential). It had its early setbacks, however. When Young took the gear to Scapa Flow it did not work at all well—it was ultimately discovered that the tests at Scapa had been made on a new class of submarine in which the propeller shafts had been mounted with Michell thrust blocks and stern tube bearings of lignum vitae, which more or less insulated the shafts from the hull! Various 'Marks' up to VIII were developed, some with towed electrodes and others with hull-fitted electrodes, the number of electrodes varying from two to five according to the particular use envisaged. This towed silver chloride electrode system has also been used in peacetime for the location of wrecks (which are often good 'corrosion batteries') and of cable faults (in Transatlantic cables off the West Coast of Ireland).

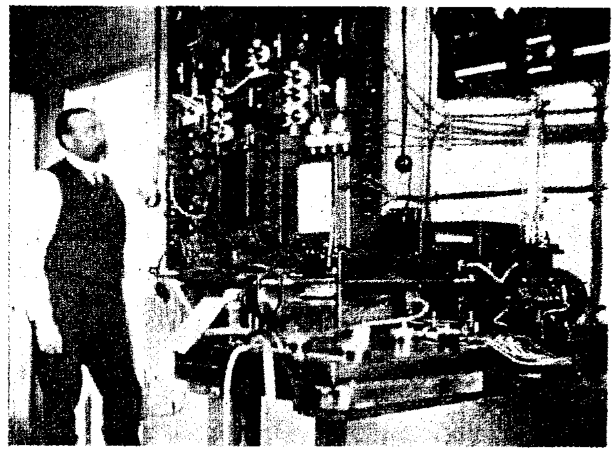
As an interesting diversion from the acoustic mine and 'loop' trials to which I have referred above, we had occasion to test an underwater siren designed by Parson's Turbines of Newcastle-upon-Tyne. This siren was similar in principle to the well-known air siren, but in this case the jet of air which caused the 'holed'-disc to revolve and produce the sound, was replaced by a high-speed jet of water forced through the siren by a water-pump in the ship. On a number of occasions range trials were made in the North Sea about 30 miles out from Harwich. Generally, three ships were used: (1) H.M.D. *Thruster,* operating the siren (F. B. Young, G. Williamson and A. Q. Carnegie on board; (2) H.M. Patrol Boat *P.31,* fitted with service hydrophones on the hull F. Ll. Hopwood and J. H. Powell on board; and (3) H.M. S/M E53, fitted also with service hull hydrophones (Lt. Leslie and myself on board). The programme was to start the trials a few miles beyond the Cork lightship, the submarine to submerge and sit on the bottom whilst *Thruster* left us at a known speed up to a range of about



'E' class submarines and mother ship H.M.S. Maidstone *at Parkeston Quay, 1918*

20 or 30 miles, making recognisable signals on the siren at specified times. The siren signals could usually be heard clearly at ranges up to and sometimes beyond 12 miles, but on one occasion, after Leslie and I in the submarine on the bottom, had heard the first signal at minimum range, not another 'dot' was heard up to the limit of time arranged in the programme. We still continued to wait on the bottom for about two hours, when the submarine commander decided to surface. We had hardly broken surface when the destroyer rushed past us at high speed and very short range measured in yards, creating a certain amount of alarm in the submarine! On reaching harbour the Captain of *Thruster* informed us that the siren ' packed up ' at the start—a piece of cotton waste having blocked the supply pipe. He had no means of letting the submarine know that the trial was a ' washout,' and was getting worried that we hadn't surfaced earlier. I always enjoyed these submarine trips in the North Sea. We got a very good lunch—submariners had preferential treatment (and rightly so) for food supplies in war-time—which, however, was only a minor part of the fun. It would be difficult to imagine a more peaceful spot than the bottom of the North Sea for the enjoyment of a quiet lunch! Sitting quietly on the bottom we could occasionally hear passing ships, even without hydrophones, the sound coming directly through the hull. The water of the North Sea is not very clear. On a sunny day it was only just possible when submerged to see the bows of the submarine from the conning tower window in the diffused light filtering through the water. During the period of the siren trials Sir Charles Parsons came to Parkeston Quay on several occasions. One of his staff, Mr. A. Q. Carnegie, was responsible for the operation of the siren.

Early in 1917 Professor W. H. Bragg suggested the use of a sound-ranging system at sea corresponding to the Army method of locating enemy guns on land. The latter employed the principle that the pressure pulse emitted by a gun on firing a shell can be detected and recorded by a series of hot wire microphones extending along a surveyed base line, using a six-stringed Einthoven recording galvanometer. Knowing the velocity of propagation of the explosion pulse (*i.e.,* the velocity of sound) the position of the gun can quickly be determined. Professor Bragg's son, Captain W. L. Bragg, was in the Army Sound Ranging Corps in France at this time and visited Parkeston Quay occasionally. Using a surveyed base line of about six hydrophones extending over several miles, it was shown to be possible to detect underwater explosions of mines, torpedoes and depth-charges at considerable ranges at sea. This important work was carried out by R. S. H. Boulding. After preliminary work at Parkeston Quay which showed that the method seemed promising, even a small charge at several miles range gave a clear-cut ' break ' on the Einthoven record. Boulding continued his experiments at the hydrophone station at Culver, near Sandown, Isle of Wight. Here he showed that an underwater explosion could be located very accurately. A detonator could be recorded at a range of two or three miles, 9 ozs. of gun cotton at 9 or 10 miles, 2¼ lbs. T.N.T. at 15 or 20 miles. It required much larger charges, around 300 lbs. T.N.T., to obtain ranges of the order 100 or 200 miles. At Culver, Boulding made a careful determination of the velocity of sound in the sea, *viz.* 1,510 metres/sec., an essential quantity on which the whole system of sound-ranging in the sea was based. This involved very accurate survey by the Admiralty Hydrographic Department of the positions of the hydrophones and of the explosive charges. It appeared from these observations, extending over several months, that the velocity of sound was sufficiently constant for sound-ranging purposes. On theoretical grounds it is, of course, obvious that the accuracy of location of a distant explosion increases with the 'projected' length of the hydrophone base lines, *i.e.*, the apparent length as seen from the direction-line of the explosion. In November, 1917, Boulding transferred his activities from Culver to St. Margaret's Bay (near Dover), the Admiralty having decided to set up a service station there, and three others, at Easton Broad (Southwold, near Lowestoft), Flamborough and Peterhead. These four stations, acting singly or combined, could keep watch over a large area of the North Sea, more particularly of the southern part off the Dutch coast. The base line at St. Margaret's Bay was about 70,000 feet, lying approximately North and South. The Einthoven records of five hydrophones and time-marker (seconds, tenths and hundredths) could, by estimation, give the time-intervals between the arrival of an explosion pulse at the various hydrophones with an accuracy of one thousandth of a second. The photographic record was made on a roll of bromide paper which, after exposure in the Einthoven camera, passed quickly through concentrated developer and fixing baths and was ready for inspection in one or two minutes. To keep a constant 24-hour/day watch at first required a continuous photographic record (about one inch per second) using miles of bromide paper! Boulding devised a relay system whereby an explosion pulse arriving at the nearest hydrophone caused a master switch to start up the recorder and switch it off again when the record had been completed by the other hydrophones. This resulted in an immense saving of material and effort (previously involving careful inspection of long lengths of useless record). The St. Margaret's Bay and Southwold stations were used to fix the positions of minefields laid off the Belgian coast with an accuracy within 100 yards at a distance of 20 to 30 miles of the English coast, and in keeping watch on them afterwards. They were also used to fix the position of monitors preparatory to the bombardment and raid on Zeebrugge (23rd March, 1918). I saw the aerial photographs from end to end of the Zeebrugge-Ostende canal covering a large wall in Captain Douglas's[5] office in Dover, when Boulding and I were discussing with him the use of sound-ranging in warfare and in peacetime hydrographic surveying. I remember some years later, 1920-22, after the war, working at the Sound Ranging Station at Cliffe Hut, St. Margaret's Bay, with Commander H. E. Browne, R.N. We were then making a more accurate determination of the velocity of sound in the sea. We were also developing the radio-acoustic method of sound-ranging (not practicable in war-time) when we discovered that one of the North Sea lightships which marked a sandbank was about a mile off the position indicated by Admiralty charts. The Hydrographer was sceptical but we repeated our observations and the French Hydrographic Department confirmed our results—the light-vessel had dragged anchor in a storm and subsequent to the latest survey by our own Hydrographic Department! As I have just indicated, sound-ranging work was continued at St. Margaret's Bay (and Southwold) for experimental purposes for several years after the war. I shall refer to this later.



Sound-ranging recording equipment at Easton Broad, Southwold, Suffolk, during First World War.

Although the greater part of the work at Parkeston Quay was concerned directly with anti-submarine problems, there were other interesting developments which could hardly be regarded in this way. Sound-ranging, to which reference has just been made, was one of these. Another, known as 'Leader Gear,' was designed to enable a ship to steer along a cable laid on the seabed. The cable was supplied with alternating current of audio-frequency (about 500 c/s.) interrupted as a recognition signal, and the ship was provided with port and starboard coils, about three feet square with their planes vertical and parallel to the centre-line of the ship. These coils were mounted on the ship's side plating abreast of the bridge. The coils were connected via a 3-valve amplifier to headphones and a 'port' and 'starboard' switch connected to the coils as required. The signals received were loudest when the direction of the ship was parallel to the cable and with the coil vertically above it,

(5) Subsequently Admiral Douglas, Hydrographer of the Navy.

the ship being steered so that strong signals were received at equal intensity on the two coils; if the signals were unequal, then steer towards the coil having the louder signals. In operation, the ship would follow a slightly zig-zag course. Such a leader cable was laid from Felixtowe for a distance of about 40 miles seawards, and towards the end of the war in November, 1918, arrangements had been made to fit some of the ships of the Harwich destroyer flotilla. This system was developed mainly by Captain Manson and H. R. Rivers-Moore at Parkeston Quay. At this time Colonel A. S. Eve was R.D.R., Professor W. H. Bragg having gone to the Anti-Submarine Department at the Admiralty. Another leader cable was laid in the approach channel to Portsmouth Harbour.

Dr. C. V. Drysdale, who joined the Parkeston Quay staff early in 1918, was interested in the leader cable problem, but was not directly concerned in the "audio" system of Manson and Rivers-Moore. He devised a controlled mine firing system which combined both acoustic and electromagnetic devices, and which became known as the 'A.C. Unit.' In this system a large loop of cable laid on the seabed surrounded a number of mines which could be selectively detonated or 'locked' by a hand-operated switch on shore. This switch caused alternating current to flow through the loop cable and to induce secondary A.C. in coils wound on each mine sinker inside the loop. This secondary current operated a sensitive tuned A.C. relay in each mine, about 25 ampere turns in the loop operating a mine 25 yards away. In addition to the A.C. relay, there was in each mine an acoustic device (my shunt-relay system, mentioned above) which operated a second relay when the noise of a ship near the mine was sufficiently intense. In the combined acoustic-A.C. unit the approach of a submarine could be indicated to the shore operator either by using the loop as an indicator, in series with a reflecting galvanometer (described above), or by independent observation of the actuation of an acoustic relay. Closure of the A.C. circuit through the loop surrounding the minefield would then (a) fire the mine or mines in which the acoustic unit was operating, or (b) 'lock' the mines in which it was not operating. The locking device prevented the closing of the acoustic relay if it was not being actuated by sound, so that reverberations set up by the explosion of the mine which fired could not cause the firing of mines which had not been actuated acoustically by the submarine. The frequency used in the A.C. unit was 10 cycles per second, the attenuation in sea-water at this frequency being very small within the dimensions of the loop. Dr. Drysdale was assisted in the development of the A.C. unit by L. Hartshorn, R. S. J. Spilsbury and A. C. Jolley. When it was transferred to Stokes Bay for sea trials, W. A. Day of Mining School, Portsmouth (later Mine Design Department, and now A.U.W.E.) also assisted. Mention of the names of Hartshorn and Spilsbury reminds me of a commemorative epitaph which they composed after months of hard work on the A.C. unit at Parkeston Quay . . .

Here Archie Charles, that sainted man,
Lingered for many a day
In peace he passed his mortal span
In pieces passed away.

At this time I suggested an alternative system, in which the 'firing' and 'locking' was operated by a direct current through a cable connecting all the mines together. This D.C. system also dispensed with the indicator loop, using preferably the actuation of one of the acoustic relays as a signal to close the main firing and locking switch. Neither the A.C. unit nor the D.C. alternative were ever used under service conditions—the war ended too soon! Dr. Drysdale's work on the A.C. unit did, however, raise a number of important problems relating to the propagation of low-frequency electromagnetic waves in sea-water, about which relatively little information was available at that time. It also led him to propose an alternative to the audio-frequency system of leader gear mentioned above. In this alternative, very low frequency sub-audible alternating current was passed through the leader-cable and the current induced in the ship's port and starboard coils operated 'red' and 'green' lights—making use of the sensitive A.C. relays which he had developed previously for the A.C. mine unit. As most of the visual leader cable work was done after the Parkeston Quay days I shall refer to this later.

Towards the end of June, 1918, Dr. A. O. Rankine and several other members of Parkeston Quay staff were transferred to Dartmouth to form a sub-station of A.E.S. Parkeston Quay. Dr. R. W. Boyle, W. F. Rawlinson, J. Anderson and - Brookes on Asdics; A. L. Hughes on towed hydrophones; W. Jevons and H. Gerrard on electrode search gear; and R.N.V.R. Lieutenants G. F. Partridge, Lunt and Nightingale were others of the scientific staff; and D. Bradbury, J. Elliott, G. Stephenson and W. D. Vick were the mechanics transferred from Parkeston Quay—not forgetting *Amy* (Commander Littlehales), *Heidra* and Submarine *C.8*. I cannot write as much about the work at Dartmouth as I could wish, as I remained at Parkeston Quay and never actually visited A.E.S. Dartmouth. I shall, however, be referring later to Asdic developments which started at Parkeston Quay and were continued at Dartmouth after June, 1918—a little more than four months before the Armistice. At Dartmouth H. Gerrard obtained some interesting records using a pair of silver chloride electrodes widely spaced across the channel. The records showed clearly the periodic e.m.fs developed in the sea by tidal flow in the earth's magnetic field. The electrodes and techniques used in making the records were those developed by F. B. Young at Parkeston Quay for submarine detection. I believe R. W. Paul was a frequent visitor to Dartmouth where he continued his experiments on magnetic mine units on the lines of his preliminary work at Parkeston Quay. Dr. Rankine and his family lived at the Royal Dart Hotel, Kingswear, which was taken over by the Admiralty for the laboratories and workshops of the sub-station.

Another line of development at Parkeston Quay which, however, did not reach 'service condition' by the end of the war, in November, 1918, was that of silent propulsion of anti-submarine vessels. The noise of 'own-ship's' propellers was an ever-present difficulty to ships using hydrophones in locating enemy submarines. Various suggestions had been made at Parkeston Quay during 1917-18 to reduce this noise, by using propellers of special types, bubble-screens, *etc.* Sir John Thornycroft had suggested hydraulic or jet type of propulsion, and Major J. H. W. Gill, R.E., had independently been led to the same conclusion as the best method for the silent propulsion of ships. In 1918 Major Gill, who was in charge of our engineering staff at Parkeston Quay, carried out a series of experiments to check theoretical points and to disprove certain fallacies regarding this method of propulsion. He made laboratory experiments to check the properties of various forms of nozzles projecting a jet of water under water, and to make measurements with a scale model of a large centrifugal pump. A further series of experiments was made with a 20 ft. steel lifeboat, with different types of pump impeller and designs of reversing buckets, also with different areas of discharge nozzle. Two trawlers, the *George Ireland* and *Henry Jennings*, were allocated to be fitted with hydraulic propulsion equipment. These were not ready for tests, however, until the A.E.S. Parkeston Quay was transferred to Shandon in 1919.

During the war much work was done on the improvement and applications of radio-telegraphy and telephony, *e.g.*, on sub-marine reception of W/T signals, I.R. signalling, and remote-control by W/T. Most of this work was being done at Signal School, Portsmouth, and we were not directly concerned at Parkeston Quay. Dr. W. H. Eccles, who was a member of the W/T Committee of the B.I.R., and occasionally visited Parkeston Quay, also played an important part in radio investigations, his experimental work being centred at Finsbury Technical College. In a recent conversation Dr. Eccles told me that Dr. R. W. Boyle did much of his early Asdic work at Finsbury Technical College before transferring to A.E.S. Parkeston Quay. Dr. Eccles was mainly responsible for the design of the Rugby wireless station and other similar stations around the globe. He liked to tell the story about his world tour to inspect some of these W/T stations after they were completed. On the arrival of his ship at one of them, in Samoa, he found the pier lined on each side with local beauties to greet him. On enquiry as to the reason for this unexpected demonstration he was referred to the W/T signal which had been received notifying his arrival: 'Professor Eccles, the wifeless expert, will arrive tomorrow . . . ' — a striking demonstration showing how an error in a single letter of a radio-signal might have serious consequences!

I have referred here and there at Aberdour, and now at Parkeston Quay, to efforts that were made to make metrical observations in underwater sound. At Parkeston Quay I used a calibrated crystal rectifier in the measurement of small microphonic currents under a wide variety of circumstances, ship noise, water noise, machinery noise, cavitation, *etc.* Towards the end of 1917, and intermittently afterwards, I made Einthoven oscillograph records of the noises made by ships and by underwater explosions in Stokes Bay near Portsmouth and at the gateships, Harwich. I required, however, a much smaller and more portable oscillograph so that I could conveniently take it on board any one of our ships and make records of submarine propeller noises outside the harbour. I worked on this with J. T. Irwin, who joined our staff at Parkeston Quay in 1918. In the end we produced a simple, if not perfect, oscillograph which we called an 'optiphone.' It was made by converting a Brown reed-telephone earpiece, employing a small optical lever to magnify the motion of the tip of the vibrating cantilever reed when microphonic currents are passed through the windings. We used this optiphone to record the propeller noise of our own submarines to obtain a wave form of the sound. We had a great thrill when we went out on M.L. 14 to make sound records of German submarines handed over at the Armistice in November, 1918. On several occasions (20th, 21st, 22nd and 27th November, 1918) we were out at the Cutler lightship near the 'rendezvous' to meet 87 German submarines. We made records using all sorts of hydrophones (diaphragm types, rubber 'chunks') and I tried to record echoes from the submarines by firing small No. 9 detonators a few hundred yards away and using a 'chattering contact' type of receiver. I had previously obtained echo-records of explosion pulses from our own ships near Parkeston Quay by firing detonators.

I have left to the last what has proved to be the main achievement at A.E.S. Parkeston Quay —ASDICS. For the sake of historical accuracy, reference must first be made to a suggestion made at the time of the *Titanic* disaster, in April, 1912, when this magnificent liner was sunk on its maiden voyage by collision with an iceberg in fog. The suggestion was made by L. F. Richardson that a beam of supersonic ('ultrasonic' now) waves should be used as a means of detecting submerged objects such as icebergs or wrecks, by 'echo'. No method of doing this, however, had been achieved before the war. The idea was revived by Paul Langevin and M. Chilowski in March, 1915, when they began experiments in Paris. In 1916 Langevin succeeded in producing vibrations of 100 kc/sec., in water, using mica as a dielectric subjected to Maxwell electro-static stresses (near the breakdown voltage) at this frequency. To receive the signals, he used a microphone with a tuned 'L.C.' circuit, as in W/T. With this arrangement and using a valve amplifier, he obtained a signalling range of about 3 km. and an echo from a large iron plate at 100 metres. This work, although not in itself of great practical importance, marked a definite advance. In August, 1916, the B.I.R. took a more serious interest in the 'echo' system of submarine detection, and Professor R. W. Boyle (Canada) was put in charge of the experiments. He came to A.E.S. Parkeston Quay in 1917 and was later assisted by W. F. Rawlinson and J. Anderson. The mechanic mainly concerned in making and maintaining his experimental equipment was George, one of the three brothers Edgar, George and James Stephenson, mentioned above. Of all methods tried by the French, ourselves and later by the Americans, the most successful proved to be that which utilised the piezo-electric properties of quartz (discovered by Pierre and Jacques Curie in 1880). Although the possibility of using quartz was seriously considered in 1916, nothing of importance was done about it as we had no knowledge then of high gain amplifiers[6]. Langevin was the first to try a plate of quartz as a receiver. Used in conjunction with a valve amplifier this gave very promising results. At Parkeston Quay good progress was made when French amplifiers became available. It is not my purpose here to enter into a discussion of piezo-electric phenomena in quartz, tourmaline, Rochelle salt and similar piezo-electric materials. Suffice it to say that in our state of knowledge in 1917 quartz was rightly considered to be the best available material. The problems of slicing it from the natural crystal into the most efficient piezo-electric slabs, the choice of thickness and voltage limits to be applied in transmission, the mounting of the quartz slices in mosaics to cover a suitable area and so on, had all to be worked out theoretically and experimentally. In the autumn of 1918 J. Anderson (later Chief Scientist, A.S.W.E.), when stationed at Dartmouth, was supervising the cutting and testing of quartz from large natural crystals at the Geological Survey Museum, then in Jermyn Street, under the guidance of Dr. H. H. Thomas (petrologist). The actual cutting of quartz for Asdic supplies was done by Farmer & Brindley, a firm of tombstone makers in Lambeth (a firm accustomed to cutting marble slabs!) The cut crystals were eventually assembled into Asdic transducers by Callender's Cable Co., Erith. I remember the earliest models were non-resonant at the frequency contemplated for use. The semi-angle θ of the primary beam, following standard optical theory, is given by $\sin \theta = 1{\cdot}22\ \lambda/D$ where λ is the wavelength of the sound and D the diameter of the transmitter/receiver. The greater the diameter relative to the wavelength the narrower the beam and the greater the energy concentration. At Parkeston Quay and at Dartmouth the whole process was one of our best-kept secrets. It was referred to in conversation and correspondence by the code name 'Asdics'—meaning 'Anti-Submarine Division-ics'. The 'ics' at the end of the code word had the same significance as in words such as physics, statics, dynamics, kinetics, electronics, acrobatics, *etc.* meaning 'pertaining to', the initial syllable(s) of such words usually being abbreviations. No reference to quartz was permitted, the code name being in this case 'ASDIVITE', the 'A.S.D.' referring to anti-submarine division, as before. When experience had been gained with 'outboard' experimental equipment, the 'Asdic' transmitter was eventually mounted in a dome or in a streamline case, let down through the bottom of the ship. In this way it was always surrounded by still water at all speeds of the ship. A controlling device was fitted by means of which the Asdic could be turned through any horizontal angle and also could be given a variable vertical tilt. Range and bearing observations on surface ships gave good results. The sea trials of Asdic equipment were carried out mainly from the barge on the River Stour and from the drifter *Hiedra*, with occasional trips to sea in ships of the Harwich Flotilla, such as H.M.S. *Melampus*. On a surface ship of 700 tons, stern-on, a range of 1,400 yards was obtained with very accurate direction. With a large submarine the maximum range 'surfaced'

[6] I have previously referred to Sir Ernest Rutherford's 'tentative' experiments with quartz in 1915.

would be about the same, rather than when submerged. During the the last four months of the war the Asdic section of Parkeston Quay was transferred to the Dartmouth sub-station, as I explained earlier. At the end of the war Asdics was coming into its own. The experimental period was just reaching the ship-fitting and development stage when the war ended.

Paul Langevin and M. le Duc de Broglie visited Parkeston Quay occasionally. I met Langevin at the end of July, 1917, and again in 1918, when he had a general look around the laboratories and the work on loops at the gateships, but, of course, was more particularly interested in Boyle's work on Asdics.

The research at A.E.S. Parkeston Quay virtually ended on 11th November, 1918, the date of the Armistice. I first heard that the war was over when I was boarding one of our ships to go out to the gateships at Harwich. When the captain told me of this startling news and said I should be wasting my time going on with 'what I was going on with', I experienced a kind of shock, but with in indescribable feeling of pleasure that it was all over. The wonderful fireworks and searchlight displays and the hooting of all the ships at Parkeston Quay and Harwich all through the night was an experience not likely to be forgotten.

Work at A.E.S. still continued, however, in a somewhat semi-enthusiastic way, completing half-finished jobs and wondering " what next." I have referred earlier to some sound recordings I made as the surrendered German submarines approached Harwich. They came in groups of 20 on each of the days of 20th, 21st and 22nd November, and a later batch of 27 on the 27th November. They were tied up to a specially laid system of moorings up the River Stour a little further to the west of Parkeston Quay, the German crews being tran-shipped and returned to Germany. It was a very interesting experience clambering over and inside these submarines, inspecting their equipment, radio, hydrophones, torpedo tubes, mine-laying equipment, *etc.* Some were put into the floating dock where we could see the under-side. I still have three valves from one of the submarines. They have *iron* fittings holding the glass bottle — Germany, thanks to our attentions, being rather short of brass, copper and tin in those days. I remember making measurements, with Lieutenant Wells, of the characteristic curves of a number of these valves (Telefunken and others).

On the day of the Armistice, 11th November, Colonel A. S. Eve, R.D.R., circulated a notice to all members of the staff, requiring, ' before 25th November,' information on: (*a*) Date of joining; (*b*) An outline of work carried out by that member of the staff; (*c*) A list of reports and patents; and (*d*) Recommendations as to future developments ' . . . and concluded, in referring to the future ' as the policy of the Admiralty is not yet known ! ' At Parkeston Quay we were all appointed on a temporary basis and some of us, including myself, were wondering whether to return to university work, industrial research, or to ' hang on ' to see what prospects the Admiralty could offer. F. B. Young and B. S. Smith and I stayed on. A. O. Rankine, F. L. Hopwood and Gerrard returned to their university work. My diary states that on 8th February, 1919, the experimental work at A.E.S. Parkeston Quay came to an end. On 11th February I left for a few days home-leave on my way to the new A.E.S. at Shandon, Dunbartonshire. I had lunch with Sir Ernest Rutherford

Photograph taken at Toulon in May, 1918, showing centre, Professor R. W. Boyle with Professor P. Langevin on his left.

at Manchester. At the University I met J. Chadwick (now Sir James) whom I had last seen in Manchester in August, 1914, when he was just *leaving* for Germany. He had just *returned* from Germany, having been interned at Ruhleben since the outbreak of the war. He looked very thin and underfed, and was unable to digest normal food, particularly anything of a fatty nature. His 'home' for a long period in Germany had been in the loft of a barn. Here, with occasional help from Hans Geiger in the supply of very simple apparatus, he persevered in the measurement of the atomic weight of one of the elements. I don't remember that he ever published the result of this research, but at least it served the purpose of preserving his mental balance !

I mentioned earlier that towards the end of 1917 (or early 1918) Professor W. H. Bragg, who was then R.D.R. at Parkeston Quay, transferred to the Admiralty, to become Scientific Adviser to the Director of the Anti-Submarine Division, his position as R.D.R. at Parkeston Quay being taken by Professor A. S. Eve. Other changes in the B.I.R. organisation were taking place, also. In January, 1918, the position was as follows:

Board of Invention and Research

I. CENTRAL COMMITTEE

Admiral of the Fleet Lord Fisher (President).
Professor Sir J. J. Thomson, O.M.
The Hon. Sir Charles A. Parsons.
Sir George T. Bielby.
Charles H. Merz (Director of Experiments and Research).

II. DEPARTMENT OF THE DIRECTOR OF EXPERIMENTS AND RESEARCH

Director: Charles H. Merz.
Deputy Director: Lt.-Col. W. McLellan.
Naval Assistant: Capt. Alan M. Yeats-Brown, R.N.

III. REPRESENTATIVES IN THE TECHNICAL DEPARTMENTS OF THE ADMIRALTY

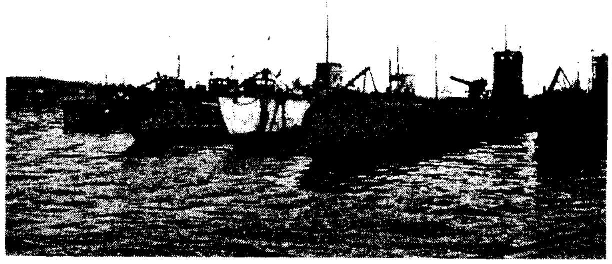
(1) *Anti-Submarine Division*
Professor W. H. Bragg, P. V. Hunter.

(2) *Department of the Director of Torpedoes and Mining*
Mining Section: Professor J. C. McLennan, F. H. Clough.
Wireless Section: Professor W. H. Eccles, F. E. Smith.

(3) *Department of Engineer-in-Chief*
Sir Dugald Clerk, A. E. L. Chorlton, and others.

So far as the scientific work at Parkeston Quay was concerned, these changes in the organisation of the B.I.R. made very little impact. In addition to the familiar faces, some of the new members of the Board, Mr. Merz, Colonel McLellan, Mr. Hunter, Mr. Clough, also came down occasionally to Parkeston Quay. At the end of the war, in November, 1918, Mr. C. H. Merz, D.E.R., submitted a memorandum to the First Lord of the Admiralty, dealing with his proposals for a new organisation of research and experiment in the Navy. This involved the closing down of a number of wartime research establishments including Parkeston Quay and Hawkcraig (still functioning under Captain Ryan). It recommended that Shandon (then used by the Lancashire and Clyde Anti-Submarine Committees), which was well-adapted as regards buildings and situation, should be made into a permanent experimental station for Naval research. It was also proposed to establish a Central Research Institution for the Navy—involving a new establishment and a new building, the director to be a man of high scientific attainments !

The net result of this was, as I have said, A.E.S. Parkeston Quay closed down at the beginning of February, 1919, and many of its staff transferred to Shandon, Gareloch (Clyde).

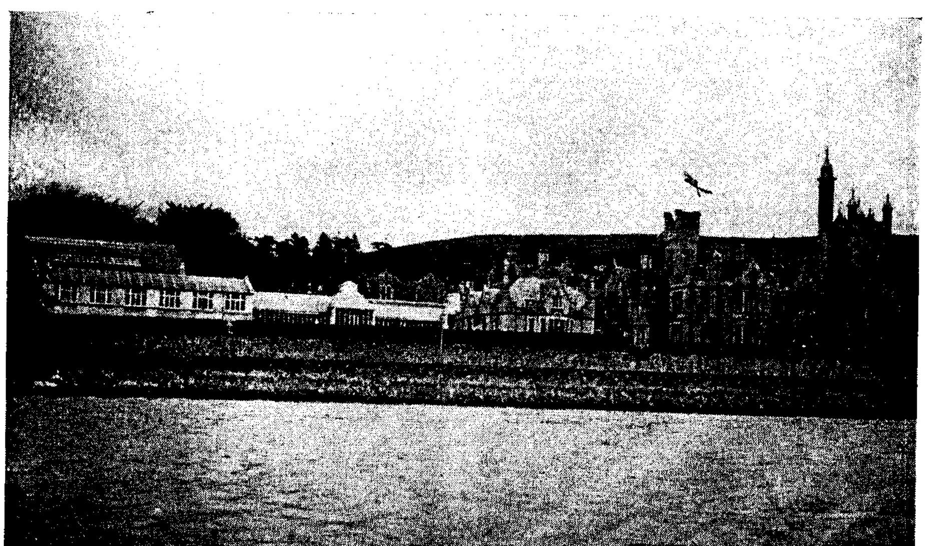


German submarines at Parkeston Quay, November, 1918.

ADMIRALTY EXPERIMENTAL STATION, SHANDON (GARELOCH) DUNBARTONSHIRE

The transfer of the Admiralty Experimental Station from Parkeston Quay (Harwich) to Shandon (Gareloch), which nominally commenced early in February, 1919, took place in fact during a period of one or two months. As I have said, some of the scientific staff returned to their pre-war jobs in universities and elsewhere whilst others decided to stay on in Admiralty research work despite the obvious uncertainties regarding its continuation. Professor W. H. Bragg had already returned to his pre-war duties at Gower Street (London University) and Professor A. S. Eve had decided to go temporarily to Shandon as Resident Director of Research. Professor Bragg's post as Scientific Adviser to the Admiralty was taken up by Professor J. C. McLennan. Somewhat vague promises were made by Professors Eve and McLennan to the scientific staff regarding appointments and salaries, but it was not until nearly one and a half years had elapsed that, in July, 1920, anything definite emerged. As may well be imagined, the transfer of staff, ships, workshops and scientific equipment was very disturbing, and this, combined with the change-over from war to peace conditions resulted in an unsettled feeling at Shandon which persisted for some time. However, most of us succeeded eventually in settling down to steady work on a more or less long-term basis. My last contact with Parkeston Quay was on 26th February, 1919, and after a few days leave I arrived at Shandon on 7th March, 1919. There I found Colonel (Professor) A. S. Eve already installed as R.D.R., Major J. H. W. Gill as Superintending Engineer, and Dr. C. V. Drysdale as Chief Physicist. At the end of March, however, Colonel Eve retired from Admiralty service and left A.E.S. Shandon. His post was temporarily filled by Major Gill, who became Acting Director.

'Shandon Hydropathic' was a magnificent stone-built edifice on the eastern shore of the beautiful Gareloch, palatial in comparison with the somewhat primitive wooden huts at Hawkcraig and Parkeston Quay. The buildings of the Hydro were situated in extensive grounds stretching from Garelochside up the hill to the West Highland Railway (Craigendoran to Arrochar). Further up the hill was the private golf links of the Hydro, and over the hill led to lovely Glen Fruin, famous for its trout stream of exceptionally clear water, subsequently used in the Glen Fruin Admiralty Water Entry Station. The Hydro, at this time changed to Admiralty Experimental



A.E.S. Gareloch—'Shandon Hydropathic'

Station, Shandon, is on the road from Helensburgh to Garelochhead about two and a half miles from Row (Rhu) and two miles from Garelochhead. The establishment was well provided with facilities for recreation—besides the golf course it had hard tennis courts and two indoor swimming pools, not to mention yachting possibilities on Gareloch and walking and rock climbing around Arrochar. It might be assumed that all this was not conducive to hard work, but the bracing climate neutralised any tendency to an easy life! In the main building was a splendid dance hall (with sprung floor), a large dining room, a lovely drawing room (which appropriately became the drawing office), and many bedrooms which housed a large proportion of the unmarried members of the staff. A large conservatory, divided into cubicles, became for a time the research laboratories, and a high-roofed building of large floor-space adjoining the main building was used as the main workshop. Housing accommodation for those who did not live in the Hydro was to be found eventually in Helensburgh, Row and Garelochhead, Shandon being a very small village with little or no spare accommodation. Brown's bus plying between Helensburgh and Shandon was chartered by A.E.S. to carry staff to and from the Hydro. It was a somewhat ramshackle affair to be careering at its top speed (not very high) on the narrow and tortuous road along the lochside. I remember on one occasion when its radiator, minus cap, was boiling furiously, John Anderson remarking to the delectation of the Hydro passengers: "What'll you have—a cup o' tea or a shave?"

I remarked earlier that Shandon was well adapted as regards buildings and situation for use as a Naval research station. Besides the capacious, if somewhat imposing, buildings, it was near the lochside, had two private piers giving easy access to deep water, whilst Gareloch itself, about five miles long (N-S) and three-quarters of a mile wide at Shandon, was almost landlocked, enclosed on three sides by hills, and connecting to the Clyde via a narrow strait (200 or 300 yards across) between Row and Roseneath peninsulars. There was, therefore, a probability of reasonably calm water for experimental purposes throughout the year. An occasional severe storm was, however, not unknown!

The scientific and engineering staff remaining at Shandon at the time of the transfer from Parkeston Quay were Professor W. M. Thornton, Messrs. W. Ryley, F. Widdowson, F. O. Hunt, A. Stubbs, H. Forman, K. Kemp, D. A. Keys, and J. M. Ford. They had hitherto been controlled by the Lancashire and Clyde Anti-Submarine Committees. Most of these, with the exception perhaps of D. A. Keys and J. M. Ford, left Shandon within a few months after our arrival from

The Staff of Admiralty Station, Shandon, 1919.
The Author is fifth from the right in the centre row.

Parkeston Quay. In addition, there was a considerable number of ground staff, mostly female, who dealt with the housekeeping side (dining and bedroom facilities, *etc.)* essential to the upkeep of the Hydro; tracers, typists, messengers, boatmen and so on. The scientists and engineers transferred from Parkeston Quay, in addition to those already mentioned and myself, were F. B. Young, B. S. Smith, W. Jevons, W. F. Rawlinson, J. Anderson, G. F. Partridge, J. H. Powell, W. M. Burgess, and D. V. Hotchkiss. C. M. Hubbard and Mr. Staddon were in charge of general stores, L. O. Cook instrument stores, and in the workshop were C. Menkens (manager), T. P. Rigby, J. Elliott, V. Allerton, H. Midgeley, E. W. Dowsett, L. Pogson, —. Kent, G. H. Jessop and others. As an indication of the attractiveness of the young ladies employed in various capacities at Shandon, no less than five or six of them subsequently married members of our scientific staff! I could supply their names on request! We had also at Shandon R.N. staff attached to the A.E.S. Captain G. L. Massey, R.N., was the Senior Naval Officer, Commander Cusack, R.N. (Accountant, Paymaster), Lieut.-Commander Garratt, R.N. (Officer-in-Charge, Ships), Lieutenant B. C. S. Martin(7) (R.N.), Lieut.-Commander H. W. Fawcett, R.N.(8) (Captain of H.M.S. *Auricula).*

Our fleet of ships included H.M. Trawlers *George Ireland, Robert Barton, William Inwood, Henry Jennings, Ebro II,* H.M. Yacht *Dotter,* H.M. Sloops *Auricula, Teviot, Blackwater,* M.L.s 478 and 498, and H.M. Drifter *Hiedra.* The last-named, which had done good service from the early Aberdour days, was paid off and presumably returned to her fishery duties at Anstruther (Firth of Forth) at the end of April, 1919.

When at Parkeston Quay I had become interested in underwater explosion expirements being made by H. W. Hilliar at Troon in Ayrshire. Prior to the Troon experiments I had met Hilliar at Norway House (the B.I.R. Headquarters) where he was developing a new mechanical method of determining the maximum pressure and the form of the pressure-time characteristic of an underwater explosion. He was then calibrating copper crusher gauges at Norway House, using a compressed air gun to accelerate steel pistons which on impact crushed small annealed copper cylinders (½ in. long and ⅓ in. dia. app.) against a steel 'anvil'. At that time the copper crusher gauge method was in use at Woolwich Arsenal to measure pressures in gun barrels when firing a shell. Hilliar used a series of steel pistons in his gauges, of various masses and lengths of travel in their steel cylinders. The outer ends of the pistons were exposed to the pressure of the underwater explosion impulse, the momentum of the piston being equal to the time-integral of the impulse. The energy of the piston is measured from the shortening of the copper cylinder, and by the aid of the calibration experiments the momentum of the piston at the moment of impact was deduced. This gives a measure of the time integral of the pressure in the water. Using a series of gauges with different lengths of piston-travel, the velocities and accelerations could be calculated, and a pressure-time curve of the explosion impulse determined. Hilliar's method gave a remarkably close estimate of maximum pressure and the pressure-time diagram of an underwater explosion. His experiments were made with various sizes of charge (up to about 2,000 lbs. of T.N.T.), and different explosives (T.N.T., Amatol, Ammonium Perchlorate and gunpowder). The observations showed that the maximum pressure was inversely proportional to the cube root of the weight of the charge. I have a copy of a letter which he sent from Troon on 12th December, 1918, to Colonel Eve(9) at Parkeston Quay giving a summary of his earlier experimental results. A final report of his work, giving details of his method and results, was printed in R.E.142/19, dated 14th June, 1919. It is of some interest to note that at this date the report, on its opening page, is addressed to "Professor J. C. McLennan, O.B.E., F.R.S., Scientific Adviser to the Admiralty: Sir, I have the honour to submit the accompanying report . . . 14th June, 1919." A few days after my arrival at Shandon, early in March, 1919, Dr. Drysdale and I visited Hilliar at Troon to see the explosion of a 1,600 lb. Amatol charge. Hilliar was then not only measuring maximum pressure and pressure-time sequence, but also damage to structures (using empty spherical mine shells as targets) at various distances from the charge. H.M. Drifter *Malapert* was used in his experiments at Troon, the executive arrangements and the working party being under the direction of Lieut.-Commander D. Errington, R.N. Hilliar was assisted in the design of pressure gauges and in carrying out the experiments by F. K. Lidstone.

At Parkeston Quay there was no 'hard and fast' organisation of scientific staff in relation to research work. Staff were allocated almost from day to day in accordance with the relative urgency of the work in hand. This arrangement worked all right under war conditions. At Shandon, the

(7) Became Admiral Martin in the Second World War. Was Captain of the cruiser *Dorsetshire,* which played an important part in the sinking of the German 45,000-ton battleship *Bismarck,* 26th May, 1941, in the Second World War

(8) Author of 'The Fighting at Jutland'— descriptions of the battle which disabled the German battle fleet in the First **World War.**

war being ended, the staff were allocated to groups, each group being primarily concerned with certain aspects of research related to Naval problems, although considerable flexibility of the group system allowed scientific staff to initiate their own problems regardless of the 'nominal' group 'title'. Monthly reports were issued[10], each group submitting its report to the Chief Physicist (Dr. Drysdale) for editing. The first of these reports, for the month ending 31st March, 1919, indicates the nominal work of the groups A to K and the scientific staff available to do it.

A. Electrical Instruments and Mining. (Dr. C. V. Drysdale, J. H. Powell, J. A. Craig, and E. Stephenson).

B. Electrode Search Gear. (F. B. Young and W. Jevons).

C. Acoustics. (B. S. Smith, G. F. Partridge and G. Burnside).

D. Asdics. (R. W. Boyle [11], W. F. Rawlinson and J. Anderson).

E. Explosions and Sound Ranging. (A. B. Wood, J. M. Ford, and F. W. Hill).

F. Loops. (Lt. F. K. Kemp, R.N., T. A. Daniell, and H. Forman.)

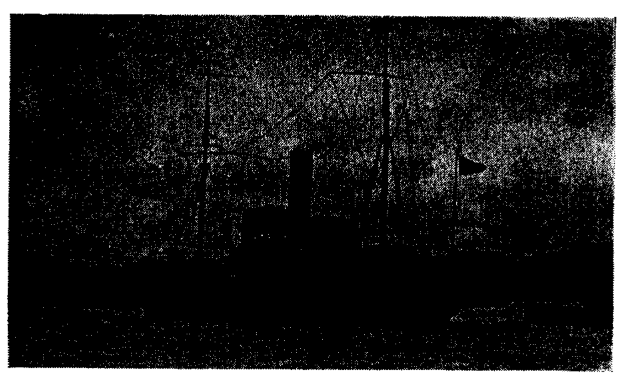
G. Laboratories. (L. O. Cook.)

H. Silent Propulsion. (J. H. W. Gill, D. V. Hotchkiss, and M. W. Burgess.)

J. Unattached. (D. A. Keys.)

K. Underwater Spark Signalling. (Dr. W. M. Thornton, F .O. Hunt, and A. Stubbs.)

Reference has been made to a visual system of Leader Gear which Dr. Drysdale was planning as an alternative to the aural system being developed at Parkeston Quay by Captain Manson and H. R. Rivers-Moore. At Shandon, Dr. Drysdale made extensive experiments on the visual system. Cables were laid (the depth varying between 10 to 20 fathoms) from Shandon to Garelochhead and to Row, extending to the full length (about five miles) of the loch. These cables were supplied with low-frequency (10 c/s) alternating current with earth return from the distant ends of the cables. H.M. Sloop *Auricula* and H.M.T. *William Inwood* were used in the trials. They were fitted with coils (with their planes at right angles approx.) running from mast to mast (forward and aft of the ship) about 25 ft. above the lower deck and extending halfway up to the W/T antennae. Spreaders 20 ft. wide inclined the two coils at an angle of about 45° to the vertical. Sensitive tuned A.C. relays were designed by Dr. Drysdale assisted by J. H. Powell and J. A. Craig, operating on about half a millivolt. These when connected to the coils operated red and green lights indicating the position of the ship relative to the cable on the sea bed. An additional white light was introduced which was operated at maximum sensitiveness of the A.C. relay and was used to give the navigator of the ship a relatively long-range indication of his approach to the cable. When the white light appeared he could switch to a somewhat less sensitive setting (controlled by suitable resistances in the relay circuits) for operation of the port and starboard lights. It was found, however, that the correct relationship between depth of water, current in the cable and sensitiveness of the A.C. relays was somewhat critical in order to obtain reliable port and starboard indications. Otherwise it was likely that 'ambiguous' indications would be obtained. As early as March, 1919, such ambiguities had been observed with currents of 10 amps in the cable in depths of 5 fathoms. Experimental curves of field distribution showed that the E.M. field became horizontal at distances of 70 or 80 yards to one side of the cable and that the limiting range for reliable steering was only about half this distance. Dr. Drysdale tried further experiments with coils inside and outside the hull of *Auricula* in order to ascertain the effects of coils beneath the water and of the screening effect of the hull as in aural leader gear. The observed ambiguities of indication which I have very briefly mentioned led him to start an extended investigation of the field



H.M.T. William Inwood. Showing the coils from mast to mast below the W/T antennae.

[9] A remark in this letter is of interest concerning Rutherford's early interest in Asdics: "A long time ago you sent me a request which was forwarded to me here, for copies of Rutherford's original note proposing the piezo-electric method for generating supersonics. I forwarded this to Victory House, with the B.I.R. number of the paper in question, and asked them to attend to the matter . . . the docket in question was charged to the A.S.D. to whom, in consequence, your request has been referred." I have no information in regard to further action.—A.B.W.

[10] A.E.S. Shandon Monthly Reports—March, 1919, to 15th January, 1921—Most of these are in existence at N.S.T.I.C. today.—Ed.

[11] Visiting Shandon occasionally.

distribution around an A.C. cable on the sea-bed. At first he tried to do this by using the coils on *Auricula* sloped at different angles, but ultimately he abandoned this approach and fitted up a barge, the *St. Adrian*, which could traverse slowly and investigate point by point the vertical and horizontal A.C. fields above the sea surface at different measured distances from the cable. In these experiments Dr. Drysdale was assisted by L. Champney and S. J. Willis. These early experiments showed unforeseen distortion of the E.M. field above the surface of the sea which could account for the ambiguities observed in the operation of the visual leader gear. The field distribution experiments were, however, seriously interrupted by a storm which wrecked the *St. Adrian* on 3rd December, 1920. In the absence of a suitable barge, sea experiments were of neccessity discontinued and work was concentrated on devising improved apparatus for exploration of weak E.M. fields of low frequency such as might be anticipated in the sea experiments. Untuned instruments were required to indicate E.M. fields at distances extending out to 300 yards or so from the cable. Resistance capacity type valve amplifiers proved useful in achieving this. Towards the end of 1920 Dr. Drysdale also made tests of the Portsmouth Leader Cable at 500 c/s which was of the type similar to that which had been proposed for a leader cable between Dover and Calais. As a result of these tests he prepared detailed designs for this cable and the power supplies necessary to operate it efficiently. It was proposed also, if considered necessary, to insert auxiliary acoustic transmitters at intervals along the cable which would facilitate long-range ' pick up ' of the cable by ships requiring to use it. For this purpose B. S. Smith's ' diaphragm sounders ' were being considered. This work on the Dover-Calais leader cable was urgently ' in hand ' just before we left Shandon for A.R.L., Teddington. So far as I am aware, however, the cable was never laid. Other activities in which Dr. Drysdale's group were concerned were a sensitive ' open-circuit ' vibrating contact for application in acoustic mines. J. H. Powell worked very patiently on this for a long time, but its adjustment was too critical for the device to have any ' service ' value. Dr. Drysdale also designed a ' Chromoptometer ' for testing colour vision of service personnel; also a gyro-compass damping device which used a heater wire mounted in the liquid-filled compass bowl near a line of thermo-junctions, a slight tilt of 20 or 30 seconds of arc causing a relay to operate from the thermo e.m.fs in 10 seconds of time. With J. M. Ford's assistance, Dr. Drysdale also designed and had constructed a Continuous Depth Indicating device using an E.M. impulse transmitter and a sensitive single-contact receiver. This equipment was only completed just before we left Shandon in 1921 and was never used for its designed purpose. The impulse transmitter served as a very useful large inductance in experiments I was doing later at A.R.L., Teddington, on explosion pressure recording.

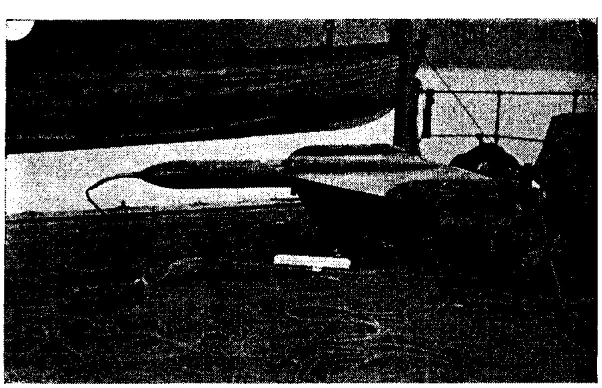
Work on the electrode search gear, developed at Parkeston Quay for short-range submarine detection, was continued at Shandon by F. B. Young and W. Jevons. The standard silver chloride electrodes used in this equipment were initially depolarised by passing a current through them for a suitable period of time. This depolarising charge is gradually lost by continued immersion in the sea and has to be repeated periodically. Young and Jevons investigated various ways of prolonging the period of effective use and laid down rules to be followed for this purpose. They also developed a technique for using the electrode search gear for detecting cable faults and applied it in locating a fault in a transatlantic cable some considerable distance out into the Atlantic from Ballinskelligs Bay, S.W. Ireland. The method requires the use of (audio frequency) alternating current in the cable to be tested, the electrodes being used to detect the E.M. field around the cable up to the point of ' break.' At Shandon the screening effect of armouring on the cable was also studied. In another application the use of an automatic firing mechanism for anti-submarine explosive paravanes was considered, but it was decided that such an automatic device was unlikely to be satisfactory. It was recommended that if electrodes were to be employed with such paravanes they should be used for observation only, the firing being controlled by hand. Electrode search gear was also used to locate submerged wrecks which were generally a potent source of electrolytic e.m.fs. I mentioned previously that widely spaced electrodes across the tideway at Dartmouth were used to record the flow and ebb of the tides, the e.m.f. varying sinusoidally due to the electrically conducting sea water flowing in the Earth's magnetic field. The results of these

Electrode search gear developed by F. B. Young.

observations were subsequently published by F. B. Young, W. Jevons and H. Gerrard.

During the Shandon period steady, if not spectacular, progress was made in improving Asdic Quartz transmitters, both mechanically and electrically. The work in this section was done by W. F. Rawlinson and J. Anderson, with occasional visits to Shandon of Dr. R. W. Boyle, who had been in charge of the work at Parkeston Quay and Dartmouth. *Hiedra, Ebro II* and *Auricula* were fitted with experimental gear, but, as I stated earlier, *Hiedra* left Naval service at the end of April, 1919, *Ebro II* was fitted with a retractable Asdic dome on the centre line of the keel. Two 10-inch diameter quartz transmitters operating at 43 kc/s. were made up for tests at Shandon. Later experience showed that in spite of the advantage of small size at higher frequencies it was preferable to use lower frequencies for long-range echo detection. By this time an Asdic group under A. E. H. Pugh and Lt. Nightingale was operating from the Signal School in the R.N. Barracks, Portsmouth, with H.M.S. *P.59* as the experimental ship. Rawlinson and Anderson left A.E.S. Shandon on transfer to H.M. Signal School in February, 1920, to take charge of the Asdic group there. The Asdic team was then controlled by W. F. Rawlinson with J. Anderson as Chief Assistant, L. S. Alder and E. A. Logan as Assistants, with Messrs. Pugh, Trigle and Kent as engineering designers.

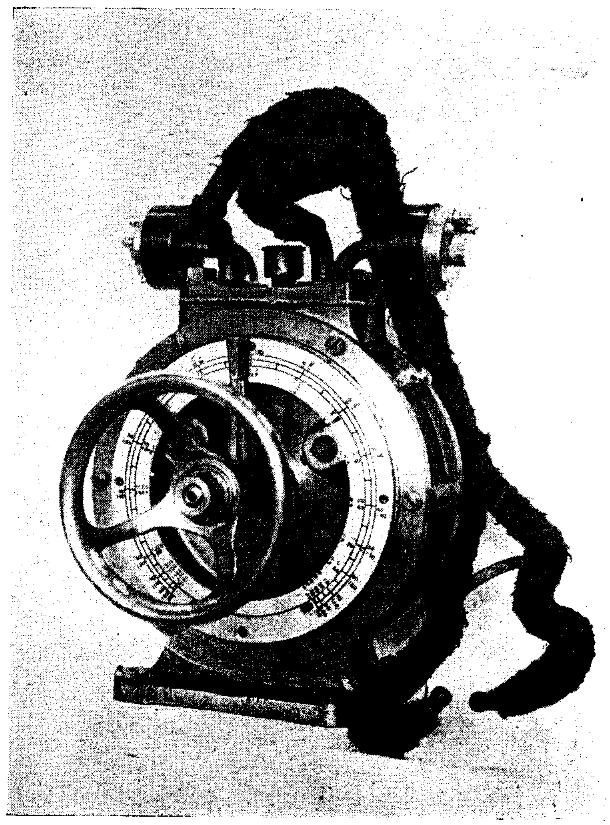
The acoustics group at Shandon, consisting of B. S. Smith and G. F. Partridge, later assisted by E. V. Mackintosh (from Malta) were involved in a number of projects, some of which had been taken over from the departing staff of the Clyde and Lancashire A.S. Committees. One of these latter projects was a steam jet underwater sound generator, frequencies ranging from audio to ultrasonic. This had been invented by Mr. Petrie of the College of Technology, Manchester. There were two types of this steam jet apparatus, one known as the 'disc' and the other the 'rod' type, the steam jet impinging from a short distance on a central hole in the disc or the end of the rod, the frequency of the principal note being of the order 1,000 c/s. in the audio equipment. The force of the collapsing steam bubbles was sufficient to cause pitting of the disc. The deflection of the jet from the centre of the hole changed the note, and when playing on a flat surface without a hole the sound intensity was considerably reduced. It was claimed that ranges exceeding 10 miles had been obtained with the disc screen. Several forms of towed hydrophone were also tested, one, bearing some resemblance in shape to a modern jet plane, being known as the 'Lancashire Fish,' which contained a binaural system of hydrophones for determining the direction of a source of sound. In conjunction with this, several forms of 'compensator' — binaural and unidirectional — were examined. Tests were also made of a Malta pattern liquid-filled microphone. This consisted essentially of a very short and small diameter hole at the tip of a glass tube connecting two containers filled with copper sulphate. Sound vibrations caused microphonic changes of resistance of the liquid in the small orifice. In addition to the testing of this and other novel forms of microphone experiments were made to improve less sensitive but less noisy and more reliable forms of magnetophone. The latter, when used in conjunction with a valve amplifier, was comparable in sensitivity with unamplified carbon granule microphones and had a much quieter 'background.' Some of these magnetophones, inboard type, were fitted to Great Eastern Railway boats operating between Harwich and Antwerp, their purpose being mainly to listen to sub-marine bells mounted on marker buoys and lightships, *e.g.*, West Hinder and Sunk, to assist navigation in foggy weather. I have referred to the diaphragm sounder which was designed for use on the Dover-Calais leader cable. This was operated by a laminated 'hammer' actuated by a solenoid, the anvil being a heavy boss on the centre of the 10 in. dia. diaphragm. The main frequency of the complex sound emitted by this sounder was approximately 500 c/s. Plans were also being made by B. S. Smith and his group towards the end of 1920 to use a smaller version of such a diaphragm sounder, 5 in. in diameter, as the sound transmitter in a system for continuous echo depth sounding. Hydrophones, already in supply, were to be used as receivers and a commutator for transmitting regular timed signals was designed. The principle of depth measurement envisaged at that time was similar to that which Fessenden had used formerly, but subsequently at A.R.L., Teddington, this was improved considerably.



The Lancashire Fish towed hydrophone.

Another investigation, begun by B. S. Smith at Shandon and later continued at Teddington, was an attempt to produce a high-frequency alternative to quartz for use in Asdics. Several designs were considered: (1) a moving conductor type; (2) a moving iron type; and (3) a diaphragm sounder type. Of these (1), the moving conductor type, seemed to give most promise. The moving conductor consisted of a straight strip of duralumin about 2 ft. long, free to vibrate between the poles of a powerful electro-magnet. The conductor was supported on a number of legs, the longitudinal stretching of these legs combined with the mass of the strip (vibrating 'edgewise'), being arranged to give a natural frequency of vibration of the conductor of 10 kc/s. The extremity of each leg was in one piece with a block of duralumin screwed to the underside of the central pole of the magnet. A large alternating current at 10 kc/s. would therefore cause the dural strip to resonate and emit sound into the water from its upper free edge (about 0·1 in. wide). A thin sheet of rubber served to make the system watertight. whilst permitting sound to be transmitted from the vibrating edge of the strip to the water. This H.F. transmitter was nearly completed when we left Shandon for Teddington early in 1921. B. S. Smith afterwards modified the design, using a circular or 'ring' transmitter instead of the long 'strip' type. The circular ring was a resonant duralumin structure of improved design, vibrating in a powerful annular magnetic field, large H.F. alternating currents being induced in it by a similar principle to that used in the audio frequency Fessenden 'oscillator.' Consideration was also given to the design of a high-frequency sounder using the longitudinal vibrations of a steel rod, suitably supported, and excited by a hammer blow at one end.

Eight months after our arrival at Shandon, Major J. H. W. Gill, acting director since 31st March, 1919, retired in December, 1919. In his work on hydraulic propulsion to produce a relatively silent ship for submarine hunting, he was assisted by M. W. Burgess and D. V. Hotchkiss. By June, 1919, sanction had been obtained for a crew for H.M. Trawler *Henry Jennings* to be allocated, but otherwise there was not much progress to report. H.M. Trawler *George Ireland*, on the other hand, had been fitted with jet propulsion equipment and in a dock trial at Southampton had registered a pull of over 4 tons at the designed revolutions, which was regarded as easily sufficient for the requirements. The vessel attained a cruising speed of 8 knots over the Stokes Bay (Portsmouth) measured mile with a maximum speed of 9½ knots. From observations made on these trials the ship was comparatively silent, but further tests were to be made at Shandon. It was reported that the ship 'handled' very well and the reversing gear made manoeuvring a simple matter. After these trials the ship was sent to Wivenhoe for completion. My own impression of the ship after she arrived at Shandon was that she was considerably quieter than a propeller-driven trawler at the same speed, but that her engines and gearing were abnormally bulky for a ship of that size, the engines occupying the equivalent of both engine room and cargo space of a conventional trawler. Of course, in view of the purpose for which it was designed, *viz.* anti-submarine work, this feature was perhaps not very important.



Compensator for binaural direction finding.

Experiments at Shandon were also made with a 60 ft. steel launch which was fitted with Kitchen's patent reversing rudders to enable the boat to be equipped for comparative tests at the same h.p. and r.p.m. using either a screw propeller or hydraulic propulsion. A model hydraulically-propelled boat was designed by D. V. Hotchkiss and was completed in July, 1919. It was a scale model of a 220 ft. twin-screw minesweeper — the model being battery-driven. Preliminary tests showed that the model 'was able to travel ahead or astern, to steer without the use of a rudder, . . . and to turn about an axis without appreciable headway or sternway.' I believe that small jet-propelled boats were found later to be very suitable for navigating in shallow weedy water in the Fen District and in the Norfolk Broads area. I am not aware whether or not jet-propelled ships were used for anti-submarine or minesweeping purposes during the 1939-45 war.

Professor W. M. Thornton from Newcastle-upon-Tyne was experimenting with a method of underwater signalling when we arrived at Shandon in early 1919. In this method he used A.C. high voltage to produce intense sparks which could be heard of a hydrophone at a range of five miles, *i.e.* the full length of Gareloch. He sometimes used multiple spark heads, absorbing about 1 kW. per spark, which it was stated could be heard in air

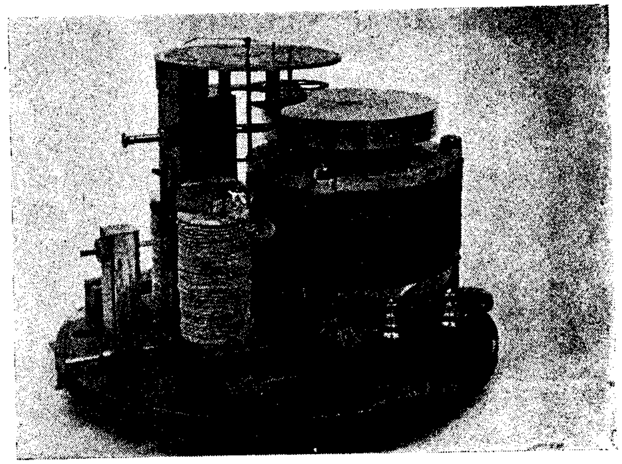
Magneto machines at the South Foreland Lighthouse, St. Margaret's Bay

at a distance of 1½ to 2 miles. Professor Thornton was assisted in these experiments by F. O. Hunt and A. Stubbs. He occasionally visited Shandon after his return to academic work at Newcastle. L. Champney, who came later to Shandon to work with Dr. Drysdale, and afterwards moved with us to Teddington, was I believe one of Professor Thornton's students at King's College, Newcastle-upon-Tyne.

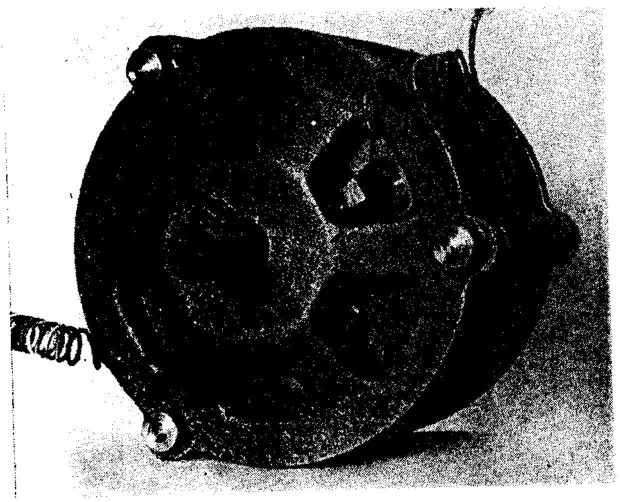
My own work at Shandon was concerned with underwater sound ranging and explosions. I suppose I inherited this from Parkeston Quay days when perhaps I showed an 'abnormal' interest in Boulding's sound-ranging work at Culver, I.o.W., and St. Margaret's Bay (near Dover), and when I became involved in the design of acoustic non-contact mines at Mining School, Portsmouth. Be that as it may, when I reached Shandon in March, 1919, I began to work on an alternative sound-ranging scheme to the one in service use at Dover during the war. The standard method used a line of 4 or 5 hydrophones, carbon granule microphones mounted on watertight metal diaphragms on tripods resting on the seabed, the recording being made on an automatic 6-stringed Einthoven photographic recorder. In the system I was proposing the carbon granular microphone was to be replaced by a single microphonic contact which, although quite unsuitable for the faithful recording of underwater sounds, was very sensitive for recording the arrival of a sudden shock such as the pressure pulse produced by a distant explosion under water. Such sensitive contacts, mounted on a stainless steel diaphragm and generally referred to as 'chattering contacts', could handle currents considerably greater than those generated in the secondary circuits of microphone transformers. Consequently they were suitable for the operation of much more robust recorders than the Einthoven string galvanometer. I had made some preliminary experiments at Parkeston Quay with a smoked drum recorder running at a constant speed, driven by a phonic motor (Rayleigh type) controlled by a low-frequency tuning fork. An electromagnetically-operated moving iron reed carrying a recording stylus, was actuated by the current passing through the 'chattering contact', in this case a spring controlled balanced wheel mounted to make contact on a boss at the centre of the receiver diaphragm. At Shandon J. M. Ford worked with me on this system of sound ranging. We succeeded in designing and constructing much more powerful iron-clad phonic motors [12] to replace the relatively feeble phonic wheel. We also improved the design and reliability of the low-frequency tuning fork which controlled the motor. After a certain amount of experimenting we abandoned the smoked drum chronograph for recording the time intervals and designed what we described as a phonic chronometer. This may briefly be considered as a stop-watch (or rather stop-clock) operated electromagnetically and fitted with three sets of dials for measuring three independent time intervals. The speed of the chronometer is governed by a tuning fork and phonic motor giving an accuracy of 1 in 10,000. Time intervals are indicated directly on the dials to 0·001 sec. The chattering contact explosion pulse receivers were designed to 'hold off' after the first break, this being necessary for use with the chronometer. Using three shock receivers, A, B, and C, the arrival of the shock wave at the nearest one, say

[12] See *J. Sci. Instruments*, 1 (1924) 160-173, and 'A Text-book of Sound', A. B. Wood. G. Bell & Son Ltd.

A, starts two of the dials AB, AC, the arrival next at, say, C, stops AC and starts CB, and the arrival at B stops dials AB and CB. The three time intervals measured in this way are sufficient to give the position of the explosion source relative to the three hydrophones. Single dial phonic chronometers of this type have had many other applications for the direct and accurate measurement of time intervals. For example they have been used for many years for the calibration of shell fuses. At Shandon the three-dial chronometer was tested by repeated sound-ranging trials in Gareloch and was used to measure the velocity of sound (small amplitude explosion waves) over an accurately surveyed base line at different times of the year, the velocity varying with the temperature of the water. Comparisons of these velocity



The first single dial phonic chronometer 1919.

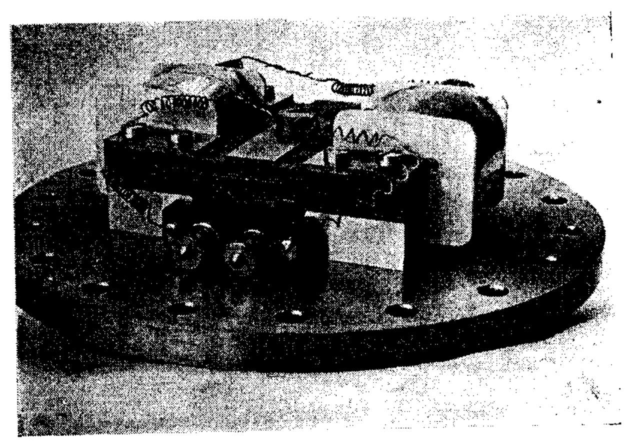


First ironclad phonic motor developed by the Author and J. M. Ford.

measurements in Gareloch were made with those made by Cdr. H. E. Browne, R.N., at St. Margaret's Bay, Dover, in the course of which the salinity coefficient of velocity was estimated—the salinity at St. Margaret's Bay being $35^{0}/_{00}$ and in Gareloch $28^{0}/_{00}$. The low salinity of the seawater in Gareloch is explained by the fact that the loch is almost landlocked and is fed by numerous fresh-water streams from the surrounding hills. Whilst this work was in progress at Shandon we had occasional visits by Cdr. H. E. Browne, R.N. (from St. Margaret's Bay S.R. Station). In September, 1920, a conference was held in D.S.R's office at which D.S.R. (F. E. Smith), C. S. Wright, Cdrs. Trischler and Browne, and myself, were present to discuss the questions of accurate sound velocity measurements and radio acoustic sound ranging at St. Margaret's Bay. The following day we all visited St. Margaret's Bay to survey the 'scene of operations'. This work was eventually carried out after A.E.S., Shandon, transferred to A.R.L., Teddington. Further reference will be made to an accurate determination at St. Margaret's Bay of the velocity of sound in the sea under different conditions of temperature. The three-dial phonic chronometer tested at Shandon was made by L. O. Cook[13].

In continuation of the work I was doing at Parkeston Quay, further improvements were made in vibration integrators for use in acoustic non-contact mines and A.C. relays. The latter, untuned, would operate reliably on 5×10^{-8} watt in the audio frequency range. Experiments were also made with quartz strip and biplate electrostatic oscillographs.

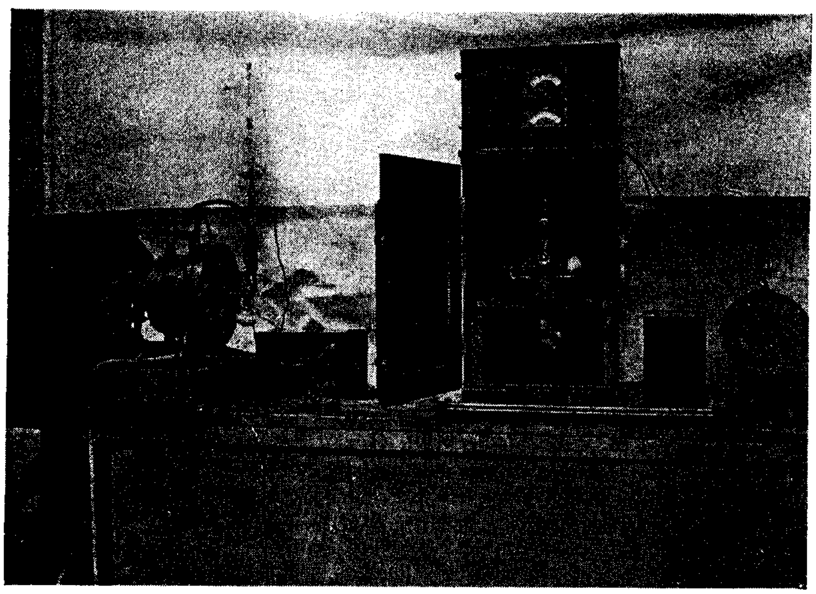
An interesting device described as an 'induction micrometer' was designed by J. M. Ford. This was an electromagnetic method of measuring small displacements. In principle it consisted of a pair of laminated iron-core transformers having a common laminated iron armature with 45°



Induction micrometer by J. M. Ford.

sloping faces forming two equal air gaps with the main cores. The transformer primaries were connected in series and supplied with a small intermittent or A.C. current, the secondaries being connected in opposition through a suitable measuring instrument. When the two air gaps are equal the secondary e.m.fs just neutralise each other. Displacement of the armature to one side or the other upsets the balance of e.m.fs and the meter gives a measure of the displacement. In its application the transformers were rigidly fixed in a reference position whilst the armature was attached to the moving element. Intermittent D.C. was supplied to the two primary circuits using a motor-driven commutator with two contact rings, one ring serving to make and break the primary current whilst the other ring served to cut out the galvanometer at 'make' only. The device was very sensitive, displacements of the order 10^{-4} in. being easily detectable. The design was supplied to Admiralty Engineering Laboratory to test as a torsion meter for engine shafts and was eventually used in measuring the torque and consequently the power transmitted by propeller shafts in ships.

I have referred above to the explosion pressure research at Troon in which H. W. Hilliar was using the copper crusher gauge technique very successfully to obtain a point-by-point pressure-time characteristic of an underwater explosion. Although these experiments represented an important advance in the study of explosion phenomena they were in a number of ways incomplete. An elegant solution of the problem of recording explosion pressures was suggested by Sir J. J. Thomson[14]. In the method proposed the pressure is applied to a layer of piezo-electric crystals, quartz or tourmaline were suggested, and generates a proportional electric charge. The charge is to be recorded instantaneously by means of a cathode ray oscillograph, the record giving the pressure-time sequence of the explosion. This method, which eliminates lags due to inertia and gives a continuous record, was being developed at Shandon by D. A. Keys when we arrived from Parkeston Quay in March, 1919. Using J. J. Thomson's original e/m cathode ray apparatus (which should have been preserved as a 'museum piece') and pressure gauges of quartz and tourmaline. Keys had made records of explosions of 2¼ lb. guncotton charges. In making these records his oscillograph was mounted in a hut on shore, the charges and piezo-electric gauge being suspended, at appropriate depths and distances apart, from a nearby raft. An overhead line carried the electric charge from the gauge to the oscillograph in the hut. The cathode ray tube was evacuated by a hand-operated backing pump and a Gaede motor-driven mercury pump. To



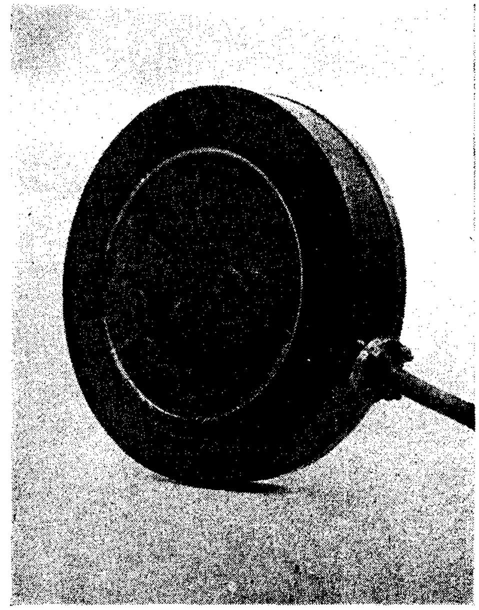
Cathode ray oscillograph and apparatus at Shandon 1919 - 20

[13] Further instruments were made by the Cambridge & Paul Instrument Company to a design prepared by J. M. Ford, and single dial instruments of a much simplified design were made later by H. Tinsley & Co.

[14] See *Engineering*, **107** (1919) 543.

reduce the time interval between switching on the cathode rays and the detonation of the charge a double switch was used. The time base for the recordings being A.C. at 70 c/s., the cathode ray spot was, of necessity, on the photographic plate for an appreciable time before and after firing the charge. This generally resulted in serious fogging of the plate obscuring a considerable part of the record. In addition to this, most of the time of exposure of the cathode ray spot was spent at the turning points of the A.C. base line. Consequently there was a strong probability that a part of the explosion pulse would appear at that part of the base line where the x velocity of the spot was zero. This in fact is what often occurred. In his records Keys often recorded large negative pressures which he ascribed to surface reflection with reversed phase. I shall refer to this later. His results can be seen in Shandon monthly reports between April and September, 1919, and were published later[15]. The work was, of course, in its early teething stages and considerable difficulties were encountered in obtaining good recording spots, whilst vacuum leaks, electrical leaks, *etc.*, were not infrequent. Prior to his leaving Shandon, I was asked to take over and continue the work Keys was doing on recording underwater explosions. On 2nd September we went from Shandon to Troon in H.M.T. *Robert Barton* with the intention of recording the explosion of a number of 300 lb. Amatol (ammonium nitrate and T.N.T.) charges, the arrangements being directed by Lt-Cdr. Errington, R.N., who had worked with Hilliar at Troon. Unfortunately the apparatus which had been used in the hut at Shandon proved in many ways to be unsuitable on board ship, and two days later we had to return to Shandon to effect necessary repairs. We returned again to Troon about a fortnight later with even more disastrous results. Failure of the vacuum apparatus, cracking of improvised waxed joints and occasionally of glass tubes due to vibration when the ship's engines were running made it again necessary to abandon the enterprise and return to A.E.S., Shandon. Soon after this, in September, 1919, Keys left Shandon for the U.S.A. and I became responsible for further work, in additon to the normal work of Group E. From what Keys had already done it was clear that the method was workable in principle but a complete re-design of oscillograph and vacuum arrangement were necessary, the A.C. time base was obviously unsuitable, and the large negative pressures (tensions) in the water were of doubtful reliability. In his earlier experiments Keys had used quartz crystals and had failed to record an electrical charge even when shortening the range

[15] *Phil. Mag.*, **42** (1921) 473.



5 inch diameter tourmaline explosion pressure gauge for use with the C.R.O. 1919

to the point of pulverising the crystals. Apparently it was not then realised that quartz was quite unsuitable for use with hydrostatic pressure, as the charge developed by pressure on the faces of the quartz crystal was neutralised by an exactly equal and opposite charge developed by pressure on the edges. In the case of tourmaline, on the other hand, the 'face' and 'edge' effects are both of the same sign and hydrostatic pressure produces the maximum effect. Eventually Keys used small irregular tourmaline plates of the order 1 in. linear dimension and 3/16 in. thick, only sufficient to cover a small area of gauge surface. As a consequence of these earlier difficulties the whole system of recording explosion pressures by the piezo-electro cathode-ray method was re-designed. A more robust and reliable cathode-ray oscillograph, new piezo-electric gauges and pressure calibration apparatus were designed and a linear time base was substituted for the A.C. time base. This involved a considerable amount of work, commenced in October, 1919, and continuing (unfinished) at the time of our leaving Shandon in January, 1921. The new C.R.O. was designed to reduce the amount of glassware to a minimum—a robust glass bulb for the discharge tube and a plate glass window for observation of the fluorescent screen. As in J. J. Thomson's apparatus the cathode rays were arranged to fall directly on to the photographic plate when making a record, and in the new C.R.O. the door of the camera formed also the fluorescent screen which was removed when making an exposure. At first the camera was designed to use a roll film with an electromagnetic arrangement to wind it. This was a failure, however, due to dessication and consequent cracking of the film in the vacuum, as well as the considerable increase of pumping time required to dry out the film. Paget 'half-tone' plates and later Schumann plates were eventually used, quarter-plates ($4\frac{1}{4} \times 3\frac{1}{4}$ ins.) being cut into four pieces $2\frac{1}{8} \times 1\frac{5}{8}$ ins. in size. The filaments used in the C.R. tube were either tungsten or lime-coated platinum wire surrounded by a small cylindrical sheath which served to converge the cathode stream on to the pinhole anode. Vacuum-type greased conical plugs fitted in the side of the C.R.O. were used (1) to open and shut the door of the camera when making a record and (2) to rotate the hexagonal block carrying the photographic plates, this enabled the operator to make six records without the necessity of opening up the C.R.O. and admitting air. A circuit containing a large inductance was provided to obtain a single linear traverse of the cathode-ray spot when making a record. This was found to be a great improvement on the A.C. time base method, and nice 'clean' records were made of A.C. wave forms and later of explosion pressure-time impulses. For the latter purpose it became necessary to invent a pressure-switch operated by the explosion pulse in the water at a definite instant (about 0·001 sec.=5 ft. distance in water). The p/t record, lasting one or two milliseconds only, falling on the middle of the photographic plate, the total time of the spot crossing the plate being of the order of about three milliseconds. This method eliminates the uncertainty of time delays in firing the detonator. A fresh supply of black tourmaline was obtained for the construction of explosion pressure gauges. The first of these were 5 in. effective diameter with a tourmaline layer embedded in vaseline on each side of an aluminium disc. Trouble was at first experienced with the new supply of tourmaline as the cut slabs (about 1 cm. thick) contained veins of electrically conducting material, mainly iron oxide, and it was demonstrated theoretically and in the laboratory that the electrical leaks thus provided could result in pressure-time records apparently showing considerable negative pressures following the applied positive pressure pulse. Chemical treatment, *e.g.*, boiling in aqua regia, removed the iron oxide with satisfactory results. A high pressure calibration apparatus was constructed which permitted test of piezo-electric gauges up to approximately 1 ft. in diameter. A self-sealing pressure joint was designed for the steel cover plate (1 in. thick) and a thin copper diaphragm about $1\frac{1}{4}$ in. diameter, sheared by a hand-operated circular cutter, provided a sudden release of the hydrostatic pressure (up to $\frac{1}{2}$ ton per sq. in.) applied to the piezo-electric gauge. This method of pressure calibration of gauges proved very useful and reliable, giving not only the maximum pressure on bursting the copper diaphragm but also an indication of the rate of leak of charge from the gauge, a quantity which must be negligible over a time of 5 or 10 milli-seconds when making explosion records. An A.C. time base was used at first in calibrations but this was replaced by a linear (repeated) traverse with 'flyback' by means of a rotating potentiometer.

It should be noted that in making explosion records by the method I have described above no amplification of the piezo-electrical counterpart of the pressure impulse was then possible for fear of introducing distortion. The electrical charge developed on the piezo-electric gauge in the water a short distance from the explosive charge was conveyed to the C.R.O. either via an overhead line or a low-capacity cable in the water. It was essential to keep this capacity C as low as possible and to use a sensitive low-voltage oscillograph to record the piezo-electric charge Q so that the deflection voltage V (equal to Q/C) is as large as possible. The oscillographs used in these explosion experiments were the first low-voltage hot cathode oscillographs capable of recording high-speed phenomena, impulses and H.F. alternating current waveforms, in a single traverse[16]. The apparatus and techniques which I have briefly described above were subsequently improved and applied at Mining School (Mine Design Department), H.M.S. *Vernon*, Portsmouth, and at Teddington. I shall have to refer to further developments when I write later about the early days of the Admiralty Research Laboratory at Teddington.

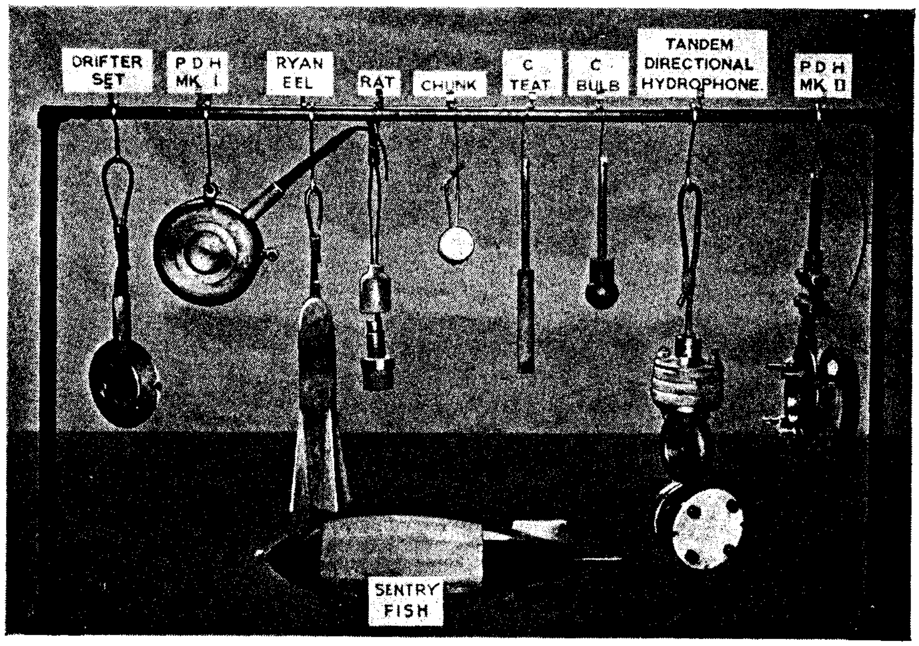
I have referred above to the more important items of research which were in progress at A.E.S., Shandon, between February/March, 1919, to January, 1921. There were others, *e.g.*, loop investigations and analysis of ships' signatures to derive their magnetic constants, this work being done by Lt. Kemp and Mr. Forman. I have said very little about personalities, visitors and social activities. In May, 1920, there was an outbreak of smallpox in Glasgow and many of the staff, particularly those likely to visit or to cross Glasgow on their way south to meetings in London, had to be vaccinated by a Naval doctor at Shandon. An interesting event was the planting of a commemorative tree in the grounds by Captain Massey, R.N., some time during 1920, with a few coins sprinkled amidst the roots. I wonder if it still stands—I was told that the Hydro has since been demolished. We were described in the local Press as Admiralty 'limpets' desecrating the loch-

[16] See papers by A. B. Wood: *Phys. Soc. Proc.*, **35** (1923) 109: *Journal I.E.E.* (1925) 1,046 and A.R.L. *Report*, S/12, 1924 (A. B. Wood and E. H. Lakey).

side with our activities in Gareloch and around the Hydro ! We all regarded this as a libel. What the reporters thought of the relatively recent desecrations, long after our departure, can only be imagined ! In the two summers during which we occupied the Hydro we gave parties in the grounds for the local children of Shandon and Garelochhead. These parties were very popular. We had occasional visitors, the First Lord of the Admiralty, and later, Admiral Commanding the West Coast of Scotland (20th September, 1919). J. C. McLennan, then Scientific Adviser to the Admiralty came on 11th April, 1919; I think that was the last time I saw him. F. E. Smith visited us on 23rd October, 1919—he had then succeeded McLennan to the title of Scientific Adviser to the Admiralty.

on 4th April, 1919, I heard that Sir Ernest Rutherford had been elected to the Cavendish Chair of Physics at Cambridge. I had lunch with him at Manchester on 30th June, a few days before he left Manchester University to succeed 'J.J.' at Cambridge. He always retained an interest in the progress of Naval research.

Major J. H. W. Gill, who had been Acting Director at Shandon from 1st April, 1919, retired, as I have already stated, in December, 1919, leaving Dr. C. V. Drysdale in charge as Scientific Director. There was a sale of the Hydro furniture on 22nd-23rd January, 1920. I still have a sale catalogue listing the items and the various rooms in which they were to be found, but I cannot clearly remember this sale although I was at the



Miscellaneous hydrophones circa 1919

He came again in February, 1920, accompanied by Major C. S. Wright. This was my first meeting with C. S. Wright. An interesting visitor on 26th July, 1919, was Sir Henry Jackson, who did so much in the early days of Marconi's experiments, to arouse Naval interest in 'wireless telegraphy.' Other visitors I have recorded in my diary were Captain C. P. Ryan, R.N. (of Hawkcraig, Aberdour), then at Mining School, Portsmouth; Cdr. H. E. Browne, R.N., of the Sound Ranging Station, St. Margaret's Bay, Dover, who visited us on several occasions in 1920; Dr. G. W. Walker (Chief Scientist) and F. Pickford, both of Mining School, Portsmouth, in February, 1920. In March or April, 1919, Professor W. H. Bragg (formerly R.D.R. Hawkcraig and Parkeston Quay) was knighted, and

Hydro at the time. In forwarding the final 'monthly' report, 1st December, 1920, to 15th January, 1921, to D.S.R.[17] Cockspur Street, S.W.1, Captain G. L. Massey, R.N., Senior Naval Officer, remarks: 'Research work stopped on 15th January, 1921, and time is now being devoted to getting away machinery and stores, and to all the work incidental to closing down an establishment of this nature . . . . During the last 12 months . . . . it has been rather a period of anxiety and uncertainty. During the first portion of the time the place was in a state of getting apparatus and general facilities completed, and when this had been done it has

[17] Note F. E. Smith's change of title from Scientific Adviser, Admiralty, to Director of Scientific Research.

been a question of taking it all to pieces again, so that conditions have not been too favourable for a smooth output. However, in spite of these disadvantages it is understood that a good deal of valuable research work has been accomplished. It is a pity that the new station at Teddington is not further advanced, as it makes the turnover more difficult, but it is hoped that when settled down the work may continue efficiently and without feeling the loss of Shandon . . . a final report will be sent on the closing of the station and as to the date and condition of turning over to the Disposal Board.—Signed G.L.M. 3/2/21.' It was considered that it would take to the end of March to get things clear. After reviewing the work of the scientific staff during the month, Dr. Drysdale suggested provisional arrangements for the disposal of the staff until the Admiralty Research Laboratory at Teddington was ready for occupation, *viz.*, Dr. Drysdale and F. B. Young at the Admiralty to deal with reports and reorganisation; A. B. Wood to Mining School, Portsmouth, for explosion pressure research and sound-ranging; J. M. Ford to supervise construction of phonic chronometers, *etc.*, by Cambridge & Paul Instrument Co.; Messrs. B. S. Smith, G. F. Partridge and E. V. Mackintosh to continue work as facilities permit on high-frequency sound-transmitters; J. H. Powell to be attached to Mining School, Portsmouth, for trials on dip and sag of buoyant mines; J. A. Craig to finish preparations for visual leader gear trials at Portsmouth; S. J. Willis and L. Champney to remain at Shandon to continue experiments on E.M. field distribution around A.C. cables. W. Jevons was allocated to H.M.S. *Vernon* but he left Admiralty service soon after the Shandon closure to take up his spectroscopic researches again at Imperial College with Professor Fowler. We were therefore temporarily scattered after January, 1921, until A.R.L. buildings, near N.P.L. Teddington, were ready to receive us. On 1st February, 1921, I remember visiting N.P.L., where I first met Inst. Commander T. Y. Baker, R.N., R. W. Cheshire and Colonel Benson. They were then working for the Admiralty in the N.P.L. Optics Department and awaiting the completion of A.R.L. buildings before moving in. After returning to Shandon to make final arrangements for my temporary remove to Portsmouth, I left for an official visit to the Cambridge Scientific Instrument Co. There I met Sir Horace Darwin and discussed with Mr. R. Whipple and Mr. Collins the arrangements for construction of triple-dial phonic chronometers, tuning forks, *etc.* On this visit to Cambridge, I also met Sir J. J. Thomson, had lunch with D. A. Keys (Corpus Christi) and dinner with J. Chadwick (Caius). The next day I spent with Sir E. Rutherford at his new home in Queen's Road. On 24th February, 1921, I 'reported for duty' at H.M. Mining School, Gunwharf, Portsmouth, where I met Captain Palmer, R.N., Dr. G. W. Walker (Chief Scientist) and F. Pickford.

ADMIRALTY RESEARCH LABORATORY, TEDDINGTON, 1921 to 1936

At this stage of my narrative I have begun to realise that the rate of progress has been much too slow! The previous three parts have each covered a period of two years, only six years in all, leaving me still at the somewhat distant date of 1921. At such a rate the project of covering the period from 1915 to the present would probably never be completed! I am reminded of a book of reminiscences in which the author's first sentence reads 'Wanted, a detective to arrest the flight of time!' Consequently in this 'part four' I shall endeavour to cover a considerably longer period. Unfortunately this may have to be done at the risk of my reminiscences degenerating into a list of scientific staffs and research items. The tendency to do this has in this case been increased by the availability of A.R.L. quarterly and half-yearly 'confidential' and 'secret' series of reports from 1921 onwards, which are on the library shelves at A.R.L. These reports, however, give no clue as to who was doing the work, and certain items of research on account of their secret nature were not reported at all! However, all the items mentioned in the period with which I am dealing have now no secrecy grading and can be regarded as unclassified!

As I explained in the Shandon story, F. E. Smith (later Sir Frank Smith) succeeded J. C. McLennan as Scientific Adviser to the Admiralty and soon afterwards changed his title to Director of Scientific Research, Admiralty. Dr. C. V. Drysdale was appointed the first Superintendent of the new Admiralty Research Laboratory, Teddington, in 1921. After January 1921 the Shandon staffs were temporarily scattered until the new laboratories were ready for occupation. In my own case, I was at that time very much concerned with acoustic mine mechanisms, underwater explosions, and marine sound ranging. Consequently on 23rd February, 1921, I went to H.M. Mining School, H.M.S. *Vernon*, Gunwharf, Portsmouth, where

The Physics Board at their visit to the Mining School, Portsmouth, on 27th June, 1921. F. E. Smith is second from left in the centre row and on his left Professor Sir E. Rutherford, Professor Sir J. J. Thomson and Professor Sir W. H. Bragg, Sir H. Tizzard sits on the right-hand side of the same row.

Dr. G. W. Walker, who came from Eskdalemuir Observatory, was then Chief Scientist. He was mainly interested in (a) the analysis of 'loop' records of ships to determine their principal magnetic characteristics for use in the design of magnetic mines, and (b) the pressure and damage phenomena of underwater explosions; but he showed a very reluctant interest, if any, in my own work on recording the pressure-time characteristics of explosions by means of the C.R.O. and piezo-electric gauges which I had brought from Shandon. Towards the end of my short stay at Mining School we had a visit from the Physics Board on 27th June, 1921. They included a number of distinguished scientists and representatives of the 'Services,' whose object was to inspect the work being done by the various government research establishments. On this occasion they included Sir J. J. Thomson, Sir Ernest Rutherford, Sir William H. Bragg, Dr. F. E. Smith and Mr. Henry Tizzard. The visit included a run out to Spithead on a destroyer to see the area reserved for the explosion of large charges—mines and depth charges. Soon after this I returned to A.R.L., Teddington, where others of the Shandon staffs—scientific, workshop, drawing office and stores—had re-assembled under somewhat confused conditions. Some of the Shandon staff had left us and we had additional new staff—notably the optics group who had been temporarily accommodated with the N.P.L. Optics Division whilst awaiting the completion of the A.R.L. building.

The new laboratory, built adjacent to the N.P.L. in Queen's Road, Teddington, was a good-looking if somewhat small building with two entrances, one at the rear and the other in front facing Queen's Road. The latter entrance was very seldom used, apparently reserved for V.I.P's only! The building was provided with well-equipped 'individual type' laboratories, clerical offices, drawing office and a large workshop. In addition, a large concrete tank 80 ft. long, 15 ft. wide and 10 ft. deep was provided. At first this tank was exposed to the weather, but later it was enclosed in a spacious building fitted out as a laboratory to be used mainly for underwater acoustics research. The optics group had a large laboratory on the upstairs floor of the main building.

The organisation of research staff into groups followed much the same lines as at Shandon, with the addition of three more groups, (a) Optics under Instructor Commander T. Y. Baker, R.N.,

(b) Chemical, *etc.*, under Dr. R. T. Beatty (c) Mathematical and Electrical under S. Butterworth, and later, in 1925, the Gyro group under A. L. Rawlings arrived from Greenwich. As the laboratory was now remote from the sea, much of the time of the research staffs was spent in planning and preparing at A.R.L. for sea trials at other places, *e.g.* in the Portsmouth, Dover, Sheerness, Devonport, Gareloch and Loch Long areas. The disadvantage of not having the sea and ships 'on the doorstep' was, however, partially compensated by certain advantages—proximity to the N.P.L. where scientific advice and sometimes assistance were available, and the nearness to the H.Q. at the Admiralty, London, made it very convenient for staff having to attend conferences at short notice. We were also brought within easy reach of naval bases and experimental establishments (such as H.M.S. *Vernon* and Haslar), and scientific staffs could attend meetings of scientific, engineering and other learned societies, not to mention many other facilities in and around London.

As I have said, Dr. C. V. Drysdale was the first Superintendent of the new laboratory, but in addition to his official duties in this capacity he also found time to continue the researches which he initiated at Shandon. His work on the magnetic field and current distribution around a cable carrying alternating current when lying on the sea-bed, had been interrupted at Shandon by the wrecking of the barge *St. Adrian* in a storm on Gareloch in December, 1920. The object of this investigation was to elucidate unforeseen difficulties arising in connection with the visual leader cable scheme to which I referred under A.E.S. Shandon. The experiments at Shandon had revealed unforeseen distortion of the E.M. field above the surface of the sea which could account for ambiguities in the indications of the visual leader gear (V.L.G.). The barge was replaced and L. Champney and S. J. Willis were left behind to continue the field measurements around the A.C. cable. The details of their observations are given in a series of A.R.L. reports[18]. At Teddington our staff had been joined by S. Butterworth[19] who became immediately interested in the problem of the E.M. field round Dr. Drysdale's A.C. cable. He worked on the theoretical aspect of the problem and carried out small scale laboratory experiments. In the latter he used a sheet of lead lying on a long table with a wire carrying A.C. along a straight line beneath the lead sheet. Using small search coils he explored the E.M. field distribution (vertical and horizontal fields) above the lead sheet. The results of Butterworth's theoretical and small scale work appear in a number of A.R.L. reports 1921–23[20]. A complete record of the full scale investigations of Dr. Drysdale and the theory and small-scale research of Butterworth was published in the *Phil. Trans. of the Royal Society*[21]. The whole investigation provides an excellent example of the value of small scale laboratory research in providing a solution to a protracted full scale investigation of a very difficult problem. The investigation provided valuable data not only in connection with the visual leader gear problem from which it arose, but it also derived fundamental data with regard to the propagation of low-frequency electro-magnetic

(18) A.R.L. Reports Nos. 17, 18, 19, 21, 23 and 25 (1922).

(19) From Manchester University, a short time in 1918 at H.M. Signal School, Portsmouth and 1919-21 at the electrical Standards Laboratory, N.P.L., Teddington.

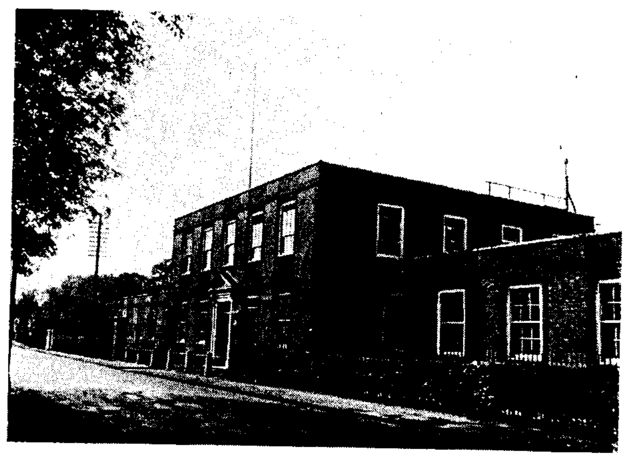
(20) A.R.L. Reports Nos. 11 (1921), 22, 24 (1922) and 26 (1923).

(21) *Phil. Trans. Roy. Soc.* **224** (1923) 95-184. "The Distribution of the magnetic field and return current round a submarine cable carrying alternating current."

Members of the Physics Board aboard H.M.S. Tarpon *at Spithead, 27th June, 1921. The author is in the centre talking to Sir William Bragg.*

waves in sea-water, data which have since proved valuable in their application to other problems.

At the conclusion of this work Dr. Drysdale turned his attention to an entirely different problem for which his extensive electrical engineering knowledge was eminently suitable. This was the fire control of naval gunnery, in which great precision was required in the control of elevation and bearing of large guns on fighting ships, often under conditions of rolling and pitching in heavy seas. He was assisted in this work by J. M. Ford and later by J. Bell, T. N. Whitehead and T. J. Tooley. His A.R.L. group was at first designated the 'Fire Control Group.' He designed various types of step-by-step motors, clutch brake motors and transmitters, synchronous motors, *etc.*, all possessing novel features of particular application to the gun control problem. It was soon realised that these control mechanisms had application also to searchlights, gyros and other devices requiring great accuracy of direction and stability in spite of ship's pitch and roll in a sea way. Consequently in 1923 the group changed its description to 'Low Power Transmission' which dealt with numerous forms of follow-up mechanisms and indicators for both gunnery and searchlights. Other types of electric motors were designed by Dr. Drysdale, and J. M. Ford provided a valuable advance in technique by his introduction of compressed air follow-up motors. For the automatic telemeter control of searchlights, *etc.*, the remote control of compressed air power motors was provided by rotating field electric motors. Searchlight and gun control research led inevitably to the design of stabilisers for the automatic neutralisation of the effects of pitch and roll. These stabilisers made use at first of gyro controls, but as a simple alternative compound pendulums were used. These consisted of long-period wheels of large moment of inertia suitably pivoted and having a small adjustable out-of-balance to provide the necessary restoring force when slightly displaced. Such a 'pendulum' behaved as a good 'indicator of the vertical.' An early example of such a 'flywheel' pendulum had a period of 30 seconds, but in later designs the period was increased to 60 or 120 seconds, and the motion of the 'flywheel' was damped by filling the interior with liquid. Details of all the equipment I have just mentioned can be found in A.R.L. Quarterly reports for the years 1921–25. In March 1926, I made experiments with an optical follow-up system[22] using photo-electric cells (Selenium or other types). This system employed a semi-cylindrical screen with its edge obstructing half of the intermittent light passing through a slit-focus and thence falling on a selenium or similar photo cell. Any slight change of position of the edge (in practice both edges were used with two photo cells) resulted in an out-of-balance of A.C. in the cell which was amplified, rectified and used to operate a relay controlling a pilot air-valve and air-motor drive. With this arrangement it was found possible to follow with an angular accuracy of ±10 minutes of arc when the stabiliser pendulum was swinging through ±20 degrees with a period of 10 seconds (time). This system was applied successfully in ship trials of the searchlight stabiliser (with 'flywheel' pendulum) and was also used for gyro controls. In 1927 J. M. Ford introduced the oil transmission gear drive for gun and searchlight control. In this year also Messrs. Vickers completed the large rolling table[23] above the far end of the tank laboratory. The table is 12 ft. diameter, and has a maximum *travel* of 17 ft. *horizontally* with a *pitch* of ±5° and periodic time 10 seconds, and a *roll* up to ±30° with any periodic time between 9 and 28 seconds, and it can



The Admiralty Research Laboratory, Queens Road, Teddington. Built 1921.

be *trained* at any speed up to 4 r.p.m. in either direction. When loaded it weighs nearly 30 tons; its movements are very smooth and only require a total of 5 h.p. to drive it. It will carry about 5 tons of gear. The large glass building covering the rolling table became the most conspicuous external feature of A.R.L.

This 'table' which could simulate the large angular motions of roll and pitch of a ship was invaluable in the tests of full scale searchlights controlled by the compound pendulum and auxiliary devices, oil drives, stabilised platforms, gyros and even personnel (for resistance against sea-sickness!). It greatly facilitated preliminary

(22) See A.R.L. Quarterly Reports 18a to 24a. 1926-27.
(23) For description see A.R.L. Q.R.a. 25 (1927).
(24) See A.R.L./S/23, 'A.R.L. system of Stabilised Searchlight Control.' February 1930.

tests of gun and searchlight control gear and obviated the necessity for many expensive sea trials. Consequently the gun and searchlight control equipment was ready for full scale sea trials in 1928. The searchlight stabilisation gear, with compound pendulum control and oil unit drive was fitted in H.M.S. *Champion*, where it remained on test till 1929, when it was taken over as 'ship's equipment'[24]. Similar control gear was about this time (1928) supplied to H.M. Signal School for the stabilisation of 20-inch signalling projectors.

In October 1929, Dr. Drysdale left A.R.L. to become Director of Scientific Research at the Admiralty in succession to Dr. F. E. Smith (later

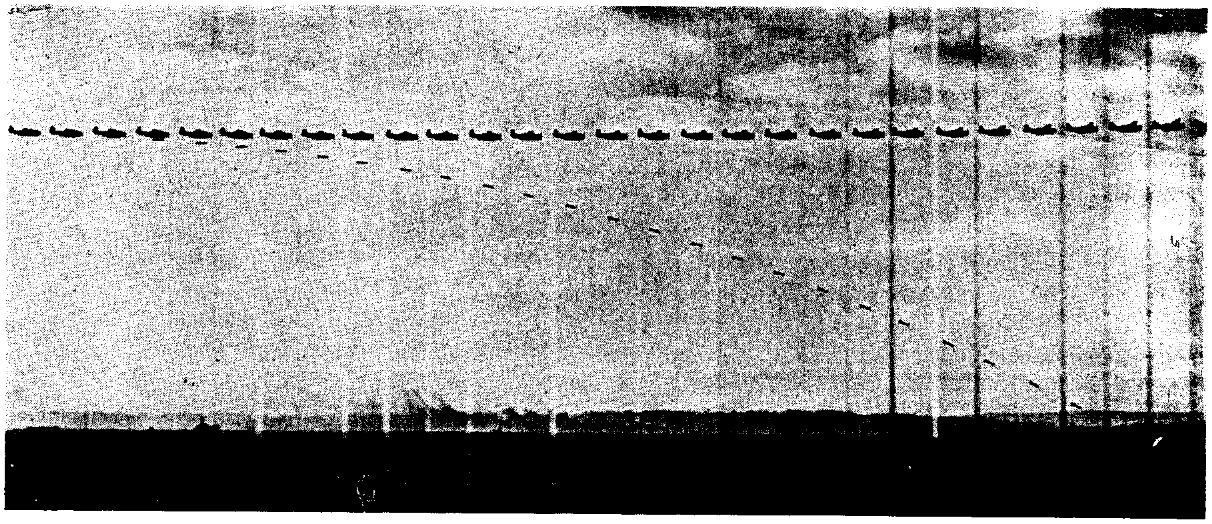
The A.R.L. 'Rolling Table' erected in 1921

Sir Frank Smith) who had accepted the post of Secretary to the Department of Scientific and Industrial Research (D.S.I.R.). J. M. Ford now took over the active direction of the work of the low power transmission group, assisted by J. Bell, S. J. Willis and T. J. Tooley as before. Dial or follow-the-pointer motors were developed. One of these, known as the *Magslip* (magnetic slip-ring indicator motor), a small A.C. repeater motor 2 or 3 inches in diameter, gave very accurate remote indications of dial readings or the angular position of any rotating mechanism. The magslip transmission[25] was subsequently used in the services very extensively for fire control, *e.g.* it was fitted in H.M.S. *Barham* in 1932, it was tried successfully at Army manoeuvres at Datchet for transmitting the training and elevation deflections from an A.A. predictor to the guns. The results were very satisfactory and it was decided to use magslips for fire control operations. Rolling table tests of searchlight control gear designed for use in H.M.S. *Exeter* indicated in 1930 an accuracy of stabilisation of ± 3 minutes of arc for a 15° roll amplitude. Two sets were fitted in the ship and were still functioning satisfactorily in 1932. The oil motors, torque amplifiers, oil pumps, *etc.*, designed by Ford and his group resulted in considerable reduction of weight compared with the corresponding items using air or electric motors. The oil drive system was incorporated in the control of stabilised platforms fitted in H.M.S. *Iron Duke* and other large vessels in the Navy. It was also incorporated in the design of stabilised controls for radio direction-finders in ships. In 1934 a 'Homing Beacon' was designed in co-operation with Signal School, Portsmouth. This was installed in H.M. Carriers *Courageous* and *Ark Royal* in 1936. A power stabilised 'director sight' showed in trials on the rolling table an accuracy of ± 3 minutes of arc for a 15° roll amplitude and a 10 second periodic time.

Stephen Butterworth's assistance to Dr. Drysdale in the Leader Cable problem and in the study of the propagation of E.M. waves in the sea has already been mentioned. He also did valuable theoretical work and gave helpful advice in connection with problems arising in the researches of other groups, more particularly those relating to underwater acoustics and explosions[26]. His theoretical work on the beam shapes (directional characteristics) of H.F. sound transmitters and on the equivalent electrical circuits of magnetostriction and quartz transmitters[27] played an important part in the development of these devices. Underwater explosion research was also a subject of great interest to Butterworth. Following the development by the writer of the piezo-electric C.R.O. method of recording explosion pressures (see A.E.S. Shandon), he developed a theory of underwater explosions which gave a good representation of the pressure-time characteristic of an explosion pulse recorded experimentally. He also made a theoretical estimate of damage to ship's plates by an underwater explosion[28].

In addition to applying his knowledge as a mathematician in difficult theoretical problems,

(25) See A.R.L./S/29, January 1933.
(26) See 'Stephen Butterworth — An appreciation.' *J.R.N.S.S.* **1**, 3 (January 1946).
(27) See A.R.L./S/24, A.R.L./S/25, A.R.L./S/26, 1930.
(28) See A.R.L./S/12, A.R.L./S/5, A.R.L./S/10, A.R.L./S/11, 1924.



A 'strip' camera photograph showing the fall of a torpedo released from an aircraft.

Butterworth did much experimental work to test his theoretical deductions. In this he was assisted by J. A. Craig and later by M. W. Burgess. He designed sensitive moving coil relays, of the order of 2 micro-amps sensitivity, for use in non-contact mines, and stable galvanometers which could be used in a rolling ship. Another of his interests related to the external ballistics of guns. He devised and used a solenoid method of measuring the muzzle velocity of shells—using a critically damped Einthoven oscillograph for recording[29]. He also measured the velocity of recoil of guns, the expansion of the gun barrel, and the deflection of 16-inch guns in triple turret firing ('gun-jump'). His work at Shoeburyness range on the measurement of the recoil velocity and acceleration of a 6-inch gun was carried out in 1931, and his report[30] gives details of the method. The detection of enemy submarines, including 'midgets,' by means of loops of cable laid on the sea-bed across channels and estuaries, was made difficult on account of industrial and terrestrial magnetic perturbations. Butterworth devised various methods of reducing or neutralising the perturbations, *e.g.* by '3-D. balancing' of loops. His double-galvanometer which acted as a very low-frequency filter was an ingenious method of discriminating between perturbations and the submarine's signature. His early interest in the problems relating to the stability of torpedoes when running in a swell led Butterworth to make valuable suggestions to improve the depth control of torpedoes. In association with J. A. Craig he was concerned in the development of a very successful 'strip camera' for the photography of air trajectories dropped from aircraft into the sea. This camera was fitted with a very ingenious shutter which exposed a photographic plate in a succession of adjacent strips whilst the telescopic view-finder was continuously aligned on the aircraft and/or the following torpedo. The trials of this camera were carried out off Stokes Bay pier. One of Butterworth's more important contributions to research at A.R.L. was his model tank for the experimental study of 'entry' and 'trajectory' of underwater projectiles—in particular, torpedoes, depth charges, and aircraft-laid mines. In this experimental study, commenced early in 1936[31] he was assisted by J. A. Craig and M. W. Burgess (in the early stages). During the period of which I am writing (*i.e.* to the end of 1936) the investigation was concerned mainly with measurements of the drag-coefficients of torpedo-shaped bodies of model size about 1/20 full-scale. These were fired at high speed under water (at first from a horizontal air-gun muzzle inserted through the end of the tank) and the velocity and deceleration were measured by recording the passage of the torpedo through a series of coils spaced along the trajectory of the torpedo in the water (on the same principle of the shell velocity measurements at Shoeburyness to which reference has been made above). Various shapes of torpedo head—conical, ogival, hemispherical, *etc.*, were tried—and conditions of entry (splash, up-or-down, turn, *etc.*) were studied when the airgun was, at a later stage, arranged to fire the projectile from a point *above* the level of the water in the tank. Oscillations of the projectile in the cavity were observed when the photographic technique was introduced. As we now know, this technique has been further developed at A.R.L. by

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[29] A.R.L./35. See also *Journ. Sci. Insts.* **4, 1,** October 1926, 8. S. Butterworth, A. B. Wood and E. H. Lakey.
[30] A.R.L. Report/52, July 1931.
[31] See A.R.L. Quarterly Reports QR.58a to 61a, 1936.

J. A. Craig using high speed photography, and is now used in many other laboratories elsewhere. It has yielded valuable information on the trajectories and general behaviour of underwater projectiles, resulting in a great saving of time and expense in carrying out full-scale trials, and has indicated important lines of improvement in the design of underwater weapons.

Dr. F. B. Young, who at Shandon had been mainly concerned with development of the electrode search gear, moved with Dr. C. V. Drysdale early in 1921 to an office in our Admiralty headquarters to deal with reports and re-organisation, whilst awaiting the completion of the new laboratories at Teddington. He continued for some time after the re-assembly of staff at Teddington to assist Dr. Drysdale with papers, *etc.*, and it was not until some time after the conclusion in 1923 of the A.C. cable experiments in Gareloch that L. Champney was free to assist Dr. Young in experimental work. In 1923 Dr. Young devised methods of recording the displacement of ship's plating and bulkheads in explosion damage trials. These were first tried out in the *Monarch* trials[32] in August 1923, in which many others, including myself, were involved, but with different objects in view. I shall have to refer to these trials later. The details of Dr. Young's methods of measuring the bulkhead movements are described in his report[33]. Briefly his device consisted in principle of a pair of telescopic tubes, the end of one being attached to the bulkhead and the end of the other to a relatively rigid part of the ship's structure. Movement of the bulkhead would cause one tube to slide in the other, the relative movement of the tubes being recorded either (a) mechanically by means of a scriber mounted on a massive low-frequency (200 c/s) tuning fork which scribed the displacement, and incidentally the time scale, on a copper strip, or (b) electrically, using a sliding potentiometer contact and recording by means of an Einthoven oscillograph with time marker. Fifteen of these time-recording displacement battens were used in the trials. The records showed rather complex displacement-time features. The first maximum of approximately one foot displacement was reached in about 0·1 second followed by a second maximum of nearly the same amplitude after 2 seconds, with further small-amplitude oscillations to follow. Both mechanical (T.F.) and electrical types of 'battens' gave much the same indications, the latter being considered to be more reliable.

An important problem in which Dr. Young, assisted by L. Champney, was engaged from 1924 to 1933 related to the automatic plotting of the course of a ship on a chart. Between 1930 and 1932 he was assisted also by E. H. Lakey in the development of the Type B course plotter which later became standard for all ships[34]. In 1924 when the work commenced there were already in existence several types of course plotters which, for various reasons, were unreliable. These were systematically tested in the laboratory for accuracy and reliability and an instrument constructed which embodied the best features of all types (*e.g.* in the Villiers Odograph and the Booth & Brewerton Course Plotters). The new instrument included (a) resolving gear for bearing (controlled by ship's gyro) (b) driving gear for range (controlled by the ship's log), (c) clock for operating time marker and controlling (b) when the log was out of action, and (d) the plotting table with gear for the continuously variable plotting scale. Subsequent to the construction of the 'composite' course plotter a number of basic improvements were made in the A.R.L. instrument to ensure reliability up to a range of at least 1,000 miles. Early in 1925 the course plotters were ready for sea trials. On account of various defects the Brewerton plotter was withdrawn from the trials. The A.R.L. plotter[35] was fitted in H.M.S. *Hood* and was thoroughly tested on the spring cruise. Based on these trials the Commander-in-Chief, Atlantic Fleet reported that the plotter was satisfactory. Soon afterwards a second course plotter (A.R.L. type) was fitted in H.M.S. *Revenge* with very favourable reports. The distance error was 0·3% and bearing error less than half a degree. In a later, improved type, the 'Spot of Light' type, fitted in H.M.S. *Warspite*, the errors were less than ¼% in range and ¼ degree in bearing. This result was reported after a run of 5,000 miles (naut.) without adjustment or cleaning, with an instrument having been constructed throughout, to A.R.L. design, by an 'outside' firm. The course plotter fitted in *Revenge* was ultimately transferred to H.M.S. *Nelson* and in 1927, like the one in H.M.S. *Warspite*, was reported to be very satisfactory. Five further A.R.L. course plotters were then made for trial in the Atlantic and Mediterranean Fleets, and sent to H.M.S's *Rodney, Norfolk, Revenge, Devonshire* and *Berwick* (Q.R. September 1932). A special type of course plotter (A.R.L. type B) had already been fitted in A/S vessels but in 1933 this type was recommended at the Admiralty as 'The Standard Service Course Plotter' to be fitted in A/S and non-A/S vessels. The final specification for the A.R.L. course plotter was supplied to

(32) H.M.S. *Monarch* was a battleship scheduled for destruction under the terms of the Versailles Treaty after the end of the 1914-18 war.

(33) See A.R.L./S/7, "The deflection of bulkheads in *Monarch* Trials." 1923.

(34) See *J.R.N.S.S.* 2, 2, (March 1947) 58. (Illustrations of A.R.L. Course Plotter Mark V).

(35) See various A.R.L. Quarterly Reports, between March 1924 and March 1935.

D.T.M., Admiralty who took over the responsibility for supply of plotters for 1934 and subsequently. A course plotter (fitted with 'view plot projector') was sent from A.R.L. to Navigation School, Portsmouth, in 1935. This satisfactory outcome of the course plotter research by Young and Champney marked the conclusion of a very fine piece of work. I well remember with some pleasure in the early days when the plotter was fitted in a ship bound from Plymouth to Gibraltar (about 1,000 miles)—the 'plot' arrived at Gibraltar at 'the same time and place' as the ship! I am reliably informed that the essential features of present day plotters remain the same as those designed by Young and his assistants Champney and Lakey.

In 1927 Dr. Young and Champney, in addition to their course plotter investigation, took up a problem designed to save the exchequer much expense. This was concerned with the occasional necessity of the electrical re-wiring of battleships. Large ships, owing to failures of cable insulation (mainly rubber), had to be re-wired completely after a period of approximately two-thirds the expected life of the ship. This involved a serious hold-up and much expenditure of time and money. It was considered that if the life of the insulation of the cables could be prolonged, to be equal to or greater than the life of the ship, all this expense might be saved. With this object in view Young and Champney started a prolonged research into the factors likely to cause the deterioration of rubber insulation on cables in naval ships. The work was done in collaboration with Admiralty Engineering Laboratory, West Drayton, where the reports on progress were issued. I never actually saw any of these reports, but I remember seeing some of the experiments in progress at A.R.L. To the best of my knowledge the important factors in prolonging the 'life' of the rubber were, as far as was practicable, to keep down the temperature and the presence of oxygen to a minimum. I have no information as to whether or not the ultimate object of the research was achieved.

In July 1934, F. B. Young became Superintendent of A.R.L., when C. S. Wright became D.S.R. Admiralty on the retirement of C. V. Drysdale. Dr. Young, in addition to his official duties as Superintendent, continued the researches to which I have referred, in collaboration with L. Champney.

A new group joining our staff at A.R.L. in 1921 was controlled by Dr. R. T. Beatty assisted at first by A. G. Milligan and later (in 1923) by J. A. Hey. Beatty's main interest at that time was concerned with the infra-red transmission of dyed films[36], opaque in the visible spectrum and transparent in the 1 μ region of the infra-red. For the test of these dyes Beatty designed a monochromator which covered the whole spectrum range—ultra violet, visible and infra-red. The screens were required by R.N. Signal School, Portsmouth, for use in Dr. H. Smith's infra-red signalling experiments in which short wave infra-red signals were rendered visible to the eye by means of a 'discrasite screen.' Milligan made Beatty's I.R. screens in the new chemical laboratory across the corridor from Beatty's laboratory. Here he prepared also phosphorescent screens of zinc sulphide, and various photo-sensitive materials. He made a study of the photo-electric conductivity changes in thallium sulphide, and made the important discovery that when this material was slightly contaminated with silver sulphide its sensitivity was much increased. Its sensitivity was now equal to that of Case Thalofide cells. Milligan provided me with thalofide cells for some experiments to which I shall refer later. In 1922 Dr. Beatty set up a thermostat equipment for growing large crystals of Rochelle salt which was then only available in small crystals. It was required by A.R.L. acoustics group, then under B. S. Smith's control, and by the Asdics Group at R.N. Signal School, Portsmouth. The temperature of the solution in a large crystal growing-tank had to be regulated within 0·01°C and allowed to cool extremely slowly over a period of several days to obtain large crystals. By the end of 1922 Beatty was growing crystals $4\frac{1}{2}$ in. × 3 in. × 1 in., and had devised a technique whereby many crystals could be grown at the same time between parallel shelves of plate glass, the seed crystal being so arranged that the resulting slab of Rochelle salt crystal was of the 'Asdic' type (*i.e.* electric axis in same direction as applied pressure). This resulted in much reduced wastage in cutting crystals for use in asdic transmitters—only edges having to be trimmed. These crystals were grown in considerable quantities for R.N. Signal School for various experimental transmitters, and receivers —a 15-inch long strip receiver (1925) and a 2-ply 5-inch diameter receiver (1926). Further supplies were made later when the asdic work was transferred to Portland (1927). In the chemical laboratory Milligan was becoming interested in the problems arising from impurities in the plates of lead accumulators. This problem was of course of considerable importance to D.E.E. in its

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(36) Transmission of Dyes in the Infra-Red region (R.T.B.). Phosphorescent and Photo-dielectric sensitivity of Zinc Sulphide. (A.G.M.). } A.R.L./S/1

(37) George Bell & Sons—Publishers. 1932.

(38) See A.R.L./S/18. 'Television,' R. T. Beatty and J. A. Hey. December 1925.

(39) See A.R.L. QR (a) Report No. 10a (March 1923).

(40) NOTE: Dr. Rawlings left A.R.L. in 1928; then W. Burnside directed the Gyro group.

application to the large lead batteries used in submarines. Milligan was ultimately transferred in 1931 to continue this work at the Admiralty Engineering Laboratory, West Drayton.

In addition to his infra-red work, Dr. Beatty was very interested in acoustics and radio (W/T) problems. He wrote an excellent book on *Hearing in Man and Animals*[37] and numerous articles on 'Wireless' for technical journals. He did some experiments on television[38], assisted by J. A. Hey, in which he devised interesting methods of scanning and the use of various photoelectric devices. The optical group were also involved in the television transmission of photographs—telephotography[39] —from aircraft to ships or shore bases.

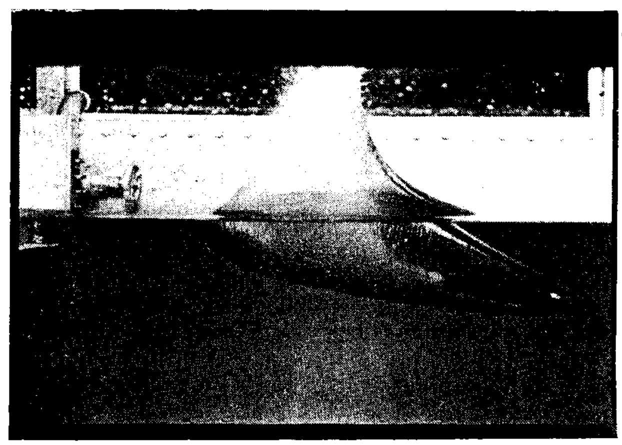
In 1925 a new research group arrived at A.R.L., or perhaps it would be more correct to say that a group already established at Greenwich Naval College was transferred to A.R.L. This group headed by A. L. Rawlings[40] included W. Burnside, W. G. Heatley, N. H .A. Warren and S. Ward. They specialised in gyros for which there were numerous applications in addition to their original purpose for navigation. The work they were doing on arrival at Teddington was first reported in A.R.L. Quarterly Report No. 16a for September 1925. At this time they were concerned in (a) Gyro compass trials in H.M.S. *Rapid,* (b) Gyro compass laboratory tests, (c) Angular torpedo control and (d) Turret training control. Tests of the Brewerton gyro compass showed it to be unsatisfactory, whilst the Sperry compass Mk. VI which had a period of 100 minutes was giving bearing (Skefco) trouble. In 1926 the optical follow-up which I had designed for the searchlight compound pendulum (flywheel) stabiliser in Dr. Drysdale's group, was also found to be useful for gyros. Much of the work of the group was concerned in the design, or improvement of existing designs, of a 'master gyro' compass for gunnery applications, turret training control, *etc.* New compasses made by S. G. Brown and Anschutz were thoroughly tested in the laboratory and in H.M. Ships, Sperry and Brown gyro tests were made at A.R.L., and Anschutz compass trials were made in H.M.S. *Nelson*[41].

Another important application of gyros with which the gyro group were concerned with the depth and direction keeping control of torpedoes [42]. Gyros were also used with the master stabilised platform to which I have already referred in Dr. Drysdale's group in connection with searchlight and gun control operations[43]. They were also used in connection with stabilised director sights.

[41] See A.R.L. Q.R.30a to 34a (March 1929-March 1930).
[42] See A.R.L. Q.R.30a, and A.R.L./S/28, January 1932.
[43] See A.R.L. Q.R.55a, June 1935.

As my knowledge of gyros is very scanty I have refrained from remarking about the scientific and technical aspects of the research work of the gyro group. I should recommend those interested in this work to consult the original A.R.L. Quarterly and special reports.

This remark applies also in regard to the Optics Group under the direction of Inst. Capt. T. Y. Baker, R.N. Gyros and optical instruments for Naval use tend to become 'highly specialised' and, speaking for myself, only those of us who are in constant touch with the research work, *i.e.* those who are actually *doing* the research, are in a position to criticise or make intelligent remarks on their design and use. I shall therefore confine my remarks about the Optics group to the 'headlines' and leave discussion of important 'details' to those more competent to do it. Cdr. (later Capt.) Baker's staff included R. W. Cheshire, E. T. Hanson, H. S. Young, M. O. Pelton, J. F. Sutton, P. Laird, Col. Benson, Col. D. C. S. Evans. Army and Navy representatives were attached temporarily, as liaison officers, to the Optics



Photograph of a projectile in an air cavity, in the water-entry tank.

group. This group, as would be assumed, was concerned mainly with the design and improvement of optical instruments for use by the Navy, covering the entire field. Their researches included a large number of items—sometimes more than 20 were on the list although some of these appeared occasionally in A.R.L. Q.R.'s as 'nothing further to report'. The first Q.R. report in December 1921 mentions: Prismatic astrolabe, Binoculars of various types including 'Night Glasses', Range-finders, Tetragonal prisms, aircraft predicting instruments and height-finders. In addition to this type of instrument research which could mostly be done in the laboratory at A.R.L., about this period the Optics group were engaged in the problem of 'bending of ships in a seaway'. This problem of course related to long range gunnery for battleships. Trials of the experimental equipment[44] were made in H.M.S. *Repulse* in 1922. A deflection of 60 seconds of arc was observed on a 190 ft. baseline. In connection with the problem of height-finding of aircraft, a 'gun layer *teacher*' was designed which incorporated a 'minifying telescope'! Other interesting items which were being investigated in 1923 were: A photographic triangulation camera for marking 'fall of shot', rangefinders and inclinometers, bubble sextant for use when the horizon is invisible, filming of glass surfaces in optical instruments, an A.R.L. anti-aircraft predictor with corrections for wind effects, and T.V. transmission of photographs (telephotography). The prismatic astrolabe[45] (mentioned above) was designed by T. Y. Baker for the observation of stars at an altitude above the horizon as low as 45° compared with an altitude of 60° which was the lowest previously possible. Experiments were also being made to take photographs through the periscope of a submarine. With suitable colour filters it was found possible (in 1925) to obtain pictures in which objects were readily identified, with an exposure time of 1/50 second at F.2. An optical level was designed for gunlaying during bombardment when heavy smoke obscured visibility. A mercury pool was used for this purpose. I seem to recall that this device was unsuccessful in trials on account of vibration and general motions of the ship. During subsequent years much effort went into the design of rangefinders and binoculars for special purposes. Apparatus was designed for training personnel in the use of specialised optical equipment. An investigation of the properties of optical glass was commenced in 1933 in co-operation with Chance Bros. on a manufacturing scale. Another interesting research dealt with a determination of the lack of parallelism in binoculars, particularly night-binoculars for submarine or aircraft spotting. An important factor relating to this problem was that of 'heterophoria' in Observers[46]. This is a squint in the relaxed condition of the eyes, such as would exist for example on a starlight night over an infinite sea with no definite object on which to focus the eyes. This squint amounts to 2 or 3° on the average, seriously affecting night lookouts' powers of observation! Another physiological factor concerning lookouts which was also studied was that of red illumination of the bridge at night[47]. I have mentioned the master stabilised platform designed by Dr. Drysdale's group. This was used not only by the 'low power' group but also by the gyro and optical groups in tests of their instruments at sea. Both Dr. Drysdale and Capt. Baker were concerned in the design of a power stabilised director sight.

I have mentioned only a few of the problems with which the Optics group were concerned. Some of these may seem unimportant and some which I have omitted more important to those particularly concerned in naval applications of optics. To those requiring further enlightenment I should advise them to consult the original A.R.L. reports from 1921 onwards[48].

I now come to the Acoustics Group which between the years 1921 and 1927 was directed by B. S. Smith on the lines outlined under A.E.S., Shandon, of this series. Assisting him at A.R.L. in 1924 onwards were G. F. Partridge (from Parkeston Quay, Shandon), F. D. Smith (from Parkeston Quay but not at Shandon), E. V. Mackintosh (from Malta and Shandon) and H. F. Bellars (designer, came to A.R.L. in 1921), later in 1926 joined by J. A. McGeachy. As I have already mentioned S. Butterworth provided considerable theoretical (mathematical) assistance. In 1927 I took over the work of this group in addition to my own, when B. S. Smith left A.R.L. to take charge of the Asdics Research and Development Establishment at H.M.S. *Osprey,* Portland. During the six years, 1921-27, at A.R.L., B. S. Smith was mainly concerned with developing high frequency transmitters and receivers as alternatives to the quartz asdic, and from 1923 in developing an audio frequency echo depth sounder. I referred very briefly under A.E.S. Shandon to the electromagnetic strip oscillator. At A.R.L. this long strip was modified and became a 'ring', in reality a very short cylinder, diameter about 20 inches and 'length' about 3 inches, which vibrated axially. The axial section of the ring consisted essentially of a duralumin resonator having its main mass concentrated on the inner edge (in air) and the smaller mass at the outer edge (radiating into the water), whilst the elastic 'leg' connecting the two masses completed the resonant system. A thin flexible edging around the cylinder served to locate the resonant ring in the applied magnetic fields and to make the system watertight. A powerful annular magnetic field, D.C. with superposed H.F. alternating field, caused the ring to vibrate axially at its resonant longitudinal frequency. In principle the excitation of the ring is similar to that employed in the Fessenden audio frequency transmitter, but in the high frequency case no diaphragm is used, the sound emitted to or received from the water proceeds via the *edge* of

[44] See A.R.L. Q.R's 2 to 6, 1922.
[45] See A.R.L. Report No. 36.
[46] A.R.L. Q.R.49, December 1933.
[47] A.R.L. Q.R.57, December 1935.
[48] Available in the Library at A.R.L. and at N.S.T.I.C. as 'unclassified' reports.
[49] See A.R.L. Q.R.12(a) to 14(a), 1924-25.
[50] A.R.L./S/2, A.R.L./S/3, 1923.

the ring. These H.F. rings of various frequencies 10, 15 and 20 Kc/s. were made and sent to H.M. Signal School Asdic Division, Portsmouth for test[49]. The efficiency was stated to be about 70% when the magnet poles were laminated, falling to 40% with solid poles. In later sea trials in 1925-26 difficulties were encountered due to 'double-peak' resonances and trouble with the valve oscillators driving the ring. When these difficulties had been surmounted, however, it was still considered that the H.F. ring transmitter was not a serious competitor to the quartz asdic, from the point of view of various mechanical difficulties in manufacture, *etc.* S. Butterworth wrote a paper on 'The theory of ring and strip transmitters and the distribution of sound around various transmitters' which also dealt with beam shapes of ring, line and disc sources. A description of the design of 'The moving conductor H.F. transmitter' is also given by B. S. Smith in A.R.L./S/3 report[50]. The ring transmitter to which reference has just been made was essentially a continuous wave (C.W.) type, the length of the pulse transmitted being readily controlled. The second type of transmitter which B. S. Smith designed used a resonant steel rod, which was struck a powerful blow at one end by an E.M. operated hammer (later replaced by one pneumatically operated) emitting into the water from the other end of the rod a pulse consisting of a damped train of H.F. waves. In this case an independent tuned receiver of H.F. sound had to be used. At first the sound emitted from the end of the steel rod was disappointing, until it was discovered that cavitation at the emitting face was the cause. When this face was enclosed in an oil-filled dome under pressure and free from dissolved air or bubbles, the sound-output was considerably increased. This type of rod transmitter was designed for deep sea echo sounding, and in 1926 was handed over to H. Hughes & Son to manufacture for this purpose. Tuned high frequency microphones were designed for use at asdic frequencies. These were of a double diaphragm type enclosing carbon pellets such as were used in audio telephones. Rochelle salt was also used for reception of H.F. sounds and a few transmitters were also made. The latter however could only be used for experimental work, with very low power outputs. For reception, however, Rochelle salt had many advantages, particularly that of high p.e. sensivity compared with quartz. Its main disadvantage was of course its great solubility in water!

A very useful device designed by B. S. Smith at A.R.L. was 'an instrument for measurement of the strength of asdic echoes'[51], later known as the signal strength meter. This worked well in the range of asdic frequencies and proved valuable in research at H.M. Signal School, Portsmouth and later at H.M.S. *Osprey*, Portland. Perhaps the most important of his achievements at A.R.L. was the Echo Depth Sounder (telephonic audio-frequency system). He had contemplated designing a continuous E.D.S. at Shandon in 1920 but it was not until we were installed at Teddington that serious work on it was begun. The system employed has often been described[52] and the following brief outline may serve to explain the basic principle. The source of sound is a steel diaphragm 5 or 6 inches in diameter, which emits a heavily damped train of audio frequency waves when struck at regular intervals, about three times per second, by sudden blows from an E.M. operated hammer. Current through an electro-magnet causes the hammer to compress a spring which, when the current is cut off, drives the hammer into sudden and violent contact with a boss on the diaphragm. A small hydrophone receives the echo from the sea-bed and some of the direct sound. The transmitter and receiver are mounted in water-filled tanks on opposite sides of the ship, the hull forming a partial screen to the direct sound. A constant-speed motor drives two commutators through suitable gearing. One of these which consists of a metal disc with an insulated segment causes the hammer to strike the diaphragm when this segment passes the brushes. The second commutator on the same shaft as the first short-circuits the telephones in the receiving circuit except for a brief period, provided by an insulated segment, during which the 'phones can 'listen'. There is consequently very little background ship noise and only the direct sound or the echo can be heard at full strength. The position of the 'phone 'pick-up' brushes can be displaced by hand relative to the 'zero' or transmission instant, so that an interval of time, proportional to the angular displacement of the brushes, elapses between the initial transmission instant and that at which the echo is heard in the 'phones. With a knowledge of the velocity of sound in the water, the angular displacement of the 'phone brushes to the 'echo' position can be calibrated in terms of depth. The first sea trials of this equipment were made with an 'outboard' experimental set-up in H.M.S. *Kellett* in September 1923 which gave promising results. It was found however that with inboard transmission and reception, through the hull plating, it was necessary for careful selection of the positions of the hammer and the hydrophone to obtain reasonable listening conditions,

[51] A.R.L./S/21, B. S. Smith, June 1927.

[52] See for example A.R.L. Report 27, 'Continuous Depth Sounding by the telephone method.' B. S. Smith, April 1923. F. E. Smith, *Proc. Roy. Inst.* **24** (1924), 342, A. B. Wood, *Sound*, p. 472 (1st Edition Bell, 1930).

which varied from ship to ship. This audio frequency 'telephone' sounding system was eventually fitted to a considerable number of ships in the Navy and re-named 'Shallow water Echo Sounder'. The audio frequency E.D.S. was in 1925 handed over to Henry Hughes & Sons for manufacture and fitting in both Naval and commercial vessels. In practice it worked fairly well up to depths around 200 fathoms, but reports of hammer and spring failures were frequent. A more powerful set was made for 'oceanic' soundings but this met with much trouble in service. In 1927 an audio-frequency echo sounder was made for installation in survey motor boats but the acoustic screening between transmitter and receiver was found to be an insuperable difficulty, to which I shall refer later.

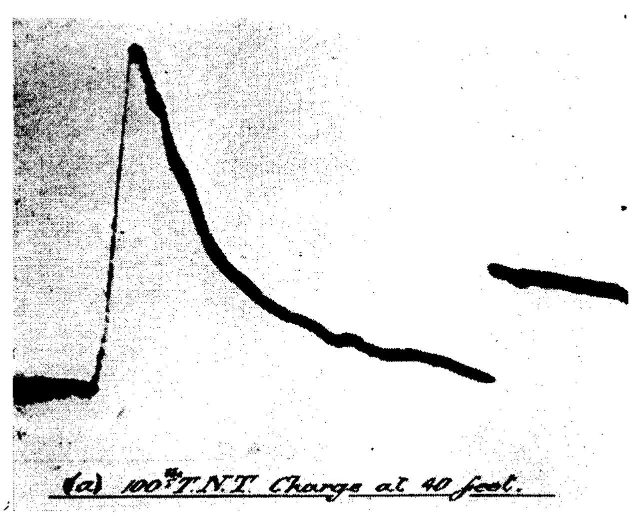
On leaving A.E.S. Shandon in February 1921 my headquarters were temporarily transferred to Mining School, H.M.S. *Vernon*, Portsmouth, until the end of June. Here I hoped to resume my research on underwater explosions, using the cathode ray oscillograph and piezo-electric (tourmaline) gauges which I had made at Shandon, but on this occasion this did not materialise, although I made some progress in improving the technique of recording explosion pressure-time characteristics as far as this was possible in the laboratory on shore. I also analysed for Dr. G. W. Walker, Chief Scientist, a considerable number of 'loop' records, to derive magnetic data of the ships which had passed over the loops. Notable events, from my point of view, in this brief period at Mining School, were (a) the visit of the Physics Board to which I referred earlier, and (b) the Foundation meeting of the Institute of Physics in London on 27th April, 1921, which I attended. At this meeting some of the speakers were The Rt. Hon. Lord (A. J.) Balfour, Sir J. J. Thompson, Sir William H. Bragg and Sir Robert Hatfield. Lord Balfour, a tall and impressive figure, was a powerful speaker — a memory not likely to be forgotten by those who heard him. At the end of June 1921 I left Mining School and after a short period of leave returned to A.R.L., Teddington. My new 'lab' was at the extreme right-hand end of the block, when facing the building frontage in Queen's Road. J. M. Ford who was working with me at Shandon was now in Dr. Drysdale's group, although he continued to take an interest in the work I was doing on phonic chronometers, shock receivers, *etc.*, which we had been developing for sound ranging and other applications. I was now joined in September 1921 by E. H. Lakey, a new arrival on the staff. In continuation of my work at Shandon I was intermittently concerned, during the years 1920-22, in sub-marine sound ranging by various methods and in making accurate measurements of the velocity of sound in the sea. This I did in co-operation with Cdr. H. E. Browne, R.N., who was in charge of the sound-ranging station at St. Margaret's Bay near Dover. The velocity measurements were made by a special multiple charge technique, using four hydrophones on a baseline extending over 12 miles long lying N–S approximately, the length being known to one part in 10,000. Temperature measurements were made along the base line, at the firing points of the explosive charges and at various points in the locality, and observations were made during winter and summer conditions of temperature. The salinity coefficient of velocity was estimated by comparing velocities measured at Shandon and at St. Margaret's Bay where the salinites were 28 and 35 parts per thousand respectively. The results of these observations were published in A.R.L. Reports and later in the *Proceedings of the Royal Society*[53]. These velocity measurements provided reliable data not only for sound-ranging and survey purposes but also later for echo depth sounding which was soon to become a standard method in ships all over the world. The values obtained for the velocity of sound in the sea at different temperatures and salinities have recently been shown to be reliable within one part in 5,000 by accurate laboratory measurements at N.O.L. and N.R.L., Washington, U.S.A. In addition to the velocity measurements a new system of sound ranging and location of sub-marine explosions was developed, by a method permissible in peace time but not during a war. This was known as the *Radio-Acoustic Method*[54]. A ship firing a small charge and requiring a position 'fix' would radio the S/R station, *e.g.* at St. Margaret's Bay, and ask by radio for a 'fix.' A radio 'dot' was transmitted from the ship on detonation of the charge. This dot was recorded at the S/R station with the subsequent arrival of the sound wave at the various hydrophones on the surveyed base-line. A knowledge of the velocity of sound in the sea and the various times of travel of the explosion pulse gave the range of the explosion from the individual hydrophones. This method gave very accurate 'fixes' in a few minutes. During the course of experiments it detected an error of a mile in the position of a lightship marking a sandbank and was used to navigate a destroyer along a difficult channel between sandbanks off the Dutch coast.

(53) *Proc. Roy. Soc.* **103,** (1923) 284. A. B. Wood, H. E. Browne and C. Cochrane.

(54) See A.R.L. Reports Nos. 13, 14 and 15, 1921, and *Proc. Phys. Soc.* **35,** p. 183, 1923. A. B. Wood and H. E. Browne.

(55) See A.R.L. Q.R.26, March 1928.

Another investigation of a relatively subsidiary nature was to provide a recorder to measure the speed of torpedoes when running in the range at Loch Long. At this time in 1922, 'markers' (men with flags) were stationed in huts on rafts in a line of known positions along the range, they dipped a flag 'by hand' as they saw the torpedo (or its bubble stream) pass the raft and observers using binoculars noted the times by stopwatch as they saw the successive flags 'dip.' In conditions of poor visibility this was unsatisfactory. We had chattering contact hydrophones at each raft, connected to a six-pen recorder at the firing point. This recorded the instant of firing and the passage of the torpedo at each raft. It gave good results for torpedoes running at speeds 25, 30 or 35 knots and worked well in dark and stormy weather when 'human' markers on the rafts were useless. It was in use at Arrochar torpedo range for several years and became particularly valuable when trackless torpedoes were introduced[55]. Whilst these experiments were in progress preparations were also being made at A.R.L. for further explosion trials at Mining School, Portsmouth. Improvements were made in the design of the cathode-ray-oscillograph and the piezo-electric gauges. To test the C.R.O. at A.R.L., records were made of high-speed transient electrical phenomena (condenser discharges and other forms of impulse) and of high frequency wave-forms up to about 10^5 c/s. A proposal was also submitted to C.S.R.D. Woolwich to use the C.R.O. and P.E. method to record the pressure in gun barrels on firing a projectile. A C.R.O. was supplied and it was used for this purpose, also for recording the blast pressure of 16-inch guns at Woolwich proving ground. J. A. Craig made the blast pressure records in 1923 using a 'strip' type p.e. gauge and C.R.O., the pressures being measured at ranges around 60 ft. on a bearing about 50° from the muzzle of the gun[56]. Other interesting applications of the C.R.O., the first of its kind to record a single-traverse suitable for recording high-speed phenomena, could be mentioned but this would occupy too much time and printing space! To return to the original purpose of the C.R.O. and p.e. gauge; E. H. Lakey and I made preparations for an extended series of explosion trials, (a) damage trials against H.M.S. *Gorgon* and H.M.S. *Monarch*, two battleships scheduled for destruction under the terms of the Versailles Treaty, and (b) a series of trials with special charges from a few pounds to a ton of explosive (T.N.T., Amatol, *etc.*) to obtain pressure, momentum and energy values, effect of varying range and depth of charge, shape and type of container (*e.g.* depth charge, bouyant mine, *etc.*). The *Gorgon* trials took place in September 1922 when T.N.T. charges of various weights (250 to 2,000 lbs.) were fired in proximity to the hull, pressure gauges of various kinds (Hilliar crusher gauges, copper diaphragm gauges and piezo-electric gauges) were used. One record (250 lbs. T.N.T. at 15 ft.) made by the C.R.O. and p.e. gauge (about 2 ft. from the pressure hull and inside the 'blister') was of particular interest. It showed the sudden rise ($<10^{-4}$ sec.) of pressure followed by the usual exponential fall but this was suddenly cut off by the reflected pulse, reversed in phase, from the air-backed hull of the ship. The *Monarch* trials (August 1923) were similar in character to those for the *Gorgon*. The results of both these interesting and important trials were fully reported in Mining School 'Summaries' in 1922 and 1923, and the C.R.O.-p.e. measurements are also described in A.R.L. reports[57]. With regard to (b), the explosion pressure measurements using special 'research' charges, here again 'Hilliar,' copper diaphragm and piezo-electric gauges were used. A large number of C.R.O. records were made showing the almost instantaneous rise of pressure followed by the exponential fall in the explosion pulse. The p.e. records supplied the necessary data for measuring maximum pressure, momentum and energy in the explosion pulse, and the effects of varying weight of charge, range and depth[58].



C.R.O. and piezo-electric record of pressure-time curve of a T.N.T. explosion underwater

[56] See A.R.L. Q.R.6a, 7a and 8a, 1923.

[57] See A.R.L. Q.R's 1922-24 and A.R.L./S/12, 1924. (A. B. Wood and E. H. Lakey.)

[58] See A.R.L. Report on "The nature of the pressure impulse produced by the detonation of explosives under water. An investigation by the piezo-electric cathode-ray oscillograph method." A.R.L./S/12, 1924. A. B. Wood and E. H. Lakey.

Records were made showing 'bottom' and 'surface' reflections following the direct pressure pulse. The method of explosion pressure pulse recording established in this period (1922-1923) has subsequently been in use continuously to the present day[59] both here and in U.S.A. On the theoretical side, I have already mentioned the contributions of S. Butterworth relative to the form of the explosion pulse under water and the damage to structures, in particular to ships' plating. His theoretical conclusions agreed reasonably well with the results of experimental trials. The explosion trials at Mining School, Portsmouth, were concluded at the end of 1923 but I was fully occupied during the first quarter of 1924 in analysing between 400 and 500 C.R.O. records and in preparing a report on the experiments[59]. Between February 1924 and February 1925 Lakey left me, to join a Mining School party (with Johnson and Colquhoun) on Southern latitude 'Loop' trials at Ceylon, Jervis Bay (Australia) and Singapore.

In 1924 D.S.R. (F. E. Smith) asked me to take up the problem of a 'hornet' aeroplane, a radio-directed pilotless plane which would detect and 'home' on an enemy plane at any time of the day or night. 'Some' physical characteristic of the enemy plane was to be used to operate the control mechanism of the 'hornet.' The first part of this problem obviously involved the investigation of the various possible physical characteristics which might be used. Assisted again by E. H. Lakey the work was done at A.R.L. with field tests at the Royal Aircraft Establishment, Farnborough. Observations were made of 'likely' and 'less likely' properties of the plane which might be used. Some of the preliminary work served to eliminate a few of the 'less likely' items, *e.g.* detection of exhaust gases (CO, CO_2), air currents and ionisation in the wake, electrical capacity effects (at short range only), optical image of plane effect on a system of photo cells (selenium and thallium sulphide—useful in daylight only). Some very interesting observations were made in the course of these experiments but they were mainly of academic interest and held out little hope of solving the main problem. Acoustic and infra-red methods seemed more promising for appreciable ranges of detection. In the course of acoustic observations of planes in flight over Lafan's Plain, Farnborough, in a frequency range from about 100 c/s to 20 kc/s, it was noticed that the attenuation of sounds in the higher frequency range was much greater than that anticipated from theoretical data. A plane flying low overhead emitted high frequency (order 10Kc.) sound at high intensity but at a distance of a quarter of a mile or so this was almost undetectable. Subsequent experiments over the N.P.L. sportsfield confirmed these observations and

Charge fired shallow at Spithead

showed that the greatly increased attenuation, not predicted by classical theory, was due to the presence of water vapour and was a function of humidity[60]. (This phenomenon had been discovered independently by V. Knudsen in U.S.A. in laboratory experiments). It was concluded that infra-red measurements of thermal radiation from aircraft must be made. For this purpose experiments were made to obtain a quick-acting sensitive thermopile. Various commercial types were examined in the laboratory, but eventually one made at A.R.L. proved to be the most suitable. Bismuth-antimony junctions made by cathodic sputtering on thin slips of mica had rather high resistance (mainly due to the antimony film) and were too slow in response (due to the mica base). An improved method of making constantan-manganin or constantan-bronze junctions resulted in a successful thermopile. It was found possible to unite these pairs of alloys without the use of solder, using flux only, the junction remaining mechanically strong and sharply defined even when rolled to a thickness of 0·0005 inch. Attempts to make even thinner junctions by

(59) See "Underwater Explosion Research", 3 Vols. Published in 1950 by Office of Naval Research, Washington, U.S.A.

(60) See A.R.L. Report No. 32, 1935. "The attenuation of high frequency sounds (up to 15 kc/s) in air"—with an appendix on high frequency sounds from aeroplanes.

'beating' (as in the manufacture of gold leaf) were unsuccessful due to difficulties of annealing. With these thermojunctions at the focus of a good quality mirror eight inches diameter and front face silvered, measurements were made on aircraft tethered to the ground and in flight at Farnborough during 1925-26. Infra-red spectrum measurements indicated the maximum energy in the spectrum of the emitted I.R. radiation to be near a wavelength of 5 or 6μ[61], in agreement with the temperature of the engine. Exploratory measurements showed that most of the thermal radiation of wavelength less than 10μ came from exposed parts of the engine, the exhaust manifolds and flame, if any, at the exits of the exhausts. The thermal radiation from the slip-stream was either too small to measure or was of long wave-length corresponding to exhaust gases diluted and cooled by a large volume of cold air. An estimate of thermal energy detectable by infra-red, up to wavelength 10μ was of the order of 1 or 2% of the horsepower of the engine, and depended critically on the amount of screening used in the design. Records were made of sky radiation day and night, using I.R. filters of different cut-off wave-lengths (up to 15μ), in order to discover what background interference was likely to be encountered when 'looking by I.R.' at a plane in flight. As a result of this, a differential thermopile was designed which had a selective effect in distinguishing the 'point image' of a hot aeroplane engine from the 'extended' image of a small portion of the sky background, and also improved angular accuracy. Attempts were also made to obtain a 'filter' to cut off all radiation below 4 or 5μ, *i.e.* to be selective for the aero-engine radiation. A detailed report of this work which was handed in manuscript to D.S.R. appeared in May 1927 as an A.R.L. report[62]. As will be seen the original 'hornet' research failed, for in day-time any infra-red device would 'head' for the sun, a much more potent infra-red source than any aeroplane! This seemed clear to me at the outset. The investigation, however, yielded a certain amount of valuable information about thermal radiation from aircraft and from the sky and was on that account far from disappointing. Of course as a means of detecting aircraft much of this was completely outdated in 1935 with the development of radar — what we needed in 1925 was a prophet!

Another outcome of the infra-red experiments in 1926 was due to an accidental discovery in the laboratory at A.R.L.—the application being secret infra-red signalling and station keeping between ships at sea. It happened in this way. In October 1926 Lakey and I were making some sensitivity tests of a Thalofide cell which had a maximum sensitivity around 1μ (just beyond the dark red visible part of the spectrum). The cell was being exposed to a metal filament lamp source a few yards away and the change of galvanometer deflection, due to the fall of resistance of the Thalofide cell, was being observed. To cut off the radiation from the lamp a sheet of ebonite 1 mm. thick, which was handy, was interposed in front of the cell. Much to our surprise there was still a large signal indicated by the galvanometer. Following up this observation and using an infra-red spectrometer, we discovered that the ebonite had a maximum transmission near 1μ. Polished ebonite, as would be expected, was found to transmit more and scatter less than the matt variety which is used for electrical insulation. A thalofide cell and a polished ebonite screen[63] in front of the source was therefore an ideal combination for infra-red signalling. For this purpose we decided to use as I.R. source a tungsten arc (pointolite) with ebonite screen interrupted at an audio-frequency, whilst the thalofide receiver current could be amplified (with 3-stage valves) to operate telephones or a loud-speaker. Testing this system across Bushy Park from the roof of A.R.L. loud signals could be heard at $1\frac{1}{4}$ miles using a 10 in. dia. receiving mirror, and much louder when a 10 in. mirror was used also at the transmitting end. J. M. Ford designed the motor-drive, signalling key and mountings for the revolving slotted shutter, 10 inches diameter, which obscured the 1μ radiation 300 or 400 times per second. In November 1926 this infra-red signalling apparatus was tested by H.M. Signal School at Southsea Castle when Admiral Burmester's committee were present[64]. Very loud signals were heard when a destroyer (transmitting to Southsea Castle) was at 1, 2 and 3 miles range, the visibility being described as 'moderate' in mist and heavy rain. The Burmester committee's report was very favourable but to the best of my knowledge this infra-red signalling and station-keeping method was not used in service.

At the end of 1927, the explosion research and infra-red investigations having been completed or handed over to others for development, and B. S. Smith having left A.R.L. for H.M.S. *Osprey*, Portland, my main responsibility gradually turned to underwater acoustics again. At first this continued on the lines previously followed by the Acoustics group, *viz.* development of the 'ring' and 'rod' transmitters and the audio-frequency echo depth sounder. The reports of the work of the Acoustics group were, after a short time, divided into two parts. The part dealing with high frequency sound transmission, *etc.* insofar as it related to

[61] In this connection μ is 10^{-4} cm., or 1 micron.
[62] 'Thermal Radiation from Aeroplanes.' A.R.L./S/20, May 1927.
[63] The ebonite must be good quality free from "loading" materials.
[64] Admiral Burmester, Capt. im Thurm and Cdr. Foote.

Asdics was incorporated in H.M.S. *Osprey* half-yearly reports, whilst others of a less secret nature appeared in the ordinary A.R.L. quarterly reports. In addition to myself, the staff of the Acoustics group now consisted of G. F. Partridge, F. D. Smith and J. A. McGeachy. At a later stage we were joined by N. Shuttleworth, C. A. Luxford and by J. A. Hey (who left A.R.L. to join H.M.S. *Osprey* in 1932). We received considerable help on the mathematical side from S. Butterworth on many occasions. It would take too long and occupy too much printing space for me to describe the many new items of research which were introduced in the period 1928-36, for details, reference must be made to A.R.L. and *Osprey* periodical (Q.R. and halfyear) and special reports. In addition to 'hardware' for use in Asdics, Echo Sounding, *etc.*, we initiated more 'basic' (or 'semi-basic') research on such fundamental problems as cavitation, sound propagation as modified by surface reflection and temperature gradients, measurement of sound intensity under water, velocity of sound in sheet materials and so on. As always, even to-day, we were asked to deal with 'subsidiary' problems which were outside our normal programme. Before dealing with the latter, I shall mention briefly two of such 'problems.' One of these related to the recovery of 'lost' torpedoes. As everyone knows torpedoes are expensive items which frequently run astray or fail to 'blow' at the end of practice runs. At the end of a run a considerable amount of residual air at a pressure of several hundred pounds per square inch remains. In our solution of this problem we proposed to use this residual air to operate a small pneumatic tapper which 'hammered' the hull of the torpedo, the sound thus emitted into the surrounding water being detectable under good weather conditions at a range of several miles. A directional hydrophone of the type designed at Hawkcraig. Aberdour in 1916 was used for locating the origin of the sound proceeding from the 'bottomed' torpedo. The only specimen of this hydrophone which could be found at this time, 1929, was in the Science Museum at South Kensington, and a copy was made at A.R.L. for the purpose of the experiments. The first trials were made at the torpedo range at Arrochar where Mr. Devine was the Superintendent. He was a remarkable character, a great philosopher with a very practical outlook who will be affectionately remembered by all who were privileged to know him. He always gave us so much assistance and encouragement whenever we visited the range. On this occasion a torpedo was sunk early one morning, in a position 'unknown' to us and in the afternoon we were asked to find it. With the portable directional hydrophone over the side of a motor boat we could hear the 'tapper' in the torpedo quite clearly when we were at the starting point, and had no difficulty in finding it in a bay about two miles down the loch, the bubbles rising up from the torpedo being then clearly visible. A diver lowered to the bottom some distance from the tapper could walk in the correct direction towards it, and indicate to the boat above him in which direction to proceed to find it. At the end of this very successful trial of the tapper, Mr. Devine, after offering his congratulations, tactfully informed us that he had never yet lost a torpedo on the range, in fact he was 'one up,' having found one more than had been fired! Mr. Devine told many tales of divers, some probable and some not. There was the story of the diver who was lowered 'plumb on top of the torpedo.' His pay depending on 'time' as well as on 'depth,' he thereupon sat on the torpedo, took out his pipe and had a comfortable smoke for a spell! Further trials of the torpedo tapper were made at Portsmouth, using an outboard directional hydrophone, when it was heard and located at ranges of several miles.

I referred earlier to Dr. Young's work on course plotters in which an accurate ship's 'log' (speed indicator) was required. Existing 'logs,' *e.g.* the Pitometer log and others depending on the use of 'pitot and static' tubes were suspected of having errors of various kinds, revealed in Haslar and N.P.L. tank tests. It was therefore decided in 1929 to carry out careful tests of 'pitot' type speed indicators in Loch Long at Arrochar, using a motor launch provided with suitable outboard fittings[65]. The trials which were carried out in May and June 1930, were made in good weather conditions using the standard Pitometer pitot-static tube, and various specially designed p-s tubes of A.R.L. design. Runs were made at carefully measured speeds, with the tubes at various depths and angles of 'yaw.' The commercial pilot-static tube showed peculiar characteristics as the yaw was varied whereas the A.R.L. tubes followed more nearly a cosine law which varied only slightly from normal 'ahead' indication over a considerable angle of yaw. The results of this investigation[66] were I understand communicated to the manufacturers and resulted in the adoption of the A.R.L. design.

An urgent and very important requirement by H.M.S. *Osprey* in 1927 was a sheet material for use in the design of Asdic 'domes.' It was more important that this material should be mechanically strong to withstand the hydrodynamic forces on the dome when carried beneath the A/S vessel at high speed, whilst it should interfere as little as possible with the transmission and reception of the H.F. pulses used in the asdic detection of sub-

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(65) See A.R.L. Q.R. No. 33, December 1929, and Q.R. No. 35, June 1930.

(66) See A.R.L. Report on "Speed Indicators for Ships" No. 54, December 1931. A. B. Wood and E. H. Lakey.

marines. Consequently an acoustic goniometer was designed for the measurement of the reflection and transmission characteristics of sheet materials as the angle of incidence was varied continuously. The experiments were done to scale at a frequency of 275 kc/sec. using a pair of circular quartz transducers (a 'modern' expression indicating in this case transmitter and receiver) of diameter about 2½ inches. Thin sheets of a large variety of materials metallic (steel, aluminium, alloys such as *Alpax* etc.) and non-metallic (ebonite, bakelite, lorival, 'dermatine' and various plastics and other insulating materials) of graded thicknesses were used. The results were extremely interesting and useful. They were definitely unforeseen and indicated that the classical theory of Rayleigh on transmission through thin sheets immersed in water was insufficient to explain many of the observations. An omission from Rayleigh's theory was the possibility of transverse waves in the sheet material as well as the longitudinal (thickness) vibration assumed. No special report on these observations was written, but the information can be found in H.M.S. *Osprey* half-yearly reports around 1934. Great care had to be taken before testing a sheet of material that all air films and bubbles were removed from its surfaces. On one occasion when testing a sheet of *Alpax*, which had been lowered into the tank when I was out of the laboratory, I found an unbelievably high reflection and low transmission of the incident sound. On inspecting the *Alpax* sheet it was discovered that this abnormal effect was due to a large paper label stuck on the sheet addressed to The Superintendnt, Admiralty Research Laboratory, Teddington ! The air film was responsible. Thin metal sheets were found to give high transmission of sound at angles of incidence near the grazing angle, whilst non-metallic 'plastics' showed very low transmission at such angles of incidence. In developing a theory of sound transmission through thin sheet materials it was required to know the velocity of transverse waves in the sheets and a special technique for measuring this velocity was developed[67]. Various methods were developed for the direct measurement of sound intensities in water. In one of these methods the Rayleigh disc principle was used. The conventional mica disc, as used to measure sound-intensity in air was shown to be over 2,000 times in error when used in water ! Making allowance for the water load on the disc and using discs heavy compared with water, satisfactory measurements were made in agreement with theory[68]. Discs of tungsten and platinum were used to measure the sound outputs and directional characteristics of quartz and nickel transmitters. About this time also, *i.e.*, in 1934–35, I made some small scale experiments in the laboratory tank (80 ft. long, 15 ft. wide and 10 ft. deep) to investigate the interference effects (Lloyd's fringe type) between direct and surface-reflected sound waves. These experiments produced some very interesting results and indicated also the presence of refraction phenomena due to temperature gradients in the water [69]. The result of this small scale research finds application in sound transmission in deep (oceanic) waters.

N. Shuttleworth who joined the Acoustics group in 1931 came from *Osprey* with considerable Asdic experience both in research at Portland and at sea in the Mediterranean. In 1931–34 he designed and developed high frequency alternators as alternative to valve oscillators as used for asdic purposes, resulting in a considerable saving in weight and cost. These alternators, operating in the frequency range 15 to 25 kc/sec., were constructed in various sizes, from trawler sets having an output of 100 watts to machines having 7·5 KW output for larger A/S vessels and for research purposes. A sensitive relay and governor system was designed for the accurate frequency control of these alternators. Shuttleworth also devised a novel form of directional sound transmitter in the form of a rod loaded at regular intervals, equivalent to a line source transmitting *in* the direction of the line. It consisted of a rod of tin about 2 ins. diameter and 2 ft. long, with equispaced grooves turned in it so as to form a wave-guide in which the velocity of propagation was equal to that of the surrounding water. To protect the 'tin pagoda,' as it was called, from the side thrust due to its motion through the water when projecting vertically beneath the ship, it was enclosed in an oil-filled streamlined sheath of phosphor bronze. It behaved 'according to theory' but was never used 'in service.' Nevertheless it demonstrated a very interesting principle which may sometime have other applications, *e.g.* as a long-time-delay for computers !

I must now revert back again to the year 1928, and to moralise a little on how careful one should be not to be too dogmatic in research. It came about in this way. Dr. E. P. Harrison who was at this time Chief Scientist in Mine Design Department, H.M.S. *Vernon*, Portsmouth, was a frequent visitor at A.R.L. to see me about explosion pressure research and allied problems. He had for some time taken an academic interest in magneto striction[70] (M.St.) a phenomenon in which

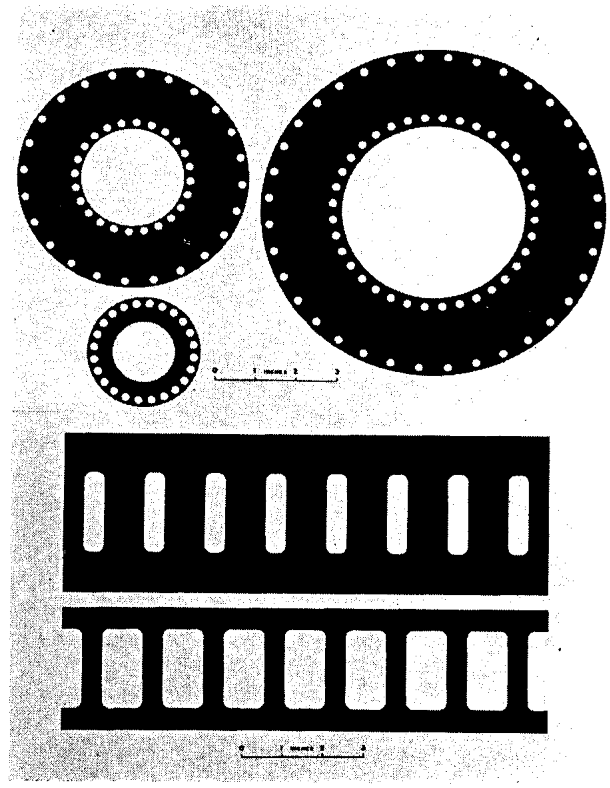
[67] 'The Velocity of Sound in Sheet Materials'. *Proc. Phys. Soc.* **47**, (1935) 149 and 185. A. B. Wood and F. D. Smith.
See also 'Frequency and Velocity of Sound in Small Discs'. *Proc. Phys. Soc.* **47**, (1935) 794. A. B. Wood.

[68] 'Correction to the theory of the Rayleigh Disc as applied to the measurement of Sound Intensity in Water.' A. B. Wood. *Proc. Phys. Soc.* **47**, (1935) 779.

[69] See H.M.S. *Osprey* half-yearly reports 1934-35.

[70] As I shall have to use this word frequently, I propose to write M.St. instead of 'magnetostriction'.

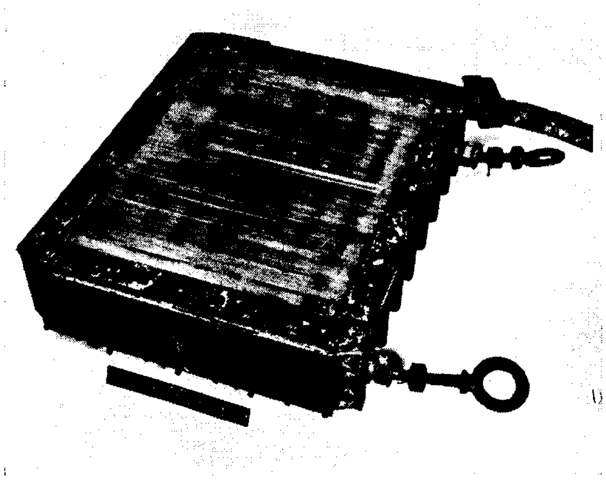
magnetisation of a ferromagnetic material such as nickel produces a small change (a few parts in a million) of its linear dimensions, or conversely an enforced change of length develops a change in its state of magnetisation. As a result of his experiments with wires of M.St. materials at audio frequencies, he suggested that we might use this M.St. effect as an alternative to the piezo-electric (p.e.) effect in quartz for use in Asdics. My immediate reactions to this proposal were (a) if the transmitter were laminated to make it electrically efficient it would be a poor resonator and as a consequence would be mechanically *in*efficient; (b) on the other hand, if the transmitter were not laminated to make it mechanically efficient at high asdic frequencies (around 20 kc/s) it would be *in*efficient electrically. Dr. Drysdale and F. D. Smith both agreed with this somewhat specious argument, but Harrison was very persistent and returned repeatedly ' to the charge.' At last it was decided to make a few fundamental measurements to prove it was no good ! ' We made up a pile of consolidated annular ring stampings of annealed nickel, wound toroidally with a D.C. magnetising winding and an A.C. excitation winding, to obtain a circle diagram for the nickel resonator. As we expected it indicated a low efficiency of conversion and excessive damping, but not so serious as to suggest it might be quite useless. Then it dawned upon us that the circle-diagram test should be made with the nickel vibrator *in water !* When this was done it became clear that it was much more efficient, the internal damping of the laminated structure being considerably less than the useful water-damping. From that point, we settled down to a thorough investigation of the magnetostriction problem in all its aspects: choice of material which eventually led to annealed commercial nickel, form of stamping or other forms of lamination—tubular rolls, annular ring stampings, and window-type rectangular strip stampings. A completely closed magnetic circuit was essential to all these designs. The insulation of the laminations from one another involved much research, but in the end it was found that nickel oxide, formed when the stampings were annealed in air, served the purpose nearly if not quite as well as insulating varnishes which consolidated the pile of stampings. S. Butterworth and F. D. Smith[71] worked out the theory of the equivalent circuit of the magnetostriction ' oscillator ' (now described as ' transducer '), and I carried out many experiments in the tank to obtain the best conditions of excitation, water-damping, *etc.* As in the case of piezo-electric quartz the magnetostrictive transmitter functioned also as a receiver. With quartz, however, high voltages and extremely good insulation conditions are essential, whereas with nickel low voltages and large currents with moderately good insulation are required. The first M.St. transducers, scroll and ring types, proved to be very efficient both as transmitters and receivers. They were ' permanently ' magnetised by a ' flash ' D.C., all that was required in subsequent use being the A.C. winding. Later designs used D.C. windings, permanent magnets, and rectified A.C. for polarising the M.St. transducers.



Types of magnetostriction stamping rings and strips used in transducers around 1930.

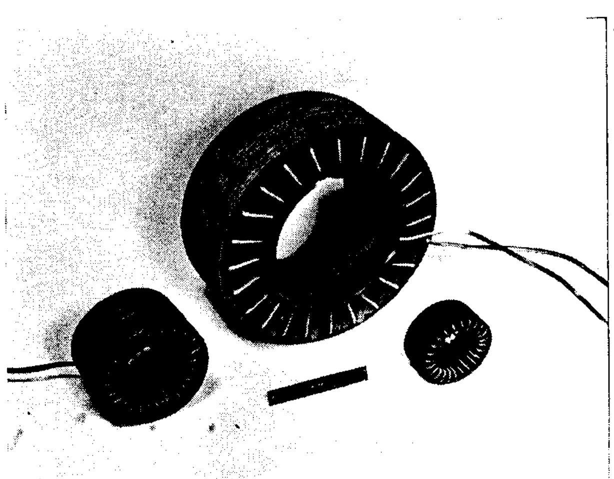
I referred earlier to an attempt by B. S. Smith in 1927 to use an audio-frequency echo sounder in a survey motor boat. This failed on account of lack of screening by the hull between the transmitter and receiver. The only hope of success appeared to lie in the use of *high frequency* sound pulses which could easily be made directional and hull screening less important. During 1929 a motor-boat echo depth recorder was designed and tested in the laboratory tank. At first a small 16 kc/s rod sounder, operated by an E.M. hammer similar to that in the audio frequency E.D.S., was used as the transmitter to give a regular series of H.F. impulses. The receiver was of the M.St. nickel ' scroll ' type,

[71] A.R.L./S/25. June 1930. See also *Proc. Phys. Soc.* **43** (1931) 166. Later F. D. Smith wrote a series of A.R.L. papers on the design of magnetostriction 'oscillators'.



Strip window type magnetostriction transducer of 1930.

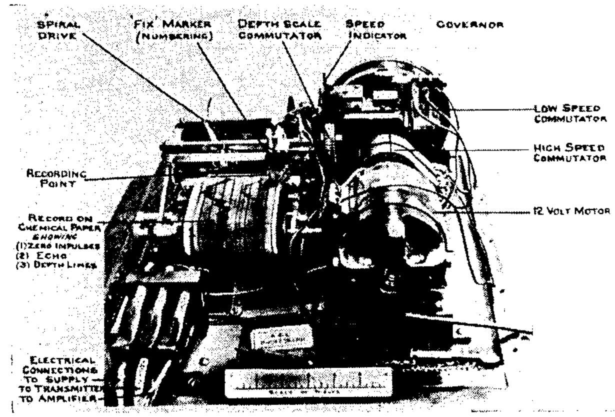
used with a 3-valve amplifier. The first recorder was designed to give a linear record of depths from 0 to 200 feet, using the chemical paper[72] soaked in potassium iodide and starch solution—(as used by Michael Faraday originally over a hundred years ago !)—but later the depths were increased to the maximum to be found in the oceans. Soon I replaced the spring-driven hammer and H.F. rod by a condenser discharge, at a suitably high voltage, through the low-impedance winding of a magneto-striction nickel transmitter—a good example of the electro-mechanical analogy. This produced a powerful damped train of oscillations in the transmitter in tune with the receiver, the energy in the pulse being given by $\frac{1}{2}CV^2$ joules. It should be unnecessary here to describe the M.St. echo depth recorder beyond the remarks I have already made. At its first sea trials at Sheerness[73] from February onwards in 1930 it gave excellent records showing the sea surface and the contour of the sea-bed. On the first run across the dredged channel, about 100 ft. deep, it started from the boat camber, 4 or 5 ft. deep, across the 'deep' channel to the other side, the record being remarkably clear. On the far side the record indicated only a few feet beneath the keel and I called out to the Coxswain 'Look out, we're nearly aground !' He replied, 'There's plenty of water Sir,' but the words were hardly out of his mouth when we were stuck on the mud ! There *was* plenty of water, but it was mainly in the horizontal direction ! Luckily we were on a rising tide. Captain Edgell, Hydrographer of the Navy, came to Sheerness to see the demonstrations and expressed great satisfaction with the depth recorder. He asked on the spot that it should be left at Sheerness with one of his staff for a week or two to make a survey of the channel at Sheerness, and this was done. The M.St. echo depth recorder was next tested in a motor boat in Moray Firth off Fraserburgh in May 1931 and gave good records up to 120 fathoms[74]. In these trials a pile of annular ring stampings of nickel, mounted inside a truncated conical reflector, was used—the frequency of transmission being about 16 kc/s. The Hydrographer then asked for a 'survey ship set' to be fitted in H.M.S. *Flinders* to record 150 fathoms reliably. Preliminary experiments in the laboratory tank, transmitting and receiving through steel plates of various thicknesses up to $\frac{7}{8}$-inch indicated a considerable probability of succeeding in this without having to cut a hole through the $\frac{3}{8}$-inch plating of *Flinders*. We used again M.St. annular ring stampings, frequency about 16 kc/s, for both transmission and reception. These were fitted in air-filled conical reflectors and mounted inside water-filled tanks clamped on the hull close to the bulge keel of the ship. McGeachy, somewhat optimistically I thought, designed a new spiral drive recorder which covered the depth-range 0 to 150 fathoms with zero shifts to allow the record to be extended in two further steps, 150–300 and 300–450 fathoms. Both 'inboard' and 'outboard' recordings were made, and the condenser discharge damped-impulse method was compared with short pulse continuous wave transmission. All recordings were made with the ship running at its normal cruising speed, off the west coast of the Isle of Lewis towards the Flannen Islands in which range the depth increases from



Annular ring magnetostriction transducers. The largest worked on 10 kc/s.

(72) Chemical recorders. *The Fultograph*, were in use by Wireless Pictures (1928) Ltd. The principle had also been adopted by N. Shuttleworth at H.M.S. *Osprey* to record asdic echoes.
(73) See A.R.L. Report "Echo depth recorder for Survey Motor-boats." A. B. Wood and J. A. McGeachy, No. 49, December 1930.
(74) See A.R.L. Report No. 53. A. B. Wood and J. A. McGeachy. July 1931.

16 fathoms (near Stornoway) to 1,000 fathoms. Excellent records were obtained by all methods up to the maximum of 450 fathoms which could be tackled by the recorder[75]. So McGeachy was right and a certain person who predicted, as we were leaving for Stornoway, 'Our name's mud if we don't record 150 fathoms' was not disappointed We were awarded the Thomas Gray Prize by the Royal Society of Arts for this the best invention in Navigation in the year 1932–33. (A. B. Wood, F. D. Smith and J. A. McGeachy). Details of the magnetostriction echo depth recorder including the principles of design and the description of the A.R.L. tests, the Sheerness, Fraserburgh and Stornoway trials was published later[76]. The manufacture of the M.St. echo depth recorder was taken over by Henry Hughes & Son (now Kelvin Hughes Ltd.). The equipment is fitted to most sizeable ships throughout the world—motor boats, trawlers, merchantmen, liners, and of course the Navy. It is used not only for navigation, but also for hydrographical survey, fishing, geological survey of the sea bed and for research purposes in oceanography. Before leaving the subject of 'the Admiralty pattern high frequency magnetostriction echo depth recorder' as it is called, this can be cited as one of the few examples of an Admiralty research project having made a large commercial profit in addition to its direct value to the Navy! Besides this echo sounder application much work was done on magnetostriction transducers for research and asdic applications. Dr. Drysdale, F. D. Smith and myself took out a number of secret (then) patents relating to particular designs and multiple arrays of such transducers. In addition to the cylindrical scroll and annular ring types which I have mentioned a long strip type having a series of equispaced legs and windows proved very effective. F. D. Smith also designed 'piston' transducers having a large steel plate emitting area excited into vibration by a large number of nickel tubes. These were constructed to have frequencies of 5 kc/s and 1 kc/s. Another type had a 'flat' frequency characteristic intended for use in H.F. sound research at *Osprey*, Portland. F. D. Smith and J. A. Hey also worked on a multiple H.F. sound transducer[77] using a series of water-filled pipes[78] each containing a scroll type nickel vibrator (about 1 in. dia.). With this system the resultant emitted beam could be swung through any desired angle by phasing either (a) mechanically moving the line of nickel vibrators in the tubes or (b) electrically by phase-scanning circuit. C. A. Luxford assisted in the acoustics research at a later stage. Attempts were also made to produce a uniform limited beam (flat-topped directional characteristic) with a M.St. transducer having 'phased' sections, the object being to reduce the



The recorder used in the first Echo Depth Recording Trials at Sheerness in 1929.

secondary beams of a 'normal' transmitter to a minimum. S. Butterworth did the theoretical work on this problem[79]. It was anticipated that the removal of secondaries would result in an improvement of signal to noise ratio in echo detection of submarines, Cathode-ray oscillograph records were made of the beam shapes of various forms of directional transducers from 5 kc/s to 300 kc/s—quartz asdics, echo sounders, the tin pagoda, large and small M.St. transducers (circular, square, strip and multiple types), which served to check theoretical deductions. In the first tests of a large (12 inch square) magnetostriction transducer of the 'window' strip-stamping type having a frequency of 18 kc/sec., we were measuring the sound output in terms of the A.C. electrical input. At first the output increased uniformly with input, but at higher inputs the sound output began to 'flatten out' and then to decrease. A defect in the M.St. transducer was suspected and it was dismantled and rebuilt. Further tests confirmed what had been previously observed. The tests had been done with the transducer 5 or 6 ft. deep, and on raising it near to the water surface whilst still transmitting H.F. sound it was noticed that bubbles were issuing in a stream from the face of the transmitter. On illumination of the water in the tank by a submerged high power

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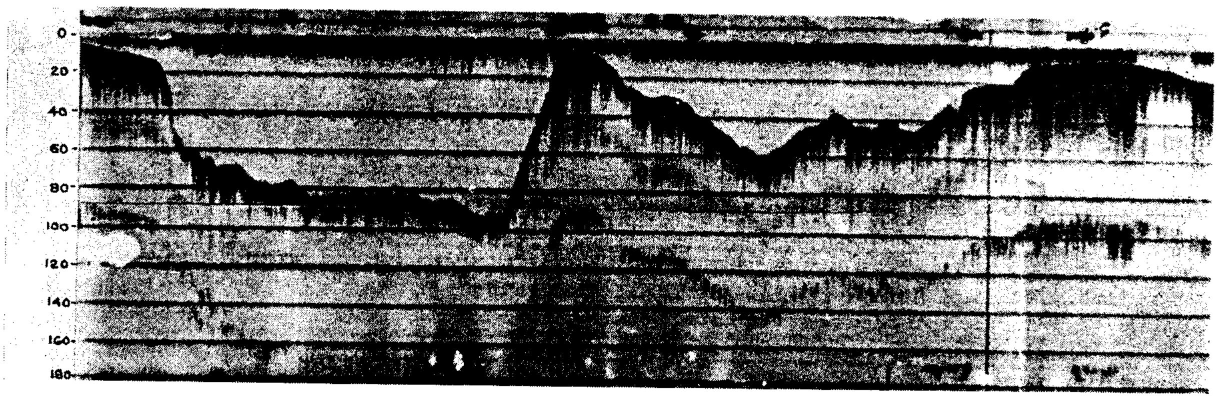
(75) See A.R.L. Report 'Echo Depth Recorder. High Frequency Magnetostriction type. Stornoway trials". No. 55, December 1931. A. B. Wood and J. A. McGeachy.

(76) 'A Magnetostriction Echo Depth Recorder'. A. B. Wood, F. D. Smith and J. A. McGeachy. *J.I.E.E.*, **76**, (1935) 550 and British Patent 375.375.

(77) See A.R.L./S/26, "A Multi-spot line source with Magnetostrictive Elements." S. Butterworth and F. D. Smith.

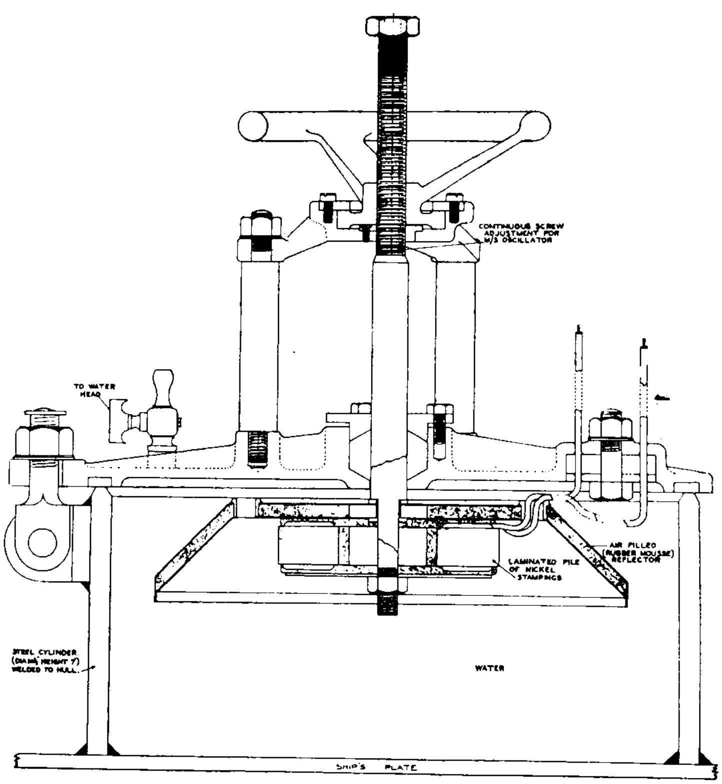
(78) See A.R.L./S/30, "Propagation of H.F. Sound in water-filled pipes". F. D. Smith and J. A. Hey, 1932.

(79) See A.R.L./S/24, "Production of limited sound-beams of Uniform Intensity", S. Butterworth, February 1930.



The first records made with a magnetostriction echo depth recorder.
In the sea off Sheerness in 1929.

lamp, the bubble stream could be followed to the remote end of the tank about 60 ft. away when the transmitter was transmitting on full power. The cavitation effects[80] which we were observing were very complex on and near the active face of the transducer, but a few feet away the bubbles appeared to be of a more or less uniform size travelling at a fairly high speed along the axis of the primary sound beam. On inserting a disc of thin tin-foil (mounted on a metal ring) normal to the bubble stream it was found on withdrawal from the water to have been punctured and indented by the small bubbles driven along the axis of the sound beam of the transducer. The diameter of the majority of the indentations and holes in the tin-foil corresponded approximately to the theoretical diameter of bubbles having the resonant frequency of the sound source. This observation of cavitation with the large M.St. transducer started a research on H.F. sound cavitation for prolonged continuous waves and for short pulses. Passing the sound beam through a glass container, filled with air-free water, immersed in the large tank revealed the cavitation bubble stream on both sides of the container but not within it — indicating that dissolved air in the water was the source of the bubbles. Observations were subsequently made with water containing known amounts of dissolved air, from none to supersaturation. A large flask of ether (containing much dissolved air) gave spectacular cavitation effects when placed in the underwater sound beam. A bottle of soda water (with stopper removed and frothing reduced to a more or less quiescent state) frothed violently even at the extreme range (about 70 feet) in the tank. I had ideas at the time of using a bottle of soda water as a means of measuring sound intensity, the effect was so marked ! Talking of cavitation of the large M.St. transmitter reminds me of a ' tame ' eel which lived in the large tank, often looping itself over the lifting eyebolts of the transmitter and going to sleep. This eel was presented to us



The magnetostriction transducer tank as used in the Stornoway trials.

[80] See H.M.S. *Osprey* half-yearly reports March 1933 to March 1934.

by the N.P.L. electricity department and had been used, with a number of other eels, to indicate equipotential lines in a shallow water-filled tank when a high voltage was applied between electrodes in the water. The eels had a preference for equipotential lines to avoid electrical shocks (they were, I should explain, not electric eels) ! Our eel, therefore, came to us with a preliminary Scientific training of N.P.L. standard. It was very inquisitive and interested in ultrasonics—more particularly in cavitation phenomena. When the large M.St. transmitter was cavitating I remember the eel nosing up to the bubble stream but, on reaching it, going rapidly 'into reverse,' without turning round! Cathode ray oscillograph records showed that with the onset of cavitation, the waveform of the sound emitted from the M.St. transmitter ceased to be sinusoidal, the harmonic content of the waveform increasing with increased electrical input. This effect no doubt explained to some extent the loss of efficiency at the higher sound outputs. Using this large transmitter I measured the sound output in various ways. One of these was the Rayleigh disc method to which I have referred. In another method I used a bundle of thermo-junctions one end of which was enclosed in *Plasticene* whilst the other end was exposed directly to the water. The H.F. sound, falling on the 'bundle' heated the *plasticene* end, due to absorption of sound energy, but left the other 'cold' end unaffected. As both ends were in the tank there was no effect due to variations of water temperature. The thermo-electric effects were easily measurable on a pointer milli-voltmeter, and gave good results which showed that the heating effect in the *plasticene* was proportional to the square of the 'input' current in the transmitter. In 1936 F. D. Smith devised a very ingenious method of using magnetostriction nickel wires and rods for stress measurement. He developed the method later at the Admiralty Engineering Laboratory at West Drayton, as an engine 'indicator' and stress meter for girders, *etc.* I remember Dr. B. N. Wallis from Vickers-Aviation visiting A.R.L. in April 1936 to see a demonstration. He was proposing to use the device to measure the stresses in the geodetic structure of the Wellington bomber aeroplane which he had designed.

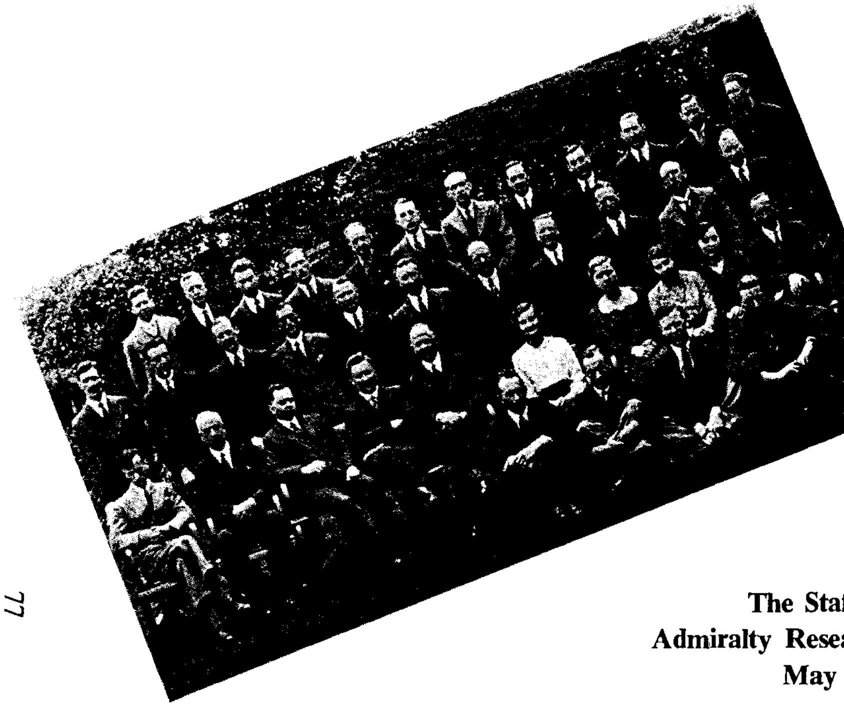
On many occasions during 1935-36 I visited Orfordness, and later Bawdsey Manor, Suffolk, to keep in touch with the remarkable experiments which were being made by Robert A. Watson-Watt and his staff to locate aircraft in flight at considerable ranges. They were starting a new technique which used H.F. radio pulses to detect echoes from aircraft whereas I had for a long time been interested in the use of H.F. sound pulses to detect echoes from submarines. Previous to visiting the research station at Orfordness I would have prophesied that the radio-location of aircraft by echo was unlikely to succeed. But of course the asdic detection of submarines also seemed unlikely to succeed when it was first proposed in 1915-16 ! On my first visit to Orford in 1935 A. F. Wilkins and E. G. Bowen were obtaining ranges of detection of 35 kilometres, and I was very much impressed by the possibilities of the method when I saw the echo 'pip' on the C.R.O. linear time base. The wavelength then in use for the pulse transmissions (triggered by the 50 cycle/mains) was about 8 metres. During my frequent visits to Orford I learned the details of the transmission and reception techniques and took part with the staff there in many discussions. I remember one morning asking Watson-Watt whether the phase at ground reflection was reversed (like that of a sound wave at the sea-air surface) or not. He gave his opinion, but that afternoon Dr. R. L. Smith-Rose arrived from the N.P.L. and expressed the opposite view. This led to an enlightening theoretical discussion in which Sommerfeld's theory, the state of polarisation of the transmitted beam and 'Brewster's angle' were often quoted![81] I advocated that much shorter wavelengths should be used, down to centimetre wave but these were not possible until later[82]. It is not my purpose, however, to discuss the early developments of radar. I mention it mainly to show (a) that A.R.L. took a lively interest in its possibilities in detecting and locating aircraft, ships and particularly submarines, and (b) to explain how it came about that in December 1936 I transferred my activities to H.M. Signal School, Portsmouth where I remained until October 1937, when I became Chief Scientist at Mining School, H.M.S. *Vernon* on the retirement of Dr. E. P. Harrison.

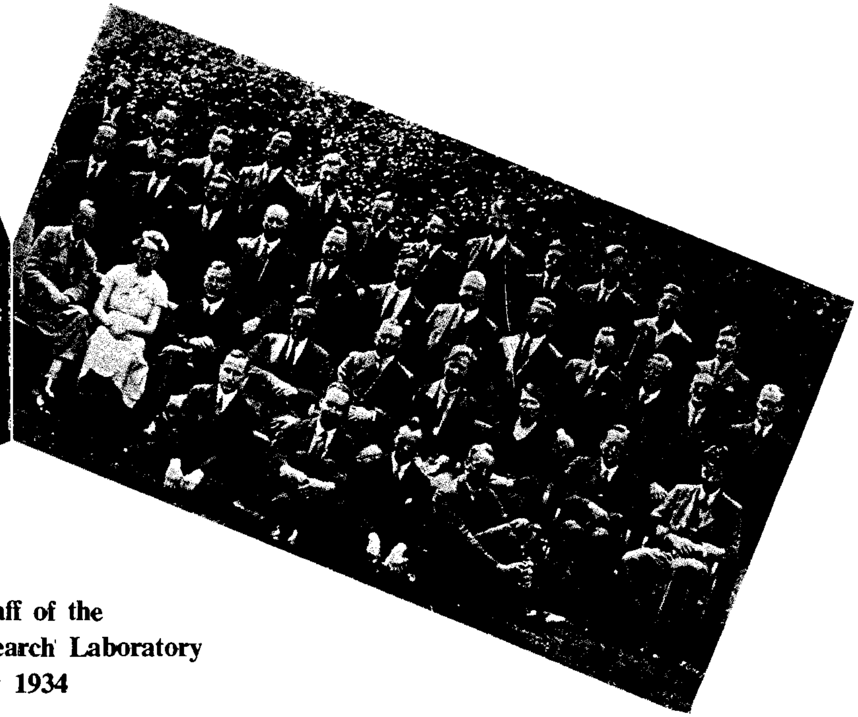
So far I have only referred to the scientific staff at A.R.L. and their work. Many of the workshop, drawing office, clerical and stores staffs came from Shandon to Teddington and their numbers were considerably augmented as some of the more important research items developed. It would be invidious to mention a few of these staffs by name whilst omitting others, so I shall refer the reader to the photograph shown. This shows the whole of A.R.L. staff in 1934[83]. It was taken when Dr. C. V. Drysdale retired from the post of Director of Scientific Research, Admiralty, and was succeeded by C. S. Wright, then Superintendent of A.R.L. F. B. Young became Superintendent, A.R.L. in July 1934, continuing in that appointment until his retirement in October 1937. I have

(81) I wrote a report on this in 1937 when I was at H.M. Signal School, Portsmouth.

(82) I pursued this suggestion at Signal School in 1937 and sketched out a multiple split-anode magnetron—which was never made !

(83) The names of all the individuals shown on this photograph are available.





The Staff of the
Admiralty Research Laboratory
May 1934

said nothing about the social activities at the laboratory nor of our very friendly relations with our neighbours The National Physical Laboratory. In the field of sport, cricket, tennis, football etc. A.R.L. was regarded as equivalent to one of the N.P.L. departments. Space does not permit more than this bare reference to this important aspect of staff activities. The Director of the N.P.L. during the period of which I am writing was Sir Joseph Petavel who, when Professor of Engineering at Manchester University, was closely connected with the work of the B.I.R. during the first world war. He was always keenly interested in the progress of research at A.R.L. and invariably placed the facilities of his great laboratory and specialist staffs at our disposal when required. Both N.P.L. and A.R.L. suffered a great loss when he died on 31st March, 1936.

In concluding this part of my narrative, I am very conscious that my remarks probably include items which may appear unimportant and have omitted others which may justifiably be regarded as more important. I realise that I have a strong tendency, not uncommon in those who 'write,' to say more about things in which I was personally concerned to the neglect of work done by others. As an excuse I take refuge in the fact that I write best about what I know best. After all, this is just 'reminiscences,' not a history. For the seven years after the end of 1936 I was not officially on A.R.L. staff, although I was a very frequent visitor, my work being more closely connected with Signal School and Mining School, Portsmouth, two old and important Naval Establishments both interested, amongst other problems in the application of research emanating from A.R.L. Whilst in these Establishments, however, I was still on the Admiralty Research staff of the S.R.E. Department, later to become the R.N. Scientific Service.

THE WAR PERIOD, 1937–1945

In the previous pages, I have dealt in each case with my connection with a particular research establishment. During the period of which I now write, I was, however, directly involved with several establishments in various parts of the country. This has consequently made it necessary to choose a simple and yet more comprehensive title. To those of my readers who were familiar with events in the two or three years preceding the outbreak of the second world war on 3rd September, 1939, my title 'The War Period' commencing 1937 rather than 1939 will be understood. It will be very clear to anyone who has read Winston Churchill's *The Second World War*, in particular Volume I, *The Gathering Storm*, that these years prior to September 1939 found the whole of Europe, ourselves not excluded, in a state of acute tension. Hitler's intensive rearmament and re-occupation of the Rhineland in March 1936 followed by the occupation of Austria and Czechoslovakia in 1938, and his entry into Poland in September 1939 made war inevitable.

My frequent visits to Orfordness and Bawdsey during 1935 - 36 where the work on radio location of aeroplanes and ships (now known as 'radar') was making such remarkable progress, impressed me with the possibility of its vital importance in the event of a second world war. This impression was deepened during the subsequent years leading to the outbreak of war in 1939. I have already explained how interest in this work resulted in my transfer, in December 1936, from A.R.L. Teddington to H.M. Signal School, Portsmouth, where 'radio-location' was to be my primary concern. At Signal School Captain J. W. S. Dorling, R.N., was the Naval Officer in Command, Commander F. J. Wylie, R.N., Experimental Commander, and G. Shearing, Superintending Scientist. Others of the scientific and technical staffs at this time were F. Brundrett, W. Ure, W. F. Rawlinson, L. S. Alder, C. E. Horton, A. W. Ross, J. D. S. Rawlinson, Ambrose Wilkinson, H. G. Hughes, H. Noble, H. Smith, E. G. Hill, C. R. Evershed, N. Pemberton, R. A. Yeo, W. P. Anderson, E. M. Gollin, E. J. Grainger, and others whose names I do not recall as I write. Yeo was at Orfordness and Bawdsey at the time when I was there from 1935 onwards. He and Anderson and later C. F. Bareford were working on the radio-location problem from the Naval aspect, on the lines of that at Orfordness, at a station at Eastney Barracks. My office desk, sited in Ambrose Wilkinson's frequency standardisation laboratory was, however, not well situated for my type of experimental work, so for a time I was busy working on the theoretical aspect of the transmission of electromagnetic waves over a conducting earth and the sea. This was mainly concerned with the interference between the direct ray and the surface-reflected ray — a problem analogous to that of sound propagation in the sea. In the radio case, however, polarisation effects had to be taken into account and Sommerfeld's theory of E.M. wave propagation, Brewster's angle, *etc.* had to be invoked. I remember discussing this problem with Watson-Watt at Orford and again when he visited Signal School in July 1937 with Professor E. V. Appleton. For the detection of relatively small objects near the surface of the sea, *e.g.* a submarine periscope, it seemed to me on theoretical grounds preferable to use very short waves, of the order of cms., rather than the longer waves, several metres, used for the detection of high flying aircraft. At this time E. M. Gollin was experimenting with a split-anode magnetron for generating cm. waves to be used at short ranges for signalling and station-keeping between ships at sea. The theory of the magnetron at that time was rather obscure but J. J. Thomson's electron theory and E. C. Megaw's work indicated that the higher the frequency the smaller must be the diameter of the cylindrical split-anode surrounding the hot cathode. Even at a high efficiency this implied that a single magnetron oscillator for cm. waves could not handle much power without overheating. At this time also I was experimenting with an infra-red method of detecting ships' funnels at sea. In the I.R. case billions of E.M. oscillators are involved and it seemed an obvious step to make a cm.-wave oscillator, *e.g.* a magnetron, into a *multiple* system also. I sketched out two such systems. In one of these, two concentric cylinders with corrugated walls formed an annular ring of small interconnected 'split-anode' cylinders each having its own heated cathode. In another, I planned a cylindrical annular block having six or eight small cylindrical holes, each with a slit leading into the central cylindrical cavity containing a common central cathode. The whole of the 'multiple magnetron' was to be enclosed of course in an evacuated glass container with the usual valve technique. When I showed these sketches to Shearing he seemed very dubious and said Hughes's valve transmitter laboratory, which at the time was making large silica valves for the fleet, was too busy. At Orford I had pointed out to Watson-Watt that the H.F. pulses sent out by the radio-locator transmitter were operating at a very high voltage for only a very small fraction of the total transmission time—about a tenth of a millisecond every fiftieth of a second, *i.e.* about $\frac{1}{200}$ th of the total time It seemed to me that high voltage sparks could excite a Hertzian resonator with much the same result but with much smaller 'installation and running costs.' In the spark method of course the sequence of pulses would probably be somewhat irregular compared with the valve technique, but that difficulty might possibly be overcome by arranging that the transmitting spark should trigger the C.R.O. time-base and so synchronise the transmitted pulse and the received echo pulse. With O. L. Ratsey, who joined me in July 1937, I made a few experiments with this 'spark' scheme. We succeeded in producing good transmitted pulses of the desired frequencies, using Hertzian type resonators excited by sparks and, later, Ratsey succeeded in obtaining good echoes from the pylons on Portsdown Hill — the transmitter, *etc.* being installed at Eastney Barracks. I could mention here other important work going on in Signal School in 1937, *e.g.*, *Radio D.F.* by C. E. Horton and A. W. Ross, *Infra-red signalling* by H. Smith and E. G. Hill, *Transmitting Silica Valve research* by H. G. Hughes, *Radio receivers* by W. F. Rawlinson and L. S. Alder, *etc.* Any detailed discussion of this work is however best left to those who were doing it, if they are still 'available'.

Significant events which occurred during the few months in 1937 whilst I was at Signal School were (1) in March, the Anti-Gas Course at Tipnor, attended by Admiralty Staffs in the Portsmouth Command, to prepare us for possible surprise Gas Attacks, (2) 12th May, the Coronation of King George VI, (3) 20th May, Naval Review in Spithead, (4) 28th May, resignation of Prime Minister Baldwin who was succeeded by Neville Chamberlain. Apart from the Coronation, of course, these events could be regarded as a 'sign of the times'.

In October 1937, after about 10 months at H.M. Signal School, I was appointed to be Chief Scientist at H.M. Mining School (later Mine Design Department), H.M.S. *Vernon* on the retirement of E. P. Harrison. As already mentioned in earlier articles of this series I had from 1917 onwards been much interested in underwater explosions and in the possibilities of Non-contact Acoustic and Magnetic mines, Loop detection of submarines, *etc.*, which were the primary concern of Mining School, Portsmouth. On many occasions I had worked at Mining School in co-operation with members of the Staff, so I was not a 'stranger' when I arrived. At the time of my arrival Commander R. H. F. de Salis, R.N., was Superintendent of Mine Design and Captain A. U. Willis, R.N., was Captain of *Vernon*. F. B. Shaw was Chief Technical Adviser and other members of the Technical and Scientific Staffs were F. Pickford, W. R. Steele, H. J. Taylor, J. H. Powell, E. C. Wadlow, A. C. Main, G. F. Turner, L. C. B. Johnson, F. J.

Tindall, H. Gollop, J. B. Swann, N. E. Noble, F. Pearson, G. L. Turney, H. Rowe, W. F. B. Shaw, H. W. K. Kelly, G. N. S. Farrand, F. L. Hill, W. A. Day, A. C. Edwards, J. T. Crennell, T. P. Rigby who was with the B.I.R. staff in the Aberdour days in 1916 was now in charge of the Mining workshop. It is hardly necessary to say that the main concern of Mine Design Department was mining but there were other closely related activities which formed a very important part of their functions, sweeps for dealing with all types of mines in existence or foreseen at that time, depth-charges for the destruction of enemy submarines, indicator and mine loops for the protection of harbours against enemy submarines, Anti-non-contact (A.N.C.) protection of ships against magnetic pistols of non-contact torpedoes and mines, research on underwater explosions and damage to ships, *etc*. The staff available, about two dozen scientific and technical grades, was lamentably small to deal effectively with such an extensive and important programme. The proof of this was demonstrated after the outbreak of war when the staff was increased to five or six hundred. When we came 'face to face', so to speak, with enemy submarines, non-contact mines and torpedoes in large numbers, the importance of the situation as it affected the safety of the country became obvious to all. Even with our small staff, however, much valuable information and hardware was accumulated and when war did begin we were by no means unprepared.

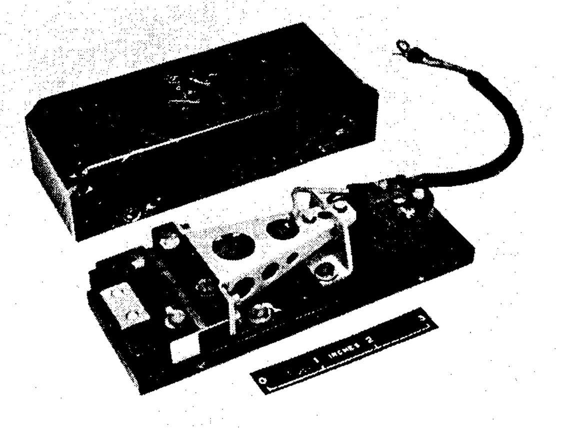
At this stage it seems appropriate to give a brief sketch of the state of things from late 1937 up to the outbreak of war in September 1939. First consider mine design. Mines can be divided broadly into two classes, contact and non-contact, an alternative classification could be buoyant and non-buoyant (ground mines). It is not possible in this brief summary to mention the many varieties of mines which have been used in war and designed in peace[84]. I shall refer at present only to a few of the more important types in course of development in 1937. The old contact type buoyant mine with its lead horn and glass tube containing bichromate and sulphuric acid, extensively used in the first world war, was becoming obsolescent and the horns were being replaced by spike switch horns. The latter, when pushed aside on impact with the hull of a moving ship, closed an internal switch which fired the mine. Prolonged studies were made, both on a full scale and on models of the oscillations and the 'dip' of buoyant mines in a tideway, and on various types of depth-setting mechanisms to ensure that the mines were not exposed to view at low tide and were efficient for their primary purpose, *i.e.* did not dip too much when the tide was running strong. The contact type mines were used in large numbers where wide channels had to be closed to enemy ships, particularly submarines, in deep water where ground mines would be ineffective. It should be noted that all mines of whatever type were subjected to stringent actuation and countermining trials before adoption for service use. Even a simple type of mine such as the spike switch-horn type gave a certain amount of trouble in both actuation and C.M. trials before a satisfactory design was obtained. In 1937 two types of non-contact magnetic mine were being investigated. One of these, known as the A.-E. unit, was designed by E. P. Harrison, assisted by G. L. Turney and H. Rowe. This operated on change of resistance of annealed *mumetal* wires due to change of ambient magnetic field. It was known as a 'total field' unit and was very sensitive to small changes of magnetic field whatever the direction. This ingenious device, however, never got into service in a mine but was sometimes used as a magnetometer in magnetic surveys around steel ships. The other type of magnetic mine unit was designed by L. C. B. Johnson and was known in its early stages of development as the C.R. unit, later to be incorporated in the C. type J. and M. type E. magnetic mines. C.-R. signifies coil-rod — a *mumetal* rod about two inches in diameter and three or four feet long (dimensions varied according to requirements) and wound with a coil several thousand turns in which is developed a considerable e.m.f. for comparatively small changes of ambient magnetic field. This e.m.f. is capable of operating a sensitive moving coil relay and firing the mine. The C.-R. unit was tried out in both buoyant and ground mines. Buoyant mines, however, oscillate transverse to the direction of tidal flow and the perturbations due to this motion in the earth's magnetic field sometimes cause the C.-R. unit to operate the relay. As a ground mine which, after laying, remains at rest on the sea-bed, the C.-R. unit was very successful. It could be laid in any steady earths magnetic field whilst retaining its full sensitivity to a change of field such as that produced by a submarine or a steel surface ship passing over the mine. Ground mines of all types, including the C.-R. unit, were of course designed to be laid either from ships or from aircraft. In the latter case dropping trials were necessary, as well as the usual actuation and countermining trials, to ensure that the components were not damaged on impact with the sea. In addition to the C.-R. unit, Johnson also devised an ingenious and simple device in which a small *mumetal* rod was pneumatically fired into, or out of, a coil generating an

[84] For a comprehensive description of mines, etc., see Capt. J. S. Cowie's book on 'Mines, Minelayers and Minelaying,' Oxford University Press, 1949.

e.m.f. proportional to the ambient magnetic field. This 'pistol magnetometer' as it was called was used extensively in the magnetic survey of ships, providing valuable information which was used in the design of magnetic mines and, during the war, on the problem of demagnetising ships to protect them against enemy magnetic mines.

As mentioned earlier, I had designed an acoustic non-contact mine unit (the Shunt-relay unit, with chattering contact and anti-countermining device). This N.C. unit was available at the time of which I am writing, but was not being considered then as a likely 'runner.' Reference will be made to this later, however, when enemy acoustic mines appeared !

Another mine being developed by M.D.D. at this time was the antenna mine which was first devised in U.S.A. during the first world war. This mine although electrically operated should be regarded as a contact mine having a much increased radius of action as compared with the 'horn' contact mine. In principle it depends on a sea-water cell formed by the negative steel hull of a ship and the positive copper electrode of the mine. The buoyant mine carries above it a long antenna wire (50 ft. long) having a small float which is submerged about 10 ft. below the sea surface. The wire passes through an insulated gland into the mine where it is connected to a relay controlling the firing contacts of the mine. A steel ship, making a good contact with the float or the antenna wire causes a current to flow through the relay to the copper plate and fires the mine. In some cases an additional antenna about 80 ft. long was fitted below the mine also, forming part of the mooring. This was of use against submarines in deeper water. The chemical section under H. Gollop were mainly responsible for the research and development of the antenna mine which had many teething troubles of an electrochemical nature. They also developed a *Staybrite* jumping wire as a net indicator for submarines. Contact of the *Staybrite* steel wire with the mild steel mesh of the net giving a change of electrical potential which was indicated in various ways—pointer, red light and/or bell—inside the submarine. H. Gollop, F. L. Hill and later V. Flint, J. T. Crennell, G. N. S. Farrand and A. C. Edwards developed many ingenious vital 'accessories' for mines—soluble plugs of various kinds, electrolytic (copper) time delays to replace expensive and complicated clockwork mechanisms. They also developed an improved electrode method of detecting submarines as an alternative to the 'loop' method, under the new description of U.E.P. (Underwater electric potential). H. M. Kelly and I designed a very small and simple magnetic unit (M. unit) which could be used in buoyant mines as an alternative to contact horns. It would operate at a



The microphone from a German acoustic mine.

distance of 3 or 4 ft. from the steel hull of a submarine and was immune to the normal movements of a buoyant mine in the sea. A portable magnetometer was designed on the same principle, proving useful and convenient in exploring magnetic fields around ships in dry dock.

Either just before or just after the outbreak of war I provided D.T.M. (Director of Torpedoes and Mines, Admiralty) with a list of possible mines, with suggested sweeps, which the enemy might use. This list was based on the physical characteristics of ships—magnetism, noise, water displacement, *etc.* —which could be utilised in designing a mine. It is of interest to note that one of the mines on the list was the pressure mine which was later used by the enemy and known as the oyster mine. We had in November, 1940 (at W. Leigh) prepared designs for such a mine but it had not been laid as there was at the time no satisfactory method of sweeping it.

Up to the outbreak of war the only depth charge in service was the one designed by H. J. Taylor and used extensively in the first world war. This depth charge in its cylindrical case, known as the 'ash-can,' carried a 300 lb. charge of amatol (T.N.T. and ammonium nitrate) and could be set to detonate at any of six depths between 50 and 500 ft. Its rate of descent was about 10 ft. per second. It was dropped or thrown in patterns of five or ten in one or two more-or-less superposed layers, according to the depth of water. The efficiency of this method of destroying a submarine or compelling it to surface was known to be rather low. Consequently much thought and discussion was concentrated in an effort to improve it. Assumptions, based on explosion damage trials of the radii of lethal and serious damage to a submarine of average dimensions, speed of submarine, rate of entry and of sinking of depth charge, *etc.* were made in attempts to calculate probabilities of destruction under various circumstances. Consideration was given to the best use of the explosive, whether to use it in one large non-contact charge or in numerous small contact charges. As depth charges of whatever kind were to be used primarily by A./S. vessels whose duty was to detect and locate the enemy submarine, it seemed only common sense that the planning of the techniques of depth charge attacks should be made by the co-operation of both explosives and A./S. experts. Consequently periodical monthly meetings were arranged to be held alternatively at M.D.D., Portsmouth, and H.M.S. *Osprey*, Portland, to discuss these matters. F. B. Shaw, myself, F. Pickford, H. M. Kelly from M.D.D., and B. S. Smith, W. E. Dawson from *Osprey*, as well as naval A./S. officers, were usually present. These meetings served a very useful purpose and provided a basis which was used later (during the war) for the design of depth charges and methods of attack, *e.g.* a large number of small—or a small number of larger fast-sinking depth charges. *Osprey* made a multiple small-charge experimental thrower and M.D.D. experimented with patterns of larger charges, but it was not until the war that the 'hardware' aspect of the problem was pursued energetically. The possibility of a magnetic non-contact depth charge pistol on the lines of the mine C.-R. unit had been considered, but so far as I know very little was done about it. In the early days of the war Professor P. M. S. Blackett and Dr. Williams made some experiments with an electro-magnetic rotating non-contact depth charge pistol, but I do not remember it reaching service use.

In the first world war buoyant contact mines of the horn and antenna types and non-contact ground magnetic mines had been laid, whilst acoustic non-contact mines were ready to lay when the war ended. Paravane sweeps with mooring-rope cutters were in general use for all types of buoyant moored mines, and cable sweeps of the A. and L. types were used at the end of the war to clear our own magnetic minefields. This was the minesweeping position just before the second war. The A. sweep, for magnetic mines, was a loop of cable towed astern of two ships, carrying sufficient current to sweep M. mines as it passed over them. The 'return' current was carried by 'earths' at each ship. The 'Single L.' (longitudinal) sweep was a straight cable with earth return towed by one ship. The main objection to the A. sweep was the difficulty of sweeping a buoyed channel without sweeping the buoys and fouling the moorings of ships. Experiments were made at M.D.D. with the L. sweep carrying direct currents of the order of 10 amps. in experiments to sweep M. type E. mines (C. type J. magnetic units), but the ranges with currents of this magnitude were, not surprisingly, rather small. Other alternative magnetic mine sweeps which were tried were towed permanent bar magnets (*a*) arranged at intervals along a loop of cable like an A. sweep and (*b*) larger and more powerful magnets on towed lines like the L. sweep astern of a single ship. There was of course a risk of losing the magnets when towed in this manner over a rough bottom. In January 1939 at a meeting at the Admiralty consideration was given to the design of a large electromagnet built into a ship to sweep M. type E. mines at a range of 300 ft. ahead of the ship. The weight of this magnet estimated by myself at M.D.D. and S. Butterworth at A.R.L. seemed prohibitive at 200 to 300 tons, but in the sequel after the war started it was built and was successful in sweeping enemy magnetic mines in the manner envisaged.

Soon after my joining M.D.D. staff in *Vernon* in October 1937 I attended an A.N.C. meeting at which Captain John Carslake was Chairman, A.N.C. indicating 'Anti-Non-Contact' and relating to the protection of ships from non-contact torpedoes with magnetic pistols and possibly also non-contact magnetic mines. The method of protection to be used was to magnetise the ship very strongly by a current-carrying cable in a horizontal plane surrounding the steel hull. To deal with magnetic fields of both 'red' and 'blue' polarity alternating current of 1 c/s was employed. The cable current used was 1500 amps. and 45000 ampere turns. When I witnessed the trials of this system on H.M.S. *Curaçoa* at Weymouth in April and May 1938 it was quite successful in touching off the magnetic pistol of an approaching torpedo at a fairly safe range. The effect of the large magnetic field developed in the ship was wonderful to behold! Pendulous ferrous objects such as hanging steel chains and the like were set into forced oscillation at 1 c/s., making a weird spectacle! At the first A.N.C. meeting which I had attended in 1937 I was shocked at the idea of *magnetising* a ship to protect it against magnetic pistols. I said it was playing into the hands of the enemy, as it was much easier to make a very *insensitive* magnetic pistol than a very *sensitive* one. Why not try to *de-magnetise* the ship instead? Captain Carslake and G. L. Turney disagreed and the *Curaçoa* was magnetised, to be followed later by similar treatment of H.M.S. *Iron Duke*. In the event, after the war started, it was our job to take out of these ships the magnetism put into them by A.N.C.! It will be inferred from my remarks that I thought magnetising a ship to protect it was a bad thing; I thought so then and I think so now.

One of the M.D.D's duties was to provide protection of our harbours and approaches against the entry of enemy submarines, excluding harbour defence asdics which was the concern of H.M.S.

Osprey, Portland. The method ultimately used and which proved very successful was the use of 'indicator loops' on the seaward side and 'mine loops' on the harbour side. The indicator loops provided a warning of the approach of the enemy submarine and the 'mine loop' containing its shore-controlled mines could destroy it. The design of techniques to be used in operating these loops of cable on the sea-bed was not without its difficulties. N. E. Noble, H. Rowe and Commanders James and Alston of M.D.D., J. Colquhoun of *Osprey* and S. Butterworth and N. F. Astbury of A.R.L. made a study of the problem and provided solutions to neutralising 'industrial' and 'natural' magnetic perturbations, to such an extent that the loops could detect midget submarine loop signatures above the general 'noise' level. I have referred earlier to Southern Latitude Loop Trials, preparations for similar trials were being arranged in October 1937 for Northern Latitudes (Iceland). The main purpose of the existence of M.D.D. was of course to design weapons to sink, or otherwise damage, enemy ships in wartime. A study of the effects of explosions under water was therefore of prime importance. In previous parts of this series I have referred to explosion pressure measurement by the piezo-electric cathode ray oscillograph method and its relation to damage to ships' structures. This work, commenced just after the first war ended, was now being continued by J. H. Powell at M.D.D. In co-operation with D.N.C. (Director of Naval Construction) experiments were being made on damage by underwater charges of various sizes and at various ranges, to ships' plates and full-size structures representing sections of a ship's hull. The Chatham Float and 'Job 81' (Submarine section), were examples of this type of full scale damage measurement. Later in the war, in January 1943, this research on underwater explosions had grown to such an extent that it was agreed by the Admiralty to form a separate establishment[85] for dealing with large scale engineering work of this nature.

In my opening remarks of this paper reference was made to the state of tension during the period of two years or so prior to the actual declaration of war in September 1939. Evidence of this could easily be seen locally, in the Portsmouth area, in various ways. For example, in January 1937 members of the staffs of Naval establishments including Signal School and M.D.D. *Vernon*, were attending Anti-Gas Courses at Tipnor in anticipation of a possible gas attack. Again in September 1938 seamen were digging trenches in the grounds of the Gunwharf, H.M.S. *Vernon*, and gas masks were issued to the Civilian staffs of M.D.D., followed in February 1939 by tests in a tear-gas chamber. Soon after the coronation of King George VI on 12th May 1937, Prime Minister Baldwin retired and was succeeded by Neville Chamberlain, and a spectacular Naval Review was held in Spithead. The visits of Neville Chamberlain to see Hitler in Germany and the 'piece of paper' episode are now history and require no comments of mine. A matter of more personal interest to me in this period was the death of Lord Rutherford on the 19th October, 1937. I had known him well since 1909 and in various ways had been in close contact with him up to the time of his death. It was through his suggestion that I joined the Admiralty service (the B.I.R.) in 1915. During the first world war he was closely concerned, as a very active member of the B.I.R., with the research for the Navy and retained a lively interest in it for the rest of his life. As is well known his work on atomic physics and his theory of the nuclear atom form the basis of our present-day knowledge of nuclear physics. He was always an advocate of the possibilities of atomic power for peaceful industrial and research purposes. He would, without doubt, have been strongly opposed to its use for atomic bombs, except perhaps as a deterrent. The first of four volumes of his collected papers has just been published under the editorship of Sir James Chadwick[86].

The inevitable crisis came on the 3rd of September 1939 when war was declared on Hitler's Germany after the invasion of Poland. On the 17th a meeting was called very early a.m. at the Admiralty to discuss immediate steps to be taken as a result of the mining of *The City of Paris*. Non-contact mines, magnetic mine sweeps, buoyant mine sweep detectors were among other items urgently discussed. Darwin's, Turton's and Swift Levick's of Sheffield were urged to supply large quantities of permanent magnet steel for M. sweeps. F. B. Young (who on 20th September returned from retirement[87]), S. Butterworth and myself were planning the design of current carrying cables for sweeping magnetic mines, the existence of which was still uncertain and the type unknown. The day following this discussion the First Lord of the Admiralty, Mr. Winston Churchill, came to *Vernon*, and a week later Professor Lindemann was here also. High speed (20 knots) M. sweeps were designed and constructed using large cobalt steel bar magnets mounted like an A. type cable sweep.

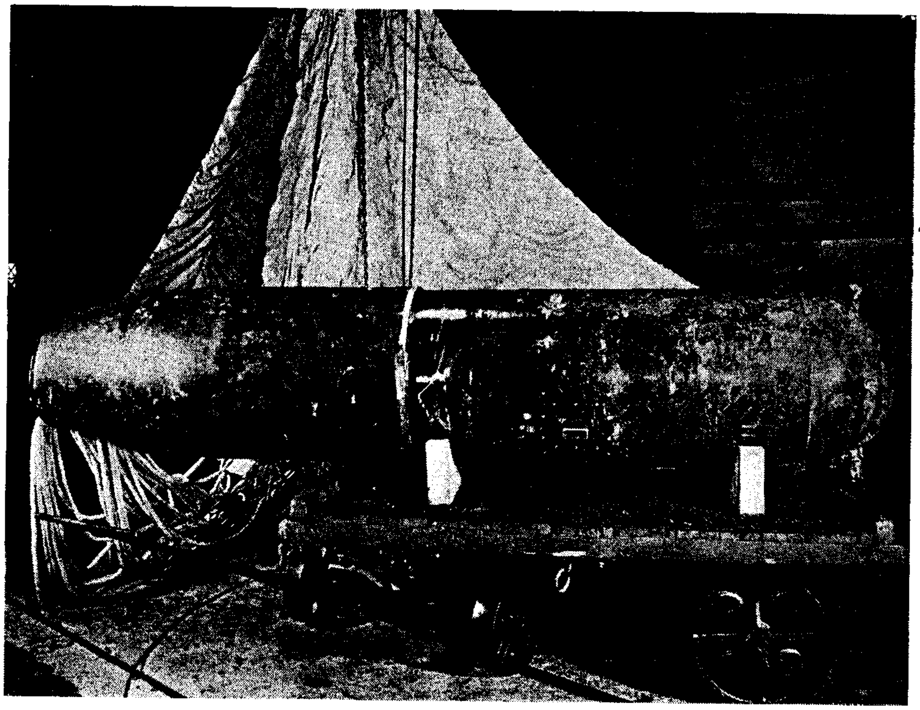
[85] Now the Naval Construction Research Establishment at Dunfermline and Rosyth.

[86] The Collected Papers of Lord Rutherford of Nelson, O.M., F.R.S., Vol. 1 (Publisher George Unwin, London, 1962).

[87] F. B. Young, Superintendent A.R.L., retired on 30 October, 1937 and was succeeded by S. Chaffer. The latter died on 27 June, 1939. F. B. Young joined my staff in M.D.D. in September, 1939 after war was declared.

Young, Butterworth and I also discussed, both at M.D.D. and A.R.L., the possibilities of demagnetising steel ships by cables wound in a horizontal plane round the hull, and on 10th November, 1939, S. Butterworth and N. F. Barber came to M.D.D. to plan, with Young, Lakey and myself, the possibilities of *demagnetising* a destroyer, in contrast with the *Curaçoa A.N.C.* method of *magnetising* it much more strongly, a method to which reference has already been made. On the morning of Thursday, 23rd November, 1939, I was attending a meeting on M. sweeps with D.S.R. (C. S. Wright) and Sir Frank E. Smith at Westminster when I was requested by 'phone to go to Southend where a German parachute aircraft mine was exposed on the beach at low tide. Rear Admiral Minelaying arranged for a car to take me to Southend and thence to Shoeburyness where I met Commander Maton, Lt. Commander Ouvry, Lt. Commander Lewis, Warrant Officer Baldwin and (A.B.) Vearncombe. I was equipped with waders and a bull-terrier followed me out to the mine around which Ouvry, Baldwin and Vearncombe were standing. I met Lewis on my way out and he held a small aluminium object in his hand which he thought was the magnetic mechanism of the mine and proposed opening it to see. I advised him to wrap it in cotton wool and send it by car to Woolwich Arsenal to be X-rayed—it turned out to be a bomb fuse! On arrival at the mine the bull-terrier began 'ratting' under the horned (anti-roll) nose of the mine which had a diaphragm about four inches diameter fitted in it. This diaphragm made me suspect the possibility of an acoustic firing unit, although the aluminium body of the mine suggested a magnetic pistol. I sent the bull-terrier home! The process of recovery of this mine, and another one like it about 200 yards away, and the subsequent examination of its contents in M.D.D., *Vernon,* is described in a report which I dictated on my return to Portsmouth[88]. In the conclusion of this report it was stated: 'It is clear now that the German Mine is of the pivoted magnet type operating on changes of vertical magnetic field . . . in the direction of N.-pole downwards — a feature common to all steel ships in N.-latitudes. Assuming all the German mines possess this characteristic (although it certainly does not apply to British M. mines), then a simple method of making ships immune at once presents itself, *i.e.* to magnetise the ships so as to have no north pole downwards, or if any polarity is shown it should be south downwards—a method obviously simpler than that of de-magnetising . . .' The recovery of the magnetic mine had of course a very important influence on methods of sweeping as well as indicating how to make steel ships safe to pass over them. Copies of the M. unit were made and used on ranges to test ships which had de- or re-magnetising coils fitted. Subsequently magnetometers, loops, *etc.* were used, instead of mine replicas, to measure the residual fields beneath ships fitted with demagnetising coils. In course of time enemy magnetic mines were made bipolar, operating on either N.- or S.-poles, and more sensitive. This made demagnetising more difficult and mine-sweeping easier. The first N.-pole mine required about 50 milli-gauss to fire it; about a year later the M. mines were N.- or S.-pole operating on ±20 milli-gauss. Later mines were fitted with automatic latitude adjustment to compensate for ambient magnetic field, and sensitivities were increased for actuation by only a few, 4 or 5 milli-gauss N. or S. change of field. Soon after the outbreak of war Captain R. F. de Salis, Superintendent of Mine Design (S.M.D.) left for active service on Minelayers and Captain G. B. Riley became Naval head of M.D.D. I was made Superintendent Scientist in June 1940. Immediately after the recovery of the German magnetic mine on 23rd September, 1939, we had a constant stream of visitors, some 'just curious,' others anxious to be helpful. On 19th December, H.M. King George VI came to M.D.D. and Ouvry and I showed him the German mine and demonstrated the mode of operation. Admiral Darlan (C.-in-C. French Navy, and later during the German occupation of France, head of the French Republic, eventually assassinated in N. Africa) came to see the enemy magnetic mines at M.D.D. on 22nd December. On 13th January, 1940, The Right Hon. Winston Churchill with Mrs. Churchill and their daughter Mary came to see the German magnetic mine. Mr. Churchill took a very keen interest in the operation of the mine, firing a detonator by waving the N.-pole of a magnet near it and explaining to Mrs. Churchill how it worked. He was obviously very delighted and could see the important implications, in respect to protection of our ships. Lord Chatfield and Admiral Wake-Walker, Admiral James, Sir Charles Darwin, Professor Blackett, were other visitors at this time. Some time later, in April 1940, Admiral Fenard who later succeeded Admiral Darlan (in high office in France) after his assassination, also came to see our collection of German mines and spent some time in M.D.D. to assimilate the details and counter-measures. Just before his return to France he invited Commander Oliver Bellairs, E. C. Bullard and me to lunch at the Queen's Hotel, Southsea. The historical events which followed in France made these visits of Admirals Darlan and Fenard one of our outstanding occasions! Commander Gelix visited me frequently about this

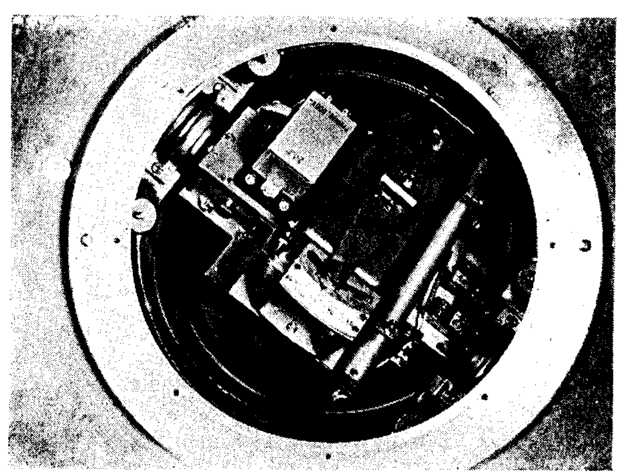
[88] German Aircraft Mine dropped near Shoeburyness on 22 November, 1939. Summary No. M.S. 684/Nov., 1939. See also Summary No. M.S. 688/Jan., 1940 for further details.



The first German magnetic mine recovered at Shoeburyness.

time. He was a French liaison officer who took a very keen interest in all the happenings at M.D.D. at this time. On 6th December, 1939, I gave a demonstration of the German M. mine at A.R.L. and discussed also various methods we proposed to protect ships against it and methods of sweeping it. Present at this demonstration were Sir W. H. Bragg, Professor W. L. Bragg, Professor G. P. Thomson, Dr. A. O. Rankine, Sir Henry Tizzard, Sir Charles G. Darwin and members of A.R.L. staff. Experiments we were making with small scale L. and LL. sweeps were described.

In January 1940 Commander G. B. Sayers, who had succeeded Commander J. S. Cowie, left M.D.D. for other Naval duties and was replaced by Commander G. Thistleton-Smith as Commander M. We were in very close collaboration throughout the war mainly in regard to the recovery, examination and countermeasures relating to enemy mines. He became responsible for a group of very gallant Naval officers whose primary duty was the recovery of enemy mines. They were subsequently known as 'The Suicide Squad'. One of my staff, L. Walden, worked with them and was present at the 'making safe' and recovery of many of these mines. Walden, and Lt.-Commander Armitage, received the George Cross for this work, Lieutenant Glenny the D.S.C., and others were also 'decorated'. H. M. Kelly who received the M.B.E. decoration, and N. Thompson on my staff became responsible for the inspection of enemy mines which had been brought in by the Suicide Squad and for issuing detailed instructions to the Suicide Squad regarding the methods of handling enemy mines, *i.e.* what to do and what *not* to do. On 8th August, 1940, when a German mine (type C) was opened in the Mining Shed on the Gunwharf an explosion took place and several men were killed or wounded. This mine was about the 9th or 10th mine hitherto examined. Kelly and I had been present at the opening of the earlier ones but fortunately, for us, we were away on duty elsewhere on this occasion. Recovery of fragments of the exploded mine showed that the main charge had not detonated. The fragments revealed certain



View of the magnetic firing unit and A.C.M. pendulum of the first German magnetic mine at Shoeburyness.

unusual features which indicated that a small booby trap charge (a few pounds of T.N.T.) had been fired by a switch which closed when the rear door of the mine was removed. A portable X-ray van from Woolwich Arsenal was requested for the inspection of the next mine before opening—Messrs. A. R. Greatbatch, W. J. Wiltshire and D. E. Barnes operating the X-ray apparatus. It was then found as we had suspected that a booby trap switch was located just inside the mineshell near the flange of the rear door. It then became the rule that all enemy mines must be X-rayed before opening and a 400 kV. Victor X-ray outfit was ordered, the Woolwich equipment and staff being employed until the new outfit arrived and was installed in a chalk-pit at Buriton (near Petersfield) on the South Downs. For official purposes this place was known as Mirtle Range'. Here L. Walden was in charge of the routine X-ray inspection of mines before opening them for examination. The X-ray apparatus was remote controlled so that the worst that could happen, if a mine under test were to detonate, would be the loss of the apparatus. A second X-ray outfit was ordered in case of such an eventuality but it was never required. Mines which could not be brought to Buriton and were not easily accessible were examined on the spot by means of gamma rays from a 1 gram radium tube specially purchased for this purpose. This tube of Ra was left in the custody and for the use of a London hospital when not required for mine examination. It would take too long to describe even briefly the various types[80] of magnetic mines used by the enemy. They contained some beautiful examples of good mechanical and electrical design which, fortunately for us, were rather complicated and must have been expensive to produce. Clockwork devices were used somewhat lavishly—*(a)* for switching on the firing circuit after a sufficient time delay after laying the mine, *(b)* counter or 'clicker' (Zahl kontact) clocks to prevent firing until the mine had been actuated 'n' times (up to 12 usually) to make sweeping operations difficult, *(c)* to scuttle the mine after a certain predetermined time had elapsed after laying *(d)* clocks for automatic latitude adjustment, *etc.* Mines were not only laid from aircraft, but also by ejection from the torpedo tubes of submarines. Samples of these were obtained from a captured German trawler masquerading as a Dutch fisherman near Scapa. The B.M. 1000 was an interesting magnetic mine, the first news of which came to us from a German prisoner — B.M. meaning Bomb Mine, a bomb if it hits a ship or the ground, a mine if it falls in the sea. When we recovered a badly damaged one which had fallen on land it was found to be shaped like a bomb with an ogival nose, and was dropped from aircraft *without* parachute. On removal of the rear steel cover of this mine a second cover, like a top-hat in shape, which had two broken plate-glass windows about 3 inches diameter, was revealed. The mine had only partially detonated and on examining the debris under the second cover Kelly and I discovered broken batteries and relays and the bent sensitive plates of two small photo-electric (selenium) cells. The latter could only 'make sense' if light actuation was intended via the two plate glass windows, which were normally in the dark under the outer rear cover of the mine. This could only be an optical booby trap — to prevent inspection of the mine. Notices of this were immediately issued to the 'Suicide Squad' instructing them to open B.M. 1000's only in the dark or in very subdued light. Soon afterwards a more perfect specimen was recovered—confirming our conclusions about the optical booby trap. Later we received a signal from Suez notifying us that 'the Germans are using a new mine, the B.M.1000, which is fitted with two plate glass windows behind which can be seen, with the aid of a torch, two carbon granule microphones but there is no booby trap ' ! Someone in Suez had been *very* lucky ! One night in August 1940 low flying aircraft were seen to drop parachute mines deliberately, one in a field at Southwick (Boarhunt) near Portsmouth and another, also in a field at Puddlehinton (near Dorchester). Both were type C German mineshells. The one near Portsmouth was badly smashed due to the explosion of a small auxiliary charge and contained an interesting and miscellaneous collection of booby traps but no main charge. Commander Thistleton-Smith and some of his Suicide Squad assisted by Walden went to Puddlehinton armed with a trepanning tool with remote control (designed by Oliver Thornycroft), to cut an inspection hole in the mine shell. But the trepan cutter jammed and Commander Thistleton-Smith decided to open the mine a quicker way by attaching a small charge to the shell and firing it electrically from a safety point behind a wall surrounding the field. This charge having been fired, the party proceeded towards the mine across the field. They were well on their way towards it when a second explosion occurred ! This was no doubt due to the booby trap charge in the mine having operated via a time-delay. This mine also contained a collection of booby traps. The inference which we drew was that M.D.D. (Portsmouth and A.S.E.E. (Portland) scientific and technical staffs were not popular in Germany and these two mines were specially sent from Germany to create vacancies !

With our rapidly growing staff—recruited from

[80] Detailed descriptions of the German magnetic and other types of mines are to be found in various M.D.D. reports (M.S. Summaries and S.S. Reports) from November, 1939 onwards.

N.P.L., B.E.A.I.R.A., Greenwich Observatory, the Universities and Technical Colleges, *etc.*—it became increasingly necessary to find additional accommodation. Early in 1940 we expanded into the evacuated Old Grammar School (for laboratories for the scientific section), Commercial Buildings (for main offices), The Washington Hotel (for Dr. H. R. Hulme's D.G. analysis section) and the Clarence Pier Hotel (for Dr. Bullard and Commander Hext Lewis's D.G. Section). Many heavy air-raids during June, July and August 1940 which did much damage in Portsmouth seriously hindered work and caused us to evacuate on 1st September, 1940, to West Leigh and Leigh Park, Havant, five or six miles out of Portsmouth. Here we had much more commodious accommodation and wasted much less time in shelters during air raids. The D.G. and Commander M.'s sections came out to West Leigh soon afterwards for the same reason. In September 1940 Dr. Hulme's D.G. ranging and record analysis section moved to Ardencaple Castle, Helensburgh, Dunbartonshire. Rumours of imminent German invasion resulted in many of us at West Leigh and Leigh Park doing a spell of rifle practice at the Tipnor range!

To introduce a little light relief into what may seem a rather dull narrative I propose at this point to refer to an episode which occurred in March 1940 and, to me, was rather unusual.

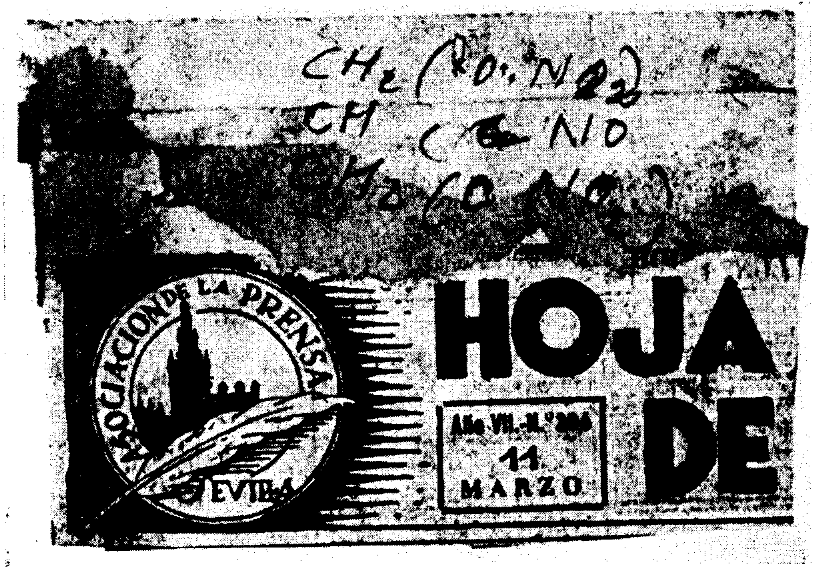
In the afternoon of 7th March Captain G. Middleton 'phoned from the Admiralty to say that I was required at the Admiralty immediately with my passport as I should probably be going 'abroad' by air. No explanation could be given on the 'phone but the matter was very urgent. I guessed it was to fly to Cherbourg re d - g, but it wasn't. J. T. Crennell drove me in my car to Havant station to catch the Portsmouth-Waterloo train—but there I discovered it wasn't due to stop at Havant. However I persuaded the stationmaster at Havant to stop the train by putting the signals against it! So I reached the Admiralty without loss of time. There I met Captain A. G. Talbot (D.A./S.W.—Director of Anti-Submarine Warfare) and Lt. Commander E. C. Bayldon, who explained that we were to go to Spain (possibly Barcelona) to meet a German who had secrets to sell for a large sum of money in cash. He, the German, was said to carry a revolver so Captain Talbot was to do the same. Treasury officials brought us the money in Bank of England notes in a diplomatic bag, which we later referred to as 'Adolf', and amply sufficient money for travel. Discussions with various people, N.I.D., Treasury officials, *etc.* went on until late, and that night I spent in Captain Talbot's flat. The next day we had more discussions and instructions at the Admiralty when we were told to proceed by night train to Plymouth and Mount Batten, where after breakfast we were to fly in a *Sunderland* seaplane to Gibraltar. There we should be briefed by someone in the office of the Admiral Superintendent, Admiral Sir Dudley North, C.-in-C. Gibraltar. On arrival at Gibraltar in the late afternoon we were informed of the sort of secrets the Germans had to sell and that arrangements had been made for us to meet him next day in Jerez (pronounced Hereth). At the desk at the Rock Hotel we were informed by a Spanish clerk that the hotel was full but Captain Talbot demanded to see the manager and two rooms were forthcoming without delay! T. and B. (Captain Talbot and Lt. Commander Bayldon) shared a double room on this occasion and always afterwards, as they had charge of 'Adolf'. The next day, Sunday, after lunch, Captain Hilgarth (Capt. H.), Naval Attaché from Madrid, met us in his car and took us across the Spanish Frontier without inspection or 'dating entry' of our passports. At Jerez we went to Williams and Humboldt's Sherry Bodega and, escorted by Mr. Williams, duly sampled the best sherries in Spain. Then we were taken to meet Mr. 'Wainwright' (Dorfer) in a summerhouse in the grounds. He wanted the money before disclosing his 'secrets' but of course we didn't fall for that. He was a good-looking young fellow—looked a Naval officer type. He said he knew all about the defences of Singapore, which was interesting but seemed a bit irrelevant to the purpose of the meeting. After more fruitless talk we decided to conclude our first meeting and meet again in Sevilla the next day. He said he was being followed and daren't risk staying long in one place. Gomez Beare (G.B.) took Mr. W. in his car that evening to Sevilla and we followed in Captain H.'s car. On reaching our hotel (Andalusia Palace) Captain H. left us and returned to Madrid. Next day Captain T. met Mr. W. in a restaurant and gave him a few pounds for his travelling and hotel expenses in exchange for the formula of a new German explosive which Mr. W. said was much better than anything we had. Captain T. brought this formula, which Mr. W. had written on the edge of a newspaper, to show us in the hotel. It was the formula for nitroglycerine with a slight error! In the hotel later that day we met the two British agents R.M. and A.D. who told us the earlier history of 'Dorfer' who had three secrets to sell:

(*a*) a new explosive,

(*b*) a ground n.c. mine which could leave the sea-bed on the approach of a ship and behave like a torpedo to sink the ship, and

(*c*) a harbour defence A.S. scheme (alternative to and much more effective than loops).

That evening we left Sevilla in G.B.'s car on the way to Madrid where a further meeting with Mr.



A copy of the portion of the Spanish newspaper on which the 'new' formula was written.

W. was to take place. We spent the night at Merida in a queer little hotel (more like a prison—with thick walls and bars across slits of bedroom windows). We had been instructed not to recognise R.M. and A.D. when they arrived later in their own car and we were to leave early about 4 a.m. the next morning for Madrid. As usual T. and B. shared the same room with 'Adolf' and the 'gun'. On the road to Madrid we had breakfast in a rather primitive wayside inn where the only choice on the menu was tortillas (omelettes fried in plenty of oil). In Toledo, where we stopped for lunch, Gomez Beare took us to a restaurant where the special dish was a sort of winkles (like snails) which he said was a favourite dish of Lord Beaverbrook. After lunch we inspected the very interesting ruins of the Alcazar in Toledo which had been bombed and shelled by the Reds. There we saw some strange and gruesome sights, including the swimming bath (below ground) and cubicles which were used as a temporary burial place by the besieged garrison. We also saw the room where José Moscardo the Alcazar general talked on the phone to the attacking Red General. The latter said he had captured Luis the son of Moscardo but would release him if Moscardo would surrender, otherwise the boy would be shot. José spoke to the 19-year-old boy on the 'phone and asked him if he was prepared to die for the cause. The boy replied 'yes', there was no surrender and he was duly shot by the Reds. The walls and furniture of the small room still containing the telephone were pock-marked by hundreds of bullet holes fired through the window from the roof of an adjoining building. Moscardo resisted the besiegers for 72 days before being relieved by the troops of General Franco. In Madrid we had several meetings with the Embassy officials and with R.M. and A.D. in their 'commercial' office. The majority, against me, were in favour of giving Mr. W. the money, based on the argument that the country was spending over a million pounds a day on the war so what was n-teen thousand pounds! After the nitro-glycerine episode in Sevilla and having heard what the harbour defence system was likely to be, I wouldn't agree to pay! However, we waited two or three days in Madrid for Mr. W. to come but he didn't turn up. We had one afternoon 'off' to see the world-famous Valasquez painting in the Prado Art Gallery and Museum. Then a message came to say that Mr. X. would meet us in Valladolid. Whilst in Madrid my temperature was around 104° F.—I was on a milk diet just before leaving England and my digestion didn't improve on Spanish food! Captain H. took us the next day in his Buick from Madrid to Valladolid. On the outskirts of Madrid there were many signs of the revolution—devastation due to shells and bombs. We zig-zagged up a snow-covered pass on the Guadarramas and on reaching the cutting at the summit a rope was stretched as a barrier across the road. H. said 'I am going, rope or no rope', but, on reflection, 'perhaps I'd better see what is going on'. On inspection, he returned with the information that the road on the other side had disappeared in a landslide! So we zigzagged down again and tried another route, this time with more success, and soon we were in Valladolid. There we proceeded to the 15th century English Monastery (Monseigneur Henson)[90] where Roman Catholic priests were trained for the

[90] I had the pleasure of meeting M. Henson again in 1951 during a holiday tour in Spain with my wife. He recalled all the details of Dorfer's visit.

ministry. Nuns brought us tea and M. Henson told us that Mr. W. was in another room waiting for us. But Mr. W. continued to insist on 'money first' and he eventually departed without it. M. Henson thought it might be a trap and that we might be waylaid and robbed on our way northwards. So he got in the car with us and piloted us first southwards towards Madrid, and then turned off the main road on to *very* secondary roads round Valladolid to rejoin the main road to the north, where he left us. The Buick was running well at about 70 m.p.h. until we reached the outskirts of Burgos when it quietly came to rest, for no apparent reason, the engine still running. Another car following us pushed us, bumper to bumper, into a garage where we left the Buick for inspection whilst we had lunch. On returning to the garage we were told that the main driving shaft had parted, so that was that! We had been travelling in an Embassy car which was to take us across the Spanish Frontier into France—but not now. Captain H. obtained a taxi to take us on to San Sebastian but of course we could not cross the Frontier as our passports were out of order, not having been inspected and stamped when we entered Spain from Gibraltar. So Captain H. 'phoned the British Consul at San Sebastian and asked him to escort us, after our arrival at his office, across the frontier into France at Hendaye. We arrived at the Consul's office about 10.30 p.m. and explained the situation. He didn't seem over-pleased with his job and appeared to have some difficulty when he left us in the car for a while at the Spanish side of the frontier. However, the barrier was opened at last and the Consul dumped us about 100 yards beyond the French frontier. After a coffee in the local inn we managed to hire a taxi which took us to the Carlton Hotel at Biarritz, arriving about midnight. No food was obtainable and the water was cut off from the taps in our bathrooms. But Captain T. fetched out the Manager and we were transferred to the next floor above—the three of us walking up the grand staircase in pyjamas, carrying our clothes and suitcases! The plane which should have met us the next day to bring us back to London did not arrive owing to bad flying conditions, and we were advised to travel to Paris by train, where we arrived, via Bordeaux and Angouleme, at 11 p.m. The next morning, in Paris, we visited the Naval Attaché's office leaving 'Adolf' (intact) with him for safe custody and transmission to London. With some difficulty, owing to the rush of English people in Paris trying to get back home—the German invasion of Paris being considered imminent[91]—the N.A. managed to get us three seats on a commercial plane from Le Bourget. To do this I had to be described, like T. and B., as a Naval Officer on urgent Government business. We reached Heston aerodrome late afternoon, Saturday, 16th March and after calling at the Admiralty, I arrived home in Portsmouth late that evening. The following Monday (18th March) we gave a talk at the Admiralty, with Admiral Fraser the Controller in the Chair, describing our meetings with Mr. W. (Dorfer) and the results of our mission, and our opinions on the explosive, the submarine detector and the 'approach mine'. Not long afterwards I was shown a paper with a drawing by Dorfer, which someone at the Embassy in Madrid had bought from him, describing the wonderful mine-torpedo (the 'approach' mine), which was pure rubbish and didn't contain a suggestion of anything useful, so that all three of Dorfer's secrets were just bunkum, and I was glad we had brought back the money. The sequel to all this I discovered when I unexpectedly met A.D. at the office of Dr. E. T. Paris at Millbank in September 1941. Both R.M. and A.D. had then left the service. Dorfer had said on several occasions that he was being followed. Now A.D. told me that he had been 'found shot' after we had returned to England.

As I explained earlier, the first ships to be made 'safe' against the magnetic mine were *re*-magnetised to make them S.-pole downwards (in N. latitudes). It was realised that this could only be an interim system to be replaced as soon as possible by one which neutralised the ships' magnetism. Demagnetisation was later re-named 'de-gaussing', D.G. In this connection the coil system was first applied to the Trawler *Sawfly* and to the light cruiser H.M.S. *Manchester*. The latter was successfully demagnetised by 13th December, 1939, against the type of German M. mine recovered from Shoeburyness on 23rd November. It was soon discovered that D.G. coils at first wrapped outside the steel hull, would operate well if simply laid on the deck and eventually they were found to work all right if laid conveniently in steel tubes near the steel hull inside the ship. S. Butterworth and his assistants N. F. Barber and M. W. Burgess at A.R.L. made scale model ships for de-gaussing experiments and improved the techniques by using main-, fore- and quarter-deck coils (M.F. & Q. coils), this more elaborate system being used only for the larger and more valuable ships in the Navy and Merchant Marine. With the acute shortage of cable required for an enormous number of ships other methods of de-gaussing were devised, *e.g.* 'flashing' a large current through a 'temporary' coil left a degree of permanent magnetisation in the ship which after sufficient trial experience could neutralise, and not under- or over-compensate its natural magnetism; another method suggested by

[91] The Germans entered Paris on 14th June, 1940.

Dr. C. F. Goodeve and used extensively on smaller ships was known as 'wiping' — a long horizontal cable carrying a suitable heavy current, being hauled repeatedly by a line of sailors on the deck, close to and up and down the sides of the ship. Many names could be mentioned as outstanding in developing D.G. systems, besides those I have mentioned, F. B. Young and S. Butterworth, E. C. Bullard, C. F. Goodeve (Lt. Cdr., R.N.V.R. then), Commander J. Hext-Lewis, Commander Oliver Bellasis, Dr. H. R. Hulme, R. E. d'Atkinson, R. Gossage and many others. The D.G. organisation grew rapidly and magnetometer ranges were established all around the coasts and in other parts of the world. Special treatment was of course required for ships in southern latitudes and for ships crossing the equator N.-S. or S.-N. Obviously volumes could be written to give details of the countermeasures to enemy mines—minesweeping, degaussing, *etc.* and it is difficult in a short article such as this even to mention the many important features involved. The D.G. system grew so rapidly in extent that a separate D.G. department was formed by the Admiralty under the direction of Admiral Lane-Pool, R.N. The Director of Electrical Engineering (D.E.E.) Admiralty J. S. Pringle and his staff, and the cable manufacturers had an exceptionally busy time providing the machinery, cables and 'coiling' the ships. Very large numbers of ships had to be treated in this way before going to sea, and the degaussing organisation played a major part in keeping our ships afloat throughout the war. Steel minesweeping vessels of course received exceptionally careful degaussing treatment for they had to pass over live minefields in their routine operations.

Demagnetising our ships was of course only part of the problem of countering enemy magnetic mines. Another important alternative was to 'sweep' them, *i.e.* to detonate them without damage to the 'sweeper'. As already mentioned the electric cable A. and L. sweeps and the towed magnet sweep (A. type) were already in existence before the war. The 'Borde' magnet (300 ton) sweep had already been planned and Mr. Churchill gave orders that it must be ready and in action by 1st January, 1940. It was ready by that date and was successful in detonating enemy magnetic mines at a range of about 100 feet ahead of the ship. The shock felt on the bridge of the ship when a mine detonated was sometimes rather more than unpleasant! The Germans later used these large magnets for minesweeping and described the sweepers as 'Sperrbrechers' (boom breakers). Reference will be made to these later. Another early type of M. sweep was known as the D.W.I. (Directional Wireless Installation!) This consisted of a pair of rather large and heavy coils mounted on the wings of an aircraft (Wellington bombers) and supplied with as large a D.C. current as weight of batteries or machines would permit. The plane had to fly very near the water surface to create sufficient magnetic field on the sea bed to detonate a mine, and thereby ran the risk of being caught by the plumes sent up by the explosion. The D.W.I. sweep was very successful in clearing the Suez Canal of M. mines. The most satisfactory method of sweeping magnetic mines was known as the 'double L.' sweep which was a magnified-modification of the old A. and L. sweeps. It consisted of two buoyant L. cables towed in parallel from two small wooden sweepers, and carrying a very large current, of the order of 2000 amps. The current, with earth return, was pulsed first positive then negative and the magnetic field produced in the rectangle about 600 yards long by 100 yards wide, formed by the floating cables was sufficient to detonate all M. mines + ve or − ve inside it. The next pulse of current was passed through the cables when the ships had covered a distance a little less than the cable length and so on. There was of course a great deal of effort involved in urgently designing and producing the equipment—the buoyant cables about 3 ins. diameter containing a half-inch flexible copper rope to carry the heavy current, the copper 'earth' electrodes and the machinery to supply the current. The introduction by the enemy of S.-pole as well as N.-pole mines was fortunate in respect of the design of suitable copper-earth electrodes. With a D.C. current of two or three thousand amps., these dissolved 'like sugar' in the sea, but the enclosure of the electrodes in a suitably padded 'sacking' bag resulted in the retention of this dissolved copper 'in the bag' at the first pulse ready for use in replating it on the electrode on the reverse pulse! Some of those principally involved in the design and first trials of the L.L. sweep were Professor B. P. Haig, C. F. Goodeve, O. Thornycroft and H. Gollop, as well, of course, as Admiralty electrical engineers involved in the design of the necessary machinery and fittings to ships. The rapid growth of the minesweeping section of M.D.D. resulted in the formation of the M.S. Section at Fettes College, Edinburgh, J. K. Roberts (later succeeded by A. F. Pickles) and F. Pearson were Chief Scientist and Engineer in charge of this Scottish minesweeping branch.

Between August and October 1940 various reports were received of enemy 'mine' explosions which had been observed, sometimes sinking small ships and sometimes exploding at a considerable safe distance from larger ships. A meeting was called on 16th October at the Admiralty with the First Lord of the Admiralty, Mr. A. V. Alexander, in the Chair, to discuss the probable nature of these enemy mines. Statements had been made that these may be unexploded bombs, that they could not possibly be magnetic mines, and that acoustic mines were 'impossible'. It became necessary to point out that acoustic mines were designed, tested and were ready for use by our Navy in the first world war, and moreover the characteristics of behaviour of the unknown enemy mines were essentially 'acoustic'. On 2nd November, Walden X-rayed at Mirtle an unusual C-type M. mineshell (magnetic normally) recovered from Ogmore River near Cardiff. On opening this mine it was found to contain a carbon granule microphone mounted on a mechanised amplifying lever, with circuits, CuO rectifier, two moving coil relays and a 6-day clock. There was no diaphragm on the mineshell. Other similar mines were recovered on 8th to 10th November from Birchington and Fowey. The amplifying lever on which the carbon granule microphone was mounted served to tune the microphone to a frequency near 250 c/s. Following the receipt of these and other gratuitous samples from the enemy we rapidly instituted countermeasures. One of the first of these was to use as an acoustic sweep a hammer-box which consisted of an electrically driven road drill which struck a rapid succession of heavy blows on a steel plate forming part of the casing. The noise this emitted when immersed in the sea would explode acoustic mines at distances up to a mile. Another method was to use modified Fessenden oscillators. These were normally designed for underwater signalling purposes to have a resonant frequency of 500 c/s., but as the enemy mines resonated at 250 c/s. the 'Fessendens' were modified to suit this frequency. H. Margary was in charge of this work at Allen West's factory near Brighton. It is interesting to note that some time after these were in use we recovered a German acoustic mine which had an electrical filter incorporated to reject signals of 500 c/s.—evidence of the efficiency of the enemy's spy activities in wartime—but of course this had no effect in preventing the 250 c/s. Fessendens from sweeping the mines! At a later stage of the war the enemy were using acoustically controlled torpedoes which could automatically 'home' on ships' propellers. Towed noise sources, hammer-boxes and pairs of steel rods, which made more noise than the ship, were used as 'foxers', the torpedo circling round the noisy foxer in preference to the ship's propeller. A sound-recording range was set up at Innellan (Clyde) with hydrophones laid out in channels frequented by our own ships. Records were made of their characteristic noises over a wide frequency range, for a wide variety of ships and speeds. This station was manned by E. H. Lakey and P. H. Parkin. Miss (Dr.) Ross of M.D.D. minesweeping division, Edinburgh, was mainly responsible for the analysis, the results being of considerable value for the design of acoustic mines and minesweeping equipment.

By June 1941 the enemy were laying mines, both from submarines and aircraft, which contained combined acoustic and magnetic firing devices. These A.M. type mines, referred to as 'Sammies', usually contained anti-sweep Zahl Kontact (clicker-counter) mechanisms and occasionally booby traps. But the minesweepers were suitably equipped with appropriate sweeps, and their crews showed great courage and endurance in their dangerous but very valuable occupation. Of course the arrival of the German acoustic mine raised the question "Why don't we have an acoustic mine?" The answer being that we had had one since the 1914 - 18 war but it was not used because of its variability! It was quickly resurrected and laid in buoyant mines, resulting in considerable destruction of enemy shipping. We had in service a considerable repertoire of mines, horned contact, antenna, magnetic, acoustic, *etc.* laid in large numbers from minelaying surface craft, submarines and aeroplanes. Designs had been prepared for a pressure mine but this was never laid, in accordance with Admiralty policy, as we had at that time no satisfactory sweep for it. The German Navy, however, took a different view and towards the end of the war, at the time of the Normandy landings, they laid a considerable number of pressure mines, which were often called 'oyster' mines. These mines operated on the principle that every moving ship in shallow water (say up to 20 fathoms or so) produces a small reduction of hydrostatic pressure on the sea-bed, depending on its displacement and speed. This suction effect, of the order of a few inches head of water, persists for a short time only, a few seconds, whilst the ship passes over a mine on the sea-bed. Its magnitude was estimated theoretically by Sir G. I. Taylor for various classes of ship, speed and depth of water. The German 'oyster' unit was very simple. It consisted essentially of a cylindrical metal container divided into two compartments by a diaphragm, a small leak-hole round the edge of the diaphragm connecting them. The outer end of one of the compartments was closed by a flexible rubber bag exposed to the sea. When the mine is laid the pressure on the opposite sides of the diaphragm is equalised via the leak-hole and slow variations due to tide and swell are equalised in the same way. If, however, a ship passes over the mine there is a more rapid variation of pressure which the leak-hole cannot equalise and the flexible partition diaphragm is displaced and closes the firing circuit of the mine. This type of mine is difficult to sweep and the requisite suction on the sea-bed to actuate it can generally only be produced by an actual ship or a submerged body approximately the size of a ship. Two such towed bodies met with some success, *(a)* the egg-crate sweep—the flooded framework of a ship with loose plating which was kept just afloat by buoyancy chambers at the ends, on sweeping an oyster mine the pressure pulse and bubble passed more or less freely through the 'egg-crate' framework without causing much damage, and *(b)* the 'water-blimp' — a water-filled bag of large volume towed astern of the sweeper — the suction produced by this would operate an oyster mine and the pressure pulse passed freely through it. Other types of sweeps for this mine were suggested but the most satisfactory one was the sea itself ! When designing our own variety of pressure mine however we had instituted at the same time wave rcording stations on the South and North coasts of Cornwall. These stations obtained data relative to wave-periods, wave heights and suction pressures on the sea-bed. Consequently our own design of 'oyster' was made to cope with probabilities in sea states. The German oysters, however, had no such protection and when they were laid in Seine Bay at the time of the Normandy landings they were 'touched off' in considerable numbers by the swell coming up the Channel from the Atlantic. Combining the pressure unit with a magnetic or acoustic unit to prevent such premature operation made little difference, for our M. and A. sweepers had only to sweep when the Channel swell was suitable to operate the mines. There is, I believe, still scope for a reliable and efficient sweep to deal with the pressure mine.

In pre-war days much time and effort at M.D.D. went into the sea trials of each type of mine and its modifications, both by the technical and the naval staffs, before it could be accepted for Service use. As a consequence it might be a matter of a year or more before a new type of mine could possibly be useful. In peacetime this principle had much to recommend it but in wartime when the scientific and technical staffs were so much increased, many new ideas and suggestions for new types of mine firing units were forthcoming but, under the old conditions, could never reach fruition. As most of the components of the Service mines—batteries, relays, C.R.s, microphones, chattering contacts, circuitry, *etc., etc.*—had been tested and retested *adnauseam* it appeared that small changes in circuits, using standard components could be made to produce valuable results without further sea-trials. When I suggested this early in 1940 it was considered heretical and against all the basic principles of mining ! It was not until over two years later, in November 1942, that serious consideration was given to the suggestion. It was mainly through the efforts of Professor H. S. W. Massey and his team, R. A. Buckingham, F. H. C. Crick, D. R. Bates and J. C. Gunn, who joined us in November 1941, that the formation of the M.X. group in M.D.D. took place in November 1942. Early in 1943 it began to be appreciated at the Admiralty that more rapid methods of utilising new ideas in the design of mine firing units were required so that immediate use could be made of any fresh information of enemy minesweeping methods. We were already aware that it would require a period of two or more months before the enemy could adapt his sweeping techniques to a new type of mine-firing unit—this estimate was based on our own reactions to enemy mines dropped on land or otherwise recovered. Consequently the M.X. department was set up for the purpose of designing and fitting out new actuating circuits—small batches of mines, having special circuits for special destinations, being prepared by trained Wrens supervised by designers and Naval officers. The designs could be changed as frequently as required and made to suit prescribed requirements. About 50 mines a week were made up in this way, and shipped to appropriate aerodromes for 'air mail' delivery to the strategic points. Altogether about 5000 of such mines were constructed and delivered. As examples of M.X. output special insensitive magnetic mines, operating on 'gauss' rather than 'milli-gauss,' were prepared to deal with large German Sperrbrechers carrying sweep magnets weighing 1000 tons. In another variety, designed as a result of aerial reconnaissance photography, it was known that Sperrbrechers sometimes escorted U-boats and important surface craft from certain harbours to ensure safety against our magnetic mines: The special M.X. mine for this purpose was designed to ignore the intense magnetic field of the minesweeper and operate on the relatively small magnetic field produced by the submarine which followed—*i.e.* the mine unit operated if the *sequence* of the magnetic fields was correct. In another system, the sweeper simply switched on the magnetic firing system to be 'ready' for the next ship of whatever type. It was found that the enemy's reaction to some of these mines was to use two and sometimes three Sperrbrechers to precede the U-boats ! Variations on similar lines were made with acoustic firing units and combinations of A. & M. units. The M.X. department of M.D.D. certainly provided serious problems for the enemy and did much damage to enemy submarines and shipping.

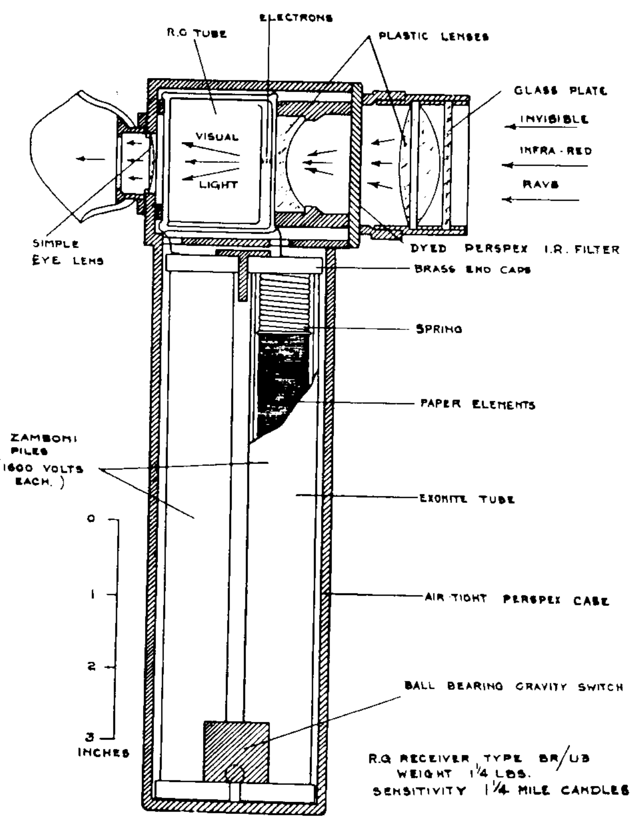
In November 1942, Dr. C. F. Goodeve was made Assistant Controller (Research & Development) and visited Leigh Park and West Leigh where he addressed the staff on general policy and inspected the research laboratories, *etc.* The following month Captain F. H. M. Vaughan was appointed as successor to Captain G. B. Riley, as Superintendent of Mine Design (S.M.D.). Captain Riley, who died in September 1943, had been Naval head of Mine Design Department from the early days of the war

The new building at the Admiralty Research Laboratory Teddington, 1943.

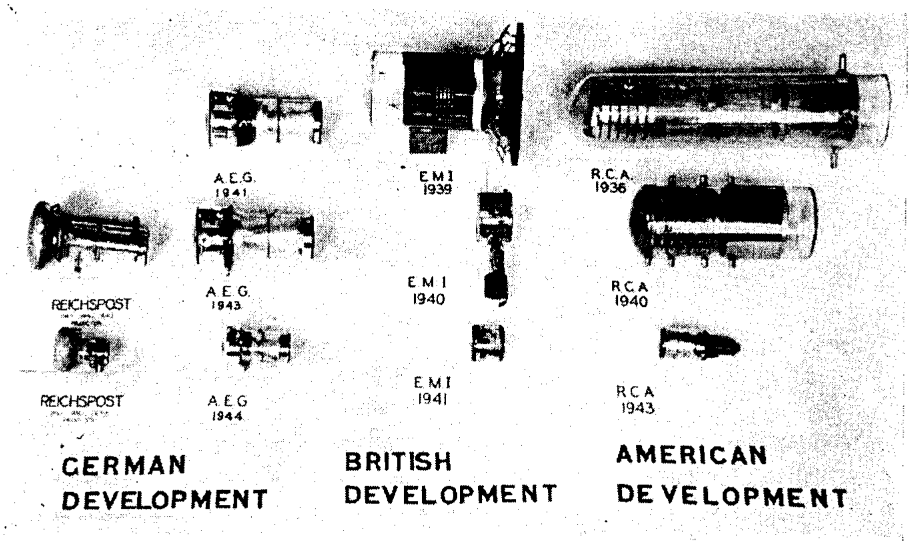
to the end of 1942, three very strenuous years of great responsibility which had seen many important developments in mine warfare. Much credit is due to Captain Riley for his leadership during these early and difficult days of the war. After the removal of M.D.D. from H.M.S. *Vernon* Gunwharf, Portsmouth, to West Leigh and Leigh Park, Havant, our establishment was gradually dispersed to numerous other places. The workshop moved to Fareham, Horsea Lake and the open-air swimming pools at Hilsea were used for explosion research and testing of hydrophones, *etc.* Minesweeping division was moved to Fettes College, Edinburgh, Acoustic measurements of ships to Innellan (Clyde), Loch Long and Greenock (R.N.T.F.), and so on. For some of us this resulted in much night travelling to and from Scotland. U.D.E. Portland had also moved to Fairlie (Ayr), so that the Anti-submarine depth charge and loop liaison meetings were held alternately in Portsmouth and Fairlie at monthly intervals. We had D.G. ranges, coiling and wiping stations all round the coasts and indeed all over the world. The organisation of this D.G. work became so great that, as I have said already, it became a distinct Admiralty department with Admiral Lane-Poole as Superintendent of degaussing. In September 1943 I spent three weeks in hospital for an abdominal operation and soon after my return to West Leigh I was transferred to A.R.L. Teddington again in November 1943. Professor H. S. W. Massey was to take my place as Superintendent Scientist at West Leigh but before he could commence duties he was whisked off to U.S.A. at very short (2 or 3 days') notice. I guessed at the time, and later confirmed, that he had gone there to work on atomic fission problems, *i.e.* atom bombs.

At A.R.L. in November 1943 the former 'Fire Control' or 'Low Power Transmission' group initiated by Dr. C. V. Drysdale and later taken over in 1929 by J. M. Ford, had developed into a much larger group than that I had known in 1936 when I had gone to Portsmouth. It had now, in 1943, split off from A.R.L. to become the 'Admiralty Gunnery Establishment' under Colonel A. V. Kerrison as Superintendent who was also functioning as Superintendent of A.R.L. It was intended that as soon as suitable accommodation could be found A.G.E. should break away from A.R.L. leaving the latter in its original form minus the gun and searchlight control section including that part of Optics required for gunnery purposes. During the interim period before Gunnery departed to its own establishment—ultimately this proved to be Portland—I was to superintend the A.R.L. side. This I did from 1943 to 1946 when I transferred to the Admiralty as Deputy D.P.R. During my absence in Portsmouth, 1937-43, the new A.R.L. building had been erected, in 1939. This building is described even to the present day as the Fire Control Building. On my return to A.R.L. in November 1943 some of the old groups were still actively functioning; one or two had disappeared, and new groups had been formed. The large 80-foot-long tank, formerly used for underwater acoustics, was dry and was being used as an infra-red dark tunnel underground, the large acoustics laboratory above it having been absorbed by the workshop stores. I shall not attempt to describe the work of the Gunnery department, A.G.E. This part of A.R.L.—A.G.E. was Colonel Kerrison's special concern, assisted by J. M. Ford, J. Bell, L. Champney, T. J. Tooley, *. *. Field, R. F. Stewart, N. H. A. Warren, W. Burnside. They were concerned with gun and searchlight problems such as those I have mentioned earlier — Stabilisation, follow-up mechanisms, magslips and hydraulic gear, predictors, *etc.* The Optical Section under R. W. Cheshire also worked in close co-operation with A.G.E., Commander Leighton and Major French were respectively Naval and Military Liaison officers in A.G.E., R. W. Ditchburn (from Dublin University) in the Optics Group of A.R.L. was mainly concerned with visual problems — night vision testing of 'look-outs', visual problems in director control towers and the use of red lighting in the Navy. Other research work in the Optics section dealt with optical rangefinders for various special purposes, *e.g.* A.A. gunnery, instrument lighting, prism devices for use in marking results of '20° Throw-off', H.A. practice anti-aircraft firings, *etc.* Other members of the Optics Group at this time were C. T. Wright, J. F. Sutton, P. A. Laird and J. Tunstead. The Acoustics group at A.R.L. in 1943 had changed in character compared with the group I left in 1936. Then it was mainly *anti*-submarine, now it was inclined to be *pro*-submarine. The group was in charge of F. R. Carling assisted by W. Burns, R. S. Hogben, B. Hensel. One of their main problems was that in which R. T. Beatty had been working before the war, *i.e.* reduction of the noise of auxiliary machinery in submarines. Ranges at which these machines, ballast pumps, *etc.* could be heard were measured in Loch Long—followed subsequently by the installation of the Acoustic Range in Loch Goil. Underwater transmitters having a flat characteristic over the audio frequency range were designed for use in testing acoustic equipment. Resilient mountings for auxiliary machinery in surface craft and submarines were designed, resulting in a marked reduction of noise emanating from ballast pumps, mono-trimming pumps and sea-water circulating pumps. X craft, midget submarines, received particular attention from the point of view of silence, the diesel engine main motor and gear-box being mounted as one unit on a common frame on special neoprene flexible mountings. In this case the range of detection was thereby reduced from 10,000 yards to less than 200 yards. The acoustics group also designed an expendable noise maker, known as 'Publican', for use against the enemy acoustically homing torpedo known as the *Gnat*. The 'Publican' was of the 'hammer-box' type which had a very large sound output. Another interesting device produced by the acoustics section was known as 'Chickweed'. This was a flexible line hydrophone intended to hang vertically from a drifting vessel but this proved impracticable in service. The hydrophone consisted of a long flexible cable threaded through a large number of short magnetostrictive nickel tubes designed to operate at ultrasonic frequency.

A new and flourishing section at A.R.L. in 1943 was concerned with the transmission and reception of invisible infra-red radiation in regard to service applications—*(a)* for carrying out security operations at night when visible light must not be used, *(b)* for location of invisible targets for fire control purposes, and *(c)* for control of directive mechanism in homing missiles. The Infra Red Group at A.R.L. in 1943 were a strong team under E. G. Hill who, soon after my arrival in November 1943, left to become Chief Scientist at the Admiralty Underwater Explosion Research Establishment at Rosyth (Undex). A. Elliott took his place in control of the I-R. Section at A.R.L., other members of the team being E. Lee, L. E. Mayes, T. H. Pratt, G. G. McNeice, B. W. Soole, J. Starkiewicz, F. Kicinsky, E. W. Jackson and B. Horwood. Their investigations covered the whole range of I-R detectors, photo-emissive and photo-conductive cells, thermopiles, bolometers, *etc.* but their principal achievement was the development of a small photo-emissive image converter (about 4·5 cms. diameter



Sectional diagram of the R.G. Receiver BR/U3.



The development of infra-red photocells from 1936 onwards.

and 4 cms. long), known as the R.G. tube, in co-operation with E.M.I. at Hayes, Middlesex[92]. This small tube converted invisible short-wave I-R. into visible radiation. The high voltage required to operate the tube was provided by a simple Zamboni 'dry' pile of coated paper discs[93]. Dyed plastic infra-red filters were also produced in co-operation with the 'Ernoid' plastics factory at Stroud. These I-R. filters were used to render powerful light sources invisible. A great variety of transmitters and R.G. receivers were designed during the war to meet service requirements—Navy, Army and Air Force. Large numbers were used operationally in combined operations in Europe and in the Far East, and in night driving operations with armoured formations. The R.A.F. used I-R. equipment on a large scale for identification and recognition. The German armed forces also used infra-red equipment for night driving, target location and fire control. L. E. Mayes went over to Cherbourg several times in 1944 to inspect such enemy equipment, and with A. Elliott he toured Germany immediately after the end of the European war (May 1945) to recover I-R. material used by the enemy. One type of German image converter known as the 'Seehund' was supplied to submarines for signalling purposes. Of course Radar superseded the use of infra-red as a possible method of long-range detection of aircraft.

One of the older research groups at A.R.L. which might be described as the Underwater Ballistics and Electromagnetics Group was still under the direction of S. Butterworth. This group which also included J. A. Craig and M. W. Burgess was concerned with a wide variety of problems. One of these dealt with the photography of the water entry of projectiles such as torpedoes, depth charges, and other bodies projected or dropped from aircraft. A study was made of the air cavities carried down into the water and the consequent effect on the underwater trajectory of the projectiles. One improvement was known as the 'Kopfring' which reduced the air cavity considerably. At this time also the large Glen Fruin (Helensburgh) water entry tank was constructed and used for testing projectiles on a much larger scale than was possible in the A.R.L. tank. Reference has already been made to Butterworh's interest in German magnetic mines, degaussing, *etc.* Assisted by N. F. Barber and M. W. Burgess a 'model' shipyard was developed at A.R.L. where ships were built magnetically to scale and used to test coiling methods of de-magnetising ships. H. F. Willis (with Mrs. Willis) after working at A.S.E.E. Portland and Fairlie, joined A.R.L. staff in May 1945 and ultimately took over the E.M. work of Butterworth's Group when he retired (on 11th August, 1945).

Reference was made earlier to our designing a 'pressure' mine (X or 'oyster' mine) which would fire when a ship passing over it produced a small change of pressure (a suction of a few inches head of water) on the sea bed. It was realised that waves and swell might produce such a pressure change, but experimental information on this point was lacking. Consequently wave recording stations were set up on the south and north Cornish coasts to observe the period and height of waves and swell coming up the Channel from the Atlantic. Apart from its immediate objective, this work raised the question as to the advisability of forming an oceanographical section of Admiralty research to

[92] Prof. Trueman and Dr. McGee were in charge of R.G. image converter tube manufacture at E.M.I. at Hayes.

[93] Paper discs coated on one side with tinfoil and on the other side with manganese dioxide.

obtain data on the fundamental characteristics of the sea. In April 1944, Dr. G. E. R. Deacon, who was then on the staff of A.S.E.E. at Fairlie (Ayrshire), came to see me at A.R.L. to discuss the possibility of forming a 'wave-group' or 'oceanographic group' at A.R.L., and it was decided to do so as soon as possible. Dr. Deacon 'reported for duty' to control the Oceanography Group at A.R.L. on 5th June, 1944, when he was joined by Messrs. N. F. Barber, C. H. Mortimer, W. Cotsworth, *. *. Alexander, M. J. Tucker, J. Darbyshire, G. Collins and F. Ursell. Ursell had joined A.R.L. at the end of December 1943 and worked with S. Butterworth to gain experience in applying his excellent, but more academic, mathematical ability. He demonstrated the wisdom of this course after he joined Dr. Deacon's wave group and in his subsequent career[94]. The Oceanographic Group commenced research on the improvement of techniques for measuring sea waves and methods of predicting waves, swell and surf from meteorological observations. Analysers of wave height and period were designed for the study of complex wave-records and these led to a method of prediction of the time of arrival of storms and the location of the areas where the storms originated. Representatives from many countries, U.S., India, Australia, New Zealand, Mauritius, *etc.*, visited the laboratory. and the wave-recording station at Perranporth and many other oceanographic research stations have originated as a result. The A.R.L. group discovered as a result of the examination of the Kew seismographic records that microseisms could be explained as being due to the action of sea waves and swell coming from distant storm areas, the pressure effects being transmitted along the sea bed. Another branch of oceanographic study relates to the physical state of the sea—temperature, salinity and density, which influnce the effective range of transmission of sound in the sea and have considerable importance of course in the detection of submerged submarines. Electric currents in the sea due to its motion in the earth's magnetic field, and internal waves in the sea were other important subjects studied by the oceanography group. Much more could be said about the work of this group but space does not permit. It grew from strength to strength until in April 1953 it became the 'National Institute of Oceanography' which transferred from A.R.L. to its present headquarters at Wormley (Surrey) — an organisation which possesses its own research ships and is well known internationally all over the world.

Flying bombs (V1 type) were a source of annoyance in the Teddington area for several months from June 1944. Many passed over but a few fell in the district and caused some casualties. One fell in the High Street, another in the N.P.L. grounds and another in Hampton Court grounds. A solitary (V2) stratospheric flying bomb fell near the gas-works in Teddington. 'Samples' of V1 and V2 bombs[95](V1 in July and V2 in November 1944) were on view at R.A.E. Farnborough, where Butterworth, Ford and myself went to see them. They were very ingenious in design, but the impression we took away was that they were a *very* expensive kind of bomb which had every sign of 'desperation' inscribed on it! As we know now the antidotes to V1 were soon found and the V2's were hardly 'under way' before D-day and the end of the European war. I suppose these flying bombs were 'a little before their time' and may now be regarded as the precursors of recent space rockets!

My very brief outline of the 'war period' requires some apology! It is clearly impossible in a short paper to deal adequately with the war years in which important events inevitably crowd one upon another. Under such conditions it is often minor occurrences which are retained by the memory to the exclusion of others which in perspective were far more important. This is the impression I get on looking through what I have written. I have just referred almost haphazardly to *some* of the outstanding features of the period as they concerned me personally. I have now arrived at the point where the Royal Naval Scientific Service—R.N.S.S. —was formed. This important event occurred on or about 8th September, 1944. During the war the contribution of civilian scientists and engineers in research, technical design and development of new devices had been so important and the numbers of personnel had so greatly increased that a complete re-organisation became necessary. All the scientists and engineers hitherto employed in the Admiralty scientific, technical and chemical pools were now to be embodied in a new organisation—the R.N.S.S. The head of this organisation was Mr. C. S. Wright (later Sir Charles Wright) who had from 1934 to 1944 been Director of Scientific Research, Admiralty. Before the 1914 - 18 war there was no civilian scientific organisation—in 1915 I was one of the first two civilians employed by the Board of Invention & Research (Admiralty); I was the physicist and H. Gerrard was the electrical engineer. As a result of the developments in the 1914–18 war a considerable number of scientists from universities and industry joined the Admiralty civilian scientific service. At the outbreak of the 1939–45 war these

(94) F. Ursell after working on the theory of ocean waves and swell in Dr. Deacon's group later became a Fellow of Trinity College, Cambridge University and is now Professor of Applied Mathematics at Manchester University.

(95) The V2 flying bomb was 46 ft. long, 5 ft. 6 in. diameter, weighed nearly 15 tons (at take off). Carried 9 tons of liquid oxygen and alcohol as fuel, and 1 ton of explosive. Radio-controlled from ground. A very fine achievement mechanically and electrically.

numbered about 600. By the end of 1944 they were increased by about 3,000 temporary personnel. I suppose the larger proportion of these were absorbed by the radiolocation, 'Radar,' Service which worked in close collaboration with the Air Force and the Army. Great advances in asdics, mining, minesweeping, torpedoes, degaussing, *etc.*, to which I have referred also required spectacular increases in scientific staffs. In September 1945, almost immediately after the conclusion of the war in Europe and the Far East, the Chancellor of the Exchequer presented to Parliament a white paper dealing with the administration of the Scientific Civil Service[96] which was concerned with 'Reorganisation and Recruitment during the Reconstruction Period.' It dealt with the complete reorganisation of the Scientific Civil Service with 'substantial improvement of salaries and careers.' It created a Scientific Officers Class recruited from highly qualified scientific graduates on salaries 'aligned at certain points with those of the administrative class.' There was also created an 'Experimental Officer Class' to replace the 'Scientific Assistant Class' recruited partly from youths and girls about 18 or 19 who had specialised in scientific subjects and partly from university graduates and persons with experience in industry and engineering. Recruitment to the Scientific Civil Service was centralised in the Civil Service Commissioners and Dr. C. P. Snow was appointed to assist them. The Institution of Professional Civil Servants which in 1945 comprised some 35,000 civil servants, remarked 'that the proposals represented some improvement long overdue.' The scientists in question, it said, were 'the back-room boys who, with their colleagues in industry and the universities had been responsible for such fundamental scientific and technical developments as Radar, jet propulsion, the answer to the magnetic mine, *Mulberry, Pluto, etc.*, and played a part in the development of the atomic bomb.'

Looking back over the period from 1915 when the Admiralty Board of Invention and Research was formed to 1944 when it became transformed into the Royal Naval Scientific Service, the civilian scientific and technical staffs have good reason to be proud of their achievements in two wars and the intervening period. There has been no lack of achievement from 1944 to the present day and I have no doubt the future holds much more in store. All those of us who have lived through the two war periods must hope that the call for war science will never come again, and the process of converting 'swords into ploughshares' will long continue.

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[96] Cmd. 6679. September 1945.

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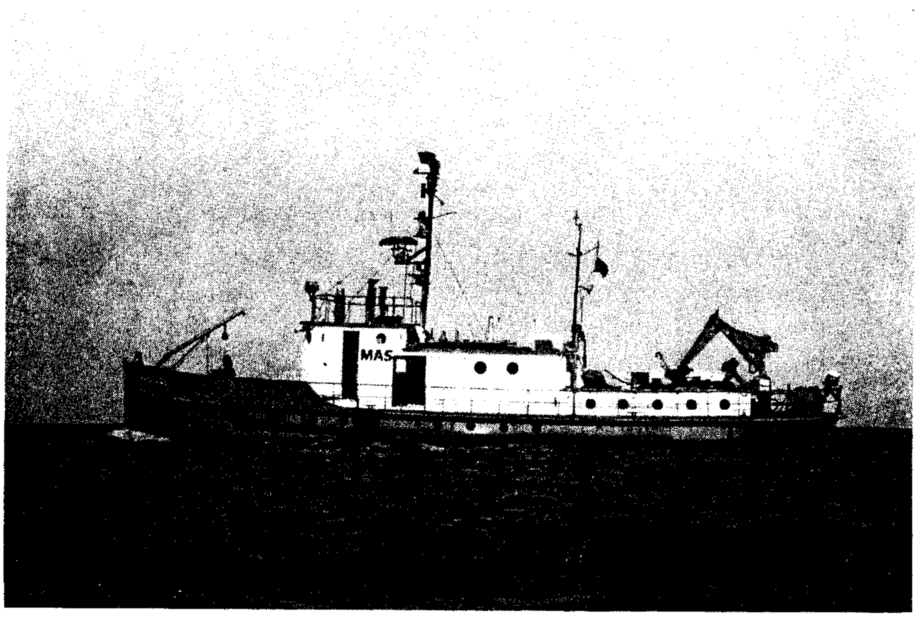

Research Vessel A. B. Wood, added in 1964, to the fleet of Marine Acoustical Services Inc., Miami, Florida.

ROYAL NAVAL SCIENTIFIC SERVICE