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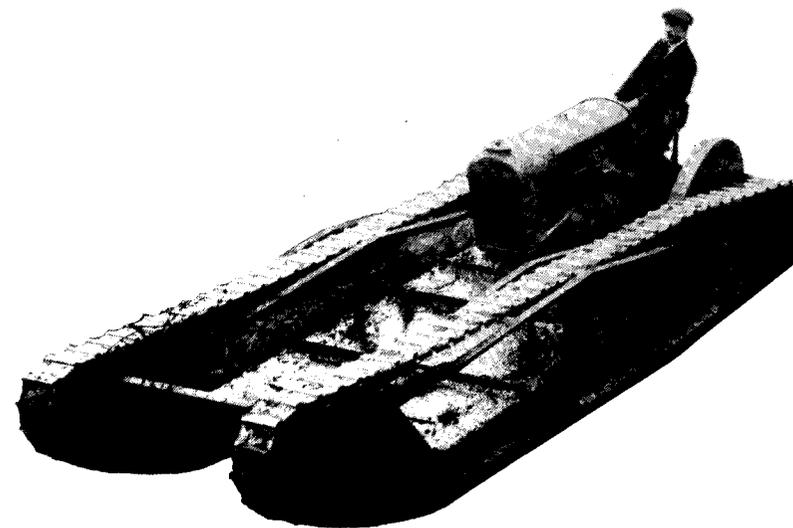
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1| **The War of
Invention** |

2| *Scientific Developments, 1914-18.* |

by

4| **GUY HARTCUP** |

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'When the history of the present war is really written one of the most curious chapters will be the marvellous manner in which in almost every field the scientific layman has come to the aid of executive ignorance'.

KARL PEARSON, FRS, 1919

Preface

In recent years the employment of scientists in World War Two and post-war military applications of science and technology have received considerable attention, especial interest being kindled by the clash of personalities like Lord Cherwell and Sir Henry Tizard and by the arrival of new technologies such as the development of the atomic bomb, radar and the decyphering machines used in cryptanalysis. Yet, apart from a number of valuable studies on naval and military scientific policy, few attempts have been made to assemble and assess the scientific and technological equipment introduced to try to end the tragic, drawn-out struggle that was the First World War — the opponents themselves immobilised on account of the power of modern weapons. It was, indeed, the first major technological war in history.

This book is an attempt to fill the gap and to relate well-known inventions like the tank and the introduction of chemical warfare with less familiar advances involving physical, chemical and medical research which changed the face of warfare. Above all, it was a war in which, to a surprising extent, the man of science (scientist was still an unfamiliar synonym) and the engineer began to assume an importance which would vastly increase over the next forty years. The book is as much about these men — and women — the first 'boffins', as an account of the techniques and equipment that they were responsible for developing.

I have taken advantage of the voluminous documentation on World War One in the Public Record Office at Kew. By comparison the French, German and Austrian archives contain much less material throwing light on the technical side of war, but at least they have yielded some information. Although the United States did not become one of the Allies until 1917, American scientists had responded to the threat of war long before the politicians. However, space has not permitted more than brief references to their activities.

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East Sheen
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GUY HARTCUP

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Introduction

The first contact of the British, French and German armies in August 1914 was made by cavalry patrols armed with rifles and lances. There were, indeed, a few aeroplanes on both sides making reconnaissances or controlling artillery fire. Yet within four years the character of war had utterly changed. Movement across the ground had become impossible without preparation entailing the expenditure of thousands of tons of high explosive shells; poison gas and tanks had been used, though with little appreciation of their best method of employment, to break the deadlock of trench warfare. Blockade, either by German submarine or by the Allied navies, compelled both England and the Central Powers to turn to their chemists and physicists to develop new processes whereby substitutes for raw materials originally brought from overseas and necessary not only for munitions but for medical supplies might be obtained, or for substitutes to compensate for the lack of foodstuffs. The air became an additional sphere of conflict; rival air forces fought for superiority over the battlefield; while more powerful aircraft, both lighter and heavier than air, were developed to launch attacks on industry, or to lower the morale of the civilian population by bombing.

All these changes could not have been achieved without the cooperation of scientists and engineers, and the creation of research establishments and laboratories drawing extensively on the limited resources of scientific manpower. In the autumn of 1915 an English physicist could truthfully write: *It is beyond any doubt that this war is a war of engineers and chemists quite as much as of soldiers*^{1*} Yet in 1808, only just over one hundred years earlier, Napoleon, in the middle of the war against England, allowed the great chemist Humphrey Davy to come to Paris and receive an award for his electro-chemical discoveries.

How did these revolutionary changes come about? By the middle of the 19th century, war was being transformed by science and technology. Rifled, breech-loading guns improved the accuracy of artillery and in 1850 the invention of gun cotton marked the birth of explosives more powerful than gunpowder — the high explosives. Such new developments and others in

* Superscript numbers refer to notes at end of book.

pyrotechnics, for example, all required the attention of chemists. The effect of them would eventually lead to the break-down of what had been an international brotherhood of men of science meeting each other and exchanging ideas. It was a change of attitude that was to have a profound effect upon the history of warfare.

In England the change was first marked by the Crimean War which began in 1854 and demonstrated to the British Army that it could no longer rely on the muzzle-loaded musket and the cast iron smooth bore cannon with which it had fought the Napoleonic Wars. Already the War Office had asked Michael Faraday, who was then professor of chemistry at the Royal Military Academy at Woolwich, to provide advice, but on conclusion of the war in 1856, it appointed the twenty-seven-year-old Frederick Abel as War Department chemist.² Abel had not long been professor of chemistry in succession to Faraday, and had also been consulted during the recent war. Belatedly recognising the advance of technology, the War Office, in 1864, asked Abel to form a small research department at Woolwich to investigate chemical and metallurgical problems. By 1871, Abel had built up his staff of assistant chemists to eleven and they covered the whole field of chemical research and inspection. Abel served the War Department until 1888 and made several important contributions to military science. At the same time, the study of ballistics was begun by the Reverend Francis Bashforth, an ex-Cambridge don, who was induced to leave a remote Essex parish to become Professor of Applied Mathematics at Woolwich. In that capacity he investigated the reasons why British artillery had failed to make any impact on the Russian defence at Sevastopol. Although Bashforth returned to Essex in 1872, he was recalled the following year as adviser on ballistics to the War Office and retained that appointment for the next five years. Bashforth's laws on the resistance of projectiles in flight continued to be relevant for another forty years.³

By the outbreak of the American Civil War in 1861, breech-loading guns and rifled barrels were in general use. During that war, primitive machine-guns, sea mines and torpedoes were used for the first time, while telegraphy, photography and balloons improved the efficiency of communications and reconnaissance. In the medical field, anaesthetics were used for the first time to alleviate the sufferings of the wounded. Abraham Lincoln was possibly the first national leader to recognise the importance of science when he appointed the National Academy of Sciences in 1863 to provide the Federal Government with scientific advice. Yet the new weapons were not 'war-winning' as they generated logistical problems which were then impossible to solve; hand-to-hand encounters characteristic of traditional warfare persisted, but with heavy loss of life due to the power of modern weapons.

A few years later, the Franco-Prussian War was remarkable for the use of railways as a means of bringing armies rapidly into action, and for improved types of firearms and artillery. Less well known was the original and quite

extensive use of civilian scientists by the French Government, particularly during the siege of Paris when *ad hoc* committees were formed for the purpose of making recommendations both on technological aspects of military operations and the nutrition of the civil population.⁴ One of these scientists was Marcelin Berthelot who became a leading French chemist and an expert on explosives. In 1887 he was appointed president of the *Commission d'Examen des Inventions de Terre et de Mer* which eventually had five scientific members in addition to naval and military officers. In 1906 the Commission (still headed by Berthelot, then Professor of Organic Chemistry at the Collège de France) was reported by an English military observer to be far ahead of the War Office's Ordnance Committee, which could only boast of two scientists among its members.⁵ There was a close rapport between scientists and the armed forces in France; scientists taught in military and naval academies and corresponded with the Academy of Sciences.

By the last decade of the 19th century, further significant changes had taken place in the technology of war, including improved breech-loading guns resulting in higher rates of fire, the magazine rifle, the submarine and the torpedo. The value of a number of these weapons lay in the introduction of smokeless powder for ammunition. In this the French led the way with smokeless ammunition for their Lebel magazine rifle.⁶ Of greater significance, however, was the invention of ballistite by the Swedish chemist Alfred Nobel. This was a celluloid-like material composed of glycerine and nitrocellulose which could be cut up into suitable portions for use in the projectiles of small arms, artillery and even for the recently invented machine-gun.⁷

Nobel was more than an inventor. He was a superb commercial organiser and by the end of the century had set up a chain of firms manufacturing explosives in England and Germany with branches in France, America and Australia. While their products were primarily intended for industrial use, such as mining, there was no doubt about their value in war and the leading armament manufacturers became keenly interested. The centre of research for the Nobel ring of explosive firms was the *Centralstelle für Wissenschaftliche Technische Untersuchungen* near Potsdam. Founded in 1897, the laboratory was probably the most up-to-date of its kind in the world, carrying out experiments on the properties of nitrocellulose and investigating the strength of gun barrels. The great firm of Krupp, principal supplier of arms to the German services, was represented on the board of trustees and naturally benefited from the research.⁸

While continental powers like Germany and Austria-Hungary introduced ballistite for their armed forces, the British decided to find an alternative. In 1888 Abel, assisted by the physicist James Dewar, produced cordite. This could be cut into strings or cords, the rate of burning depending on the thickness of the cords. Cordite differed from ballistite in that it was made with insoluble rather than soluble nitrocellulose.

Chemical research had indeed become an essential adjunct to the development of weapons; chemists were appointed as members of ordnance committees, and the major armament firms like Krupp, Schneider, Le Creusot and Armstrong-Whitworth had their own experimental establishments. By the end of the century, a small number of scientists were working on explosives, torpedoes and developing wireless technology. What the general staffs of Britain and the continental powers did not anticipate, however, was the possibility of a *long* war, demanding both the expansion of the munitions industry and the necessity of finding alternative forms of raw materials like nitrates after normal supplies had been cut off by naval blockade.

Fortunately for the military, the organic chemical industry had made great advances in the latter part of the 19th century and the plants for producing dyes and fertilisers could be rapidly converted to warlike use. The country that was farthest ahead in exploiting these new processes was Germany. Production had to be complemented by a corps of scientists to assist in their preparation. Again, the Prussian Government had taken steps before other nations to ensure that the research chemists in the universities met the requirements of industry. Anticipating the growth of the chemical industry, the government had from 1864–75 stimulated the creation of a number of technical institutes, or *Technische Hochschule* as they were called, which specialised in applied chemistry, their students eventually forming a cadre which would be employed by industry to carry out research. Further moves to strengthen the links between science and industry were taken in 1911 by the founding of the *Kaiser Wilhelm Gesellschaft zur Förderung der Wissenschaften (KWG)* by private enterprise, the intention being to promote the sciences by the foundation and support of research institutes. One of them was the Kaiser Wilhelm Institute for Physical and Electrochemistry (*KWI*) which would become the centre of research for chemical warfare from 1915 onwards.

Although scientists like W. H. Perkin had pioneered new processes such as indigo dye in organic chemistry, British industrialists failed to exploit them. Unlike Germany, relations between universities and industry in Britain were remote; eminent men of science like Ramsay and Rayleigh, after following an academic career, would retire to conduct further experiments in their private laboratories. Some of the younger scientists, however, appreciated what was happening in Germany and during the turn of the century formed pressure groups, like the British Science Guild, urging the Government to follow the German example and provide a state laboratory to investigate the latest advances in physics, and an institution for the training of scientists and technologists.⁹ Their efforts led to the foundation of the National Physical Laboratory (NPL) at Teddington near London modelled on the *Physikalisch-Technische Reichsanstalt* in Berlin. It was administered by the Royal Society and funded partly by the Government and partly by scientific and technical institutions. Its prime purpose was to provide

reliable physical standards and methods of testing scientific instruments; secondly, to carry out original research in physics. In 1907, five years after the founding of the NPL, and after further agitation by scientists and a few science-oriented politicians like Richard Haldane, the Imperial College of Science and Technology at South Kensington was created on the lines of the *Königlich Technische Hochschule* at Charlottenburg in Berlin. Completion of the laboratories came just in time for their extensive use during the war. Meanwhile from 1900 onwards, a small organic chemical industry was growing around Manchester and its university; it, too, would be used for wartime scientific applications.

Likewise in France little had been done to cultivate relations between industry and academic science. The state had not created an equivalent of the NPL or the *Physikalisch-Reichsanstalt*. In the sphere of organic chemistry and the industries that were based upon it, France was no further advanced than Britain; ironically it was Berthelot, the authority on explosives, who was opposed to the atomic theory from which the latest chemical developments were derived.¹⁰ France had, however, seen a resurgence in physical research since the Franco-Prussian War. New institutions such as the *École Supérieure de Physique et Chimie* took their place alongside the long standing *École Normale Supérieure* and the *Collège de France*. The emphasis on the study of electricity and metallurgy was to find an important outlet in war technology.¹¹ Another new centre of research was the *Institut Aérotechnique* of the University of Paris established in 1911 and which reflected the considerable interest of the French in aviation. Scientists, engineers and the military foregathered there to study aerodynamics.¹² Paris had also become a world centre for the manufacture of binoculars though in the production of lenses the French, like the British, were a long way behind the Germans. The French automobile industry led the world and later provided a foundation for the production of tanks and heavy motor vehicles.

1

Prelude to Armageddon, 1900–14

The fourteen years of peace preceding the 'Great War' — known variously as the Edwardian era in England, the triumphant conclusion of the Wilhelmine period in Germany, and the recovery of confidence in France after the Franco-Prussian war and the Dreyfus affair — also witnessed the germination or early development of most of the technology in modern warfare such as submarines, torpedoes, improved propulsion for warships and even radar. We shall be concerned for the moment with four of them: new high explosives like trinitrotoluene (TNT); electrical transmission for controlling heavy guns; wireless; and the new science of aeronautics. All of them demanded the employment of chemists, physicists, and engineers.

However, while the continental powers like France and Germany had civilian scientists serving on ordnance or inventions committees, the British naval and military authorities adopted an attitude of complacency. A scientific advisory committee, originally formed by Abel after the Crimean War, was dissolved in 1891 despite its warning to the War Office that '*unremitting systematic investigation and practical experiment [were] absolutely indispensable*'.¹ How far the technological backwardness of the British Services which, as a chemist working at Woolwich was later to remark, had relied on a classical education and the old school tie to win wars, had gone was revealed in the Boer War. The British found in South Africa that they were not only being outwitted by the enemy, but that their armament and the supply of munitions were undoubtedly sub-standard.² Some British scientists had used the Services' neglect of these matters as yet another stick with which to berate the government for its failure to support science and technology.

Explosives

On 6 April 1900, just over a month before the relief of Mafeking, Major F. L. Nathan, who had a chemistry degree as well as being Superintendent of the Royal Gunpowder Factory, suggested to the Director General of Ordnance, Major General Sir Henry Brackenbury, that there ought to be '*a small committee of experts to direct experiments and researches*' in order to

keep abreast of foreign powers.³ Brackenbury, a well known authority on artillery, who had already observed on the outbreak of the war that the British were '*attempting to maintain the largest Empire the world had ever seen with armaments and resources that would be insufficient for a third class military power*',⁴ wasted no time. Within a matter of weeks, he had obtained permission to invite a small number of scientists to suggest how the Army's guns and projectiles could be improved.

The president of the Explosives Committee, as it became known, was Lord Rayleigh, former Cavendish professor of physics and shortly to receive the Nobel prize for his discovery of argon. Supporting him were Sir William Crookes, the celebrated chemist and President of the Royal Society at the outbreak of war; Sir William Roberts-Austen, metallurgist and chemist at the Royal Mint; Sir Andrew Noble, chairman of Armstrong-Whitworth, who had made significant contributions to the advancement of modern ballistics and gunnery; and, finally, the Liberal Party member and savant, Richard Haldane, shortly to be Secretary of State for War and probably the prime mover in suggesting the names for the committee since he knew the leading scientists of the day. After the death of Roberts-Austen, Alfred Ewing, Professor of Mechanical Sciences at Cambridge, joined the committee for a brief period before he was appointed the first Director of Naval Education. In that capacity he began to remedy some of the deficiencies in science and engineering in the Royal Navy; and early in the war he was to become celebrated for founding Room 40, the birthplace of British naval cryptanalysis.⁵

Within a year, the Explosives Committee had been responsible for establishing a small team of chemists under the direction of Oscar Silberrad, a brilliant organic chemist who had studied in Germany, to carry out such experiments as were necessary. The age of this team, according to one of them, '*did not exceed around twenty-five, but they were full of beans and worked till all hours of the night to make a success of the Chemical Research Department*' as they were called.⁶ An up-to-date laboratory was built to the design of Silberrad, quite distinct from the Royal Laboratory of the Arsenal, concerned with designing shells and fuses. It worked hand in hand with the Proof and Experimental Establishment, responsible for the proof of guns since the 16th century, which was conveniently situated nearby.

The use of high explosive, as opposed to shrapnel, shell was still quite novel and the Research Department played an important part over the next six years studying continental practices and suggesting new fillings for shell which were both sensitive to detonate and safe to handle. The filling of a high explosive shell consisted, firstly, of the fuse, a mechanism designed to produce a flash at the point at which the shell was to burst. It had to be capable both of being roughly handled before firing and of resisting the great pressure placed upon it when discharged from the bore. Secondly, there was a capsule which provided a spark to ignite an intermediate explosive packed

in the *gaine* (or sheath) which in turn detonated the main filling; the latter also had to be insensitive to the shock of discharge but sufficiently sensitive to transmit the initiating flash to the next stage, once the shell had left the bore.

Silberrad's first problem was to improve on the picric acid used as an intermediary in the *gaine*. He investigated a new compound called trinitrophenylnitramine at that time no more than a laboratory curiosity. After test tube experiments and field trials, this compound, renamed tetryl, was adopted for use by both Services and proved to be safer and more effective than previous substances.⁷ The Research Department also investigated the possibility of using TNT instead of lyddite as the main charge of the shell. Lyddite, invented by Abel and similar in composition to the picric acid used by continental armies and navies, had not come up to expectation in the South African war, failing to detonate properly, especially in small shell when it '*just fizzled*'. Considerable pressure to adopt TNT was applied to the War Office by several British dye manufacturers producing it as a by-product. In fact, TNT was safer to handle, more chemically inert, and cheaper to manufacture than lyddite. Crookes urged the Ordnance Committee to adopt TNT for the Services, pointing out that it was already being extensively used abroad.⁸ However, in 1908 the Ordnance Board, as it had now been renamed, decreed that lyddite should continue to be the main filling for shell, principally because it was more powerful than TNT and there was some doubt about using fulminate of mercury in the capsule to detonate the intermediary charge.⁹ It was a decision that the War Office came to regret in the Autumn of 1914.

Experimental work on TNT was nevertheless continued by the Research Department and it was used in a very pure form as an exploder charge for field artillery. Meanwhile, the manufacturers of TNT continued to campaign for the introduction of the new high explosive, in particular the Chilworth Powder Company which had acquired the ex-secretary of the Explosives Committee — Major T. G. Tulloch — who was one of the first to anticipate the use of tracked vehicles for military applications, as well as the need to introduce TNT. As late as April 1913, he persuaded a German scientist to lecture to the staff of HMS *Vernon*, the naval torpedo and mining establishment at Portsmouth, on the merits of TNT as a filling for shell, mines or torpedoes. Tulloch also told naval authorities that 6-inch shell filled with TNT could pierce 12-inch armour plate '*without even igniting the explosive*'.¹⁰

The propellant required to fire the shell needed to be improved. Hitherto the British had used cordite — a combination of nitroglycerine and nitrocellulose. This had the drawback of causing rapid erosion in gun barrels and was unstable in warm climates and when an unexpected change in temperature occurred.¹¹ The defects had been responsible for a number of serious accidents on land and at sea. The Research Department found that much greater stability was obtained by reducing the proportion of nitroglycerine

to nitrocellulose from fifty to thirty per cent. This would have the effect, according to Rayleigh, of doubling the lives of the bores of guns. In November 1901 Cordite MD, as it was called, was recommended for use by the Services in guns of all calibres. By the end of that year, the Ordnance Committee had approved large scale production of Cordite MD for heavy calibre naval guns and, before long, improvements in their operation were reported. In May 1904, the Commander-in-Chief Mediterranean noted that whereas six-inch guns were capable of firing only eight hundred rounds without serious deterioration with the old type of cordite, they could now fire as many as two thousand rounds without undue damage to the barrels.¹²

Reforms in the War Office, such as the creation of a General Staff and Army Council in 1904, the appointment of Haldane as Secretary of State for War in the Liberal Government of 1906, committed to a large programme of social services, had important repercussions on the direction of research at Woolwich. Scientific work was now put more directly under the control of the Services. These changes became imminent when the Director of Artillery, responsible for implementing decisions taken by the Ordnance Board, expressed the view in the Autumn of 1905 that the Ordnance Board and Explosives Committee should work more closely together; it would also save money. The impending resignation of Rayleigh would make a change easier to execute.¹³

However, the opportunity was taken to make one more improvement by adding a metallurgical section to the Chemical Research Department. Criticisms had recently been made, in particular by Sir Benjamin Baker, the distinguished civil engineer and long-standing member of the Ordnance Committee, that there ought to be facilities for research on metals at Woolwich to improve the quality of artillery as there were '*in all Foreign Establishments*'. Baker complained that the practice as regards research '*has been to begin experimenting, and finally to drop it without coming to any definite conclusions, as there was no one able to devote his time to the work*'.¹⁴

The Explosives Committee held its last meeting in April 1906 and control of research passed to the Ordnance Research Board, shortly to be amalgamated with the Research Committee — the two bodies eventually becoming known as the Ordnance Board. Although distinguished scientists like Crookes, Noble and other Fellows of the Royal Society continued to act as consultants, they exerted far less influence on the proceedings. In 1907 (a year in which there was a serious explosion at Woolwich damaging the laboratory), a Service officer replaced Silberrad as Superintendent of Research. All research and the trials and proving of guns were now included in a single Research Department. A young Scots chemist named Robert Robertson, recently home from India where he had been advising on safety measures in cordite magazines, became head of chemical research and in that capacity was responsible for the development of explosives until after the war.¹⁵ Robertson was a good organiser but, so it was said, terrified his

staff. These numbered no more than a dozen; they carried out a number of important experiments on the stability and detonation of high explosives and propellants, but their recommendation that more attention should be given to the development of TNT for the Services was not accepted by the Ordnance Board.

Fire Control of the New Warships

Just as the Boer War had revealed deficiencies in the British Army's equipment and munitions, the new breed of capital ships like *Dreadnought* and fast battle cruisers created several new problems for long-range naval gunnery. Firstly, the firing of salvos now needed to be more flexible and concentrated; a system of fire direction was required. Secondly, when warships were operating at high speed and at great distances from the enemy, it was very difficult for fire control officers to estimate the course, speed and bearing of a target.

The problem of fire direction was largely solved by Captain Percy Scott who had made his mark as a gunnery expert and was commanding *Excellent*, the naval artillery experimental establishment. He appreciated how difficult it would be to elevate and train guns on a target, especially when the latter was obscured by smoke or sea spray. In 1905, he proposed that the elevation, train and movement of heavy guns should be determined by a single fire director placed high up on the foremast. This post would contain an observer officer, a layer and a trainer with telescopes providing elevation and azimuth respectively.¹⁶ The layer elevated or depressed his instrument to get the target on the *horizontal* line of his telescope and the trainer moved his instrument to get the target on the *vertical* line of his telescope. The intersection of the two lines provided the aiming point. These movements were transmitted electrically to dials in the gun turret. Here the gunners followed them, as indicated by a needle, elevating and depressing the gun in accordance with the directions from the fire director's post. When the target appeared on the cross wires the gun was fired. One drawback was that in a rough sea the firing ship might roll through angles between two and twenty degrees. Up to two degrees the layer could operate the telescope quickly enough to hold the target, but when the roll increased, the target was only visible for a few seconds making it impossible to obtain an accurate fix.

Scott's proposal did not meet with unanimous approval at first, but after trials on the battleship *Neptune*, it was acknowledged that the ability to fire guns simultaneously and in poor visibility would probably increase the fighting efficiency of the fleet by about fifty per cent. In 1913, the fire director was approved and, by August 1914 eight battleships had been equipped with directors for their main armament.

The problem of fire control proved to be more difficult to solve. There were two main operations: (1) finding the correct rate of change of range and

the rate of change of bearing and (2) integrating this information and continuously impressing the results on the gun sights. A further problem was how to counteract the motion of the ship when bringing the guns to bear on the target.¹⁷ The first attempt to provide a correction was made by Lieutenant (later Rear Admiral) J. S. Dumaresq who invented a trigonometric slide calculator named after him which, used in conjunction with a rangefinder, when set with the firing ship, course and speed of the target and its bearing, could estimate the change of range rate and the deflection. But any variation in setting had to be guessed and, in order to provide greater accuracy, another device called the Vickers clock, with its face divided into ranges instead of hours, was introduced. From the clock, range rates and bearing rates from zero ranges and bearings previously obtained could be used and, by integrating the data, the range and bearing of the moment could be read. However, this instrument was also unreliable because the change of range rate would alter considerably between settings, which had to be done by hand.

What he believed to be a system overcoming these deficiencies was submitted to the Admiralty by Arthur Hungerford Pollen, the forceful managing director of the Linotype Company, who since the Boer War had been obsessed with the idea of devising a method of enabling naval guns to fire with an accuracy equal to that obtained by artillery used by the Army. Pollen's system could obtain from simultaneous mechanical transmissions of range and bearing a plot of the true course and speed of the enemy ship. From this plot by means of a clock (later known as the Argo* clock) the future range and bearing at any particular moment of the enemy ship were obtained by a mechanically integrating process. Pollen also worked out how to combine with the mechanical transmission of range and bearing a gyroscopic control to eliminate errors of aim due to the yaw of the firing ship and slight changes of course. Pollen, who had influential friends like the great scientist Lord Kelvin, won the support of Admiral Fisher, First Sea Lord and his Director of Naval Ordnance, Captain J. R. Jellicoe; both were officers with an open mind of new methods of naval warfare. A number of trials with the Pollen system were carried out by the Navy from 1905 to 1910.

Meanwhile the Navy was trying to improve the Dumaresq-clock system by developing a new manually-operated fire control system. The inventor was Commander F. C. Dreyer who submitted his first idea to the Admiralty in 1906. He had recently served on *Dreadnought* for an experimental cruise and in 1907 was appointed assistant to Captain R. H. S. Bacon, the new Director of Naval Ordnance. Although without academic qualifications, Dreyer had a scientific background as his father was a distinguished astronomer and his brother, serving in the Royal Artillery, also had a talent for invention and, indeed, helped him to improve his instrument. The Dreyer fire control table,

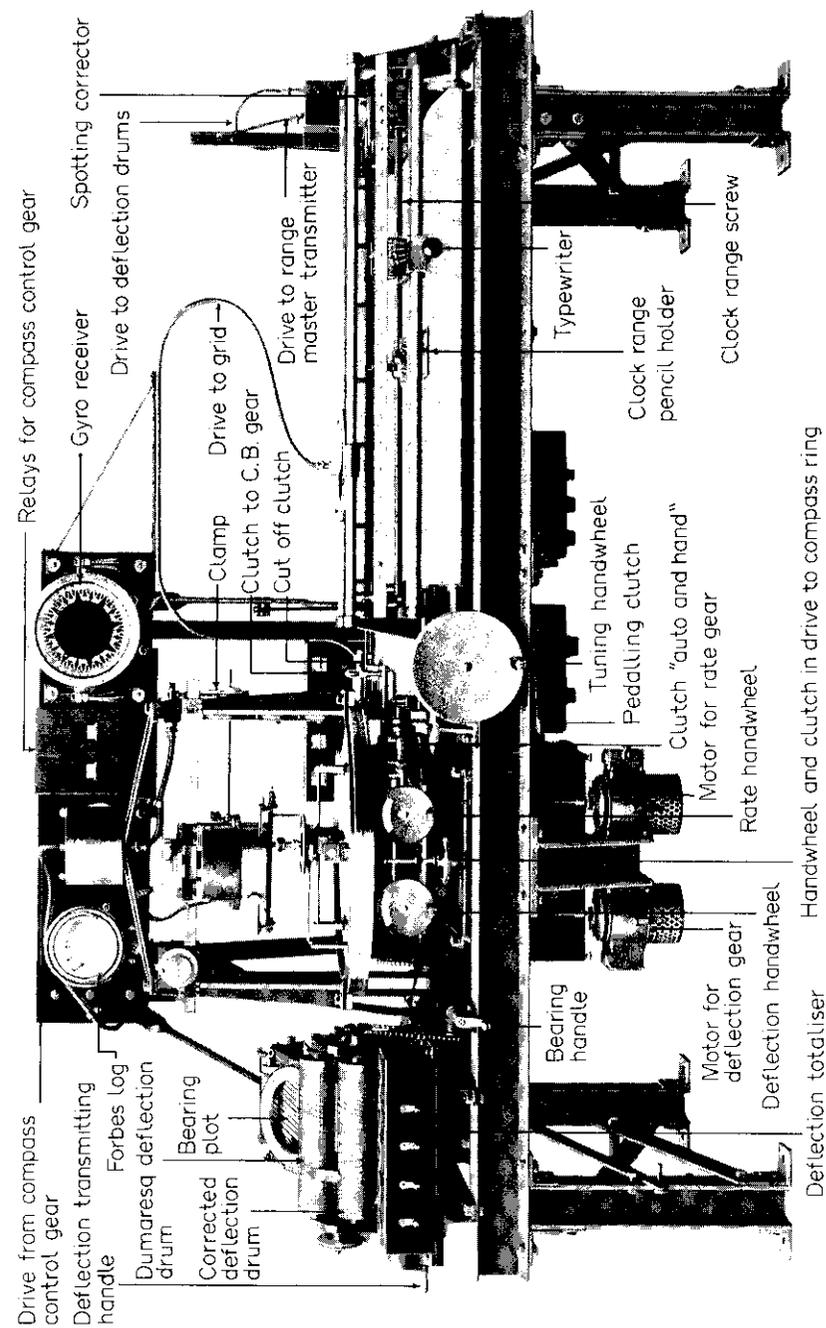
* The Argo Company was formed by Pollen in 1908 to make integrating systems.

as it was called, provided (1) plots of time and range and (2) time and bearing from information provided by the rangefinders which was then converted through the combined Dumaresq-clock into change of range and change of bearing.¹⁸ The plots were recorded by pencils on a moving sheet of paper. But there was one serious drawback to the Dreyer table. This was that accurate readings could not be taken when the firing ship and target were converging or diverging at steep angles and at high speed, or when the firing ship was under helm.

Trials to test the reliability of the two systems were held in the winter of 1907-08 in the cruiser *Ariadne* under the direction of the sixty-seven-year-old Admiral Sir Arthur Wilson, recently Commander-in-Chief of the Channel Fleet, who had seen action in the Crimea and in several colonial campaigns, but who may not have appreciated the significance of recent advances in gunnery.¹⁹ Captain Bacon, his chief adviser, although very technically-minded, did not believe that long-range guns would be effective in the murky weather usually experienced in the North Sea which was the most likely place for a contest with the German fleet. Before the trials a good deal of prejudice had arisen against Pollen who, for his part, became convinced that Wilson never grasped the advantages of his scheme. Moreover, the trials failed to assess the value of the Pollen plotting system as both the firing ship and its target were made to steam at almost equal speeds and on parallel courses. Wilson, in his report to Fisher, claimed that Pollen's instruments were unreliable and recommended that the Dreyer table should be used by the Navy. His decision was confirmed by the Admiralty which considered that the Dreyer table was possibly easier to operate and cheaper than the Pollen apparatus.

After 1908 Pollen was excluded from further fire control experiments though he continued to press his ideas on the Admiralty with great vehemence. In 1911, assisted by Harold Isherwood, he further improved the Argo clock by introducing a slipless drive which enabled an automatic and continuous integrating process to take place instead of having to reset the clock after each correction of bearing. On 4 September of that year, Pollen and Isherwood assigned their invention to the Admiralty as a secret patent and it remained on the secret list until long after Pollen's death in 1937. As a result, Dreyer soon abandoned manual operation and eventually incorporated so many features of Pollen's apparatus that in his Mark V table (introduced late in the war) the Dumaresq-clock combination was almost identical with corresponding parts in the Argo clock. Dreyer tables began slowly to be installed in battleships from 1910 onwards and the Admiralty purchased five Argo clocks which, after some time, were incorporated into the Dreyer Mark II table.

Instead of relying on inventive naval officers or private inventors, the German Admiralty assigned the design of its fire control system to the experienced electrical firm of Siemens & Halske.²⁰ From 1892 they had



1.1 Dreyer fire control table used on British capital ships during the war. Naval Historical Library, Ministry of Defence.

experimented with electrical transmissions for controlling the fire of coastal batteries and then naval guns. This work was directed by August Raps, a physics lecturer from Berlin University, and the firm's engineers installed the first electrical control system for warships in the early 1900s. Known as the direct current 'six roller' system, it computed figures for elevation and lateral training of the guns. But the apparatus, which required endless tapes to carry the data, was inconveniently large when installed in the ship's command post. In about 1905, the engineers of Siemens & Halske reduced the size of the apparatus by introducing an entirely new system in which electrical transmitters and receivers operated by very small motors provided essential data for firing the gun, being mounted alongside the gun itself. A powerful receiver was also put in for simultaneously adjusting the telescopic sight. All the gunner had to do was to set the target on his sight and fire. At the same time the process of measuring range was improved by employment of a base range finder in which the target was sighted from two points at a prescribed distance from each other. When the measuring device was coupled to an alternating current transmitter, the transmitters of the various instruments were connected in series. The arithmetical mean of the estimated range was then transmitted to the telescopic sight telegraph to indicate finally the required elevation of the guns. Orders were placed in 1913 for equipping the High Seas Fleet with this new apparatus, no expense being spared.

Raps, who by then had become enthusiastic about seeking ways of improving fire control, began to consider the use of gyroscopes but his experiments had to be abandoned on the outbreak of war when ships were no longer available for trials. At about the time that the British and German experiments were being conducted, the French began to introduce into their fleet a fire control system rather similar to Dreyer's.

Continuous Wave Wireless Telegraphy

The possibility of improving communications in war by wireless telegraphy — and eventually by wireless telephony — was quickly appreciated, though it was equally well understood that wireless was also extremely vulnerable to interception. Its use in naval warfare was perceived as being its most valuable application. In 1896, Marconi offered his invention to the British Services not realising that a British naval officer, Captain Henry Jackson, had been following the same line of development and had just succeeded in obtaining intelligible signals along the length of his ship.²⁰ Marconi formed a company in England and Jackson, who was soon elected a Fellow of the Royal Society for his experiments, was put in charge of equipping the Royal Navy with wireless supplied by Marconi's and instructing staff to use the equipment. A small wireless section was formed at HMS *Vernon*, the torpedo school, where the staff contained a number of officers trained as

electrical engineers. A close relationship was formed between *Vernon* and Marconi and one of the latter's engineers was attached to the establishment to supervise experimental work and train operators; he was H. A. Madge, a young Cambridge graduate, who continued to work for the Royal Navy until the outbreak of war.²¹ By 1908 spark sets were being operated by the Fleet and experiments in direction finding were in progress. At the same time, the German Fleet was being equipped with wireless by the *Telefunken* Company. This had been formed by Professor Adolph Slaby and Count Arco, who amalgamated with the firm of Siemens & Halske. Wireless was being installed in units of the French Fleet by the physicist and naval officer, Maurice de Broglie.²²

In the British Army, wireless became the responsibility of the Royal Engineers. During the Boer War, its use was subject to continuous interference due to climatic conditions. Then, in the early 1900s, wagon and pack sets based on the *Telefunken* system were already operating with the cavalry and modest development was taking place at a small signals experimental and training section at Aldershot. Most of the experienced wireless operators, in fact, received their training from the Post Office and were contained in a special Territorial Army battalion.

It soon became apparent that the Army was not keeping abreast of recent developments. In 1911, a special committee was appointed under Sir Henry Norman MP, an enthusiast for new technology such as automobiles and wireless, to suggest how Army wireless communications could be improved.²³ Assisting him were Bertram Hopkinson, Professor of Mechanical Engineering at Cambridge, and Russell Clarke, a barrister and early wireless 'ham' who was to play an important role in the interception of German naval signals during the war. A study was made of the equipment made by foreign wireless manufacturers and evidence was taken from, among others, Colonel George Squier, the American military attaché in London, an electrical engineer with a degree from Johns Hopkins University, who was interested in both wireless and aeronautics. The committee reached the depressing conclusion that the state of wireless in the Army was such that it would be better to abandon it altogether as '*an inefficient wireless service in war would be a constant source of doubt and danger*' — a verdict with which the Chief of the Imperial General Staff concurred.²⁴ The committee recommended that wireless operators should be better trained, the experimental section enlarged and moved to Woolwich, and that mobile sets should be transported in motor rather than in horse-drawn vehicles.

Much greater interest was shown in wireless by the French Army on account of thirty-five-year-old Gustav-August Ferrié, commandant of the *Radio-télégraphie Militaire*, who was a qualified electrical engineer and responsible for military wireless throughout the war. In 1903, he established an experimental station on the Eiffel Tower offered to him by the builder in order to save it from destruction. From the top of the tower, long

distance communication was established with units of the French Army as far away as Morocco.²⁵

What particularly occupied scientists engaged on radio research up to 1914 was the need for replacing the spark transmitters by a system for the transmission and reception of continuous waves to improve the quality of sending morse signals and making long distance wireless telephony possible. This could be done either by using the Poulsen arc system invented in Denmark in 1903, or by a thermionic tube or valve, the most promising being the three electrode valve (known as the audion) devised by the American engineer Lee de Forest in 1906 and which was already being used for amplifying normal telephone conversation. Slightly less successful attempts to emulate de Forest was made by the *Telefunken* engineers in Germany, while in France Ferrié actually acquired an audion valve after a visit to Paris by de Forest but neglected to do anything about it. In England, experiments with thermionic valves were being made by a small group of engineers at Marconi's. The intention was to adapt these valves for use by the Fleet but nothing had been installed by the summer of 1914.

By this time the Russians and the Japanese had made use of wireless at the battle of Tsu Shima and the Royal Navy had recognised it as being a 'strategical factor of the highest importance', though much remained to be done in reducing the size of the apparatus and over the training of personnel to use it properly.²⁶ Experiments had also been made in transmitting signals from the ground to aircraft in Britain and on the Continent; signals could be received up to about thirty miles.

Aeronautical Research

Only three years after the first two-man flight by the Wright brothers in 1908, the possibility of using aircraft, aeroplanes or airships in war was being given serious consideration. But fundamental research to ascertain the principles of flight had to take place and following that, the needs of the land and sea forces had to be discovered. France set the pace, a number of scientists taking a keen interest in aviation, in company with the military. Fundamental research began in Paris and in Goettingen. However, the British were the forerunners of state-controlled research in military aeronautics. In 1908, again largely at Haldane's instigation, the government set up a committee under Lord Esher to enquire into the future of what was quaintly termed 'aerial navigation'.²⁷ Following up its conclusions that it was important to continue the development of both heavier and lighter-than-air craft, an Advisory Committee for Aeronautics was formed in April 1909 under the presidency of Rayleigh who had been for some time well aware of the potentiality of aviation.²⁸ Only recently he had asked General Nicholson, Chief of the Imperial General Staff, who was his companion at a dinner, whether flight would not give a new dimension to war. The General thought

not. 'Not even for scouting?' queried Rayleigh. 'Not even for scouting' answered Nicholson. 'Well, you must remember that Wolseley could see no advantage in the proposal to use smokeless powder', responded Rayleigh.²⁹

As Rayleigh's committee was to function throughout the war, some account of its members is called for. Most of them either were, or became, Fellows of the Royal Society. The chairman was Richard Glazebrook, the first director of the National Physical Laboratory (NPL), a Cambridge mathematician with experience of the business world, able to get things done, largely because he was trusted, and a man possessing inexhaustible energy. However, it was W. N. Shaw, also a Cambridge mathematician, who became the first director of the Meteorological Office, who was probably more responsible than anyone else for setting up the Committee. He was extremely bright, quick to appreciate new ideas and deliberate in his approach to his work. Horace Darwin, the fifth son of Charles Darwin, was an engineer and designer who became the first chairman of the Cambridge Scientific Instrument Company which also played an important part in the war. H. R. A. Mallock was another engineer who had been an assistant of Rayleigh's and was familiar with military problems, having been a member of the Ordnance Board. Sir Joseph Petavel, Professor of Engineering at Manchester, had a special interest in the measurement of high pressures and in meteorology which led him to design instrument-carrying kites; and his practical bent was only satisfied by actually learning to be a balloonist and to fly an aeroplane. Finally, the engineer F. W. Lanchester was outstanding even in this assembly of talent. Not only did he design the famous Lanchester car, but wrote two seminal books on aerodynamics and aerodnetics in 1907 and 1908 which are still consulted. His mind ranged over a wide variety of subjects and he wrote several remarkable papers on the theory of aerial warfare which foreshadowed operational research some thirty years later. In addition, he enlivened discussions with his sense of humour and was exceptionally quick as a committee member.³⁰

Representing the Services was Captain Bacon who, on account of his technical qualifications, prepared reports on the building and steering of airships. In 1910, he was joined by Captain Murray Sueter, RN who was interested in non-rigid airships. Major General Hadden, Director of Artillery, spoke for the Balloon Factory, the birthplace of British military aeronautics at Farnborough, and was soon joined by the new Superintendent Mervyn O'Gorman, a capable engineer and leader of men who attracted to the Factory a highly talented group of young scientists and engineers, most of whom were to distinguish themselves in various aspects of aeronautics. F. J. Selby, another mathematician and secretary to the NPL, performed similar duties for the Advisory Committee. Three other members who joined later and were to make their mark were George Greenhill with a special interest in mechanics and hydromechanics, T. E. Stanton who worked on the effect of wind pressure on engineering structures and the

fatigue of materials, and L. Bairstow who also worked on fatigue and was credited with making original suggestions.

Rayleigh himself provided a sense of direction in the new science, his aim being to define the limitations of the primitive flying machines of the day. He only wrote two short notes on the subject but, according to his biographer (his son and the fourth Lord Rayleigh), they were the foundation stone of the Committee's work. Its value was demonstrated by the quality of the flying machines produced during the war. Rayleigh indefatigably presided over ninety-six of the 126 meetings of the Committee from 1909 until 1919, a few months before his death. In his latter years, though, he became a figurehead, control of the proceedings passing to Glazebrook.

Little more than two months after the formation of the Committee, Blériot made the first flight across the Channel, dramatically proving that England was no longer isolated by a narrow strip of sea from the Continent. The effect on the public of his descent on the cliffs of Dover was similar to the first landing on the moon and must have inspired the members of Rayleigh's committee. Their first annual report, submitted to the Prime Minister, dealt with the work at the NPL on stability, propellers, light alloys and petrol engines. According to one of the first members of the staff, J. L. Naylor, the atmosphere was not unlike that of a research laboratory at a university. Scientists were used to working with their hands as '*mechanics were scarce and money short*'. '*The hours of work were laid down but were never rigid . . . ; those interested in their problems often worked late at the laboratory or continued until late hours at home as well as at week-ends . . . It was mainly a world of carry on with your own research, which people did because they enjoyed it, and when no ancillary staff were available, each man went into the workshop or office and did it himself*'.³¹ Thus aeronautical research was transformed from the uncoordinated and secretive work of a handful of enthusiasts into a highly sophisticated activity, requiring various kinds of novel apparatus and employing some of the best brains of the country.

Foremost among the new equipment was a wind tunnel (already being used by the French, thanks to the patronage of the industrialist, Henri Deutsch de la Meurthe) for testing small model aeroplanes, a fifty-foot high steel wind tower, the purpose of which was to discover the behaviour of flat plates and models in winds, and a large whirling arm (or whirling table as it was called) designed to test model propellers with the aid of a dynamometer. In the theoretical field, discoveries on the nature of streamlining were made by Rayleigh and Lanchester, and pioneer work on the nature of stability was carried out by G. H. Bryan of Bristol University. But the work at the NPL was by no means exclusively academic. After a number of accidents to monoplanes of the Royal Flying Corps, a special committee was set up to investigate the causes, and Bairstow wrote an important paper setting out methods of calculation which could be used to determine stresses in the spars of wings.³²

The Advisory Committee also set in motion experiments on fabrics for airships and was especially concerned about the permeability of covers enclosing the inflating gas — hydrogen. In February 1911, the Committee visited the first British naval airship then nearing completion in the Vickers yard at Barrow-in-Furness. *Mayfly*, as she was ironically named, broke in half seven months later when being towed out of her floating hangar.

By then the future of military flight almost certainly seemed to lie with aeroplanes. The outcome of the theoretical work at the NPL was embodied in the Reconnaissance Experimental (RE1) aircraft built at the Royal Aircraft Factory, as the Balloon Factory at the insistence of O'Gorman was now designated. In charge of its development was E. T. Busk who had obtained a first class honours degree in the Mechanical Sciences Tripos at Cambridge. He may be fairly described as being one of the first 'boffins', as war scientists were affectionately called in World War Two. Combining designing ability with practical application, his approach was quite different from that of Bairstow who was '*sometimes puzzled as to how Busk was step-by-step modifying his aeroplane to make it wholly stable*'. In November 1913, he flew his machine for several hours in winds up to thirty-eight miles per hour without the assistance of balancing, controlling or steering mechanisms except for landing. The RE1, as Glazebrook reported the following spring, was the first machine to fly for fifteen minutes without the pilot touching the controls; it was the first machine in which the '*balancing of its various parts has been so calculated as the result of experimental work that it shall be inherently stable and because in actual flight it has shown that these calculations have been verified*'.³³ The RE1 was the prototype of the BE2C which, with a speed of 140 miles per hour, was to become the standard two-seater biplane with which the Royal Flying Corps went to war in August 1914. The staff at the Royal Aircraft Factory had also designed and tested an airborne wireless set and had fitted a machine gun in an aeroplane and fired it. The Factory was the first military research establishment applying theoretical propositions to practical applications.

And yet, while in certain respects recognition of what modern war might entail was made by the small staffs at Farnborough and Woolwich, when war actually came in 1914 Britain, more than the other belligerents, had failed to make provision for a *major* war. The lessons of the South African War, such as the failure of explosives and fuses, had still not been properly digested, in spite of the probings of committees of enquiry. In fact, the capacity to wage war had even been reduced because of the Government's programmes for expenditure in other fields; and little pressure had been applied to the armament firms in the private sector to keep abreast of new developments. Prophetic words like those spoken by the Superintendent of the Royal Laboratory at Woolwich in 1906 went unheeded. '*If we ever come*', he said, '*to a really big war, ourselves, the trade, and everybody working as hard as they can go, will never keep pace with what [the Services] will want us to*

supply . . . the productive capacity of the country would be stretched almost to breaking point'.³⁴ Similar words might have applied to research and development. As a naval officer was to write in August 1923, when financial cuts were once again threatening the development of weapons and equipment: '*Peace and not war is the time for methodical research; had this country been better prepared in this respect at the outset of the late war, our advantages would have been enormous in the increased capabilities for supplying information for use in the field and afloat which was so urgently needed at the time*'.³⁵

2

Mobilising and Organising the Scientists

In each of the belligerent countries the scientific community, normally more international in outlook because of the need to study at foreign universities and exchange ideas at conferences than their fellow citizens, were no less fervent in their support for the war; foreign honours were renounced; manifestos or statements were issued by leading scientists declaring, on the one hand, that German so-called '*culture*' had fostered a military caste which now rode rough-shod over Europe and, on the other, identifying with the spirit of the German people and condoning the German Army's invasion of Belgium and France.¹ For the French intellectuals, there was no question but to retaliate immediately against an enemy that after only forty-four years was again occupying a substantial part of their homeland.

While the young scientists, who might have contributed to new techniques of war, enlisted or were called to the colours, the professors and senior engineers began to take a more sanguine view of the possible length of the conflict after the abrupt halt of the German armies on the Marne. British scientists had been warning their fellow countrymen for some years of the great advances being made by the German chemical industry. Now they had to persuade the professional soldiers and sailors of the importance of the new techniques described in the last chapter; they had to learn how to gain access to the '*corridors of power*' if new ideas were to be transformed into weapons. In each country, scientists approached the problem in a different way. The French were more politically-minded than the British; in Germany, scientists were more accustomed to dealing with industrialists; in the USA there were closer links between industry and the universities.

The Royal Society is Involved

No time was lost by the French when on 4 August 1914, the day after the German declaration of war, the Academy of Sciences put itself at the disposal of the Government and agreed to act as an agent between the latter and scientific institutions.² Two months later, William Ramsay, a senior