CHAPTER I

THE BACKGROUND OF SCIENCE I GOVERNMENT AND INDUSTRY

Science and Technology

To say that the economic life of society in general, and processes of manufacture in particular, were unaffected by science until the beginning of the last century is scarcely an exaggeration. The seventeenth-century revolution in thought and method had moulded a science which was potentially capable of effecting profound changes in the means of production, and in fact many writers on science at the time found an important justification for the study of science in the fuller exploitation of natural resources, with the consequent enrichment of human life and alleviation of daily toil which it promised. But this promise was only fulfilled through the industrial and agrarian revolutions of the nineteenth century and the changes in the organisation of economic activity which they brought about. In particular the sudden rise of engineering needs above the level of the carpenter and the blacksmith, the sudden realisation that engineering skill in all its branches was fundamental to improvements in manufacture, transportation, agriculture and the means of making war, created a situation in which scientific knowledge and method not only could be, but must be, applied, while large-scale manufacture provided the means and incentive for the application of science.

It is easy to see why the hopes of men like Hartlib, Petty and Boyle, who had written at length of the social usefulness of science, had failed of immediate realisation. The attainments of seventeenth-century science were very great, but in matters of detailed explanation it was still weak. Even the fundamental principles of chemistry, of the science of living nature, of the science of the earth, were still wanting. Outside mathematical science the natural philosopher had very little to offer to the craftsman; even where he suspected that traditional methods were wasteful and inefficient, he could not suggest a remedy. Although a few professions—surveying, navigation and instrument-making, for instance—were now based upon a firm mathematical foundation and many others were undergoing modification in the direction of scientific method, the staple occupations of mankind—agriculture, mining, the cloth industry, ship-building—were the province of tradition and craft lore, unshaken as yet by the questionings of science.

If, in studying early science, we must free ourselves from the notions of 'pure' and 'applied' science which are little more than a century old, if we find that the distinction between science and technology becomes vague, we must also recognise that this was but an aspect of a more general broadness of thought. The natural philosophy of the seventeenth century, while it knew such principal divisions as mathematics, physics, chemistry and astronomy, allowed a free intercourse between them. It was still possible for the assiduous student to embrace the whole of science in his mind, and fit himself to appreciate every important event in the intellectual history of Europe. Huygens, for instance, was not only a master of physical science, but made discoveries in each of its branches. In Newton—physicist, mathematician, chemist, theologian, economist and public servant; in Leibniz—mathematician, philosopher, historian and politician; in John Ray—biologist, botanist, theologian, philologist—we have examples of the fact that there was no breach between science, scholarship, and the world of affairs.

The diversity of interest and the power of such men as these was not unusual, for if every man of learning was not a natural philosopher, every scientist was a man of learning, and many of them lived in the 'great world'. The science they created was marked by the absence of professional narrowness. Apart from physicians, the only professional scientists were those in universities and similar institutions engaged in the teaching of natural philosophy and mathematics. The typical seventeenth-century scientist was a gentleman who, if he was unable to live on his income, entered upon the ministry of religion, the practice of medicine, or the service of the state. By the standards of a later age he was an amateur and dilettante, unconscious of a deep distinction between science and his many other occupations. He turned with equal interest from a mathematical theorem to a prodigy of nature, from travellers' tales to a trade secret. Natural philosophy was not so much a new compartment of learning—though this, as it hardened into 'science', it became—as a new way of approaching and acquiring knowledge. The collection and consideration of a type of fact which had been neglected in all previous human experience was less important than the new attitude of mind in which the task was begun.

So far was the scientific mind of the seventeenth century from observing an artificial distinction between pure and applied science —mixed science, as Boyle called it—or between science and technology, that it was a common-place of the time to explain how science could profit from the experience of tradesmen, and trades from the teachings of science. The chemists, to profit by the experience of metal-workers, studied Agricola's *De re metallica* and Biringuccio's *De la Pirotechnia*, the two great German and Italian masterpieces on the art. The Royal Society collected histories of trades, in which the whole process used in many crafts was recorded. Galileo offered the advice that mechanics might profitably be studied in the Arsenal at Venice. And in the words of Robert Boyle, who was at once a great physicist, a great chemist, a great interpreter of science, and a weighty writer on divine subjects:

> The Phenomena afforded us by these [mechanical] arts ought to be lookt upon as really belonging to the history of nature in its full and due extent. And therefore as they fall under the cognizance of the naturalist and challenge his speculation, so it may well be supposed that being thoroughly understood they cannot but much contribute to the advancement of his knowledge, and consequently of his power, which we have often observed to be grounded upon his knowledge and proportionate to it.[1]

It would be mistaken to suppose that science had ever been confined strictly within the cloister and the closet, but it is

[1] *Some Considerations touching the Usefulness of Natural Philosophy* (Oxford, 1664): 'Of the Usefulness of Mechanical Discipline, 2'. cf. John Wilkins, *Mathematical Magick.* (London, 1648), Preface.

certainly true that there was now a strong movement to draw it closer to the field, the forge, and the workshop.

Following the contemporary interpretation, we may say that the divine studied science in order to understand the works of the Creator, the philosopher in order to satisfy his intellectual curiosity, the craftsman, by instinct, in order to turn his knowledge to useful ends. None of these motives was necessarily more noble than another, and there was indeed a strong link between the first and the last, for it was universally believed that the empire of man over nature had been the divine intention, and that nothing in the creation was without some purpose or lesson for man. If many of these lessons were not yet apparent, it was because science had been neglected and the investigation of nature scarcely begun. These were not new ideas, but they received greater force, and utility became a respectable reason for the study of science. To reduce nature to the status of a machine which could be managed for man's purposes did not seem incompatible with the view of nature as the supreme example of the wisdom and beneficence of God. Yet, for the reasons already given, the progress of science was little influenced by the utilitarian outlook of some scientists, although the practical possibilities of science recommended it to commerce and government. Advancing knowledge severed rather than strengthened the links between botany and medicine, astronomy and navigation, mathematics and mensuration. The synthesis of natural philosophy and technology which had been a principal object of the Royal Society, lauded by publicists and welcomed by statesmen, was never achieved, perhaps because the real intellectual vigour of the scientific renaissance sprang from far deeper roots than they realised, and was to work a more fundamental change in the human scene than they could have anticipated.

Robert Boyle, the eloquent exponent of the 'Usefulness of Natural Philosophy', has also the distinction of being the first Englishman to use the word 'ballistics' in print in the work to which he gave that title, where he classes ballistics with pneumatics and hydraulics as a mixed science.[1] He was justified in his definition, for ballistics was the fruit of the scientific revolution which had been effected by the preceding generation, and the

[1] See below p. 78.

most finished of Galileo's two new sciences, applying the philosopher's theory of projectiles to the practical needs of the gunner and the bombardier. As a science, ballistics was studied by many of the heirs of Galileo, the mathematical physicists of the seventeenth century, until it entered upon its modern history in Newton's *Principia*; while as technology it had begun to penetrate into practical manuals of instruction and give a scientific veneer to the art of gunnery. For the scientists there was no need to explain their interest in the problems of ballistics, since they arose naturally in the course of their investigation of motion, the most fruitful and most complete of all early researches. Moreover, the solution of these problems required the highest extension of mathematical methods. If at one extreme ballistics touched upon the crude equipment and simple artifices of the gunner, at the other it played an important part in the working out of the laws of mechanics.

To put the point more generally, in ballistics physical science, technology and gunnery, which is a branch of the art of war, combine. The relations of science and the art of war are similar to those of science and technology. Indeed, from the point of view of statesmen they are identical, for the power and skill of the state in making war depend (among other things) upon its technological development, and this in turn depends upon the application of science. This truth had been dimly apprehended in the late sixteenth century, and in the age of Newton was too clear to require demonstration. It was apparent to Colbert when he founded the Académie Royale des Sciences and it was urged by Leibniz as a reason for founding a similar scientific assembly in Germany.

The requirements of military supply, in a century of almost incessant warfare (in the course of which, moreover, many new, expensive and complicated means of destruction were invented) pressed heavily upon industrial resources. To the mercantilist statesman no object was more desirable than national self-sufficiency in armaments. Scientific knowledge could assist in attaining it by the discovery of new processes and the substitution of native commodities for those formerly imported.[1] Elizabeth of England

[1] J. U. Nef, 'War and Economic Progress, 1540-1640'. *Ec*[*onomic H*[*istory*] *R*[*eview*] vol. XII (1942), p. 19.

took a benevolent interest in the progress of new ventures into mining and metallurgy, looking to them for a secure supply of brass for ordnance. For the same reason in addition to cheapness, iron ordnance were used rather than brass wherever possible, though the latter metal was usually said to be superior. The native saltpetre industry (despite the hostility of the country to the digging up of the floors of its stables and pigeon lofts) and researches into the chemistry of explosives were encouraged by English sovereigns until the East India Company's trade provided a cheap and safe source of supply of this essential chemical.[1] Prince Rupert, cousin of Charles II and one of his ablest naval commanders, encouraged the Royal Society in their experiments with explosives and projectiles.[2] Colbert set the members of the Parisian Academy to work on direct military problems, Huygens examining the traction of gun-carriages, Blondel, Roemer and De la Hire exterior ballistics.[3] To multiply instances would only suggest that the science of the seventeenth century was more practical and more military than in fact it was; these suffice to show that the history of ballistics can only be studied by considering four separate topics: technology; the relations of government and industry; gunnery; and scientific ballistics. The first two of these topics will be treated in the remaining sections of this chapter; the third in the next, and the fourth in the remaining chapters.

2. *The Manufacture of Artillery*

It is a fairly obvious cause of error in assessing the work of early scientists to suppose that, because they were not unaware of the practical value of some of their discoveries, whenever they hit upon some truth capable of a technical application it was necessarily of technological importance. Huygens found the way to regulate a clock by means of a pendulum, and thereby revolu-

[1] *C[alendar of] S[tate] P[apers], D[omestic], passim*; H. A. Young, *East India Co.'s Arsenals* (Oxford, 1937), pp. 62 *et seq.*

[2] Thomas Birch, *History of the Royal Society* (London, 1756-7), *passim.*

[3] *Œuvres Complètes*, tome. XIX, p. 48; *Histoire de l'Académie Royale des Sciences* (1733), tome I, p. 71. Papin, who derived from Huygens much of his scientific knowledge, read a paper on the same subject before the Royal Society in 1711 (*Journal Book* vol. X, p. 315). François Blondel, *L'Art de Jetter les Bombes* (Paris, 1683). Roemer's notes on the proof of cannon, etc., are in *Adversaria*, pp. 191 *et seq.*

tionised the clock-making industry and the habits of our ancestors; but Roemer's discovery of the optimum shape for the teeth of gear-wheels did not have a corresponding effect upon the design of machinery.[1] Before it is possible to declare that a certain scientific investigation was of technological importance, though it may clearly appear to later eyes to be so, before we can declare that the investigator was guided by motives of practical usefulness, we must know whether the state of technical knowledge was such that the scientific principle in question could be applied. It was profitable to the clock-maker to make Huygens' new clock; it was not profitable to the millwright to make his gears in accordance with Roemer's theorem. Before we can say how far the scientific ballistics of the seventeenth century affected gunnery, it is needful to know how guns were made and of what they were capable. Did the study of ballistics arise out of an interest in particular problems of mathematical physics, or out of governmental pressure? Were the mathematical theories relevant for practical men? Was there—to raise the general question—any relation between science and war in the seventeenth century? Such questions cannot be answered from the history of science alone, for the putting into practice of the military potentialities of science was always the work of soldiers and engineers.

The development of weapons of war has been the result of a balance between the requirements of military enterprise, the ingenuity of inventors, and the capability of artisans. If we may judge from the military writings of the seventeenth century, the soldier was tolerably well satisfied with the weapons he had, and did not eagerly welcome innovations. In this he was supported by government, which had no desire to increase the already heavy burden of military expenditure. In so far as science was supported at all for military purposes, the chemist who promised more powerful explosives and incendiary materials was favoured, rather than the ballistician who offered greater accuracy. Military conservatism and the fact that war concerned only a very small portion of the population spared Europe the development of its

[1] This point and the whole question of why early science failed to influence technology, has been discussed by G. N. Clark, *Science and Social Welfare in the Age of Newton* (Oxford, 1937), ch. I.

ordnance from the sixteenth to the nineteenth century. From the invention of cast bronze cannon in the late fifteenth century to the disappearance of the smooth-bore, muzzle-loading gun about a century ago, there was no radical change in the design of artillery. Manufacturing methods altered. Iron was introduced as a gun-metal in the mid-sixteenth century; the scale of cannon increased in the seventeenth; better boring methods were used in the eighteenth; but the guns of Queen Victoria's wooden ships were capable of little more accurate practice than those of Drake's fleet which defeated the Armada.

In this respect there is a great difference between the history of hand firearms and the history of artillery in our period. The military experts invariably, the scientists whenever they applied their hypotheses in concrete cases, wrote of the ballistics of cannon and large projectiles. The ballistics of small-arms was entirely neglected, for the state of manufacturing technique forbade their use at any range beyond the point-blank 150-200 yards.[1] Yet, through various inventions of a technical character, the hand firearm passed through a period of rapid development from about 1550 to 1650, after which it scarcely changed for almost two hundred years. None of these inventions, however, had the effect of modifying tactics or of creating a new scientific interest, since none of them increased the effective range or accuracy or the weapon. The sporting rifle, a type of gun which did much to popularise the new sport of shooting—as we may see from the *Life* of Benvenuto Cellini—was the only accurate gun. This 'fowling piece', elaborately chased and ornamented to suit the quality of its possessor, was far too precious to be placed in the ignorant hands of the common soldier, on account of the many hours of highly skilful smith's work with forge and file which had gone to its manufacture.

The military inventor was less fertile in suggesting improvements in the manufacture or use of artillery, and military departments were not so easily persuaded to adopt them. The commander in the field was less free to experiment, for the artillery was directly under the control of the Master of the Ordnance, who was

[1] There were of course discussions by military writers of the best weight, size and calibre of arms for different types of service, and of the appropriate charges of powder. See, e.g., *C.S.P.D. 1638-9*, p. 189; *1639-40*, p. 398.

accountable for every piece in fort, store or aboard ship. The trial-and-error methods which brought the gunsmith to better his skill by insensible degrees were not available to the cannon-founder; too much was at stake, in the loss of capital and the prejudice of operations. Since every hundred pounds of metal in a piece of ordnance cost about as much as a musket, even a train of field guns represented a sizeable capital investment which was expected to last for many years.[1] Though the Crown made large payments to the London Gunmakers (incorporated in 1637),[2] the usual suppliers of small-arms, the capital investment and yearly production of the gun-foundries of Kent and Sussex had a far greater value. Thus while small-arms were the product of skill at the bench on a relatively slight weight of material, which could be applied to new designs as required, gun-founding was a highly organised and costly manufacture, whose techniques were already stabilised and would not easily admit of modification even to cast a better type of gun. The smith is naturally more adaptable than the founder. However, in practice the latter was rarely required to alter his accustomed methods, since the design of artillery remained essentially unchanged, less on account of the inability of science and industry to produce better weapons than of the absence of pressure to this end. Military opinion was happy in a surviving tradition of chivalry that close combat was more honourable than a long range bombardment between invisible foes.

Artillery began to change the character of warfare in the second quarter of the fourteenth century.[3] For a century even large guns, like the famous Mons Meg at Edinburgh, were built by the smith from bars and hoops welded into a crude tube, several such sections being screwed together for greater length. Then the blast-furnace made possible the pouring of large quantities of metal. This new technique, with the cast bronze guns it produced, was introduced into England by the early Tudors, who brought over foreign workers to establish the new industry, just as Edward III

[1] Amid wide short-term fluctuations in prices of military stores, it may be assumed that in the middle of the century guns, by gross weight, were valued at about £20 a ton (iron) and £30 a ton (brass); small-arms could be bought for 15-20 shillings apiece.

[2] The Charter is printed in the *Journal of the Society for Army Historical Research*, vol. VI (1927), p. 79. The Gunmakers had petitioned for a charter as early as 1581, and it was finally granted to them in the interests of national defence.

[3] Sir Charles Oman, *The Art of War in the Middle Ages* (London, 1924), pp. 205 *et seq.*

had hired foreign smiths to make the small iron guns used at Crécy; and, as before, Englishmen soon acquired their skill. In 1543, pressed by financial difficulties which prevented the purchase of brass abroad, Henry VIII sent a French founder from the royal foundry of bronze ordnance at Houndsditch to a Sussex iron foundry, where 'gun-stones' (round shot) were already being cast, and there Peter Baude poured the first iron guns in a single casting, probably applying to molten iron the very techniques of brass-casting which Vannoccio Biringuccio described in *De la Pirotechnia*, published three years before. From this technological revolution the English iron ordnance industry was born.[1]

Though the tutelage of England in metallurgy continued for at least a century and a half, the Sussex iron industry was of immense economic and political significance. It placed a powerful source of military strength in the hands of the commercial, Protestant powers; it gave Englishmen their first sense of industrial importance. But there is no evidence that the manufacture of iron cannon in any way differed from that of brass ordnance, or that Englishmen introduced any innovations.[2] There is indeed no detailed contemporary account of the English iron ordnance manufacture, so that the published descriptions of Biringuccio (1540) and Saint-Rémy (1697), referring to Italian and French practice, with a Spanish manuscript by the navigator Diego de Prado y Tovar (1603), must be relied upon as our only complete literary records.[3]

Comparison of the accounts by these writers, substantiated by fragmentary references to English methods, suggests that the technique of ordnance-casting never advanced far beyond the primitive skill of the bell-founder; that the process known to Biringuccio was exactly that described by Prado y Tovar and Saint-Rémy, so that there were no important variations of time and place in our period; and that it was entirely unaffected by the

[1] Ernest Straker, *Wealden Iron* (London, 1931); Rhys Jenkins, 'The Rise and Fall of the Sussex Iron Industry,' *Transactions of the Newcomen Society*, vol. I (1920), p. 16; H. Schubert, 'The First Cast-Iron Cannon made in England', *Journal of the Iron and Steel Institute*, vol. CXLVI (1942), p. 131.

[2] The seventeenth-century patents for smelting with coal may, of course, be disregarded. This point is also touched upon in the conclusion of this essay.

[3] Surirey de Saint-Rémy, *Mémoires d'Artillerie* (Paris, 1697); Diego de Prado y Tovar, *Encyclopaedia de Fundicion de Artilleria y su Platica Manual*, 1603 (MS. in Cambridge University Library).