INTRODUCTION

The history of theoretical chemistry in the seventeenth century has always suffered from a major, if understandable, distortion. This distortion results in a very large part from the brilliant success of Lavoisier in creating a revolution in chemistry. By definition, a revolution implies a violent break with the past; consequently the picture drawn of theoretical chemistry in the preceding period has mainly featured those aspects which Lavoisier was most concerned to correct. Hence historians of seventeenth-century chemistry have too often concentrated either on practical achievements—the perfecting of furnaces and laboratory instruments, the discovery of new substances, the preparation of new drugs—or on the problems which the seventeenth century notoriously failed to solve one hundred years before the work of Lavoisier and his contemporaries, problems of combustion, calcination and the theory of elements. In so doing, historians have tended not only to misrepresent chemistry as it was then practised, but to exclude it from a share in the great scientific revolution of the seventeenth century, the revolution which created the new experimental, mechanical philosophy. They justify this by saying that the revolution in chemistry was delayed; and by implying that seventeenth-century chemists and physicists belonged to different species. To a certain extent this was true; but not if one considers theoretical rather than practical chemistry. The ordinary chemist of the seventeenth century was, certainly, a rational, non-mystic, practical iatrochemist, interested almost exclusively in the preparation of drugs and the discovery of new substances, which in their turn could probably be used as drugs. Yet the experimental physicists of at least the later seventeenth century were interested in chemistry, notably in combustion and detonation and theories of matter; one thinks of Hooke, Wren and Newton, and of Huygens who interested himself in problems connected with the explosion of gunpowder. And at least a few seventeenth-century chemists anticipated the eighteenth century by being also natural philosophers.

Foremost among the theoretical chemists of the age, one of the few highly-skilled chemists who made contributions to natural philosophy as well, was Robert Boyle. Because Boyle's first published scientific work, the *New Experiments, Physico-Mechanical, Touching the Weight of the Air and its Effects* dealt with physics, a new branch of physics to which he made lasting contributions, his public reputation has always been greater as a physicist than as a chemist. Indeed, in his own day chemists sometimes complained that he put too much physics into his chemistry. But he thought of himself as primarily a chemist and his influence on chemistry was enormous. If modern historians find it hard to see why, this is partly because of the complex development of chemistry during his lifetime, and partly because his contributions to the new chemistry permit no such easy categorizations as do his contributions to the new physics. There is no Boyle's Law of chemistry. Our greatest difficulty in estimating Boyle's importance lies, it is reasonable to suppose, in our own confused picture of the developments in chemistry during his lifetime. We know, roughly, the things the chemists did, but not why they did them. We know how they failed to anticipate Lavoisier, but we find it difficult to understand why they failed, or to forgive them for their failure. We need to comprehend, not only how new were the problems which they left to the eighteenth century to solve, after being the first to elevate them to the status of problems, but also the way of thinking within which they posed and attempted to solve these problems. But especially and above all we need to notice their relatively successful achievements in theoretical chemistry, which are unspectacular because they created no great controversy, but which are none the less the basis on which later progress was built. Such theoretical achievements are the better understanding of chemical composition, the development of chemical identification tests, the improvement of chemical classification and nomenclature, the attempt to explain chemical reactions. These elucidations were only begun in the seventeenth century, but they required no revolution to complete, and they showed the kind of thinking about chemical problems which could be both possible and practical. This kind of chemistry was conceived in the spirit of the new philosophy,

and its consideration should suggest that chemistry truly deserves a place in any study of the seventeenth-century scientific revolution.

When Lavoisier, with his customary interest in beginning the study of a problem by studying its origins, looked for the origins of the problems with which he was most concerned, he more often than not began with the work of Boyle. Boyle was not a great pioneer in chemistry; he was merely one of the first to be really interested in what were to be the problems of the future from a theoretical point of view. In the following study the work of Boyle will be used as a point of departure in the belief that an understanding of Boyle's work, both those apsects in which he was original and those aspects in which he was but typical of his times, will reveal what the chemistry which was a part of the seventeenth-century scientific revolution was trying to do, and what it did do to prepare the way for the more spectacularly successful revolution in chemistry which took place in the eighteenth century. Boyle is a convenient figure. His long and leisurely life, the inclination of his mind, and his scientific method all encouraged him to deal with almost all branches of contemporary chemistry. He also played an important part in the scientific revolution as a whole, both by his contributions to physics and by his share in the work of the Royal Society. He had a keen appreciation of the scientific trends of the day, and seldom neglected to investigate any new problem that might occur to him or that might be raised by others. And his technique was superb. One might instance the rapidity with which he prepared phosphorus once its existence became known to him, and the excellence of his study of its properties, far better and more complete than any made by its discoverers.

There will be no attempt here to justify the epithet—surely dating from the Victorian period's addiction to scientific heroes—of 'the father of modern chemistry'. No man was that; besides, it is by no means clear how much of Boyle's work was original, and how much was based upon others. It is certain that what he did well he usually did better than others of his time; that more of the new chemistry is found in his work than in the work of any other contemporary chemist; and that it is

more closely related to the scientific revolution in other branches of natural philosophy. As a leading scientific figure, Boyle could not fail to be influential. Much of his work was incorporated into later chemistry so completely as to leave no trace. No one, certainly, covered so wide a range in chemistry as he during the latter part of the seventeenth century. It is to be hoped that from the examination of Boyle's chemical work, and its place in the development of chemistry, a clearer picture of that development will emerge, together with a keener appreciation of the problems which concerned chemists. If so, this study should help illuminate the chemistry which immediately preceded the work of Lavoisier, and at the same time the relation between the progress of chemistry and the growth of other physical sciences in the later seventeenth century should be apparent.

CHAPTER I

THE MAKING OF A SCIENTIST

In London in 1645 there were several groups of men who sought distraction from civil strife in the discussion of intellectual matters. Politically it was an uncertain time; the Civil War was still undecided though the New Model Army was beginning to forecast the ultimate success of the Parliamentarians, and fierce controversy raged over political and religious theory and practice. In science the times were equally stirring, if more peacefully so. The ideas of Galileo were becoming widely known; scientists everywhere were excited by the Torricellian experiments to a new interest in air and the vacuum; the Copernican hypothesis, now generally accepted by younger scientists, still needed support and could provoke controversy. It was a time when the material for scientific advance lay ready at hand, and men whose minds worked that way sought one another's company to exchange ideas and information on the latest developments at home and abroad. One of the groups of men who met regularly in London at this time is well known, remembered because, after fifteen years and many vicissitudes, they regrouped themselves formally to become the Royal Society, meeting once more in their original quarters at Gresham College. Nothing can equal for authenticity the account written in his old age by one of them, John Wallis, mathematician and divine:

> About the year 1645, while I lived in London (at a time when, by our civil wars, academical studies were much interrupted in both our Universities) beside the conversation of divers eminent divines as to matters theological, I had the opportunity of being acquainted with divers worthy persons, inquisitive into natural philosophy, and other parts of human learning; and particularly of what hath been called the New Philosophy or Experimental Philosophy. We did by agreement, divers of us, meet weekly in London on a certain day and hour, under a certain penalty and weekly contribution for the charge of experiments, with certain rules agreed upon amongst us to treat and discourse of such affairs; of which number were Dr John Wilkins

(afterwards Bishop of Chester), then chaplain to the Prince Elector Palatine in London, Dr Johnathan Goddard, Dr George Ent, Dr Glisson, Dr Merret (Drs in Physick), Mr Samuel Foster, then Professor of Astronomy at Gresham College, Mr Theodore Haak (a German of the Palatinate, and then resident in London, who, I think, gave the first occasion and first suggested those meetings) and many others.... Our business was (precluding matters of theology and state affairs) to discourse and consider of Philosophical Enquiries, and such as related thereunto; as Physick, Anatomy, Geometry, Astronomy, Navigation, Staticks, Magneticks, Chymicks, Mechanicks, and Natural Experiments, with the state of these studies at home and abroad.[1]

As Wallis's summary amply indicates, the group, Baconian like, took all learning to be their province—theology only excepted—and interested themselves in both theoretical and practical knowledge. A lesser known, and much less formal group was equally Baconian in its aims, equally determined to assist a revolution in learning, and strongly influenced by the Czech educator Comenius, who tried to spread the idea of a universal reform in learning to be propagated by universal education and a universal language, all of which would ultimately lead to universal understanding, universal peace, and universal truth. The moving spirit of this group was Samuel Hartlib, its 'midwife and nurse' as one of its members called him.[2] This group had no formal organization; it met when possible and its members kept in touch with one another by letter, usually through Hartlib, who played much the same role for this group as Mersenne did for the French scientists. Hartlib always wished to formalize his society, and continually hoped and worked for Parliamentary support and aid in setting up a Philosophical College, half New Atlantis, half Comenian Christian Commonwealth. But events worked against him, and the college remained invisible. Hartlib shared his Comenian enthusiasms with John Dury, moderate divine, with John Pell

[1] Version of 1696/7, in *Works of Thomas Hearne* (London, 1810), vol. III, pp. 150–64.

[2] See G. H. Turnbull, *Hartlib, Dury and Comenius* (London, 1947); 'Samuel Hartlib's Influence on the Early History of the Royal Society', *Notes and Records of the Royal Society*, vol. X (1953), pp. 101–30; 'George Stirke, Philosopher by Fire' and 'Robert Child', *Transactions of the Colonial Society of Massachusetts* (forthcoming). That this group was independent of the group around Wallis was first suggested by R. H. Syfret in 'The Origins of the Royal Society', *Notes and Records*, vol. V (1948), pp. 75–137. To my mind, the evidence is all in favour of her theory.

the mathematician, later Cromwell's political agent to the protestant Swiss cantons, and with Theodore Haak. There was Benjamin Worsley, surgeon to Cromwell's Irish expedition, later surveyor-general of Ireland; after 1647 the brilliant young William Petty, Worsley's adversary in Ireland, who finally made the actual land survey; after 1650 Hartlib's son-in-law Frederick Clodius, the alchemist; Robert Child, Puritan, alchemist, agriculturist; George Starkey, Helmontian alchemist whose works were beloved by Newton; and numerous lesser inventors and agriculturists like Cressy Dymock, Plattes, and others, some of whom became nevertheless members of the Royal Society. But the most famous of the younger men was Robert Boyle, and it is the intellectual stimulus which he derived from this group, of which he was a part long before he was invited to join the Gresham College group, which makes it important. It is from his correspondence that we derive the name 'Invisible College', which clearly applies to Hartlib's scheme, rather than to the group Wallis describes, which with its rules and regulations was hardly invisible.[1] And it is because of his relationship with it that it deserves to be remembered and set apart from all the other seventeenth-century fantasies on the theme of Bacon's Salamons House.

In 1645 Robert Boyle was a very young man of nineteen, of bookish tastes, but otherwise unremarkable except as the youngest member of an enormously rich and influential family. Though his father, the great Earl of Cork, was now dead, the influence of that amazingly successful Elizabethan adventurer remained in England as in Ireland. Nothing except rebellion had been able to shake his control over the Irish estates and the fortune he had gained by unscrupulous skill and energy, and even rebellion and long years of civil war could not completely deprive his numerous family of their wealth and influence. Even more important, he bequeathed to most of them his brains

[1] Cf. Boyle's letters in Birch, *Life of Boyle*, pp. 66, 67, to his tutor and to Francis Tallents; cf. his letter to Hartlib of 8 May 1647, p. 67: 'You interest yourself so much in the *Invisible College*, and that whole society is so highly concerned in all the accidents of your life, that you can send me no intelligence that does not (at least relationally) assume the nature of *Utopian*.' This cannot refer to the Gresham group, but accords well with the projects discussed by Hartlib and John Hall; see Turnbull, 'John Hall's Letters to Samuel Hartlib', *Review of English Studies*, new series, vol. 4 (1953), pp. 221–3.

and his energy; as a contemporary remarked, 'Believe me, ould Corke could not begett nothing foolish',[1] and even more than most great families, the Boyles managed conspicuous success on both sides in the Civil War, without much danger of losing their wealth or their influence. His eldest son, having served bravely in the Irish rebellion, displayed his mild Royalism as little as possible, stayed in Ireland during the Civil Wars, and was rewarded for his policing of the Irish by being created Earl of Burlington at the Restoration. The second son, Baron Broghill, his youngest brother's great favourite, was a replica of his father. Talented in many directions, he had glittered in London society and had had his wedding celebrated by Suckling's 'Ballade upon a Wedding', had fought bravely against the Irish, written highly successful romances and plays. In 1645 he was still Royalist, but under skilful pressure from Cromwell, who recognized his military ability and his political importance, he served the Commonwealth first in the pacification of Ireland, then in Scotland, and finally in the new Cromwellian House of Lords. Cromwell dead, he remained loyal to Richard Cromwell, but as it became clear that a Restoration was likely, he offered his services to Charles II, took an active part in the details of the Restoration, and was rewarded by being made Earl of Orrery, and given important posts in Ireland. The third son, Viscount Shannon, was a pale and quiet copy of Broghill. The numerous daughters had almost all been firmly married off by their determined father to the sons of men of influence in Ireland; they were mostly Royalist, and some of them went into exile with the Court. Two, who made a considerable impression on their times, were firmly Puritan. The elder, Katherine, twelve years older than her youngest brother Robert, was disastrously married to Arthur Jones, later Viscount Ranelagh, of whom contemporary gossip could find no good to say at all. She lived apart from her husband in London, where

[1] The phrase was used by Sir John Leake about Lady Barrymore and Lady Ranelagh; see *Memoirs of the Verney Family* (London, 1892), vol. I, p. 206. The sources for the Boyle family are A. B. Grosart, ed. *Lismore Papers*, 2nd series, 1887–8; D. Townshend, *Life and Letters of the Great Earl of Cork* (London, 1904); Mary Warwick, *Autobiography*, ed. T. C. Croker (London, 1848); C. F. Smith, *Mary Rich, Countess of Warwick* (London, 1901); Thomas Morice, *A Collection of the State Letters of the Right Honourable Roger Boyle* (Dublin, 1743); D. Masson, *Life of Milton*, vol. III (London, 1873).

she moved in Parliamentary circles, and was a friend of Hartlib and Dury—and of Milton. Contemporaries spoke of her as 'incomparable' for her beauty, wit and piety,[1] and she exercised great influence on her two talented brothers, Broghill and Robert. She shared many interests with her much younger sister Mary, whose strong will rejected her father's domination and alone of her family made a love match. This was with a then obscure gentleman, Charles Rich; ironically, she was as unhappy with him as were any of her sisters with their unloved husbands, and equally ironically, the match was as successful from a worldly point of view as the Earl of Cork could have desired, for Charles Rich, though a younger son, eventually became Earl of Warwick in succession to his father, the Parliamentary Admiral. Mary shared her sister Katherine's Puritan interests; her autobiography and diary reveal a far less strong character and a much more despondent and gloomy piety than that of her sister. She also shared Katherine's affection for their youngest brother Robert.

In 1645, when Robert Boyle returned to England and his family after six years' absence, it was obvious that in his case the family vigour had been transmuted into the ardent practice of intellectual pursuits, but he did not otherwise apparently differ much in ability or inclinations from the intellectual brothers and sisters to whom he promptly showed himself devoted.[2] As a child he had seen little of them. He had been brought up mainly with his next older brother Francis, later Lord Shannon, about three years his elder. Their odd relationship (and Frank's remarkably sweet temper) is illustrated by the fact that, at least according to the boys' servant, Robert habitually lectured his elder brother on idleness, while surpassing him at learning and piety. This was at Eton, where Sir Henry Wotton's talents as scholar, gentleman, poet and diplomat were responsible for a movement on the part of the nobility to send their sons to him for education, rather than have them brought

[1] J. Crossley, 'Worthington's Diary and Correspondence', *Chetham Society Publications*, vol. 13 (1847), 30 January 1659/60.

[2] The best account is Boyle's autobiography, 'An Account of Philaretus during his Minority' printed by Birch in his *Life*; the original is in the Royal Society Boyle Papers, vol. 37; there is a copy in British Museum Add. MSS. 4228, made by Miles, who assembled all the material for Birch.

up by tutors at home. The Eton episode was not a success for the Boyle boys; their servant neglected them, took to wild ways, and tried to take Frank with him. Robert was spoiled by the masters. Being too young for the school at nine, he remembered that he had been allowed to read what he liked, and though naturally studious did not progress far in formal learning. After four years the boys were withdrawn from Eton, and tutored for a while in the country. At sixteen Frank was old enough for the Grand Tour, and Robert as usual went with him. They were under the care of a good Protestant citizen of Geneva, named Marcombes, who had been 'governour' to the older Boyle sons, and was to be tutor to Broghill's sons later.

The boys settled down rapidly in Geneva to begin the final process of being turned into scholars and gentlemen. Robert once more proved himself the more studious; the unlucky elder, who excelled in out-of-door exercise, was deprived of this by the stern commands of the old earl, who regarded all time away from study as idleness. Robert, on the completion of his education, was rather scornful of the scholarly pretensions of Marcombes, but his own account indicates that he received a much better education than most boys of the day. As Marcombes' letters to the Earl of Cork show (and they are confirmed by his pupils' recollections), they began by brushing up their Latin, and were then well grounded in logic. Rhetoric and logic bored them all, though Marcombes wrote 'I would I were as able to teach as Mr. Robert is able to conceive and to Learne.' They were all delighted when Marcombes decided that they were ready for 'Mathematickes and history, and specially... Geography'. Boyle described these lessons soon after his return to England, in his autobiography, the 'Account of Philaretus during his Minority', as follows:[1]

> After these slighter studies [logic, rhetoric] he fell to learn the mathematics, and in a few months grew very well acquainted with the most useful part of arithmetic, geometry, with its subordinates, the doctrine of the sphere, that of the globe, the fortification; in all which being instructed by a person, that had a greater regard for his scholar's proficiency, than the gains he might derive from the common tedious and dilatory way of teaching, he quickly grew so enamoured

[1] Letter of 25 March 1640, *Lismore Papers*, vol. IV, pp. 112–14.