PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Role of Analytical Chemistry in Academic and Industrial Chemistry [and Discussion]

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The role of analytical chemistry in academic and industrial chemistry

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It is a largely undisputed fact that analytical chemistry – or at least analysis – is of the most fundamental importance not only to all branches of chemistry but also to all the biological sciences, to engineering, and, more recently, medicine, public health, the environment and the supply of energy in all forms. Scientists and technologists need not only to establish the identity of materials but also to quantify their composition and purity and to measure contamination at even tens of nanograms per gram. Even the most abstruse academic researcher needs to be able to analyse his starting materials or products and frequently to measure minute changes in chemical composition in order to be able to draw his conclusions.

It is also a largely undisputed and rather curious fact that the United Kingdom, which pioneered the industrial revolution, has largely neglected the academic discipline of analytical chemistry and, even in industry, its position has been downgraded relative to the other main branches of chemistry. During the nineteenth century, academic analytical chemistry was not as widely established in Britain as elsewhere in the world. Furthermore, it suffered such a series of setbacks that by the beginning of the twentieth century it scarcely ranked as an academic discipline of chemistry. Some of the reasons for this astonishing state of affairs are reviewed and the present situation is assessed following the revival that occurred in the middle decades in a few of the universities of the U.K.

Academic analytical chemistry in the U.K. has always followed a completely different route from that in all other leading countries (Belcher 1980), and it is only in recent times that several Chairs of analytical chemistry have been created. Consequently, for several decades, the subject took a secondary place in advanced education, and research was very restricted. In Europe and America, such Chairs were founded over a century ago and the first in which analysis is mentioned was that of Plattner in 1842 at the famous Freiberg Academy in Saxony. His title was 'Professor of Mineralogy and Blowpipe Analysis'! The reason why analytical chemistry followed such a different route has engaged the attention of a number of chemists and various explanations have been advanced. Before we trace the development of academic analytical chemistry in this country, it is of interest to look at some of the suggestions that have been advanced to account for this neglect of the second oldest branch of chemistry.

Some consider that it was because England had only two universities until Durham and London were granted charters in 1832 and 1836 respectively. Later charters were not granted until the turn of the present century, although a number of advanced colleges existed. This suggestion hardly seems tenable when the course of events in Scotland is traced. Although England only had two Universities, Scotland, a much poorer country with a much smaller population, had at least five. The City of Aberdeen used to boast that between the sixteenth and early nineteenth centuries it had as many Universities as the whole of England. In the pioneering days of the last century and even earlier, Scottish universities made outstanding contributions to analytical chemistry, although there were no named Chairs in the subject.

One may mention Joseph Black at Glasgow and Edinburgh, Clark at Aberdeen, who developed the hardness test for water, and a series of brilliant Professors at the Andersonian University, Glasgow (later to become the Royal Technical College and eventually the University of Strathclyde): Ure, Penny and Dittmar. Yet today while England has four Chairs, Northern Ireland one and Wales one, no Scottish University has such a Chair.

FIGURE 1. Frederick Penny, 1816–99. Chemistry 1839–69.

FIGURE 2. Andrew Ure, 1778–1857. Chemistry and Natural Philosophy 1804–30.

Another suggestion, of which I seem to be the only advocate, is the unpopular one that the formation of a separate analytical society placed analytical chemistry in a separate compartment and tended to isolate it from other chemists. I have been reproved for holding this view, but I stand unrepentant; I do not think this was the main cause, but it certainly must have played a significant part (Belcher 1981; cf. Stephen 1972).

A third suggestion, advanced by D. Betteridge in a very carefully researched paper, published some twelve years ago (1969), suggests that chemists without analytical interests were appointed to the key positions in Britain and so, being responsible for policy, placed analytical chemistry far to the rear. He points out that if Liebig had taken the Chair at Kings College, or Fresenius that at the Royal College of Science, events might have taken a different course. This again must have played a significant part, but some further facts have come to light since that article was published and a great deal more investigation is needed of the extensive documents that we now know exist.

When we look at the pioneering contributions that were made in Britain, it is quite clear that they compare favourably with those made in any other country. Our first great analytical chemist was Robert Boyle, the 'father of chemistry' (Szabadvary 1966). A major part of his work was concerned with analytical chemistry and it was he who first used the term Chemical Analysis.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

In table 1 are listed a number of famous British spectroscopists dating from the eighteenth century to the beginning of the present one. In table 2 are listed some selected examples of early British general contributions.

My generation and the succeeding one believed that the first Chair in Britain containing the term 'Analytical Chemistry' was that of R. M. Caven at the Royal Technical College, Glasgow (Belcher 1979). My good friend Professor D. T. Burns considers that this was not so and that Emerson Reynolds of Dublin held the title first, i.e. Professor of Analytical Chemistry, during

Table 1. Nineteenth-century British spectroscopists

W. H. Wollaston	1766–1828	J. W. Draper†	1811–1882
T. Young	1773–1829	W. A. Miller	1817–1870
D. Brewster	1781–1868	W. Swann	1818–1894
J. F. W. Herschel	1792–1821	G. G. Stokes	1819–1903
W. H. F. Talbot	1800–1887	J. N. Lockyer	1836–1920
W. H. Miller	1801–1892	W. N. Hartley	1843–1913
C. Wheatstone	1802–1875		

† Although Draper's most significant work was done in the U.S., he was born in Lancashire.

Table 2. Some British contributions to analytical chemistry up to the mid-nineteenth century

1631	Jordan referred to acid–base indicators	1800	Cruikshank used electrolysis to detect copper
1660	Witty made similar observations	1803	Black observed effect of CO_2 on titrations, noted indicator error and developed back-titration
1660–1691	Boyle developed hydrogen sulphide as a reagent, used acid–base indicators, studied precipitation, determined the sensitivity of a test and contributed to gas analysis	1813	Ure proposed 'normal' solutions
		1814	Wollaston's logarithmic tables
1756	Home used the first truly volumetric method	1816	Wollaston's 'analytical' slide rule
		1835	Reid: micro-scale teaching
1767	Lewis used an acid–base indicator in titration, a primary standard and a weight-burette	1836	Marsh: test for arsenic
		1841	Clark: hardness of water
		1850	Penny: dichromate titration
1784	Kirwan used $K_4Fe(CN)_6$ as a standard solution for the determination of iron	1852	Andrews: microchemical methods
		1852	Herepath: colorimetric method for iron

the 1870s. However, this title was conferred by the Royal Dublin Society and not by a University. Reynolds had no undergraduate students nor a research school. Our arguments on this matter can be found elsewhere (Burns 1979). Both of us are wrong in the light of recently discovered facts; Caven was not even the first to hold the Chair of Inorganic and Analytical Chemistry at the Royal Technical College (Nuttall 1980). In 1919 the College created this Chair and one in organic chemistry. Two members of staff, Forsyth J. Wilson and Ian Heilbron, were appointed to these two Chairs respectively. However, a few months later, Heilbron resigned and Wilson asked to be transferred to Heilbron's Chair. Caven was appointed in the following year (1920).

Some 30 years ago the Royal Institute of Chemistry published a series of articles, in its now defunct journal, on Schools of Chemistry in Britain and Ireland. It is interesting to note that, in the article on the Royal Technical College, Glasgow, it merely states that Wilson was appointed to the Chair of Inorganic Chemistry and that later Caven was appointed to the vacant Chair of Inorganic Chemistry. The word 'analytical' is not mentioned. A photograph of Caven in the same article describes him as Professor of Inorganic and Physical Chemistry. This is remarkable because these were the first Chairs involving analytical chemistry created in this century; moreover, it was the only time that Scotland ever had such Chairs. This is not the only example in these historical accounts where analytical chemistry is overlooked; any student of history depending on these accounts for information can be misled, as indeed some of us have been.

British chemists will be astonished to learn that the very first Chair in the world in which analytical chemistry is involved (Plattner's simply includes the term 'Blowpipe Analysis') was created in an English University in the year 1845 (Bellot 1929). The title of this Chair, founded at University College, London, was the 'Chair of Analytical and Practical Chemistry'. G. Fownes held the Chair for two years when he died. It lay vacant for two more years and then A. W. Williamson was appointed. He held it under that name for another six years, but after that it was combined with the other Chair, which Williamson held until 1877. It has not been possible to establish whether the term 'analytical chemistry' survived until that time.

This foundation preceded even that of C. F. Chandler (1859), the founder of the American Chemical Society, although Chandler was the first to hold a Chair of Analytical Chemistry without any combination (Belcher 1980). Norman Collie (1927) has remarked that Fownes 'was not a chemist of great importance', so it can be assumed that he made no significant contributions. And yet the situation had been most favourable. Edward Turner, the first Professor of Chemistry at University College, had developed a number of widely adopted analytical methods in the course of his atomic mass determinations. Williamson's interest apparently lay outside analytical chemistry and, although he made some notable contributions, none was in the field of analytical chemistry.

At Kings College, London, when Professor Daniell died in 1845, the Chair was offered to Liebig, who accepted. Although Liebig was not an analytical chemist, he had great appreciation of its possibilities and the principle of his method for determining carbon and hydrogen is still in use. As it happened, his appointment was blocked by the Archbishop of Canterbury and the Bishop of London because he was a Lutheran! However, all was not lost: W. A. Miller was appointed Professor of Chemistry. He immediately instituted new courses in analytical chemistry and in 1851 a Chair of Practical Chemistry (Davies 1981). It was unfortunate that this was not termed Analytical Chemistry, for this was the title and main subject of the courses that were held, or even, as at University College, 'Analytical and Practical Chemistry'.

The first to hold the Chair was J. E. Bowman, said to be a brilliant experimentalist. Unfortunately he died in his early thirties and the Chair became vacant in 1855. In 1856 C. L. Bloxam was appointed to the Chair and he was to make several notable contributions to analytical chemistry during his tenure. Presumably, he had to undertake the experimental work himself because there were no research students, although he might have had some assistants. Bloxam held this Chair for 25 years. In 1875 Professor Miller died and Professor Bloxam submitted a report proposing that the two Chairs be combined as this would enable the administrative tasks of the Department to be rationalized. This was accepted and so the Chair of Practical Chemistry disappeared.

During that period Cambridge almost had a Chair of Analytical Chemistry (Roberts 1980). In 1870, Professor Liveing, because of the great expansion of classes, asked for two new Professors, one to take charge of analytical chemistry. He was granted instead an assistant and two

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

demonstrators. One might say that things have not changed, but indeed they have: nowadays one would not even get a demonstrator!

When one studies history as I do, one is often struck by the fact that Providence is sometimes determined that certain events shall take place, regardless of the impossible odds against and the insurmountable barriers to be overcome. Examples of such events are the conquest of the mighty Aztec Empire by Cortez and of the even mightier Empire of the Incas by Pizarro. Further examples are the conquest of England by William of Normandy, an event that should never have taken place but for the wiles of Providence, and the defeat of Napoleon at Waterloo: by all the laws of military strategy and tactics he should have won that campaign. So Providence seemed to treat academic analytical chemistry.

FIGURE 3. C. L. Bloxam, 1831–87.
Practical Chemistry 1856–81.

When the beginnings of academic analytical chemistry in Britain are examined it becomes clear that the situation was far more favourable than was once believed and that, if events had followed a logical course, British analytical chemistry would have run parallel to that in other countries. As it turned out there was to be virtually only one Chair in the early twentieth century (that of R. M. Caven), which lasted for 14 years, after which a quarter of a century was to pass before a similar appointment was made.

Bad luck seemed to dog the evolution of academic analytical chemistry from the beginning. Fownes was obviously unsuitable, but in any case died after two years. It would appear that Williamson only accepted the Chair to get a foothold in University College and thenceforth did nothing for analytical chemistry. At Kings College the influence of the great Liebig would

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

undoubtedly have had far-reaching effects, but this was defeated by religious bigotry. Nevertheless, a second great chance was created by Miller's foresight. Unfortunately, the new Chair he created, which to all intents and purposes was in analytical chemistry, was simply called Practical Chemistry. Bloxam filled the Chair with distinction and made substantial contributions. Possibly, in the course of time, the Chair would have been properly named. However, Bloxam himself delivered the death-blow in 1875 by eliminating the Chair completely. Cambridge did its best, but was defeated, either by shortage of funds or by sheer parsimony. If analytical chemistry had thrived at these three great centres, then it would surely have developed in other universities and followed the general pattern to be found abroad.

During World War I and later, repeated requests were made for the creation of Chairs of Analytical Chemistry, but this opportunity to compensate for past neglect went unheeded. Consequently, the golden age of analytical chemistry, the decade 1920–1930, was devoid of British contribution. During this time, inorganic and organic microanalysis came into full flower, oxine, ceric sulphate, redox indicators, the sodium reagent and the polarograph were discovered. However, British contributions were not completely negligible: two industrious young men at Imperial College, A. D. Mitchell & A. M. Ward (1932), collected all the new contributions in a small book that became widely used.

Many of the facts presented above have only come to light during the last few weeks in the course of preparing this address. During the search it was discovered that there is a vast number of documents connected with this theme that await investigation.

Academic analytical chemistry has suffered extensively owing to this neglect. Because it has not been a readily recognized academic subject it has naturally taken a back seat. There were (and are) many brilliant and dedicated young men in the universities whose main interest lay in analytical chemistry and for whom there was little incentive. As promotional prospects were poor, many emigrated and now hold Chairs or equivalent positions abroad. No analytical chemist has ever been appointed as a Professor of Chemistry and, when analytical chemists or analytical chemistry have to be assessed for any purpose, it is usually done by a panel of non-analytical chemists. One could imagine the uproar if the reverse held.

A few years ago the shortage of analytical chemists caused some alarm and three independent bodies simultaneously began to look into the problem: the Royal Society, The Royal Institute of Chemistry and the Science Research Council (S.R.C.). At some stage the first two bodies decided to leave the investigation in the hands of the S.R.C., which has recently presented a report; the Council of The Analytical Division of the Royal Society of Chemistry (A.D./R.S.C.) has set up a Committee to assess it. The S.R.C. has been very generous to me throughout my career so it is with some reluctance I have to say that this report has some shortcomings, but I will say no more as the matter is still *sub judice*.

There is little doubt that the teaching of analytical chemistry will expand in the future; hence a note of warning must be added. The tendency may be to teach the use of as many instruments as possible, resulting in the production of push-button analysts. I hope that the philosophy that persisted for decades abroad and which has always been my own philosophy will endure: that is to use analytical chemistry as a means of teaching chemistry. The highly sophisticated reactions of analytical chemistry lend themselves readily to teaching general chemistry, and the relevance of so many theories of physical chemistry can be appreciated for the first time. While a certain amount of instrumentation must be judiciously blended with classical methods, heavy instrumentation is better left to postgraduate courses.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

One of the victims of extensive instrumental teaching has been qualitative analysis, the elimination of which accounts for the ignorance of modern graduates about chemical reactions. Others have made similar observations: the late R. G. W. Norrish, formerly Professor of Physical Chemistry at Cambridge, in the last interview he had before his death, deplored the passing of the subject because of its valuable training. More recently, S. Greenfield, probably the foremost industrial analytical chemist in the U.K., in an address (1979) delivered to the Education and Training Group of the A.D./R.S.C. considered that this subject, together with classical quantitative analysis, should be an essential part of the undergraduate course.

Table 3. Relative order of importance of subject area

(From *Education, training and research in analytical chemistry in universities and polytechnics* (1979))

	theory	practical	average
		(score (%))	
titrimetry	92	89	90.5
gravimetry	85	82	83.5
ultraviolet–visible spectrophotometry	81	86	83.5
atomic spectroscopy	82	78	80
gas chromatography	82	76	79
high-pressure liquid chromatography	74	68	71
solvent extraction	74	68	71
statistical methods	67	67	67
organic analysis	66	62	64
X-ray methods	67	57	62
automation	65	57	61
distillation methods	62	58	60
thin-layer and paper chromatography	57	58	57.5
ion-exchange chromatography	58	53	55.5
infrared and laser Raman spectrophotometry	58	52	55
mass spectrometry	58	44	51
electrochemical methods	49	51	50
fluorescence and phosphorescence	49	47	48
electrophoresis	52	40	46
polarimetry	41	43	42
nuclear magnetic resonance spectroscopy	46	32	39
thermal methods	39	35	37
radiochemical methods	34	26	30
electron-spin resonance spectroscopy	22	20	21

Indeed, many teachers do mourn the passing of this subject, but they appear to be shedding crocodile tears, for nothing is done about it. The reason is not far to seek: to teach qualitative analysis properly requires a vast knowledge of chemical reactions and those endowed with this knowledge become fewer each year.

In general, new ideas emanate from the universities, and industry develops these ideas. There are of course exceptions, but this is the general pattern. British industry, apart from one or two rare exceptions, has never been slow to accept new ideas and this accounts for the fact that all leading British laboratories are as well equipped as finance permits. Instrumentation has advanced at a remarkable rate, mainly because of its value in routine analysis. However, it is of interest to refer to a survey carried out by the Education and Training Group of the A.D./R.S.C. some four years ago. All branches of industry were circulated and asked to arrange subjects (23 were chosen) in order of importance in the training of analytical chemists. The results were startling: titrimetric analysis closely followed by gravimetric analysis came top and subjects such as atomic spectroscopy and gas liquid chromatography, which might have been expected to top the list, were only in fourth and fifth places. Table 3 shows the complete results of this survey.

A good picture of the part played by analytical chemistry in industry can be obtained from the address of Greenfield (1979) and the paper by Selby (1978). Greenfield deals with solving problems in the heavy chemical industry by means of analytical chemistry and the methods of approach used. In this, he shows clearly the necessity of having an armoury of techniques available, ranging from classical to the most sophisticated instrumental methods (e.g. plasma techniques). Selby describes similar applications in the pharmacentical industry. This paper is illuminating and impressive; it is presented in an original way in that it details the analytical work essential at every stage in the development of a particular pharmaceutical. He states that analytical chemistry occupies a central, problem-solving role in the successful development of pharmaceuticals. Several techniques were used, both instrumental and classical. Among the major factors that he considers essential in applying analytical chemistry, one is particularly thought-provoking: 'First class human resources in the form of analytical chemists possessing the characteristics of scientific enterprise, skill and excellence; the problems illustrated above were not solved by instruments, but by people and the success that was achieved was due to their intellectual, manual and observational skills.'

These observations can well be borne in mind in designing postgraduate courses. Many years ago, before the M.Sc. course in analytical chemistry at Birmingham University was started, I wrote to many colleagues in industry asking them to provide examples of problems that had been solved by analytical chemistry. Of course, not everything could be revealed because of company policy, but I received a very good range of such examples. These provided some very useful oral exercises with known answers, but these could readily be expanded into projects. None of the examples received were of the same extensive nature as that described by Selby, but were more suitable for short range investigation. I believe that a project of this kind might be a useful alternative to the more conventional investigation.

Finally, I would say that in any basic undergraduate course in analytical chemistry some time should be left for the teaching of any special technique being investigated in the particular department. (If there were no research in progress, then some special interest of the staff could be incorporated.) Undergraduates are always aware of research proceeding in their own department and it is undoubtedly stimulating for them to feel that in some way they are being associated with that research and learning the latest developments at first hand.

My grateful thanks are due to the following who went to great trouble to unearth information for me: Professor M. L. McGlashan, Dr Alwyn Davies, Dr A. Legon and other staff of University College; Dr D. I. Davies of Kings College, London; Dr R. H. Nuttall and Mr J. McGrath, University of Strathclyde; Professor D. T. Burns, Queen's University, Belfast; Dr A. Townshend, University of Hull.

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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
THE ROYAL SOCIETY A
PHILOSOPHICAL TRANSACTIONS OF

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Discussion

D. T. Burns (*Department of Chemistry, The Queen's University of Belfast, U.K.*). Has Professor Belcher considered the sociological and historical implications of the separation of British science and technology since times before Robert Boyle? These may be relevant to the slow rate of acceptance of analytical chemistry as a university discipline in Britain. Boyle's early attempts at quantitative chemistry paved the way for modern or quantitative chemistry and predate those of Lavoisier, who is commonly credited with this achievement. Quantitative methods were fundamental to the arts of assaying metals, which go back to pre-Biblical days; however, these arts were largely in the hands of artisans and outside the development of chemical theory, as was most of early technical or applied chemistry. Boyle was particularly interested in technical processes and was aware of the details of conducting fire assays, quartation, acid parting, etc. The efficacy or otherwise of fire as an analysing agent was fundamental to the theoretical discussions in *The sceptical chymist* and other works. It may be of interest to note that the first book in English to discuss the theory as well as the art of assaying was by Cramer in 1741.

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Cramer, J. A. 1741 *Elements of the Art of Assaying Metals. In two parts. The first containing THE THEORY, the second THE PRACTICE of the said art...* London: T. Woodward & C. Davis.

R. Belcher. No. Although I am aware of the separation, I have not studied it in depth.

J. D. R. Thomas (*Chemistry Department, U.W.I.S.T., Cardiff, U.K.*). After Professor Belcher's superb summary of the development of analytical chemistry in the U.K., it is worth noting that the 1956 Government White Paper on Technical Education was a significant backcloth to the growth of analytical chemistry in universities in Britain during the 1960s and 1970s. Most of the Colleges of Advanced Technology (C.A.Ts), formed in England and Wales as a consequence of the White Paper quickly developed schools of analytical chemistry.

The ten former C.A.Ts are now among Britain's technological universities. The strong schools relating to analytical chemistry now existing at many of these, namely at the Universities of Loughborough, Salford and Surrey, and at U.W.I.S.T. (University of Wales), and Professor Belcher's link with the University of Aston, together represent a good proportion of the analytical chemistry research and teaching in British universities.

Finally, the existence in the university sector of U.M.I.S.T. (University of Manchester) and the University of Strathclyde can be contexted with the philosophy (modified by the Robbins Report of 1963) of the 1956 White Paper.

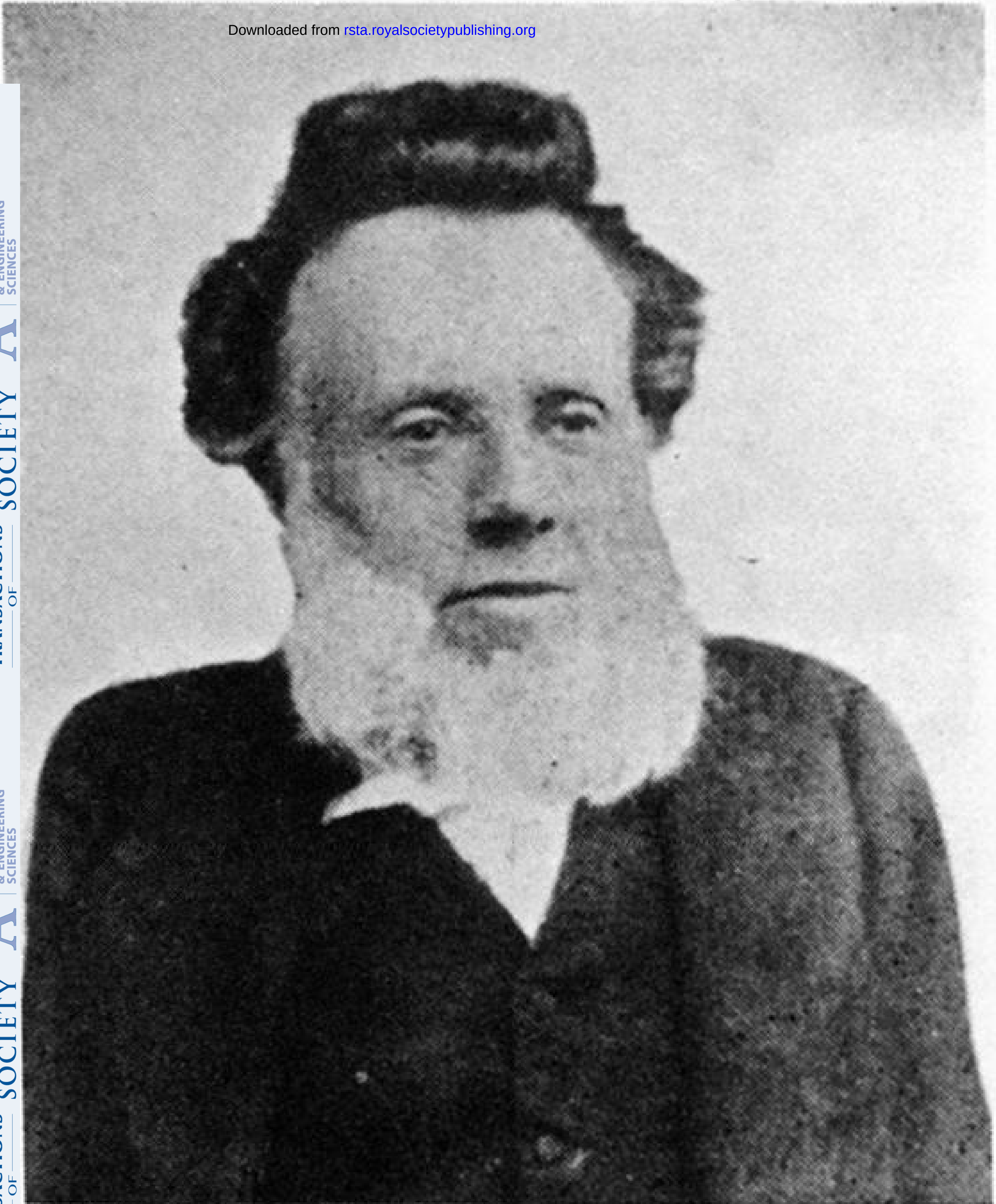

FIGURE 1. Frederick Penny, 1816–99.
Chemistry 1839–69.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

FIGURE 2. Andrew Ure, 1778–1857.
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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Figure 3. C. L. Bloxam, 1831–87.
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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES