

OBITUARY NOTICES.

HENRY EDWARD ARMSTRONG.

1848—1937.

HENRY EDWARD ARMSTRONG died on July 13th, 1937, in his ninetieth year. By his death British chemical science lost its most outstanding personality, one who by his vigorous mind, independent outlook and rare gift of expression both in speech and in writing had a profound influence on the development of chemistry during two generations. In his prime he was probably the most constant attendant, the most frequent and vigorous speaker, at the meetings of the Chemical Society. Like many men of quick brain, he was often impatient, not suffering fools gladly but criticising freely; a thorn in the flesh to many, but generous in his appreciation of good work. Unorthodox and critical, he would never bow the knee to authority, however eminent, if his reason went against the popular view. Consequently his life was full of controversy, which he thoroughly enjoyed. Few men have lived a fuller life than he, or retained a mind as unclouded as his was to the end of nearly ninety years.

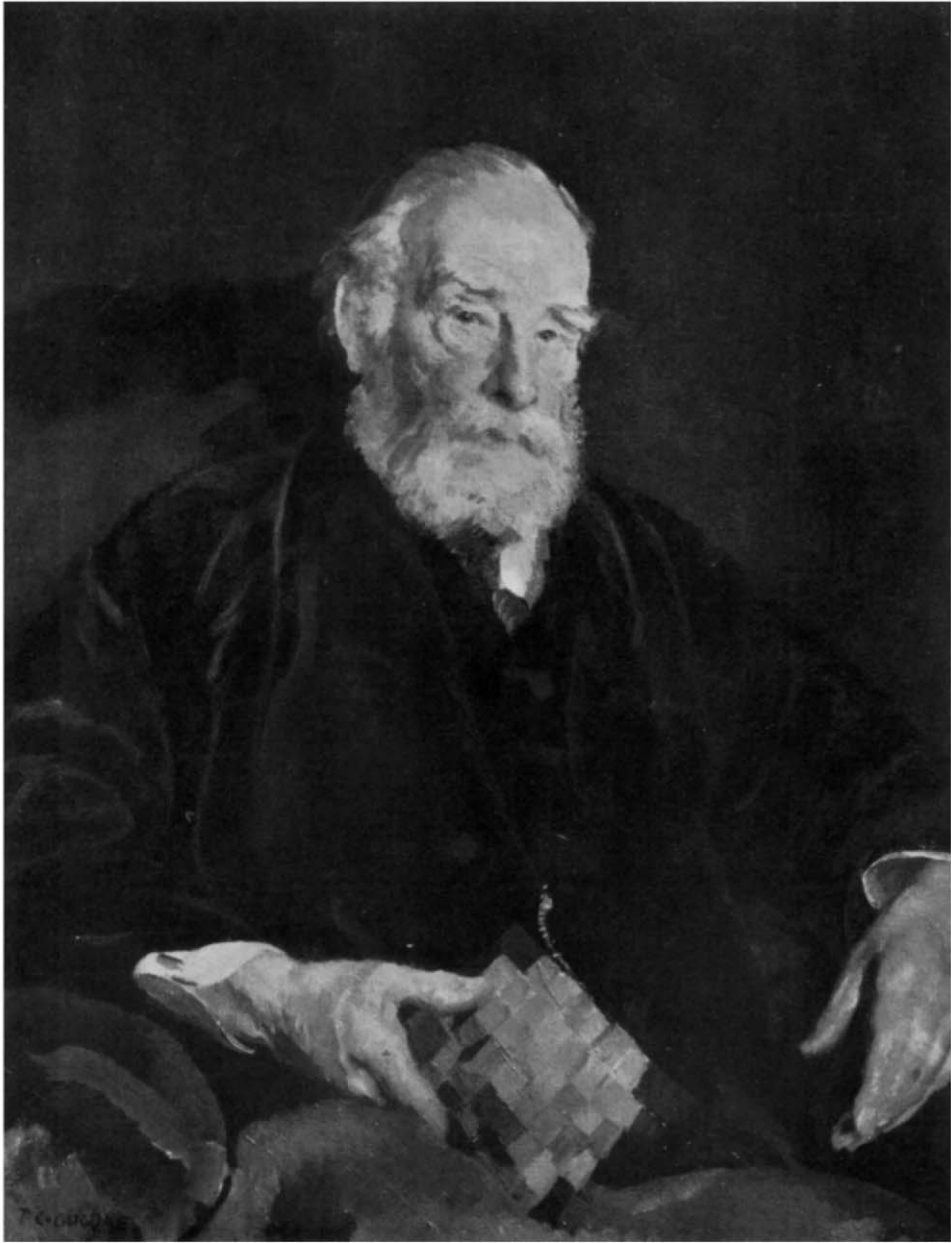
Armstrong's services to the Chemical Society were unique. He was secretary for eighteen years from 1875 to 1893, and during that period he appears to have ruled the Society with a rod of iron. From 1893—1895 he was President, following Crum Brown, and from then until his death, with two short breaks, was Vice-President. He first served on the Council in 1873, when he was but 25 years old, and from that date until his death was a member of Council almost continuously.

Armstrong was born on May 6th, 1848, at Avenue Road, Lewisham, and lived in Lewisham all his life. A year before his death, feeling that the end was near, he wrote a short autobiography, reproduced in the issue of "The Central" * of June, 1938, from which some of the following particulars are taken. His father, Richard Armstrong, was a commission agent and importer of Mark Lane, a man of kindly disposition, amiable almost to excess. His paternal grandfather, another Richard Armstrong, one time Governor of the Convict Prison of Gibraltar, was a man of most irascible disposition, with a strong objection to tobacco. Henry Edward, who also hated tobacco smoke, inherited some of his grandfather's characteristics.

Of his early years Armstrong had little recollection, he says, but his mind retained a picture of the country-side in which he played as a boy, of rivers, chalk pits and ponds and the beginnings of an interest in entomology and geology which stayed with him throughout his life. After attending small schools, he passed to the Colfe Grammar School, Dartmouth Hill, and his school career finished when he left there in 1864 at the age of sixteen, conscious, as he says, of no particular interest, but observant and an experimentalist. A book which he discovered at school had a permanent influence on his mind. This was Trench's "Theory of Words," which held him fascinated, and made him critical of meanings. This confession is illuminating to those who knew him in later years as a connoisseur of language and the stern critic of those who dared to misuse it. He was once criticised publicly for splitting an infinitive in a letter to the "Times," and he never forgot it. He was always ready to learn.

At the time of leaving school Armstrong was supposed to be delicate, and he spent the following winter at Gibraltar with his uncle; it was here that he saw the first British steam-driven iron-clad, the "Warrior." On his return in the spring of 1865 to London he entered, for no apparent reason, at the Royal College of Chemistry in Oxford Street, and so "just slid into chemistry." He was just in time to attend the College whilst A. W. Hofmann was still there; almost at once Hofmann left for Berlin, and Edward Frankland succeeded him. Chemical training in those days was not lengthy. Perkin, as is well known, left the Royal College of Chemistry at 19 to become a dyestuff manufacturer;

* The Journal of the Old Students of the City and Guilds (Engineering) College, formerly the Central Technical College.



PROFESSOR H. E. ARMSTRONG, Ph.D., LL.D., F.R.S.
President 1893—1895.

(From a portrait by T. C. Dugdale, R.A.)

[To face p. 1418.]

Horace Brown, Armstrong's most intimate friend, left at 17½ after six months training to become a famous brewing chemist; and Armstrong himself, after a year and a term, was picked by Frankland to assist him in research. He would then have been just 18 years of age.

This first research with Frankland was one in which he, in after years, always took great pride. Frankland had been appointed one of three members of a Royal Commission directed to inquire into the pollution of rivers and the domestic water supply of Great Britain. Armstrong's task was to devise methods for determining the organic impurity in sewage and of sewage matter in drinking waters. Frankland gave his assistant the minimum amount of instructions and as a result Armstrong acquired confidence as an independent worker. The method they devised for water analysis by combustion in a vacuum was used by Frankland between 1868 and 1872 for surveying the whole British water supply, and as a result of his work typhoid fever became a preventable disease, and this country soon led the world in the provision of safe domestic water.

Armstrong had a great admiration for Frankland, and in his Frankland Memorial Oration to the Lancastrian Frankland Society, delivered in 1934, has left us an intimate study of his career and of those with whom he was associated. Frankland had, as is well known, worked with Kolbe in Marburg; it was, in fact, at Marburg in Bunsen's laboratory that he discovered the zinc alkyls, which were of great importance in the development of his ideas of valency. Nothing was more natural, therefore, than that Frankland should recommend young Armstrong to go and study under Kolbe, then Professor of Chemistry at Leipzig. To Leipzig Armstrong went in October, 1867, staying there for five happy semesters. Here he had his introduction to aromatic chemistry; he had not even heard of Kekulé's benzene formula when he arrived. Kolbe introduced him to sulphonic acids, a class of compound for which he acquired a life-long affection. Kolbe must have been cast in a mould similar to Armstrong's own, or perhaps the pupil copied the master, for in later years Armstrong wrote of Kolbe the following words which might apply equally to himself: ". . . a chemist who received but scant justice from his own countrymen . . . because he dared to criticise and expressed himself in the biting terms of a clear and concise diction, in a pure German which no one else in those days had at his command; in fact, he took his countrymen greatly to task for their slovenly language." It was characteristic of Armstrong's industry that, on arriving in Germany, he should at once begin to accumulate books—a set of the *Annalen*, from which he translated many papers in order to master the language and learn to read *with attention* (his own words), and copies of Goethe, Schiller, and Lessing.

His degree of Ph.D. was gained in 1869 for a thesis, the gist of which was published in the *Proceedings* of the Royal Society (1870, 18, 502) under the title "Contributions to the history of the acids of the sulphur series, I. On the action of sulphuric anhydride on several chlorine and sulphur compounds," communicated to the Society by Frankland. In this early paper his characteristic way of challenging authority shows up. Referring to a statement in the literature that carbon disulphide and sulphuric anhydride are without action on one another, he says: "Notwithstanding this, I thought it advisable to repeat the experiment, and have by so doing found a reaction take place exactly in the sense I had expected." He found, in fact, that carbonyl sulphide was formed according to the equation $CS_2 + SO_3 = COS + SO_2 + S$. He also discovered the formation of pyrosulphuryl chloride by the action of sulphuric anhydride on carbon tetrachloride: $CCl_4 + 2SO_3 = COCl_2 + S_2O_5Cl_2$.

On returning to London, Armstrong obtained a post at the Medical School of St. Bartholomew's Hospital, under Dr. Matthiessen, taking charge of special classes in chemistry for students proceeding to the London degree; here he worked with Matthiessen on alkaloids until the latter died in October, 1870. His association with the medical students continued for about twelve years. Another post came to him in 1871 when he was appointed Professor of Chemistry at the London Institution, Finsbury Circus. His duties were to instruct students in analytical chemistry and the methods of original investigation, from 6—8 p.m. If the duties were light, so was the professional salary, £50 a year, without any laboratory allowance. But he had a private laboratory, though it was little more

than a coal-hole, so close to the lecture theatre that the disagreeable odours from his investigations of the higher-boiling constituents of coal tar were a source of considerable discomfort to the audience in the theatre. Writing of this period, Armstrong has said: "As the fees derived from the London University classes were small—never equal to my professional pay—to supplement my income I did sundry odd jobs, including examination work, but never strove to be a consultant. I thus led an erratic but varied and happy existence and had many opportunities of gaining experience beyond those of an assistant in any of the big laboratories of to-day. Living under such conditions, a critic from my youth, I could not but grow up a free-lance and an iconoclast—even a thorn in the side of my superior colleagues when I ventured to differ. It was an age of discussion—we were not fully persuaded even to believe in atoms." How many men, however, under such conditions, would have developed into the force Armstrong became? It was his enquiring mind and unquenchable energy which carried him forward. A former Professor at the London Institution had been Grove, the inventor of the unpolarisable Grove cell. Some of his apparatus still remained in the laboratory. Armstrong studied this apparatus, bought at an auction some copies of the Royal Society's *Transactions* containing Grove's memoirs, and from reading them became electrolytically minded. This circumstance influenced Armstrong's views on chemical change throughout his life. He also extended his reading and his income at this time by becoming, in 1871, an abstractor for the Chemical Society under Henry Watts.

The seventies were for Armstrong comparatively uneventful years; he was preparing for his life's work, learning what was required of a teacher and of a student; feeling his way in research; filling his retentive mind with facts; learning to write and to manage men. During this period he wrote an "Introduction to Organic Chemistry," published in 1874. This task, he says, put system into his soul but not much money into his purse. He also wrote the inorganic section on "Chemistry" for the ninth edition of the "Encyclopædia Britannica," published in 1876, and was probably the first to base an account of inorganic chemistry on Mendeléeff's generalisation. With C. E. Groves he produced a new edition of Miller's "Organic Chemistry," published in 1880, almost entirely rewritten. These undertakings, and his habit of reading current chemical literature as soon as it appeared, gave him that wide knowledge which he so often and so aptly displayed in discussions at scientific meetings. It is remarkable, and worthy of serious consideration, that Armstrong himself considered that the development of his critical faculty was notably influenced by his experience of law cases. In 1879 he took part in the action for infringement of Kolbe's salicylic acid patent brought by von Heyden against Neustadt, and he describes this experience as the coping stone of his education in scientific method. "The display of judicial method, the stringent examination and cross-examination of every particular, came to me as the acme of scientific treatment; I realised how far short we were from it in our ordinary treatment of our problems; it made me the unpleasant critic I have since been."

Armstrong's life work started when, in October, 1879, at the age of 31 he was appointed by the City and Guilds of London Institute for the Advancement of Technical Education, along with W. E. Ayrton, to organise classes in chemistry and physics in temporary premises in Cowper St., Finsbury. It must be realised that technical education, or the teaching of science with special reference to its practical applications, was at that time almost non-existent in this country, although, since the great Exhibition of 1851, the urgent need for this type of education had been realised. A definite decision was taken by the City Livery Companies of London in 1876 at a meeting at the Mansion House to devote their attention to the promotion of education throughout the country, and especially technical education. The City and Guilds of London Institute was established in 1878 and incorporated in 1880. The appointment of Armstrong and Ayrton in 1879 was for the purpose of carrying out one of the objects of the Institute, the establishment of local schools for artisans and workmen, but the success of their classes soon made it evident that a specially adapted building would be required for their development, in addition to the intended Central Institution for advanced education. Out of this need arose Finsbury Technical College, the first institution of the kind in London, the foundation stone of which was laid in May, 1881. The Central

Institution, later known as the Central Technical College, was, however, the principal objective which the City and Guilds of London Institute had in view, and they utilised the services of Armstrong and Ayrton to the full in drawing up their plans for this College. It had been recognised that when these two men were appointed at Cowper Street they were in charge of an experiment, to ascertain by trial how their subjects could most usefully be taught. It is from this time that Armstrong's great interest in the technique of education is to be dated, an interest that never wavered during the rest of his life. During the autumn of 1881 he went with Ayrton on a tour in Germany to study there the equipment of the chemical and physical laboratories, at the expense of the City and Guilds of London Institute. When the Central Institution in Exhibition Road, South Kensington, was eventually opened in 1884 by the Prince of Wales, Armstrong went there as Professor of Chemistry. After some hesitation Ayrton accepted the chair of Physics, the other two Professors being W. C. Unwin (Engineering) and O. Henrici (Mathematics). The physics appointment was offered to Oliver Lodge; had he accepted, the course of scientific research at the Central might have run on different lines, for Armstrong has put it on record that he and Lodge had many interests in common. Armstrong held his post at the Central until his compulsory retirement when the College became part of the Imperial College of Science and Technology in 1911 and the Chemical Department was closed. The final dispersion of his students took place in 1914. Thereafter he became in fact what he had always been at heart, a free-lance; a critic and commentator on affairs and the genial mentor with whom chemists of this generation were so familiar. The loss of his chemistry school and of the opportunity for directly inspiring experimental work was a blow to him. He did not let it depress him, but carried on courageously for nearly a quarter of a century of active mental life.

Armstrong's work falls naturally under three headings, chemical research, education, and activities which may be classed under the general term "affairs." He was a man who had to have a finger in many pies. This trait must have revealed itself at an early date, for, when he was appointed to the Central, W. A. Tilden, writing to congratulate him, advised him to "concentrate on this work and not try to keep so many things going at once. There is plenty of room for a school of chemistry, and here is your opportunity; but it will take some doing." The advice was utterly wasted, and "affairs" always loomed large in his life; but it must be added that they generally had a close connection with either chemistry or education. This notice must concentrate more particularly on Armstrong's contributions to chemistry through his researches.

Naphthalene Research.

Armstrong's most substantial contribution to chemistry was the study which he initiated of the laws of substitution in the hydrocarbon naphthalene. He published an isolated paper in 1874 dealing with naphthyl sulphides, but the real start of the work is found in a paper published, partly with Graham, in 1881 (J., 1881, **39**, 138). From this time until 1900 the work was continued, being described in some sixty papers, mostly very brief, appearing in the *Proceedings* of the Chemical Society. When the work started, naphthalene was very much "in the air." The chemists of the dyestuff firms, particularly in Germany, were just beginning to discover the potentialities of naphthalene derivatives for manufacturing azo-dyes. The two β -naphtholdisulphonic acids known as G and R were first used in 1878 for making respectively yellow (Gelb) and red (Rot) dyes by coupling with diazotised aniline and *m*-xylydine; Read Holliday and Sons in Huddersfield discovered Para Red (from diazotised *p*-nitroaniline and β -naphthol) in 1880; Congo Red, from tetrazotised benzidine and naphthionic acid, was discovered by Böttiger in 1884. A large number of amines and phenolic compounds and their sulphonic acids were being prepared from naphthalene by empirical methods, but their orientation was unknown and the elucidation of their structure was a matter of great difficulty. The researches of Armstrong and his collaborators contributed in a very large degree, more, it is safe to say, than those of any other group of workers, to the establishment of naphthalene chemistry on a sure basis, and were of inestimable value to dyestuff technologists. Among the collaborators were Amphlett, Davis, Graham, Houlding, Heller, Jenks, Rossiter, Lapworth, Percival, Shelton, Sindall, Streatfeild, Williamson, and, most important of all, W. P. Wynne, whose

skill and determination over a period of many years carried the work forward. It seems highly probable that the choice of this subject for his major research may have been made by Armstrong in part at least on account of its technical importance, for at the time of its commencement he was profoundly occupied with the development of schemes for the technical education of young men for industry, and in his view research must always have an important rôle in such schemes.

Armstrong's attention was first drawn to the problem of the constitution of the naphthalenedisulphonic acids when writing an article on naphthalene for a supplement to Watts's "Dictionary of Chemistry" in 1879. Ebert and Merz had shown (*Ber.*, 1876, 9, 592 *) that by the action of excess of concentrated sulphuric acid on naphthalene at 160—180° two isomeric disulphonic acids were formed, α and β . The α -acid on fusion with caustic potash gave a dihydroxynaphthalene, m. p. 186°, whereas the β -acid gave no dihydroxy-compound but a hydroxysulphonic acid which was suspected of being identical with Schaeffer's acid obtained by sulphonating β -naphthol (now known to be 2:6). Armstrong and Graham repeated the work and confirmed the identity of the hydroxysulphonic acid from the β -acid of Ebert and Merz with Schaeffer's acid; they also showed that the β -acid could be fused, with ease, to give a dihydroxynaphthalene; in fact two products were obtained. The disulphonic acid which gave more soluble calcium salts than the β -acid, and should have corresponded with the α -acid of Ebert and Merz, gave, however, a different dihydroxynaphthalene, and it became evident that there were more than two disulphonic acids. In the paper describing this work Armstrong suggested that Schaeffer's acid might be the 2:3-compound, but he was admittedly speculating with insufficient evidence.

The difficulty of separating mixtures of sulphonic acids led Armstrong, in his first work with Wynne, to apply to naphthalene a much milder sulphonating agent, chlorosulphonic acid, with which he had already had experience in sulphonating narcotine and codeine, in the hope that a single product might be obtained. This expectation was realised. Working in carbon disulphide solution, with one molecular proportion of chlorosulphonic acid, only the α -monosulphonic acid was obtained; with slightly more than two molecular proportions, a new disulphonic acid was formed, which was correctly inferred to be the $\alpha^1\alpha^4$ -modification (in modern nomenclature 1:5). When potassium β -naphthalenesulphonate was warmed with excess of chlorosulphonic acid, still another new disulphonic acid was obtained (the 1:6-isomeride). Simultaneously, work was carried out on the action of bromine on naphthalenesulphonic acids and on Schaeffer's acid, resulting in the preparation of brominated naphthaquinonesulphonic acids and the discovery that α -sulphonic groups are readily displaced by bromine, but β -sulphonic acids only when the ring undergoes oxidation. Schaeffer's acid gave a bromohydroxynaphthaquinonesulphonate and a dibromohydroxynaphthaquinone. The action of chlorosulphonic acid on α -nitro-, α -chloro-, and α -bromo-naphthalene was also studied. Whilst α -nitronaphthalene gave only the 1:5-acid, α -chloro- and α -bromo-naphthalene gave mainly the 4-sulphonic acids and in addition small amounts of an isomeric acid. The β -chloro-, -bromo-, and -iodo-naphthalenes each gave two isomeric acids with chlorosulphonic acid (*P.*, 1887, 3, 22).

To make it possible to ascertain the orientation of the numerous derivatives of naphthalene which were being discovered it was necessary to have a series of reference compounds of known constitution which could be readily identified. To this task Armstrong set himself, and he chose as the reference compounds the dichloro- and trichloro-naphthalenes. It had been observed by Cleve in 1876 that when a naphthalenesulphonyl chloride is distilled with phosphorus pentachloride it is converted into the corresponding chloronaphthalene; and that β -naphthol when treated in the same way gives β -chloronaphthalene. Armstrong announced in 1882 (*Ber.*, 1882, 5, 200) that he was using this as a diagnostic method, and with Wynne he developed it. It was shown that bromo- and nitro-substituents were also displaced by chlorine when compounds containing them were distilled with phosphorus pentachloride. As further reference compounds the chloro-substituted mono-

* This reference was wrongly given by Armstrong as *Ber.*, 10, 592, and the mistake has several times been copied.

and di-sulphonyl chlorides were prepared. Naphtholsulphonates were converted into chloronaphthalenesulphonyl chlorides by the action of phosphorus pentachloride at a moderate temperature; and naphthylaminesulphonic acids were converted into chlorosulphonic acids by Sandmeyer's method, which was given much study, whilst as an additional precaution, especially with naphthylaminedisulphonic acids, the amino-group was eliminated and the naphthalenedisulphonic acid obtained was converted into the corresponding dichloronaphthalene. In 1895, when the work was nearing completion, Armstrong and Wynne published results justifying the use of the phosphorus pentachloride method of converting sulphonyl chlorides into chloronaphthalenes (P., 1895, 11, 83). They showed that the reaction takes place when the sulphonyl chloride is heated in the absence of phosphorus pentachloride, albeit the yield of chloronaphthalene is not so good, probably because a higher temperature is necessary. When phosphorus pentachloride is used, there may take place some additional chlorination; thus a chloronaphthalenedisulphonyl chloride may give rise to some tetrachloronaphthalene in addition to the trichloronaphthalene which is the main product. This circumstance was a source of error by another worker on at least one occasion.

In later work the conversion of 6- and 7-chloronaphthalene-1 : 3-disulphonyl chlorides into trichloronaphthalenes by heating with phosphorus pentachloride was studied in detail and it was shown that intermediate dichloro-monosulphonyl chlorides were formed without change of orientation (P., 1897, 13, 152). One unexpected change of orientation was discovered, however, when 1 : 8-dichloronaphthalene-3-sulphonic acid was heated with acids under certain conditions; instead of the expected 1 : 8-dichloronaphthalene, the 1 : 5-isomeride, and, under one set of conditions, the 1 : 7-compound, was obtained. When 1 : 8-dichloronaphthalene was heated with concentrated hydrochloric acid at 290°, it was entirely converted into the 1 : 5-compound. These isomeric changes might repay further study.

The characterisation of the ten theoretically possible dichloronaphthalenes deducible from the Erlenmeyer formula for naphthalene was finally completed by Armstrong and Wynne in 1890 (P., 1890, 6, 77). Twelve had actually been described and it was clear that two at least of these were superfluous. The twelve are included in the following table, in order of ascending m. p.; the Greek letters by which they were known are given, and their finally established orientation, according to modern numbering.

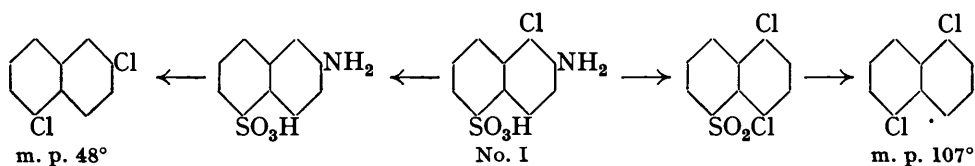
No.	Designation in 1888.	M. p. in 1888.	Corrected m. p. in Armstrong and Wynne.	Orientations.	No.	Designation in 1888.	M. p. in 1888.	Corrected m. p. in Armstrong and Wynne.	Orientations.
1	—	34°	35°	1 : 2	7	ζ	83°	82°	1 : 8
2	α	38	—	—	8	κ	94	—	—
3	η	48	48	1 : 6	9	γ	107	106·5	1 : 5
4	θ	61·5	61	1 : 3	10	δ	114	114	2 : 7
5	θ'	65	62·5	1 : 7	11	ι	120	119·5	2 : 3
6	β	68	67·5	1 : 4	12	ε	135	135	2 : 6

Of these compounds the three αα-compounds, Nos. 6, 7, and 9, and the two heteronuclear ββ-compounds, Nos. 10 and 12, were known with certainty by 1888. In that year Armstrong and Wynne published a paper (P., 1888, 4, 104) describing an investigation of the αβ-compounds. They showed that the so-called α-compound (No. 2) obtained by heating naphthalene tetrachloride with potash (curiously, this was the first ever described) is a mixture, and must therefore be removed from the table. When sulphonated, it gave two sulphonic acids which, when separated and reconverted into dichloronaphthalenes by hydrolysis, gave two compounds, m. p. 68° and 61·5°. The former is the 1 : 4-compound, and as the only αβ-dichloronaphthalene which can be expected from naphthalene tetrachloride is the 1 : 3, the orientation of that of m. p. 61·5°, θ in the table, is 1 : 3. It was further shown that different workers had confused two dichloronaphthalenes of approximately the same m. p., about 61°. The second, which could be obtained from the Badische β-naphthylaminesulphonic acid, had a rather higher melting point, 64° (later corrected to 62·5°; θ' in the table). No. 1 in the table, m. p. 34°, being homonuclear, must be 1 : 2 by exclusion. Of the αβ-compounds, therefore, either η, m. p. 48°, or θ', m. p. 62·5°, must be 1 : 6 and the other 1 : 7. This question was settled by studying the sulphonation

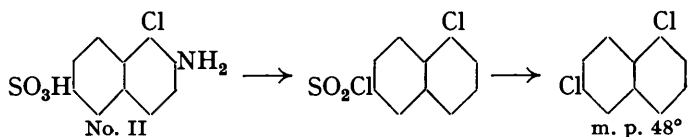
of 1-chloro-2-naphthylamine. One of the three sulphonic acids thus obtained was diazotised to remove the amino-group, and the resulting chloronaphthalenesulphonic acid converted into the dichloronaphthalene, which had m. p. 107° and must be the 1 : 5. This settled the position of the sulphonic group. The same chloronaphthylaminesulphonic acid was then reduced to remove the chlorine, and the amino-group replaced by chlorine; the chloronaphthalenesulphonic acid gave by the standard method the dichloronaphthalene of m. p. 48° . This set of experiments settled that the dichloronaphthalene of m. p. 48° (η) is 2 : 5, *i.e.*, 1 : 6; the other of m. p. 62.5° (θ') must therefore be 1 : 7. The same conclusion had been arrived at by Erdmann and Kirchoff, who had synthesised a dichloronaphthalene by condensing *p*-chlorobenzaldehyde with succinic acid, cyclising the resulting chlorophenylparaconic acid into chloronaphthol, and converting this into dichloronaphthalene, which had m. p. 61.5° . Armstrong, however, did not at this time trust the synthetic method, though he later admitted its value.

There remained two compounds of the table to be disposed of, No. 8 (κ) and No. 11 (ι). No. 8, which had been obtained by Claus from sulphonated α -naphthol, was shown to be 1 : 2 : 4-trichloronaphthalene, and goes out of the table. No. 11 was proved in 1890 to be the 2 : 3-compound by its preparation from 1 : 2 : 3-trichloronaphthalene by partial reduction.

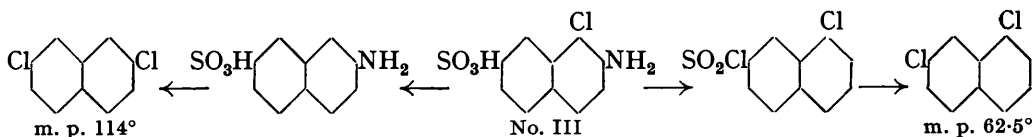
In such a manner the ten dichloronaphthalenes were identified. It will be understood that many cross-checks were provided in the course of the work. As an example, it has been stated that 1-chloro- β -naphthylamine gave three different acids on sulphonation. No. I has been shown to be the 5-sulphonic acid, since from it was prepared 1 : 5-dichloronaphthalene besides the η compound, shown to be 1 : 6, thus :



The second acid, No. II, was also converted into a dichloronaphthalene, m. p. 48° , after elimination of the amino-group, and must therefore be 1 : 2 : 6 :

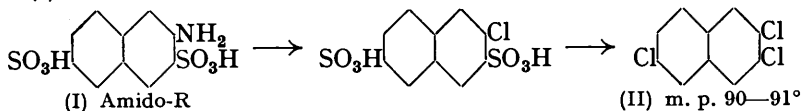


Finally the third acid gave, by appropriate methods, a dichloronaphthalene, m. p. 114° , known to be 2 : 7, and one of m. p. 62.5° , already shown by exclusion to be 1 : 7, a conclusion now doubly confirmed, since No. III must have the 1 : 2 : 7-configuration :



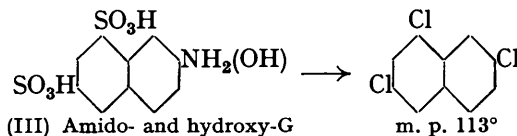
In 1889 Armstrong and Wynne started a systematic study of the tri-derivatives of naphthalene, and in the opening paper of the series (P., 1890, 6, 11) the technical importance of the project was emphasised, particularly the need for knowing the constitution of the isomeric naphthol- and naphthylamine-mono- and -di-sulphonic acids, which showed such striking differences in their behaviour with diazo-compounds and in the colour and other properties of the azo-dyes derived from them. The work on the dichloronaphthalenes had been crowned by studying the sulphonation of each with chlorosulphonic acid in carbon disulphide solution and preparing the derived sulphonyl chlorides; in the case of the trichloronaphthalenes, fourteen of which were predicted by theory, which were to serve

as reference compounds for the tri-derivatives, it was pointed out that it was still more necessary to characterise each compound, owing to the close similarity between the isomerides; no fewer than four melted at nearly the same temperature, 90—92°. It will be impossible to refer to more than a small part of the work accomplished by Armstrong and Wynne in the course of their search for the trichloronaphthalenes. One can illustrate what was accomplished by reference to the work on the two naphthylaminedisulphonic acids R and G, which were supplied by the Aktiengesellschaft für Anilinfabrikation and by F. Bayer and Co. The R acid gave, after elimination of the amino-group, the 2 : 7-disulphonic acid of Ebert and Merz. The amino-acid could therefore only have the constitution (I).



By the standard method it was converted into the trichloronaphthalene (II), m. p. 90—91°, which must be the 2 : 3 : 6.

The so-called amido-G acid gave, after elimination of the amino-group, a new naphthalenedisulphonic acid, the third to be discovered by Armstrong, which gave by the standard method the known 1 : 3-dichloronaphthalene. This settled the relative positions of the two sulphonyl groups. Now it was known that the hydroxy-G acid corresponding with amido-G was obtainable by further sulphonating Bayer's β -naphtholsulphonic acid (2 : 8); further it was stated by Caro and confirmed by Armstrong and Wynne that the hydroxy-G acid when reduced by sodium amalgam lost one sulphonyl group and gave Schaeffer's β -naphtholsulphonic acid (2 : 6). It follows that both amido-G and hydroxy-G acids must have the 2 : 6 : 8-configuration (III).



The corresponding trichloronaphthalene had m. p. 113°; this compound had already been obtained by Alén from a nitro-acid obtained by nitrating Ebert and Merz's naphthalene- β -disulphonic acid (2 : 6); the nitro-acid must therefore also be the 8-nitronaphthalene-2 : 6-disulphonic acid.

As a result of this work Armstrong concluded that it was the presence of the sulphonyl acid group in the 8-position which caused Bayer's acid (2 : 8) and hydroxy-G acid to couple so sluggishly with diazo-compounds, and prevented the corresponding amino-acids from coupling at all, an explanation which is still accepted by dyestuff chemists.

All but one of the fourteen trichloronaphthalenes were known by the end of 1890. The missing one, the 1 : 2 : 8-isomer, was eventually obtained by the synthetic method already referred to. By this method Erdmann and Schwechten had obtained from 3 : 4-dichlorobenzaldehyde two isomeric dichloronaphthols, one of which must be 7 : 8- and the other 6 : 7-dichloro-2-naphthol. Armstrong and Wynne prepared them on a large scale and converted them into the two trichloronaphthalenes; the dichloro- α -naphthol of m. p. 151° gave the known 1 : 6 : 7-trichloronaphthalene, m. p. 109°; the other, m. p. 95°, gave a new trichloronaphthalene, m. p. 83°, which must be 1 : 2 : 8. Its identity was further confirmed by synthesising it from 2-chloro-1-nitronaphthalene-8-sulphonyl chloride as described by Cleve in 1893. By 1895 Armstrong and Wynne had prepared all the 14 trichloronaphthalenes in quantities of 35—50 grams and had started on the task of further characterising them by preparing from each a monosulphonyl acid. Their constitution had, moreover, been determined by so many methods that there was no doubt that the fourteen predicted by theory, and no more, were known. It is worth while to reproduce the following table, given by Armstrong and Wynne (*P.*, 1895, **11**, 85), which shows how rapidly the scanty knowledge of these compounds which chemists had in 1888 was made

complete by 1895. The table shows in the last column how many independent checks were made of the constitution of each compound.

State of knowledge at end of 1888.		Constitution and m. p. assigned by							
		Armstrong and Wynne, 1889—1890.		Cleve, 1892—1893.	Armstrong and Wynne, 1895. No. of methods used.				
a	1 : 2 : 3	81°	Widman	1 : 2 : 3	81°	—	81°	2	
	1 : 2 : 4	92	Cleve	1 : 2 : 4	92	—	92	1	
			—	1 : 2 : 5	78·5	77, 76°	78·5	5	
	?	2 : 6	91	Forsling	1 : 2 : 6	92·5	90	92·5	4
				—	1 : 2 : 7	83—84	75·5	88 and 84	3
γ	1 : 3 : ?	103	Widman	1 : 3 : 5	103	103	103	5	
	α : 2 : 7	75·5	Alén	1 : 3 : 6	80·5	—	80·5	6	
	α : 2 : 6	113	Alén	1 : 3 : 7	113	—	113	7	
	β	1 : ? : ?	90	Atterberg	1 : 3 : 8	87 and 90	—	89·5 and 85	2
	δ	1 : 4 : 5	131	Atterberg	1 : 4 : 5	131	130	131	4
ε	2 : ? : ?	65	Cleve	} 1 : 4 : 6	66 and 56	66 and 56	66 and 56	6	
	ζ	2 : ? : β	56		Widman	2 : 3 : 5	109·5	—	109
			—	2 : 3 : 6	91	—	91	4	

The value of this series of reference compounds in determining constitutions was demonstrated repeatedly in a series of some sixteen papers under the general heading "Studies on the constitution of tri-derivatives of naphthalene," published between 1890 and 1897. Special attention was paid to the naphthylaminedisulphonic acids, of which many were put at Armstrong's disposal by the German dyestuff firms, who obviously followed his work with the closest attention. One of the most valuable papers was undoubtedly that on the further sulphonation of the four isomeric heteronuclear β-naphthylaminemonosulphonic acids. In this paper was described for the first time (P., 1890, 6, 129) 2 : 5 : 7-naphthylaminedisulphonic acid (from the 2 : 5-monosulphonic acid), which by caustic fusion gives one of the most important intermediates for azo-dyes, 2 : 5 : 7-aminonaphtholsulphonic acid, the J acid of dyestuff chemists. This work also led Armstrong and Wynne to study the sulphonation of the chloronaphthalenemonosulphonic acids, and to compare the orienting influence of the chloro- and the amino-radical.

Among other naphthylaminedisulphonic acids of which the constitutions were determined by Armstrong and Wynne were the acids obtained by sulphonating naphthionic acid, known as Dahl acid II and III, which were shown to be 1 : 4 : 6- and 1 : 4 : 7-naphthylaminedisulphonic acid respectively; Schöllkopf acid, 1 : 4 : 8; ε-acid, obtained by the A.G.F.A. by nitration and reduction of Armstrong's 1 : 6-disulphonic acid, shown to be 1 : 3 : 8-naphthylaminedisulphonic acid; and a number of others.

Arising out of the work on ε-acid an incident occurred later which is worth recording, as it illustrates Armstrong's generosity in recognising the claims of others. Messrs. Kalle and Co. had obtained what was supposed to be 1-naphthylamine-3-sulphonic acid by removing one sulphonic group from ε-acid by reduction. Armstrong and Wynne confirmed this observation (P., 1895, 11, 238) and drew special attention to the fact that the 1 : 3-acid thus obtained corresponded to the description given by Cleve of an acid which he had obtained by reducing a nitronaphthalenesulphonic acid isolated from the nitration of naphthalene-β-sulphonic acid, and which he claimed had the 1 : 3-constitution. Neither Armstrong and Wynne, nor other workers had been able to isolate the nitrosulphonic acid described by Cleve, but Armstrong and Wynne now provided decisive evidence that he had indeed obtained it.

All Armstrong's work on naphthalene was directed towards one end, the elucidation of the factors governing substitution in the naphthalene nucleus. He early recognised the so-called alpha law, that in substitution reactions the tendency is first for an α-hydrogen to be displaced, whereas β-substitution requires generally more drastic conditions. A second characteristic which he recognised was that, when a single substituent group is present in naphthalene which in benzene derivatives would give rise to *meta*-derivatives, a second substituent group enters the other nucleus, and a heteronuclear disubstituted

naphthalene results. A phenomenon to which particular attention was paid was the isomeric change to which naphthalenesulphonic acids are prone, generally resulting in the conversion of an α - into a β -sulphonic acid. One such change was discovered by Armstrong unawares. As early as 1881 (*Ber.*, 1882, 15, 200) he started a study of the sulphonation of β -naphthol, with the object of trying to cut down the large amount of sulphuric acid used by Schaeffer in preparing the acid known by his name. It was discovered that, sulphuric acid at a low temperature, or chlorosulphonic acid in carbon disulphide, being used, a sulphuric acid derivative of β -naphthol was obtained which could be readily hydrolysed back to β -naphthol, but which, by mere heating at water-bath temperature, was converted into Schaeffer's acid. He concluded that the readily hydrolysable derivative was β -naphthyl sulphate, $C_{10}H_7 \cdot O \cdot SO_3H$, and it was not until 1893 that Tobias (*Ger. Pat.* 74688) showed that it was in reality β -naphthol-1-sulphonic acid. Armstrong's mistake was excusable, for the instability of β -naphthol-1-sulphonic acid was unprecedented. The subject was taken up again in 1887, when the sulphonation of 1-bromo- β -naphthol was studied (this gave directly the bromo-derivative of Schaeffer's acid) and also the sulphonation of the " β -naphthyl sulphate." The latter operation gave, not a "sulphosulphate," but "an isomeric disulphonic acid which is of special interest on account of the readiness with which, by mere warming with dilute sulphuric acid, it is converted into Schaeffer's β -naphtholmonosulphonic acid; there is little doubt that one of the sulphonic groups occupies an α -position contiguous to the OH" (*P.*, 1887, 3, 144). It is evident that Armstrong fully recognised the mobility of groups in the 1-position of β -naphthol, and was very close to forestalling Tobias' discovery made in 1893. Armstrong went on to study the sulphonation of β -ethoxynaphthalene with Amphlett, and of the β - and α -halogenonaphthalenes with Wynne, Sindall, and Williamson. The β -halogeno-compounds gave most interesting results. Sulphonated at a low temperature with chlorosulphonic acid in carbon disulphide, both the chloro- and the bromo-naphthalene gave as major product the 8-sulphonic acid with a little of the 6-sulphonic acid, but as the temperature of reaction was raised the proportion of the latter acid increased, and the 8-sulphonic acid could be converted into the 6-isomeride by heating at 150—160°. β -Iodonaphthalene, on the other hand, whilst giving, like the chloro- and bromo-compounds, the 8-sulphonic acid as major product, gave as a minor product not the 6- but the 5-sulphonic acid. It was argued from this circumstance that also in the case of β -chloro- and β -bromo-naphthalenes the 5-sulphonic acid is probably a primary product but is instantaneously isomerised to the 6-acid. This use of the three halogens was a favourite resource of Armstrong's in attacking many problems in organic chemistry. He applied the method in studying the occurrence of iso-polymorphous series in benzenoid compounds and in his study of the strengths of aromatic sulphonic acids.

Later Armstrong and Wynne doubted whether the so-called isomerisation of naphthalenesulphonic acids is in fact such a phenomenon. More probably it is connected with the fact that α -sulphonic acids are more readily hydrolysed than β -sulphonic acids; in other words, α -sulphonation is reversible and β -sulphonation is not. Consequently, although the rate of β -sulphonation may be much slower than that of α -sulphonation, under appropriate conditions the former will be the final product. Alternatively a polysulphonic acid may be formed by β -sulphonation of the first-formed α -sulphonic acid, followed by removal of the α -sulphonic group. The former explanation was supported by the observation that in the chlorination and bromination of naphthalene a small proportion of the β -compound is formed along with the α -compound, proving a tendency, slow though distinct, to direct β -substitution.

In the course of his sulphonation studies Armstrong was impressed with the "invincible objection" of two sulphonic radicals to remain in contiguous or in *para*- or *peri*-positions to one another in the naphthalene nucleus when naphthalene or a substituted naphthalene is sulphonated. This behaviour made it impossible to obtain several of the theoretically possible di- and poly-sulphonic acids until, in 1892, a discovery was made in the laboratories of the Farbenfabriken vormals F. Bayer und Co. of a method for introducing a sulphonic group in place of an amino-group, the now well-known diazo-xanthate method. This process was revealed to Armstrong by Dr. Duisberg before the patent (G.P. 70296) was

published, and he and Wynne at once used it successfully for preparing the 1 : 2-, 1 : 4-, and 1 : 8-naphthalenedisulphonic acid (P., 1893, 9, 166) from the corresponding naphthylaminesulphonic acids. The number of known disulphonic acids was thus brought up to nine of the ten theoretically possible.

In addition to all the work which has been described, much attention was paid to the chlorination and bromination of naphthalene and β -naphthol, and to the behaviour of the halogen derivatives with nitric acid and on sulphonation, the chief collaborators in this work being Rossiter and later W. A. Davis. These studies provided much evidence in favour of Armstrong's thesis that addition precedes substitution. The fact that bromination of naphthalene, unlike chlorination, gives no 1 : 3-di-derivative is explained by the fact that naphthalene does not form a tetrabromide but does form a tetrachloride. Bromination of β -naphthol was shown to give the 1-bromo- and then the 1 : 6-dibromo-derivative, and Davis reduced the latter to 6-bromo- β -naphthol. Further bromination gave the 1 : 3 : 6-tri- and 1 : 3 : 4 : 6-tetrabromo- β -naphthols. Rossiter (P., 1891, 7, 32) also claimed that sulphuryl chloride reacted with β -naphthol to give the 1 : 4-dichloro-derivative, but this interesting claim does not appear to have been confirmed. It was also observed that 1-bromo- β -naphthol formed an addition compound with nitric acid which decomposed in two ways, with acids to give β -naphthaquinone and with alkalis to give 1-nitro- β -naphthol. This observation gave strong support to the addition hypothesis to explain substitution.

In the course of the studies of isomerisation of naphthalenesulphonic acids, Armstrong pointed out the tendency of naphthalene substitution products to assume a symmetrical structure. 2-Naphthol-6-sulphonic acid is an example of this tendency; similarly, α -chloronaphthalene, which at low temperatures gives the 4-sulphonic acid, at higher temperatures was found to give the more symmetrical 5-sulphonic acid, presumably by isomerisation. He also pointed out that symmetrically substituted naphthalene derivatives have higher melting points than those which are less symmetrical; thus of the dichloronaphthalenes the 2 : 6-compound has the highest melting point, the 2 : 3-isomeride having the next highest, then the 1 : 5-compound. This tendency for symmetrical to have a higher m. p. than unsymmetrical compounds is, however, subject to numerous exceptions, and it is evident that other factors come into play in determining fusibility.

Benzene.

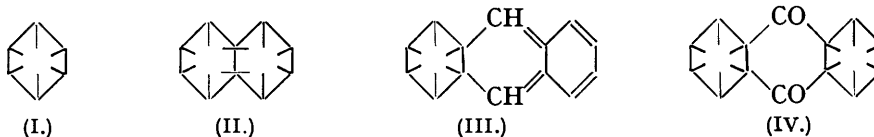
Armstrong was as interested in substitution in benzene derivatives as in naphthalene, and although he was born too late to be a pioneer in this field he nevertheless made important contributions to our understanding of the subject and in the course of his work developed clear-cut ideas. His work on the sulphonation of aniline and its derivatives is particularly important, as out of it arose the conception that the so-called *meta*-directing groups are those which have no *ortho-para*-directing influence, and are even inhibitors of *op*-substitution (P., 1899, 15, 176). He showed that when amines are converted into salts they lose their *ortho-para*-effect; thus aniline in strong fuming sulphuric acid gave metanilic acid (Armstrong and Berry, P., 1900, 16, 159). With Miss Evans it was shown that dimethylaniline gives the *p*-sulphonic acid with chlorosulphonic acid; in sulphuric acid it becomes more and more difficult to sulphonate as the quantity of acid present is increased, and to get the *m*-sulphonic acid strong fuming sulphuric acid is necessary. Another valuable line of work was the study of the bromination of ethers and esters of phenol and phenol-*p*-sulphonic acid, in which it was shown that some acyl groups, such as benzoyl, benzenesulphonyl, and benzylsulphonyl, completely protect the phenol-*p*-sulphonic acid from bromination. It was also shown that the benzeneazo-group can be displaced from benzeneazophenol by bromine exactly as the sulphonic group is from phenol-*p*-sulphonic acid.

Armstrong was the first to study systematically the recovery of hydrocarbons from their sulphonic acids by hydrolysis with aqueous sulphuric acid. This work was done in 1884 in collaboration with Miller (J., 1884, 45, 148), and it was shown that the sulphonic acids of different homologues of benzene, and naphthalene- and phenol-sulphonic acids require different strengths of acid and therefore different temperatures to effect their hydrolysis. It was attempted to use the method to effect separation of the hydrocarbons from mixtures

by fractional hydrolysis of the sulphonic acids, but the temperatures of hydrolysis were not sufficiently sharply differentiated for this purpose.

The Kekulé formula for benzene did not satisfy Armstrong's desire to form a satisfactory mental picture of the benzene molecule and to represent it by a symbol free from ambiguity. His historic centric formula (I), which was suggested independently by Baeyer, was devised to meet the drawbacks to Kekulé's formula, that it represented benzene as having three ethenoid linkages, whereas it is in no way ethenoid, and that it implies the possibility of two different *o*-disubstituted derivatives.

In the centric formula the six central affinities were assumed to neutralise each other without constituting cross linkings within the ring. They were pictured as acting within a cycle rather than merely towards the centre. Armstrong later suggested the following "centric" formulæ for naphthalene (II), anthracene (III), and anthraquinone (IV):



Crystallography.

The work carried out on benzene derivatives in the laboratories at the Central Technical College was largely concerned with crystallographic studies. Amongst Armstrong's convictions when he started teaching chemistry at the Central was one that chemists would profit by a knowledge of crystallography, which had hitherto been the almost exclusive territory of the mineralogist. As all Armstrong's pupils knew, he constantly endeavoured to get them to think structurally in three dimensions. The idea that the crystal was the solid expression of molecular structure was always in his mind. In this, as in so many of his ideas, he was a pioneer. In 1886 H. A. (now Sir Henry) Miers, who was an assistant in the Mineral Department of the British Museum (Natural History), started a class in crystallography at the Central, at Armstrong's invitation, and among his pupils were (Sir) W. J. Pope, T. M. Lowry, and A. Lapworth. From that time until the closing down of the Chemistry Department in 1912, all the chemistry students had practical training in crystallography. The last instructor was T. M. Lowry, under whom the present writer studied the subject. This early introduction to a three-dimensional world undoubtedly determined the trend of the later interests of both Pope and Lowry.

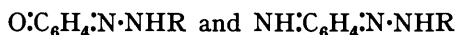
It was usual for papers on chemical subjects from Armstrong's laboratories to include a detailed description of the crystals of the new substances reported. The laboratory was recognised as an institution at which new crystalline substances were welcomed as objects of investigation, and many research workers sent substances for crystallographic description. The results of work of this kind formed the subject of some fifteen "Mittheilungen aus dem krystallographischen Laboratorium des Central Technical College" in the *Zeitschrift für Krystallographie*.

For many years Armstrong was a member of a committee of the British Association the function of which was to study crystal morphology in the benzene series. The work carried out at the Central comprised the preparation and crystal measurement of isomeric mono- and di-halogen-substituted benzenesulphonyl chlorides and bromides, and resulted in the discovery amongst the chloro-, bromo-, and iodo-derivatives of several isopoly-morphous series which were reported to the British Association. The development of the Barlow-Pope theory of crystal structure during the years 1906—1908 gave the Professor great satisfaction, since it provided a working hypothesis which he could apply to the data he had accumulated. The theory depended on two assumptions which have since proved to be untenable, that the volumes of the "spheres of influence" of the atoms in a crystal were proportional to their valencies, and that in the crystal the spheres of influence were close-packed. The writer and Dr. Colgate took up this study in 1910 and during four years examined the crystals of a very large number of derivatives of benzenesulphonic acid, checking and extending the work of earlier students. Several papers were published, and

in the fifth of the series (*Proc. Roy. Soc.*, 1914, A, **90**, 111) the whole of the data was reviewed; their only value now consists in the crystallographic constants they record. The discovery of the X-ray method of investigating crystal structure by Laue, Friedrich, and Knipping in 1912 and its development by the Braggs and others provided a wonderfully precise weapon for studying the molecular architecture of crystals, and justified to the full Armstrong's belief in the importance of the subject, confirming his early confidence that crystal structure is determined by the arrangement of the atoms in the molecule.

The Origin of Colour.

Although Armstrong did not make any extensive experimental study of coloured compounds or dyes, he was the originator of an important generalisation which soon became one of the guiding principles of dyestuff chemists, the quinone theory of colour. One has only to read the short paper (P., 1888, **4**, 27) in which the theory is first put forward, to realise that it was not just a sudden flash of genius but the result of wide knowledge and deep thinking. Nor was Armstrong, as some critics have said, oblivious of the existence of colour on either side of the visible spectrum, for in the early part of the paper he says "the unsaturated hydrocarbons are not only more reactive than the paraffins, but the beginnings of colour are manifest in them if examination be made in the regions above and below the visible spectrum." After referring to the identity which had been discovered by Zincke and Bindewald of benzeneazo- α -naphthol and α -naphthaquinonephenylhydrazone he suggests that hydroxy- and amino-azo-dyes generally should be regarded as quinonic substances of the types



and he then goes on to propose quinone formulæ for such dyes as pararosaniline and methylene-blue. In a later paper he concluded (P., 1892, **8**, 101) that the quinonoid origin of visible colour appeared to be so general that if a coloured compound was not quinonoid its formula was suspect. In this paper he suggested that *o*-nitrophenol must be quinonoid on account of its strong colour; he suspected that *m*-nitroaniline should be colourless if pure, but all his attempts with Kipping to remove its colour were fruitless, and he owned himself baffled. One of the most striking justifications of Armstrong's theory was the discovery of the deeply coloured quinones of polycyclic systems such as dibenzanthrene, many of which are valuable vat dyes. The writer cannot refrain from quoting the pregnant words used by Armstrong in the discussion of his second paper on colour, in reply to Ramsay: "It appeared probable that ultimately colour would be traced to that peculiar condition represented conventionally by a double bond, the atoms being regarded as altogether subordinate." This is the modern view, fifty years later.

The Terpenes and Camphor.

One of the major preoccupations of organic chemists during the last quarter of the nineteenth century was the problem of the constitution of camphor and of the closely related terpenes. In this work Armstrong and his school, including Kipping, Pope, Lapworth, Lowry and Forster, played a prominent part. Armstrong's first paper on camphor appeared in the *Chemical News* in 1878, when with Matthews he described a simple method for obtaining pure α -bromocamphor. A paper in the *Berichte* of the same year described experiments on the action of iodine on turpentine with production of cymene, and the following year appeared a long paper with W. A. Tilden (J., 1879, **35**, 733) describing experiments on the action of sulphuric acid of different concentrations and at different temperatures on American and French turpentine, and demonstrating the complex nature of the changes which take place. The steam-volatile, optically inactive product of the action of concentrated sulphuric acid on turpentine, which had been given the name "terebene" by Deville in 1840 and was apparently regarded as a chemical individual, was shown to consist largely of camphene, together with some cymene and a hydrocarbon $\text{C}_{10}\text{H}_{20}$. A more dilute acid produced principally "terpilene" (terpinolene, Wallach), the structure of which was later established by Baeyer.

The so-called "colophene" (the non-volatile product of the action of sulphuric acid on turpentine) was shown to be probably a mixture of polymers. Armstrong and Tilden also studied the oxidation of camphene and of camphor. From *dl*-camphene, by oxidation with dichromate and sulphuric acid, they obtained *dl*-camphor; this, by further oxidation with nitric acid, was converted into *dl*-camphoric acid, which had been previously made by Chautard by mixing the optically active forms.

In 1883, Armstrong and Miller studied the action on camphor of zinc chloride, iodine, phosphoric oxide, and phosphorus pentasulphide. The reactions are highly complex: from the product of the dehydration of camphor with zinc chloride, for example, there were isolated *p*-cymene, 1:2-dimethyl-4-ethylbenzene, 1:2:3:5-tetramethylbenzene, and carvacrol.

In 1891, Armstrong investigated the crystalline alcohol, $C_{10}H_{18}O_2$, produced from oil of turpentine by atmospheric oxidation in presence of sunlight, and gave to it its present name, *sobrerol* (after Sobrero, who first isolated it in 1851). He isolated the dextrorotatory form of *sobrerol* from American oil of turpentine and also from a Burmese oil, and the levorotatory form from French oil. With Pope, he published a crystallographic study of the hemihedral crystals of the two enantiomorphs, and also of the racemic compound prepared by mixing them and crystallising.

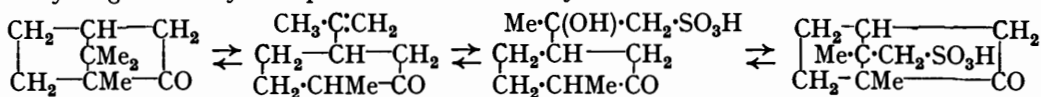
In 1893, continuing the experiments which had been begun earlier with Miller, Armstrong in collaboration with Kipping, studied the product of reaction of camphor with hot concentrated sulphuric acid. By this process, Delalande, in 1839, had obtained an oily product to which Chautard in 1856 had given the name "camphren." Camphren was later investigated by Schwanert and by Kachler, with varying results. Armstrong and Kipping showed that crude camphren contained, in addition to unchanged camphor, 1-acetyl-3:4-dimethylbenzene (isolated by its phenylhydrazone) and a substance of peppermint-like odour which yielded α -methylglutaric acid on oxidation. The complete structure of this substance, now known as carvenone, was determined later by Tiemann and Semmler.

To Armstrong's school belongs the credit of first preparing a sulphonic acid of camphor, although the action of sulphuric acid on camphor had previously been studied by many other workers. The work was carried out by Kipping and Pope from 1893 onwards, but the hand is obviously the hand of Armstrong. All the features of the naphthalene research are present, the careful investigation of conditions using fuming sulphuric acid and chlorosulphonic acid, the isolation and purification of sulphonyl chloride and sulphonyl bromide, finally the pyrogenetic decomposition of these with formation of new chloro- and bromo-camphors, the π series, as they were named and are still called. Corresponding π -sulphonic acids were obtained from α -chloro- and α -bromo-camphors, and these acids of the π series were later used by Pope and by others for the isolation of optically active compounds containing asymmetric atoms of nitrogen, sulphur, silicon, tin, and other elements.

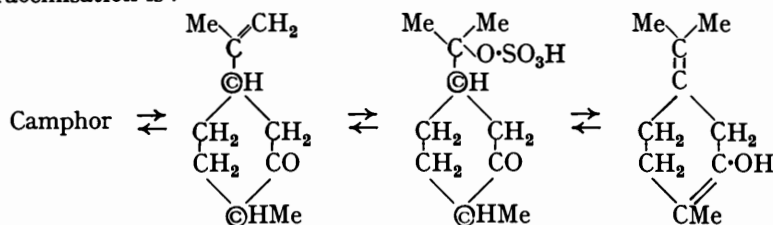
With Lowry, Armstrong carried out important work on the constitution of the sulphonic acid of camphor first prepared by Reychler in 1898 by the action of a mixture of acetic anhydride and sulphuric acid on camphor at the ordinary temperature. Reychler converted his acid into the corresponding amide, of which he obtained two forms; he considered the acid to be the α -sulphonic acid and the two amides to be stereoisomeric forms. Armstrong and Lowry applied Reychler's method to α -chloro- and α -bromo-camphor and obtained corresponding sulphonic acids from them, and found that by dehalogenation by reduction the amides gave one or other of Reychler's camphorsulphonamides. Eventually it was found that Reychler's two "sulphonamides" were not isomeric, but that one was an anhydride formed by loss of water from the other. Further consideration of the properties of the sulphonic acids, and especially the impossibility of oxidising them to camphoric acid, led to the conclusion that the sulphonic group could not occupy the α -position, and this conclusion was confirmed by the discovery that thermal decomposition of the sulphobromide gave a new (β -)bromocamphor, which was also prepared at about the same time by Forster by another method. Reychler's acid must therefore be the β -sulphonic acid.

The identity of the β -position in the camphor skeleton was unknown. On the evidence available, two positions were possible, carbon atoms 6 and 10 in the inset diagram. Both Armstrong and Lowry and also Forster favoured carbon 6, and it was not until 1923 that Wedekind, Schenk, and Stüsser (*Ber.*, 56, 633) obtained evidence showing that carbon 10 is almost certainly the β -carbon. The anhydride formation from the sulphonamide, in which the keto-group is involved, indeed seems much more understandable if the sulphonic group is on carbon 10. Later Lipp and Lausberg (*Annalen*, 1924, 436, 274) concluded that β -bromocamphor is the 10-bromo-compound, confirming Armstrong's and Lowry's view that no change of orientation occurred when the sulphobromide decomposed into β -bromocamphor.

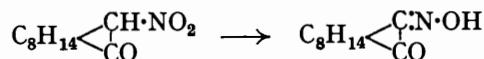
In their third paper on camphor Armstrong and Lowry (*J.*, 1902, 81, 1469) discussed the mechanism of the complex changes associated with substitution in and "dehydration" of camphor. The view is held that changes are initiated by addition at the keto-group. The process of π (*i.e.*, 8)-sulphonation, discovered in Armstrong's laboratory by Kipping and Pope, is supposed to involve the rupture of the bond between carbons 1 and 7 at an early stage and may be represented schematically thus:



This mechanism is supported by the known formation of carvenone by the action of sulphuric acid on camphor; and by the formation with the same reagent of acetyl-*o*-xylene observed by Armstrong and Kipping. It also fits in with the racemisation of camphor when converted into the π -sulphonic acid observed by Kipping and Pope, but to account for this phenomenon completely, inversion of the other optically active carbon atom, No. 4, must occur. Enolisation must be involved, and the complete scheme to account for racemisation is:



The well-known work of Lapworth and Forster on camphor chemistry was initiated in Armstrong's laboratory. Finally mention must be made of Lowry's important work on nitrocamphor leading to the discovery of the phenomenon of mutarotation, which was traced to the change



The same phenomenon was observed with π -bromonitrocamphor and the now well-known term "dynamic isomerism" was coined to describe the condition of such substances. Armstrong's work in the camphor field was thus not only valuable in itself but an inspiration to others.

The Theory of Aqueous Solutions.

Armstrong's independence of thought showed up most strongly in his determined and prolonged opposition to the ionic dissociation hypothesis as developed by Arrhenius, van 't Hoff and Ostwald ("the Three Musketeers of Physical Chemistry" as he styled them) to explain the electrical conductivity of aqueous solutions of salts, acids, and bases. His attitude was indeed consistent with his whole chemical philosophy. He had pondered deeply on the processes of chemical change, and had come to the conclusion that such changes were preceded by association of the interacting substances. The idea of the spontaneous dissociation of a molecule into charged ions was therefore distasteful and

contrary to his chemical feeling. Equally important in determining his attitude was his conception of water. "Water," he says, "is of all substances known to us not only the most active and useful but the most marvellous." How then should this powerful substance behave merely as a medium for the dance of the ions, or as a screen to keep them apart? The supporters of the theory of ionic dissociation concentrated their attention on what happened to the solute and ignored the solvent. Armstrong insisted that the solvent and the solute must play reciprocal parts in any conducting solution. He also pointed out that the mathematical formulæ on which the "ionists" relied held true only for very dilute solutions of those substances which in water formed electrolytes; that is to say, they only held true when water was in great excess. The properties of such solutions were therefore surely due to the effect of the dissolved substance on the water!

In 1909 Armstrong produced two lyrical essays on water, the very titles of which are characteristic of the man: "A Dream of Fair Hydrone" and "The Thirst of Salted Water." In these two amusing papers we get the whole case against the ionic theory, supported by apt allusion and quotation, gentle ridicule and serious warning against mass suggestion. Armstrong was one of those rare men whose heterodox opinions have a way of coming true at a later date, perhaps not exactly as he expressed them, but very nearly so. In the papers just quoted he discusses and compares the hydrides of carbon, nitrogen, oxygen, and chlorine, showing that, from its physical properties alone, water must be a complex substance, not aitch-two-oh! He then goes on to compare the behaviour of hydrogen chloride towards ammonia and unimolecular water, which he proposes to call "hydrone." He supposes that, just as ammonia combines with hydrogen chloride to form ammonium chloride, nitrogen passing from the trivalent to the quinquevalent stage, so hydrone combines with hydrogen chloride to form the complex $\text{H}_2\text{O} \left\langle \begin{smallmatrix} \text{Cl} \\ \text{H} \end{smallmatrix} \right.$, in which the oxygen becomes quadrivalent. One must admit that this is a remarkable prevision of modern views based on the octet theory, although Armstrong could not foresee that the above complex should be divisible into the ions OH_3^+ and Cl^- , as ammonia gives NH_4^+ and Cl^- . He considered that radical exchange was reciprocal in a solution of hydrogen chloride in water, with formation of two kinds of complex, $\text{H}_2\text{O} \left\langle \begin{smallmatrix} \text{H} \\ \text{Cl} \end{smallmatrix} \right.$ and $\text{HCl} \left\langle \begin{smallmatrix} \text{H} \\ \text{OH} \end{smallmatrix} \right.$, and that electrolysis involved interaction of both. He was careful to point out that he did not conceive that simple hydrate formation would account for the production of electrolytes, but that some reciprocal effect between solute and solvent was to be looked for.

That a salt or acid dissolved in water was in any way comparable with a gas was a view strenuously opposed by Armstrong, whatever mathematical analogy might be discovered by van 't Hoff and others. Fitzgerald had advanced cogent arguments against the conception in his Helmholtz Memorial Lecture to the Chemical Society in 1896, and Armstrong took his stand largely on Fitzgerald's views. He found an explanation for osmotic effects in the complex nature of water and the effect thereon of dissolved substances. Thus osmotic pressure became, in his view, "the Thirst of Salted Water." Water is a complex $(\text{H}_2\text{O})_x$ saturated with the "gas" hydrone, H_2O . A solute combines with the hydrone, thereby lowering the vapour pressure. The osmotic pressure manifested by such a solution is the hydraulic pressure exercised by the extra molecules of hydrone attracted into it by the distributed complexes. These ideas are elaborated in several papers, especially "The Origin of Osmotic Effects" (see "The Art and Principles of Chemistry," Ernest Benn Ltd., 1927).

Experimentally Armstrong attacked the problem of aqueous solution from a number of directions. Particularly he studied the displacement of salts from solution by inorganic and organic solutes; the rate of hydrolysis of esters by acids of all kinds, and the effect of the presence of salts; and the hydrolysis of sucrose and other carbohydrates by acids and by enzymes. During the years 1906—1913 papers of the series "Processes operative in Solution," over 30 in all, appeared at regular intervals, most of them in the *Proceedings of the Royal Society*. The collaborators were Caldwell, Whympier, Watson, Glover, Eyre, Wheeler, Crothers, Walker, Worley, and others. It would be impossible here to attempt to summarise all this work. The experiments on the hydrolytic activity of acids, however,

must be mentioned. These drew attention to a fact which was already known to Ostwald, that the activity of acids increased with increasing concentration, whereas if, as the supporters of ionic dissociation maintained, hydrogen ions were the active agents, hydrolytic activity should increase with increasing dilution. Another difficulty for the dissociationists was that the hydrolytic activity of acids was increased in the presence of their salts. Armstrong therefore concluded that hydrolysis had nothing to do with hydrogen ions but was affected by the break-down of a system composed of the hydrolyte, the catalyst and water. The process was therefore parallel to that of hydrolysis by enzymes, apart from the fact that the latter are specific in their action whilst acids are not.

The controversies have died down. Most chemists leave consideration of such matters to the specialists, the physical chemists, and believe what they are told. Nevertheless, the perplexing problems presented by aqueous solutions, so clearly perceived by Armstrong, are still problems. New knowledge has brought modifications to the ionic dissociation theory, and some of Armstrong's criticisms have been justified.

Parallel with his studies on processes operative in solution, Armstrong was producing two other series of papers, one on the "Origin of Osmotic Effects," the other on "Enzyme Studies." Under Armstrong's treatment, these investigations were closely related to his studies of solutions. In the former series he brought into his orbit differential septa such as the covering of the seed of the barley, *Hordenum vulgare*, on which some curious observations had been made by Adrian Brown (1909); and the substances which stimulate enzyme activity by penetrating the leaves of plants (1910). The enzyme studies were carried out in collaboration with his son E. F. Armstrong, Glover, Eyre, Horton, and a number of occasional helpers. Dr. J. V. Eyre in 1916 contributed an admirable summary of the work to the "Central" (Vol. 13, No. 39, Aug., 1916). The work was started in 1900 with the object of studying quantitatively the hydrolytic action of enzymes, especially on biose sugars. It was shown that, in absence of other disturbances, the rate of hydrolysis was constant and dependent only on the amount of enzyme present. From this and other data gained from a study of the influence of the products of change, it was concluded that hydrolysis occurred at the surface of the colloid particles of the enzyme, to which were attracted active molecules of water and molecules of the sugar. The early experimental work was done on lactase, maltase, invertase, and emulsin. Later an important study was carried out on urease, the urea-splitting enzyme, when it became known from the work of Takeuchi that this enzyme was readily obtainable from soya bean. Only the briefest mention can be made of the intensely interesting work on the cyanophoric glucosides and corresponding enzymes occurring in the bean *Phaseolus lunatus*, in cherry laurel (*Prunus laurocerasus*), in different species of flax, and in such herbage plants as birdsfoot trefoil (*Lotus corniculatus*) and white clover (*Trifolium repens*). In the cherry laurel a new enzyme was discovered which, whilst without action on amygdalin, hydrolysed prunasin, the glucoside left after one half of the glucose of amygdalin has been removed. The new enzyme, prunase, must therefore be present in the complex enzyme emulsin. Subsequently the glucosides linamarin, amygdalin, prunasin, and salicin were used as test substances in seeking for enzymes in the leaves and seeds of a very large number of plants. It was found that the occurrence of cyanophoric glucoside in white clover and birdsfoot trefoil was fortuitous and inexplicable, and the opinion was expressed that variations in enzyme and glucoside content might have an important bearing on the value of such plants as feeding stuffs. Unfortunately this important and original line of work was cut short at the flood through the dispersal of Armstrong's collaborators when his chemistry school was closed down.

Reference was made on p. 1432 to Armstrong's conceptions of the mechanism of chemical change. These views were based on those of his spiritual master Faraday, whose work on electrolysis he regarded as one of the masterpieces of all time. Every one of his students was urged to read and study Faraday's electrochemical researches. "All ordinary chemical actions are themselves electrical." To understand any chemical reaction, look for the electrolyte. Two pure substances cannot interact. Chemical reaction is a kind of reversed electrolysis, requiring for its progress a complete electric circuit. These ideas were forming in his mind as early as 1880, being strengthened by H. B. Dixon's observation in that year that water vapour was necessary for the combustion of carbonic oxide in oxygen. The

striking results obtained by H. B. Baker on the effects of intensive drying in slowing down and even preventing combustion lent confirmation to his views, and in 1885, discussing one of Baker's papers at a Chemical Society meeting, he said that "he had ventured to affirm to Mr. Dixon that some day it would be ascertained that a mixture of pure oxygen with pure hydrogen was not explosive." Seventeen years later Baker himself showed that it was possible to prepare an intensively dried mixture of oxygen and hydrogen which did not explode when sparked, and Armstrong's prediction was fulfilled. It also appeared from Baker's experiments that water alone did not suffice to make such a mixture explosive, but that something more was needed. In Armstrong's view the missing substance was something to render the water a conductor and complete the electric circuit. In spite of all evidence to the contrary he maintained that water—pure water—must be a perfect non-conductor. If the purest water obtainable still had a measure of conductivity, it was not pure water. On this question, as on some others, Armstrong allowed his feelings to go beyond the evidence.

The rusting of iron was another subject in which Armstrong took a lively interest, both because of the technical importance of the subject and because rusting was a process suspected from early days of having a voltaic origin. He believed that atmospheric corrosion would be impossible, even in presence of air and water, unless an electrolyte were present. G. T. Moody was able to show experimentally at the Central that iron could be kept indefinitely uncorroded in presence of water and a current of air from which carbon dioxide was rigidly excluded; as soon as air containing carbon dioxide was admitted, rusting commenced (J., 1906, 89, 726). Armstrong's view was that the first product when iron rusted in air was a soluble ferrous bicarbonate which was oxidised by air to an insoluble ferric compound, and in support of this Moody devised a very simple experiment. Some bright nails were put in a glass cylinder and covered to a depth of about an inch with water; a disc of filter-paper was put in the water over the nails. In time a stain of rust appeared on top of the filter-paper, the nails being practically untarnished, showing that the rust was deposited from the water. Moody's experimental results on the influence of carbon dioxide on rusting were challenged on the ground that his iron had been rendered passive before the experiment by treatment with chromic acid, and a good deal of controversy arose. Whether the simple question which these experiments tried to answer has yet been definitely settled the writer would not dare to assert.

Armstrong's beliefs regarding the mechanism of chemical change were given fully in his Presidential Address to the Chemical Society (J., 1895, 67, 1122); they subsequently underwent little modification, and pervade most of his chemical writings.

Any notice of Armstrong's life and work would be unbalanced without considerable reference to his labours in the field of education, for his name must be prominent in the history of educational reform during the last two decades of the nineteenth and the opening years of the twentieth century. The deficiencies in our educational system became apparent to him in his early teaching days at Finsbury, and he soon made up his mind that the poor quality of the average boy coming to be taught chemistry and physics was largely the result of bad elementary education. The prospect of starting a campaign against the notoriously conservative British forces of education would have daunted most men; but not Armstrong, in spite of his preoccupation with higher technical education and chemical research. He was, in fact, firmly convinced that higher education in technical subjects could only be properly built up on a satisfactory basis of elementary education.

Armstrong's first public pronouncement on methods of teaching science was made in a paper read before an International Conference on Education in 1884. In this paper he first advocates the teaching of the general science of daily life by setting the pupils to carry out practical experiments so designed that the students find out things for themselves. At the same conference a paper on somewhat similar lines was read by Professor Meiklejohn, who used the term "heuristic" to describe this style of teaching. The dictionary definition of the word is "serving to discover"; it was not to be found in a dictionary at that time. Armstrong was in rebellion against the practice of teaching scientific subjects by the didactic methods, almost universal at the time, acquired from the teachers of classical and humanistic subjects. Science is an ever-growing body of knowledge acquired by experi-

ment, observation and use of the imagination, not a static collection of dogma. In his view the only satisfactory way to teach it is by leading the young student by suitable paths to experiment and discover for himself, making every use of the natural inborn curiosity which he believed every child to possess. He quoted a saying of Lessing to emphasise the difference between didactic and heuristic methods: "If the Almighty were in the one hand to offer me Truth and in the other the Search after Truth, I would humbly but firmly choose the Search after Truth." Many years of hard work followed before Armstrong saw the truth of his arguments becoming acknowledged and the methods he advocated adopted. He worked largely through the British Association, which in 1887 formed a committee "for the purpose of enquiring into and reporting on the present methods of teaching chemistry in schools"; its members were Armstrong, J. T. Dunn, W. R. Dunstan, J. H. Gladstone, A. G. Vernon Harcourt, Francis Jones, R. Meldola, Pattison Muir, W. J. Russell, W. A. Shenstone, Professor Smithells, and Mr. Stallard—a truly representative body. Equally impressive are the names of the committee on "The Teaching of Science in Elementary Schools" which was working at the same time: Armstrong, Lydia Becker, Sir John Lubbock, Sir Richard Temple, Sir H. E. Roscoe, James Heywood, N. Story Maskelyne. The first committee issued two important reports in 1889 and 1890, in which were included lengthy suggestions for elementary experimental courses in chemistry, entirely the work of Armstrong. These recommendations were, in part at least, taken into consideration by many educational and examining bodies, and played a very large part in reforming the teaching of science. Armstrong's many essays and addresses on the subject, including the British Association report, are included in his book "The Teaching of Scientific Method," 3rd Edition, 1925.

He was helped by a number of devoted disciples, notably by Hugh Gordon, an Oxford graduate who worked amongst the teachers of the Surrey Council Schools and later for the London School Board; by E. M. Rich, who worked in Staffordshire, Ireland and later became Director of Education under the London County Council; and by E. M. Heller, who carried reform into the National Schools of Ireland against much opposition. Mr. C. E. Browne successfully introduced Armstrong's methods in the very letter and spirit, at Christ's Hospital. Armstrong's own first-year chemistry course at the Central Technical College was essentially heuristic in character. The engineers, who formed the majority of his students, made some fun of it; but many expressed appreciation of the value of the training in after life. The method is slow at first but it does inculcate sound principles and habits. To the last Armstrong was dissatisfied with the results of his efforts in the educational field. That his fears were not groundless and that the unimaginative, conservative spirit which he fought so strenuously to reform still lingers unregenerate in dark places is shown by a letter in *Nature* of July 27th, 1940, from a schoolmaster who, discussing practical science teaching in public schools, proposes abolishing all practical work until after the school certificate examination, and cramming every boy, regardless of his capacity, with Latin. "Two good science lectures weekly, with demonstrations," he maintains, "are all that are required." It is because of this spirit in educational circles that the level of appreciation of the potentialities of science is so low amongst our general public, our business men and our administrators. In spite of such die-hards there is no doubt that revolutionary changes have taken place since Armstrong began his campaign over 50 years ago, and these changes are due more to him than to any other man. It must be recorded that it was he who induced the Council of the British Association to establish the Educational Science Section in 1901, against much opposition. He devoted much time to putting it on its feet in its early days, receiving enthusiastic support from Sir Philip Magnus.

As a teacher himself Armstrong was incomparable. He lectured, at South Kensington, only to the first-year students, since he regarded the ground-work as of the greatest importance. Although his methods were essentially heuristic, leading the student on from one discovery to another, he yet covered an amazing amount of ground, and any student who followed his course carefully had a sound knowledge of the fundamentals of theoretical and inorganic chemistry, and also an appreciation of the history and growth of the science. The lectures were abundantly illustrated with carefully designed experiments which seldom failed.

His instruction of the senior chemistry students took the form of discussions rather than formal lectures. Listening to him we felt and knew that everything he told us was the outcome of his own experience and deep thinking, that we were not merely being told uncritically what other people thought. If we did not profit from his teaching, our own stupidity was to blame.

Text books were abjured ("in our subject they are rarely otherwise than collocations of dogmatism and narrow mindedness") but for general reading he recommended Kingsley's "Town Geology," Cooke's "New Chemistry," Black's "Magnesia Alba" and Faraday's "Researches in Electricity," all calculated to imbue the student with the spirit of science.

Armstrong found time, amongst all his other activities, to be an active Governor of two important schools, first St. Dunstan's College, Catford, and then Christ's Hospital, he being appointed to represent the Royal Society on the Council of Almoners of the latter school in 1896. To Christ's Hospital he gave invaluable, unstinting service. The removal of the School from Newgate St. to West Horsham in 1902 gave the opportunity for building new modern laboratories for science teaching. The design and equipment for these were his special care, besides such matters as water supply, drainage and sewage, and he paid close attention to the diet of the boys. Workshops for manual training were built and equipped at his instigation, and a revolution took place in the provision for art training. Owing to his efforts the school, which had been traditionally devoted to classics and mathematics, became the best equipped school in the country for science teaching. As late as 1929 he supervised the building of a new science block made necessary by the expansion of the needs of the school. It was at Christ's Hospital that he found the best opportunity for putting into practice heuristic teaching at a school, for at first the institution was free from interference from outside examining bodies. In 1908, however, the school was obliged by the Board of Education to adopt the School Certificate Examination as a criterion of efficiency, and the heuristic teaching had to be modified to meet the requirements of the examination syllabus. The spirit of the method was, however, maintained. Armstrong was deputy chairman of the school's Education Committee from 1916—1930, then Chairman up to 1937, when he retired owing to ill-health and was appointed Education Adviser by the Council as a mark of their appreciation of his great services.

Armstrong's many and diverse activities outside the fields of chemical research and teaching would require a full scale biography for adequate description and appreciation. Here they can be no more than touched upon. His intense interest in agriculture found expression in his long connection with Rothamsted, where he represented the Chemical Society on the Lawes Agricultural Trust Committee from its inception in 1889, becoming vice-chairman in 1918 and chairman in 1937, shortly before his death. He was responsible for inducing the Indian Government to start a Research Institute for studying indigo cultivation in India in 1915, believing firmly that under scientific control the natural product could compete with the synthetic with immense benefit to Indian agriculture. Unfortunately the experiment, which was producing results, collapsed under the economy axe in 1923. His experiences in India and elsewhere made him an enthusiastic advocate of the methods preached by Sir Albert Howard for utilising vegetable and animal refuse for enriching the soil. Pasteurisation of milk was a subject on which he held strong views, believing the practice to be wrong in principle; the tuberculous cattle should be eliminated. His friends will all remember his strong support of the British dyestuff industry and his very personal method of showing his enthusiasm by appearing at evening functions, at home and abroad, in a brightly dyed waistcoat. The waistcoat of Caledon Jade Green was perhaps the most becoming of his collection, although the one of indigo-blue with thioindigo-red facings was the most striking. At the Faraday centenary exhibition at the Albert Hall in 1931 he organised, on chemical lines, a wonderful exhibition of dyed fabrics and pigments. This exhibition was subsequently shown at a Friday evening lecture at the Royal Institution.

He had his vision of a Utopia in which the science of chemistry came into its own. He gave expression to his shape of things to come in an address "As it should be tomorrow" to the Frankland Lancastrian Society, June 18th, 1935. Since by eating we live, there should be intensive research on the influence of food on growth, both of plants and animals; particularly the influence of soil factors and fertilisers on the growth of

plants must be studied. Correct feeding he believed to be the true basis of health, and the chemist must discover what correct feeding is. At the end of seventy years of study he says "Chemistry is, after all, the science of life—as such, very difficult." In national affairs he saw the need of controlling man's actions against his most deeply ingrained instinct—the sin of covetousness, the mainspring of all commerce. Against the uncontrolled waste of industrialism, especially in our use of coal, he cried out again and again in speeches and in letters to the press. Above all he wanted to see organised planning by enlightened leaders, and deplored ignorance in high places of the findings of science and the importance of these discoveries in the lives of the people. He desired to see scientific men take their place as leaders in public affairs.

Of his work for the Chemical Society mention has already been made. His address in 1894 on the affairs of the Society is worth reading again for the picture he gives of what were and should be the scope of the chemist's activities. Much of what he foresaw has come true. Even at that time he advocated joint publications with other societies, a course to which we are now being driven. He warned the Universities and chemical manufacturers of the dangers of neglecting chemistry, fearing that our awakening would come too late and that America would go ahead of us as a chemical manufacturing country. This last prophecy is being fulfilled before our eyes. He recommended the examination and exploitation of the natural products of India and the Colonies, a matter in which we still lag behind. The whole address is still apposite; Armstrong's writings, like Shakespeare's, do not get out of date, because he dealt with fundamentals, not with superficialities.

Having lived through such stirring times in the growth of science, and known so many of the leading scientists of his time, Armstrong was specially fitted in later years to recall to the younger generation the history of his beloved science. This he did in many addresses, memorial lectures, biographies and lighter essays. This phase of his activity was foreshadowed in his Hofmann Memorial Lecture (J., 1896, 69, 637), which is a masterly summary and appreciation of the work of the great German chemist. Armstrong's writings on the famous chemists of his time are not only first-rate history from the pen of a contemporary; they are vivid and exciting in style, penetrating in their analysis of character and achievement, whilst reflecting throughout the qualities and ideals of the writer. Collected and reprinted as a volume, they would form a valuable addition to the history of chemistry.

Armstrong was the recipient of many honours. These included the LL.D. of St. Andrews; the D.Sc. of Melbourne and Madrid; the Davy medal of the Royal Society, the Albert medal of the Royal Society of Arts; the Messel medal of the Society of Chemical Industry and the Horace Brown medal of the Institute of Brewing.

To those who were privileged to know him intimately Armstrong was a man of great charm and a warm personal friend. He never forgot or neglected responsive students; he placed them in suitable posts and was always ready to help them on their way through life. Generally they well repaid his trouble. Many rose to high positions in industry, others in the academic world. He had much artistic taste, especially for pictures and pottery. He loved music, especially the opera, and although he admired Wagner and heard the "Ring" whenever possible, he could appreciate the simpler melody of Mozart. He cultivated his garden and was fascinated by the colours of flowers. For holidays he chose the Lake district, being faithful to his early love of Borrowdale. Here he had parties in spring and autumn, generally inviting one or two of his senior students or staff to join him and his family. The simple pleasure of leading an expedition up Sca Fell Pike or Great Gable gave him the greatest satisfaction. Mrs. Armstrong shared her husband's interest in his students and rivalled him in her wonderful memory, even in extreme old age, of everything concerning them.

Armstrong married on August 30th, 1877, Frances Louisa Lavers and had seven children, four boys and three girls, all of whom are still living. He and his wife celebrated their golden wedding in 1927, and Mrs. Armstrong died shortly before her husband in her 93rd year. Her fidelity and sympathy to her busy, and probably sometimes difficult, husband during that long period were gifts which he frequently acknowledged with deep gratitude.

A brilliant portrait of Armstrong was painted in 1927 by T. C. Dugdale, R.A., and was exhibited at the Royal Academy. It was purchased by Armstrong's past students and staff and was presented to Professor and Mrs. Armstrong on the occasion of their

golden wedding. The portrait, which shows the Professor in a characteristic attitude holding one of the atomic models with which he was speculating at the time, is reproduced in this issue of the Journal. After his death it went to the Royal Institution, a worthy place, but one feels it would be more at home in the rooms of the Chemical Society. For Armstrong was, first and last, a chemist. "Chemistry," he wrote, "is an art as much as a science, and the chemist is full of feeling which cannot be quantified." He himself was full of this feeling of which he wrote, and his great services to chemistry cannot be weighed and measured. His mission in life was to serve the advancement of the science of chemistry and its application to social well-being in the widest sense. He carried on his mission to the end with the fervour of a prophet, and his name will not be forgotten.

Some apology is necessary for the late appearance of this obituary notice. The delay is due in part to the illness and death in October, 1939, of Sir William Pope, who had undertaken to write the notice, and later to the conditions caused by the war. The present author gratefully acknowledges his indebtedness to Dr. J. E. Driver, who kindly put at his disposal the notes on Professor Armstrong's work which he had collected for Sir William Pope, and to Dr. E. F. Armstrong for reading and checking the manuscript.

E. H. RODD.

ALFRED BERTHOUD.

1874—1939.

It has been our privilege to attend the courses of Professor Berthoud and to collaborate in some of his work, and we highly appreciate the honour of preparing a memoir of our master, whose character as a man was as impressive as his scholarship.

To his friend and colleague, Professor Briner, we owe a moving tribute published in the *Helvetica Chimica Acta*, in which the nature of his work is pertinently discussed. The following passage is quoted from this article: "His work is the result of the endeavour to attach all observed phenomena to laws and principles whose scope and limits of validity have been the object of serious critical examination. Thus the problem is everywhere raised to a higher plane and often, as, for example, with his studies of thermodynamics, reaches the heights of philosophy, although never at the expense of scientific strictness."

At a time when attempts to explain the physical world tended to lead to harmonious syntheses that were often questionable, Alfred Berthoud remained true to the principles of the school to which he owed his training, that of Ph. Guye and P. Duhem, and the strict reasoning implied by his perfect knowledge of thermodynamics led him to mistrust instinctively even the most attractive of generalisations. This extreme prudence was to leave a deep impression on his work and form a firm, though not intransigent, moral attitude.

His career was entirely spent in the little university town of Neuchâtel whence he came. He studied at the Academy of Neuchâtel, which was later raised to the rank of University. In 1897 the University of Geneva awarded him the degree of Doctor of Science on his presenting a thesis entitled "Recherches sur l'action de l'isocyanate de phényle avec les thioamides," which he had prepared under the supervision of Professor O. Billeter of Neuchâtel. From 1898 onwards he occupied several posts in secondary schools, where his qualities as teacher and organiser were highly appreciated. In 1908 he was appointed to the recently founded Chair of Physical Chemistry and continued his duties as a school-master in conjunction with his university work, until in 1925 he succeeded Professor Billeter as Professor of Inorganic Chemistry and Analytical Chemistry. But his love of work and enthusiasm for scientific research, which were his predominant characteristics, did not allow him to limit his activities to teaching, absorbing as it was. His research work was comparatively extensive, and his contributions to scientific theory particularly important, which is all the more remarkable when it is considered how modest were the material means at his disposal, and how limited was the number of his collaborators. His publications had quickly brought him to the notice of scientific circles and he was everywhere considered an authority on physical chemistry and especially photochemistry. He was therefore often invited as lecturer and reporter to the Société helvétique des Sciences naturelles, the Institut international de Chimie Solvay and the Faraday Society.

In spite of his isolation in such a modest centre of scientific activity as Neuchâtel, and notwithstanding his indifference to official distinctions, he had become an honorary member of several learned societies, an honorary Doctor of the University of Lausanne, and, in 1938, President of the Swiss Chemical Society. He carried on a distinguished activity in this capacity until the time of his death.

Berthoud's work was chiefly in connection with chemical thermodynamics, kinetics and photochemistry. One of the problems to which he gave most attention was the elaboration of a general theory explaining the mechanism of chemical reactions and the influence of temperature on their velocity. In a series of memoirs entitled: "Théorie cinétique des gaz et thermodynamique," "Démonstration par la méthode statistique de la loi de Maxwell généralisée," and "Théorie de l'influence de la température sur la vitesse des réactions chimiques," which date from the beginning of his career, he suggested an original solution to the problem of the interpretation of the empirical formula of Arrhenius. He opened up a new method, which was followed in particular by Marcelin and Rice. The notions of "critical energy and increment," which Berthoud was the first to explain precisely by deduction from purely thermodynamic and statistical considerations, are now accepted and expounded in all classical treatises of physical chemistry.

It was, however, principally through his work in connection with photochemistry that this scholar was to distinguish himself and to attain a reputation in foreign scientific circles. Apart from his treatise of photochemistry, published in 1928, which contains a statement of our entire knowledge of the subject and occupies a place of honour in the libraries of the great English universities, the Professor, assisted by his students, created a considerable body of experimental material. The mechanism of a large number of photochemical reactions in the liquid phase, produced by halogens, was explained, and the fundamental laws of photochemistry, those of Grotthus-Draper and the law of equivalence formulated by Einstein, were subjected to a strict critical examination. Space forbids a discussion of the results obtained, but we may recall that the mechanisms suggested by Berthoud for the phenomena of optic sensitisation and the transposition of geometrical isomers are universally accepted. The report presented to the third Council of the Institut international de Chimie Solvay at Brussels, on the problem of photochemical sensitisation, is a monument to his mastery of the subject.

We also owe to Professor Berthoud important didactic works. His scientific culture was extended to every sphere of theoretical chemistry and enabled him to write a volume on the constitution of matter and the atom, which went through two editions and has been translated into English. Without producing the ordinary simplification for the layman, Berthoud succeeded in explaining to a wide educated public the recent results of scientific research in relation to a problem whose solution has always been regarded as one of the essential aims of physical science and which can leave no one indifferent to-day. Finally, in 1938, a short time before the beginning of his fatal illness, Berthoud published his fine treatise of physical chemistry, a volume of some 500 pages, in which he adequately expounded, in the light of the most recent discoveries, our entire knowledge of this science, which is now in full process of development.

This article in memory of our master cannot be more aptly concluded than by the following quotation of the last few words of Professor Briner's article mentioned above: "This work was thus his supreme homage to physical chemistry. It is indeed an act of homage, the finest one can perform for any science, to devote to it a work capable of stimulating, initiating and training for its service, a chosen body of disciples. Professor Berthoud was one of these in the domain of physical chemistry, and of exemplary rank. He loved it dearly, and to it he devoted his whole life as a scholar." W. E. BERGER.

OLIVER GATTY.

1907—1940.

OLIVER GATTY died on June 5th, 1940, as the result of an accident while he was engaged on research in the service of his country. Few men are fortunate enough to combine great and wide-ranging intellectual power with athletic talent; in Gatty's case these gifts

were coupled with an almost overwhelming modesty and great personal charm. To all who knew him, he will remain a most memorable man.

Gatty was born on November 5th, 1907, the elder son of the late Sir Stephen Gatty, Chief Justice of Gibraltar, and of Lady Gatty. He went up to Balliol College, Oxford, in October, 1926, from Winchester. As an undergraduate he enjoyed the distinction of playing for his college at rugger, soccer, cricket and squash rackets as well as being President of the Junior Common Room. He got a First in chemistry in 1930 and after a year as a lecturer became a Tutorial Fellow of the college in 1931. His interests were clearly in research rather than teaching, and after two years he resigned his fellowship to work for a time at Rothamsted. From there he went to work at Cambridge with Professor James Gray and more recently with Professor Rideal. In 1939 he married Penelope Noel Tower.

Gatty's first paper was on the dielectric constant of conducting media. After a short period of work on the thermochemistry of electrolytes he turned to electrocapillarity, a subject which had a great fascination for him and on which he published a series of papers, largely with J. St. L. Philpot, S. R. Craxford (who had been his contemporaries at Balliol), and E. C. R. Spooner. His interest in electrically charged surfaces led—almost inevitably in one with Gatty's imagination—to studies in the rôle played by such surfaces in biological phenomena. His later work was more and more concerned with biophysics, in which, but for his tragic end, he might well have made most valuable contributions.

Gatty had many interests outside his work. In 1932 he attended the Ottawa Conference as secretary to Mr. Amery, and in 1933 he joined an expedition to Spitzbergen. For a time he made a patient and critical study of a variety of allegedly supernatural manifestations. By his death science has lost an investigator of great imagination and unquenchable curiosity; many of us have lost a gay, generous, and loyal friend.

Gatty was elected a Fellow of the Society in May, 1933.

J. H. W.

PERCY GEORGE MANDER.

1881—1940.

WITH the death, at Leeds Infirmary on July 15th, 1940, of Percy George Mander, Doncaster Grammar School mourns the loss of one of its best known personalities and a devoted servant.

Mander was born in Coventry on August 20th, 1881, and was educated at Bablake School, Coventry. The years 1897—1901 were spent at Mason University College, Birmingham, and the Royal College of Science, London, where he graduated B.Sc. (Lond.) with first class honours in chemistry, and A.R.C.S. At the same time he prepared himself for a teaching career and became an Associate Member of the College of Preceptors. He was an Associate of the Institute of Chemistry, and was elected a Fellow of the Chemical Society in February, 1903.

In 1901 he was appointed science master at Ashby-de-la-Zouch Grammar School, whence he proceeded to Doncaster in 1907, and remained there until his death.

During the Great War he served in France as a Captain in the 4th Duke of Wellington's West Riding Regiment. He was invalided home after the Battle of Ypres in 1915, but returned to France shortly afterwards and was severely wounded on the Somme in 1916. After a long period in hospital he was posted to the Ministry of Munitions, where he carried out some important research work in collaboration with the late Professor T. M. Lowry. After demobilisation he returned to Doncaster to resume his duties as Senior Science Master.

During the course of his thirty-three years association with the Grammar School Mander entered wholeheartedly and enthusiastically into every branch of activity. A man of wide culture and charming personality, his largeness of heart, breadth of knowledge, and many interests endeared him to his colleagues and the boys. A keen appreciation of Nature was a salient feature of his character. He was quick to distinguish between the fundamental and the ancillary, and this found expression in his brilliant notions for demonstrating some experiment with the simplest of home-made apparatus of the cheapest kind. He was a keen advocate of the experimental in school science and viewed both ready-made apparatus and text-books with mild suspicion. The pity of it that a complete record

of his many ideas was not compiled by him! but there are hundreds of Old Danensians who hold him in gratitude for the stimulus he gave them. As Second Master and Housemaster he fostered the cheer in place of the jeer in whatever activity was afoot.

In his younger days Mander was an all-round athlete and played an excellent game of "rugger," hockey, tennis, and cricket. As a "three-quarter" for Coventry R.U.F.C. he was a keen exponent of the art of the oval ball. His war wounds curtailed his athletic activities and his chief hobby became photography. His many interests included the study of bird life, field botany, and local architecture, and to these he brought originality of outlook which made him delightful company. Genial, friendly, kind and courteous, he compelled affection and regard.

He was a Mark Mason and Past Master.

His death will be mourned by a wide circle of friends, and their sympathy will be extended to his widow and two daughters.

IDWAL G. JONES.

FRANK THOMAS SHUTT.

1859—1940.

THE death of Frank Thomas Shutt on January 5th, 1940, at the age of 80 years, marked the end of a notable career in agricultural chemistry. Born in Stoke Newington, London, England, on September 15th, 1859, a son of William Denis Shutt, C.E., and Charlotte Cawthorne Shutt, he came to Canada as a boy and graduated from the University of Toronto, B.A. (1885), with first class honours in chemistry, and M.A. Toronto, 1886. In 1914 his Alma Mater awarded him the degree D.Sc. (honoris causa). He was appointed in 1887 chemist to the Dominion Experimental Farms System with headquarters at Ottawa. In 1912 he was given the title of Dominion Chemist and was appointed Assistant Director of Experimental Farms and served in this dual capacity until his retirement under superannuation in September, 1933.

Following his appointment to the Experimental Farms System in 1888, Shutt visited Rothamsted, England, and other stations, including that of Bernberg, Germany. At Rothamsted he became acquainted with Sir John Bennet Lawes and Sir Joseph Henry Gilbert. He was also a friend of Sir Daniel Hall and Sir John Russell. He received lasting inspiration from his early contacts and became especially interested in the value of legumes as fertilising agents. He was the first in Canada to establish on a firm scientific basis the manurial value of clover and legumes in general and to distribute this valuable information to Canadian farmers. His investigations have gone far towards establishing a judicious and rational use of fertilisers. His pioneer experiments relative to the cause and prevention of "softness" in pork and bacon have been of great value to the live stock industry. His investigations of the qualities of Canadian grown wheat were extensive and had much to do with the permanent establishment of Marquis wheat. His publications contain a wealth of excellent material regarding plant food and soil fertility, farm manures, green manuring, artificial manures, fertiliser formulæ and the fertiliser needs of various crops. He was a prolific writer of articles, reports, bulletins and official and scientific documents of extreme clarity and pureness of diction and contributed nearly forty articles to the *Transactions* of the Royal Society of Canada and many important papers to home and foreign journals.

Shutt's achievements have received recognition. In 1935 His Majesty appointed him a Commander of the Most Excellent Order of the British Empire. In the same year the Royal Society of Canada awarded him the Sir Joseph Flavelle medal. He was also awarded the prize of The American Society of Agronomy for outstanding research.

Shutt was a Fellow of the Chemical Society since 1886, of the Institute of Chemistry of Great Britain and Ireland, of the Canadian Institute of Chemistry, of the Royal Society of Canada. He was a member of the Society of Chemical Industry, the American Chemical Society, the Society of Public Analysts and an original member of the American Association of Official Agricultural Chemists.

C. H. ROBINSON.