REGINALD WILLIAM JAMES

1891-1964

R. W. JAMES, born 9 January 1891, was a Londoner born and bred. His father, William George Joseph James, was an umbrella maker and shopkeeper in Praed Street, Paddington, whose forbears had lived in Paddington or Marylebone for over a hundred years. 'My family lived in the house over my father's shop, and the circumstances of my boyhood were definitely urban, mitigated however by the nearness of Kensington Gardens in which much of my childhood was spent. The family business, although neither large nor very prosperous, was enough for our needs and my childhood was a very happy one. My father's family were Baptists, and I was brought up in the non-conformist tradition, although not in the strictest one.' In 1896, at the age of five, James went to the Infant School attached to St Michael's Church, Paddington, and to the boys' school two years later. In 1903 he started his secondary education at the Polytechnic Day School, Regent Street. He showed mathematical ability and it was suggested that he should take up actuarial work; with this possibility in view he passed in 1907 the first examination for the Institute of Actuaries as well as the matriculation examination for London University. But he also obtained a London County Council Scholarship which gave him two post-matriculation years at the City of London School. In December 1908 he won an Entrance Scholarship of £80 a year for Natural Science at St John's College, Cambridge, and the next year, on leaving school, the Beaufoy Mathematical Scholarship tenable at Cambridge. He entered St John's College as a Foundation Scholar in October 1909.

From his description of his youth, it is clear that there were family influences, as well as educational ones, which led to the young James becoming a scientist. His father, although without formal scientific education, had a very deep interest in chemistry and natural history. His mother's eldest brother, Robert Avery Ward, was head of the Department of Chemistry at the Regent Street Polytechnic. His aunt was married to John Garwood Everett, who was a keen amateur botanist and a nephew of Professor J. D. Everett, F.R.S. 'I was used to hearing current scientific topics discussed at home, I was encouraged as a matter of course to observe plants and insects and to visit the Museums in South Kensington, and there is no doubt that my own interest in natural knowledge had its origin in this home atmosphere. In my later boyhood my great ambition was to be an astronomer, and

I read all the popular books on the subject I could find, and made my own observations with a small telescope from our roof. The realization that one could not do astronomy without mathematics undoubtedly made me work hard at that subject when the chance came.'

He also counted himself fortunate in having had excellent masters who stimulated and fed his growing interest in science. At the Polytechnic Day School 'The mathematical teaching was in the hands of Mr Percy Abbott, a teacher of exceptional ability and enthusiasm, who had a great influence on me, and to whom I am most grateful for the thoroughly sound training in elementary mathematics that he gave me'. At the City of London School 'It was here that my interests turned definitely to physics, and I remember being particularly attracted by the phenomena of interference and diffraction which I then met for the first time. The physics master was Mr P. J. Vintner, who stimulated us to read widely and discuss freely.

'The head of the Science Side was Mr Henry Durham, who was in many ways the most inspiring teacher I have known. He was then certainly over seventy, but he maintained a wonderful freshness of outlook and succeeded in instilling into his senior pupils much of the true spirit of research. I can still remember the excitement of hearing from him about the periodic classification of the elements, of which I had not before known. Durham, as a young man, had known and revered Faraday, and I am sure he was able to transmit a little of his spirit to us. Practical Chemistry was taught by Mr Isaac Scarf, a fine teacher and a most lovable man.

'The mathematical master was Mr F. W. Hill, formerly fellow of St John's College, Cambridge, a stimulating teacher, who treated his boys individually, making them work for themselves and giving them confidence.'

At Cambridge James read physics, chemistry, and geology for Part I in which he obtained a 1st Class in 1911, and physics for Part II. We were class-mates in C. T. R. Wilson's Part II laboratory; I remember that before the examination Crowe, C.T.R.'s laboratory boy, about eighteen, drew up a list of the classes most of us would get in our Finals. He put down James and myself for Firsts; I am glad to say he was right, as indeed he was for most if not all of our fellow students; one felt that the examiners were hardly necessary. We attended together J. J. Thomson's lectures on properties of matter and electricity which were highly stimulating, C.T.R.'s lectures on physical optics, which combined the best content with the worst delivery I have ever experienced, and the very formal and dry mid-Victorian lectures of Searle. I am sure it was C.T.R. who had the greatest influence on us, both in his lectures and in the practical class. He turned each experiment into a small research and would not let us go on to the next until we had extracted the maximum of information from it.

James wrote: 'I started research at the Cavendish Laboratory in October 1912 under Sir Joseph Thomson, and until the summer of 1914 worked on developing a method for measuring the velocity of gaseous ions suitable for use at the temperature of liquid air. I used a modification of Rutherford's

alternating-field method in which fields of unequal strength were applied in the positive and negative directions. The apparatus was just beginning to give results when I had to leave Cambridge and no paper was published.' The last remark is not surprising, for conditions in the Cavendish Laboratory were difficult at that time. Except for two or three of the very senior people, the research students had no help from the laboratory workshop and had to make all their gear with tools they were expected to provide for themselves. Funds for buying apparatus were extremely restricted. There were indeed too many students chasing too few ideas for research and too little apparatus. J.J.'s fame had attracted some forty or so to work under him. Apart from J.J. there were no leaders of research on the staff who could look after the junior people, since C.T.R. always worked quite alone and Searle had no opinion of researchers and research generally. So young people who had come to the Mecca with research grants from all over the world had a discouraging experience. Our home-made apparatus, except in the case of one or two mechanical geniuses, was quite inadequate to achieve results worthy of publication.

Then, at the beginning of July 1914, a wholly new world of experience opened for James when he was appointed physicist to Sir Ernest Shackleton's Antarctic Expedition. To Shackleton the lure of the expedition was that of an exciting and dangerous exploration but he wished also to justify it by making it of scientific value, and engaged James Wordie as geologist and James as physicist. In a memoir which he wrote for the Cape Town University magazine, Professor Schaffer gives James's own account of how he came to be appointed.

'I was about to leave Cambridge and had gone to say good-bye to a friend who was ill in a nursing home, when I was hailed from a window in a street that I had never passed through before in my whole five years at Cambridge, by a fellow research student at the Cavendish Laboratory, with the words, "Hi, James, do you want to go to the Antarctic"? I said, "No, not particularly. Why"? He then told me that Shackleton had so far not got a physicist, and had asked Sir Arthur Shipley, then Master of Christ's, to try to find a man. After a little discussion, I said he might send my name to Shipley, expecting to hear no more about it; but on returning to my rooms in the evening I found a note from Shipley asking me to come and see him after Hall. Shipley was a biologist, and knew little about physics; and plainly all he wanted was to find someone he could send to Shackleton, and he persuaded me to let him send my name forward. After that I heard nothing for about three weeks. Meantime I had got an appointment at Liverpool University . . . On my way home I visited some relatives in Manchester, and while there received a telegram from Shackleton asking me to see him next morning in London. I did so, and was appointed after an interview of about ten minutes at the outside, probably more nearly five. So far as I remember he asked me if my health was good, if I suffered from varicose veins, if I had a good temper, and if I could sing. At this question I probably looked a bit

taken aback, for I remember he said: "Oh, I don't mean any Caruso stuff; but I suppose you can shout a bit with the boys." He then asked me if my circulation was good. I said it was except for one finger, which frequently went dead in cold weather. He asked me if I would seriously mind losing it. I said I would risk that. He did not ask me about my physics, because Shipley had asked J. J. Thomson, who said that was all right . . . After this he put out his hand and said: "Very well, I'll take you." '

Here I think one comes across for the first time an unsuspected quality in James's character which was on more than one occasion to surprise his friends. He had hitherto led such a quiet and ordinary life, conforming to the pattern of any young man with an aptitude for science who had made his way through school and university, with little interest in games or sport and a restricted social life. Yet when confronted with the alternatives of the obvious safe post at Liverpool and the adventure with its unknown difficulties and dangers, he had no hesitation in accepting its challenge. He did not even ask for time to think it over in the interview which lasted for 'ten minutes at the outside'. Commander L. Greenstreet of the Shackleton party writes: ' "Jimmy" was very much absorbed in his work always and I suppose had little in common with the outlook of the seafaring side. I know I had great admiration for the fact that he had volunteered to come on such an expedition with the very sheltered background that he had. I think he was completely absorbed in the educational side, games and social life having no part in all his life then—and then to come on an expedition such as ours with no real knowledge of the outside world was a stupendous thing for him to do whereas for me at least it was no great change, brought up as I was from the age of 15½ in the hard case Cape Horners. He bore with great fortitude the privations and vicissitudes that fell to all the members of the expedition.'

This is not the place to give an account of the expedition. It may just be recalled that, after a propitious start, disaster befell it. *Endurance* became locked in the ice, and the pressure ridges so damaged the boat that it had to be abandoned in October 1915. A camp was made on the ice flow with such stores as could be saved, and when the crushed ship sank some three weeks later the party of 28 was left with three small boats and limited supplies on a floe in which water-lanes were constantly opening up and closing. Finally the floes opened up sufficiently for the party to be able to take to the boats and they managed to reach Elephant Island. There the main party made shift under their upturned boats, while Shackleton with a few companions made his famous boat journey to South Georgia to get help. James's diary is preserved in the Scott Polar Research Institute at Cambridge, and the following is an extract from the entry on 30 August 1916. 'A great day. Went out limpet gathering with Hurley in morning and had got back and was drying out in front of stove and hoosh was just being served out. We heard a few shouts outside which we took as merely warning of the readiness of food to those working outside. Suddenly Marston came in and said in quite a casual tone: "Hadn't we better send up some smoke signals?" Then

we realized what had happened and just tumbled out of that hut pell mell, some boots on, some off. Mine were on the wrong feet. There we saw a steamer out off the point. We grabbed all kinds of things and waved and lit fires and shouted and soon had the satisfaction of seeing the ship turn in and lower a boat. Soon we saw the Boss's figure in the boat and Wild was able to hail and call out "All Well".'

James had a part in the saving of the expedition. There was no radio, and after so long a time the chronometers were quite unreliable, so they had no idea of the longitude to which the floe on which they were camped had drifted. Fortunately a *Nautical Almanac* had been saved from the wreck, and James taught himself how to get the time from lunar occultations. He observed a favourable one, and this told the party its longitude and so enabled it to take to the boats when nearest to Elephant Island where they made their landing.

James did not sail from England in *Endurance*, he was helping to look after the dogs, and joined the ship at Buenos Aires, travelling with Shackleton by steamer. I remember his telling me the disastrous consequence of feeding whale-meat to some of his dogs; the wretched animals got worms from the meat which developed into a size appropriate to whales with disastrous consequences. Once at Manchester refectory where we lunched together his neighbour was Professor Tout who was particular about his food. Prodding his stew disgustedly with his fork Tout said to James: 'Have you ever eaten dog?' James, with that diffident pleased grin so characteristic of him, said: 'Yes, it's quite good.' The party had a hard time on Elephant Island; again and again a seal or a few penguins arrived on the scene just in time to save them from starvation. James was once a hero for flinging himself bodily on a seal making its way back to the sea and holding it back sufficiently for someone to run up and shoot it. Two small upturned boats had to house the party; this was achieved by making an upper story with planks and oars laid on the benches. James said he once heard the restless sleeper next to him muttering: 'Turn it over on the other side and it will be done nicely.' James grew a beard to match his red hair; he liked recalling with a chuckle that one of the sailors had said: 'Jimmy, you look just like a rat peering through a bale of oakum.' Commander Greenstreet recalls the following incident. 'After the vessel was frozen in, we had turned the large cabin, where all the scientific staff had used to berth, into the "lab" where the scientific gear was stowed and the scientists could carry out their work without outside interference. I happened to be passing the door which was open and I heard a stream of obscene and virulent invective pouring forth as I paused and looked in, and to my surprise saw Jimmy there by himself fiddling and dropping various glass tubes—he always was the most clumsy fellow with his hands I ever came across. I was dumbfounded as I had never heard him swear before and could not think how he could have picked such a selection of swear words. I tip-toed away and told some of the others, and we silently made our way back to the "lab" and stood outside shaking with silent laughter till someone

tittered and Jimmy looked round blushing to the roots of his hair that his flight into the realms of sailor language should have been overheard.' It must have been the occasion to which James referred when he told of a sailor's comment: 'Jimmy, for a landsman you're not doing too badly.'

It is clear from the accounts of his comrades that James found it difficult to adjust himself to the conditions of the expedition and find his place amongst his fellows, and this is not surprising. Most of them were tough experienced sailors, and those who were not had shaken down into ship-board life during the voyage from England to Buenos Aires which James missed because he came out by steamer. The expedition had a gruelling time which tested the most hardy. James had the frustration of not being able to do the scientific work for which he had been appointed. But one of them says of him: 'There was nevertheless something decent and honest about him which commanded respect. He gradually found his feet, and though always "just Jimmy" for whom allowances had to be made, he gained an accepted place. He never groused or complained, and I regarded him as a brave man with plenty of "guts".'

The expedition was rescued in August 1916, and James reached England that November. In January he was commissioned into the Royal Engineers and came out to the front to join the first experimental sound-ranging section, which I had established on Kemmel Hill just south of Ypres. Sound ranging is a method of getting the positions of enemy guns by recording the times of arrival of the sound at a series of microphones along a base behind the front line. The French had installed a number of sections, and it was decided in the autumn of 1915 to make a trial of it in the British sector. For more than a year the results were very disappointing. An unsuitable type of microphone was first used which was sensitive to high pitched noises, and very insensitive to the low-frequency wave from the discharge of the gun. Then the Tucker's microphone was developed at the Kemmel Section. It had just the reverse characteristic response, and revolutionized sound ranging which became an effective and trusted method of discovering the disposition of the enemy guns. James played a large part in the development of the method, one of the very few scientific schemes in World War I, and towards the end of the war he was Officer in Charge of the Sound-Ranging School, with the rank of Captain.

After the war, James joined the staff of the Physics Department at Manchester University, and was a member of it from 1919-1937 (Lecturer 1919, Senior Lecturer 1921, Reader in Experimental Physics 1934). He made a world-wide reputation for himself as an X-ray crystallographer. His bent was established by his collaboration with W. L. Bragg and C. H. Bosanquet in measuring the absolute reflecting power of rock-salt crystals for X-rays, that is, the quantitative relationship between the reflected rays and the incident X-ray beam. The object was to verify the formula for X-ray reflexion which C. G. Darwin had developed before the war, in a brilliant piece of theoretical work which had to wait for nearly a decade before experimental

technique was sufficiently advanced to test it. The importance of the state of perfection of this crystal on the intensity of X-ray reflexion had been pointed out by Darwin, and the 'B.J.B.' experiments showed that rock-salt reflected nearly as a mosaic, or ideally imperfect crystal, which is the easiest type on which to make quantitative measurements. The secondary extinction or diminution of total reflected intensity due to rays reflected by upper layers not reaching the lower layers, was measured; in fact the quantitative side of X-ray reflexion was thoroughly thrashed out. This work led to a determination of the scattering power of atoms at different angles, and so to a measure of the distribution of electrons in the atoms which could be compared with calculations being made about that time by D. R. Hartree. Another aspect was the investigation of the effect of temperature on the intensities of X-ray spectra. Before the war the Debye formula for the diminution in intensity of reflexion with rise of temperature, due to the atomic vibrations, had been tested qualitatively by W. H. Bragg. A quantitative investigation was now undertaken by James and his co-workers, first from room temperature up to about 700 °C, and later down to the temperature of liquid air. It was found that Debye's formula, as modified by Waller, was valid at low temperatures but not at high ones.

All this work culminated in two highly important papers. The first, a classical one, was the investigation in collaboration with D. R. Hartree and Ivar Waller on the intensity of reflection by rock-salt over a large temperature range. Hartree had calculated the distribution of charge in the atoms of sodium and chlorine by his method of the self-consistent field. It was shown that there was good agreement between observed and calculated scattering factors if the existence of zero-point energy in the lattice was assumed; it was in fact a direct quantitative check on the amount of the zero-point energy. The results were confirmed by further measurements made in collaboration with Brindley and Wood on potassium chloride and aluminium.

The other paper was also, in its way, a landmark. The main effort of the Manchester research school which I directed had been turned to making it possible to analyse more complex structures by X-rays. The first structures to be determined had at most one or two variable parameters which had to be determined by intensity measurements because they were not fixed by the symmetry of the structure. The quantitative measurements of absolute reflexion constituted our main weapon in dealing with structures which had a large number of parameters. The first structure to be worked out with the new methods was that of barium sulphate, which had eleven parameters (James & Wood 1925). A series of similar papers dealing with complex crystals were published by other members of the team, and the campaign culminated in the establishment of the structures of a number of silicates which reduced to order the classification of these outstandingly important constituents of the earth's crust.

One of his colleagues in the Shackleton party has referred to James's clumsiness with his hands. This was perhaps justifiable, but it was in the

sharpest contrast to his experimental work. He was a fine experimenter, neat and careful and thorough, and an excellent designer of apparatus. The zero-point energy investigation was a masterly piece of work; only a first rate experimenter could have attained the accuracy he did with the apparatus available at that time.

James's early interest in optical diffraction developed into his profound knowledge of X-ray diffraction phenomena. His book *The optical principles of the diffraction of X-rays* first published in 1948 has been reprinted four times and is recognized as the leading manual on the subject.

James spent the academic year 1931-1932 in Leipzig working under Professor Debye on the effect of temperature on the scattering of X-rays from gaseous silicon tetrachloride. No measurable effect was found; indeed they showed that no effect ought to be observed.

In 1936 James seemed to be a confirmed bachelor, well dug-in on the Manchester University staff, giving excellent lectures and doing sound research, and likely to follow his established way of life for the rest of his career. He then astonished his friends by announcing that he was engaged to be married, and had offered himself as a candidate for the Chair of Physics at Cape Town; the cable offering him the chair arrived when he and his wife were on their honeymoon. Annie Watson (they were married in December 1936) was the only daughter of John Watson of Rochdale, and was at that time Second Mistress and Senior Classics Mistress at the Manchester High School for Girls. There are three children, John Stephen born in 1938, David William born in 1940, and Margaret Helen born in 1943. He could not have had a happier marriage; the charm, humour and robust commonsense of his wife were the greatest support to him in his career. He took up his duties in Cape Town in 1937, and apart from visits he spent the rest of his life there.

James came to a University which was firmly established as a sound teaching institution and which had in its Senate men of first class academic standing and strong personality. The emphasis, however, was rather on academic training than on research. The University aimed at giving its students a sound education, and then was prepared to see the outstanding ones go to the older universities in England for their further work. James, with some of the other professors and lecturers, built up research departments at the Cape, and they were warmly supported by Davie when he became Principal. James established a research group in crystallography which did excellent work and which produced a number of fine scientists, and the physics department grew in size and reputation under his leadership. The main interests of the department were the structures of organic crystals. At the same time James kept the standard of lecturing at a high level; he spared no pains to make his lectures fresh and interesting as well as sound.

Professor Schaffer, for long his second in command and now head of the Department, says of him: 'He was considerate of his colleagues and his students—though he would never call weakness by any other name—and

his department was a most friendly and pleasant one, largely because everyone in it had complete confidence in his integrity. His personality pervaded the whole department and he had time and sympathy, and often practical help, for everyone in it. Few knew that he gave generous financial help to some who, he thought, needed and deserved it.

'James took his full share in the general work of the University. His uncomplicated wisdom and integrity were highly respected in Senior University Committees and he served his Faculty well as Dean. For some time he was Head of the University as Vice-Chancellor and Acting Principal. The fact that he always preferred scientific work, and accepted the administrative burdens of the Vice-Chancellor's Office with reluctance, in no way detracted from the quality of the service he gave to the University. In administration, as in his scientific work, he had the rare gift of seeing through complicated detail and going to the heart of the problem.'

The controversy about segregation in the universities of South Africa was raging bitterly during his last years. Davie made the first great stand against the Government's attack on the academic freedom of the 'open' universities. When James was Acting Principal after Davie's death, the Separate Universities Bill was going through Parliament. It fell to James to speak for the University on several occasions, protesting against the forbidding of the registration of non-European students, and the curtailing of the freedom of the University to admit as students those it considered academically qualified. His speeches were all the more powerful for being so factual, objective, and restrained. Their statesmanlike quality, and the way in which he rose to the occasion and met his responsibilities as Acting Head of the University, displayed another side of his character.

James had a characteristic thoroughness and integrity in everything that he did. He could not be content with partial understanding of some new idea, he had to worry it over in his mind till he felt he had grasped it completely. He was therefore naturally good at transmitting ideas to others. He took endless trouble to express himself clearly, and was very critical of what he wrote, scrapping it again and again until it conveyed just the meaning he wanted to convey with the least effort to the reader. It is doubtful whether he even gave the same course of lectures twice without making alterations and improvements. He was of course much in demand as a lecturer because his account of the Shackleton Expedition provided such excellent material, and he came to know the towns in Lancashire and the people well. He had the true spirit of scientific inquiry. Everything in nature interested him. He had a wide knowledge of birds and beasts and plants, which enlivened a walk in the country. His early interest in astronomy persisted throughout his life. He had gained much from his training in geology under Marr at Cambridge. He was always noticing interesting physical effects in the simplest phenomena. He was never bored, except perhaps at some committee meetings where his agenda became covered with marvellous faces and doodlings. In Manchester he was an enthusiastic

member of the Rucksack Club and was a great walker. He had a deep love of music though he never learnt to play any instrument. Concerts in Manchester were a constant delight to him. An unexpected side to his character was his interest in the classics. When he won the entrance scholarship at St John's College he had to do Greek and Latin for the Little-go, since he had learnt German instead of Latin at school. When in 1949 he had serious heart trouble and had to take a complete rest for six months, he re-learnt Greek with the Loeb edition of the *Odyssey*, with the Greek on one side and English on the other. At the end of the rest period he would read Homer with enjoyment and always had the *Iliad* or the *Odyssey* at hand to turn to from time to time.

James's whole life gives a rare impression of final fulfilment. For nearly twenty years at Manchester he had lived a quiet bachelor life quite settled in his ways, though one perhaps detected at times a somewhat wistful feeling about friends who had a wider experience—and then came a marriage in which he was exceedingly happy and a family of which he was touchingly proud. For the same period, he had been a member of a staff, quietly pursuing his specialized research and giving sound lectures—and then he became head of a department and successfully created at the Cape a reputation for his research team and his teaching.

His earliest scientific work had prompted his friends to nominate him as a candidate for Fellowship of the Royal Society, but for long they were unsuccessful. Then at last in 1955 his many services to science were appropriately recognized by his election to the Society, a distinction which gave him intense pleasure. He was modestly so proud to be one of the small body of Fellows in South Africa. Then again, after years as a Professor mainly concerned with the running of his department, he was chosen by his colleagues at a time of stress and danger to be their leader and representative, and he did not fail to meet the responsibilities they laid on him. Coming at the end of his active career, it was a wonderful tribute to the simple integrity and soundness of a lovable man.

W. L. Bragg

BIBLIOGRAPHY

1921. (With W. L. Bragg & C. H. Bosanquet.) The intensity of reflections of X-rays by rock-salt. I, *Phil. Mag.* **41**, 309; II, *Phil. Mag.* **42**, 1.

1921. (With W. L. Bragg & C. H. Bosanquet.) The distribution of electrons around the nucleus in the sodium and chlorine atoms. *Z. Phys.* **8**, 77; *Phil. Mag.* **44**, 433 (1922).

1925. The influence of temperature on the intensity of reflection of X-rays from rock-salt. *Phil. Mag.* **49**, 585.

1926. (With W. L. Bragg & C. G. Darwin.) The intensity of reflection of X-rays by crystals. *Phil. Mag.* **1**, 897.

1926. (With J. T. RANDALL.) The scattering powers of calcium and fluorine for X-rays. *Phil. Mag.* **1**, 1202.

1926-1927. The intensity of reflection of X-rays by crystals at low temperatures. *Mem. Proc. Manchr. Lit. Phil. Soc.* **71**, 7.

1927. (With E. M. FIRTH.) An X-ray study of the heat motions of the atoms in a rock-salt crystal. *Proc. Roy. Soc.* A, ~~118~~ 117, 62.

1927. (With I. WALLER.) On the temperature factors of X-ray reflection for sodium and chlorine in the rock-salt crystal. *Proc. Roy. Soc.* A, **117**, 214.

1928. (With G. W. BRINDLEY.) A quantitative study of the reflexion of X-rays by sylvine. *Proc. Roy. Soc.* A, **121**, 155.

1928. (With I. WALLER & D. R. HARTREE.) An investigation into the existence of zero-point energy in the rock-salt lattice by an X-ray diffraction method. *Proc. Roy. Soc.* A, **118**, 334.

missing 1929. (With G. W. BRINDLEY & R. G. WOOD.) A quantitative study of the reflection of X-rays from crystals of aluminium. *Proc. Roy. Soc.* A, **125**, 401.

1931. (With G. W. BRINDLEY.) Some numerical calculations of atomic scattering factors. *Phil. Mag.* **12**, 81; *Z. Krist.* **78**, 470.

✓ 1932. (Theoretical scattering curves.) *Phys. Z.* **33**, 737. Über den Einfluß der Temperatur auf die Streuung der [Röntgenstrahler durch Gasmoleküle]

✓ 1933. Die absolute Bestimmung der Atomformfaktoren durch Versuche mit Kristallen. *Ergebn. tech. Röntgenkunde*, **3**, 32.

✓ 1935. (With G. KING & H. HORROCKS.) The crystal structure of para-dinitrobenzene. *Proc. Roy. Soc.* A, **153**, 225.

✓ 1947. (With D. H. SAUNDER.) Some apparent periodic errors in the crystal lattice of the molecular complexes of 4 : 4′-dinitrodiphenyl with 4-iodo and 4 bromodiphenyl. *Proc. Roy. Soc.* A, **190**, 518.

✓ 1948. (With D. H. SAUNDER.) Periodic errors in the crystal lattices of some molecular complexes of 4 : 4′-dinitrodiphenyl. *Acta Cryst.* **1**, 81.

✓ 1948. False detail in 3-dimensional fourier transformations of crystal structure. *Acta Cryst.* **1**, 132.

1921 (With W. L. Bragg & C. H. Bosanquet) Über die Streuung der Röntgenstrahlen durch die Atome eines Kristalles. Z. für Phys. 8, pp. 77 – 84 ✓

1921 The Crystalline Structure of Bismuth. Phil. Mag. 42, pp. 193 – 196.

1924 Some Problems Relating to Antarctic Sea-Ice. Mem. & Proc. Manchester Literary & Philosophical Soc. 68, pp. 81 – 90.

1925 (With W. A. Wood.) The Structure of Barium Sulphate, Mem. & Proc. Manchester Lit. & Phil. Soc. 69, pp. 1 – 13.

1925 (With W. A. Wood). The Crystal Structure of Barytes, Celestine and Anglesite. Proc Roy Soc. A, 109, pp. 598 – 620.

1927 (With J. West & A. J. Bradley): Crystallography. Annual Reports of the Chem. Soc. 24, pp 273 – 291.

1928 (With W. L. Bragg, J. D. Bernal & A. J. Bradley): Crystallography, Ann. Reports of the Chem. Soc. 25, pp. 275 – 302.

✓ 1934. The Intensities of X-ray Spectra and the Imperfections of Crystals. Z. Krist. 89, pp. 295 – 309.

P.T.O.