Ernest Rutherford

The Man Who found Nucleus in the Atom

Gopalpur Nagendrappa

Rutherford was the greatest experimental physicist since Faraday. He had the most astonishing insight into physical processes, and in a few remarks he would illuminate a whole subject. He liked his physics and his experiments simple and described his work in simple and concise language. Rutherford's discovery of the atomic nucleus had solved the mystery of the matter which had troubled the world's great philosophers for centuries. He is to the atom what Darwin is to evolution, Newton to mechanics, Faraday to electricity and Einstein to relativity. These are a few remarks made about Rutherford by his students and colleagues.

G Nagendrappa was a Professor of Organic Chemistry at Bangalore University, and Head of the Department of Medicinal Chemistry, Sri Ramachandra (Medical) University, Chennai. He is currently in Jain University, Bangalore. He continues to teach and do research. His work is in the area of organosilicon chemistry, synthetic and mechanistic organic chemistry, and clay-catalysed organic reactions (Green Chemistry).

Till the beginning of the twentieth century the composition of matter and the nature of its constituents were only in the realm of speculation; atoms were objects of imagination and their existence had no irrefutable experimental evidence. But this started changing rapidly towards the end of the nineteenth century, gathering great momentum as the twentieth century began. In astonishingly quick succession the existence and nature of the atom were experimentally proved. A leading player in this great game was Ernest Rutherford. He had not only cracked the secrets of the atom but he had literally cracked it too. It had been grist to the mills of imagination of great philosophers all over the world for many centuries. The hazy picture that seemed to stay forever became clear within a decade due to the unassailable experimental results gathered by Rutherford and his associates. Without knowing the basics of the working model of an atom, science could not have been what it is today. Of course, it changed, as a consequence, every other human activity also.

Keywords
α-scattering, nuclear atom, radioactivity, atomic model, Geiger–Marsden experiment, disintegration of elements, smoke detector.

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Early Life and Education

Ernest Rutherford was born on August 30, 1871 at a small town called Bridgewater near Nelson in New Zealand's South Island. He was the fourth among twelve children of James and Martha Rutherford, who had migrated from Scotland, about 25 and 15 years earlier respectively. James was working as a wheelwright, making and repairing wheels and wheeled vehicles, and Martha was working as a teacher. The family moved to a nearby town, Foxhill, and Ernest had his school education there between 1877 and 1883. They moved again to another town, Havelock, and Ernest did not show much interest in science, but enjoyed imitating what his father was doing and expected to become a farmer.

However, Ernest's career took a different route as he got a scholarship and joined the provincial Nelson College, an English Grammar school. Later he was able to win another scholarship to study from 1890 to 1894 and joined Canterbury College of the University of New Zealand in Christchurch. There he studied mathematics, physics, English, French and Latin. He enthusiastically participated in extracurricular activities like rugby, debating and the activities of the Science Society. He obtained his BA degree in 1892. At this point he won a senior scholarship in mathematics and continued his studies in mathematics and physics. As part of physics course requirement, Rutherford did a project in which he developed two devices: (1) a timer to switch circuits in less than 10^{-5} seconds, and (2) a magnetic detector of very fast current pulses. He obtained his MA degree in 1893 with double first class honours in mathematics, mathematical physics and physical science (electricity and magnetism).

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Even with such distinction, Rutherford did not get a permanent school teacher's job. Nevertheless, he taught for a brief period in the local high school. His interest in research continued, and he set up some laboratory facility in the school basement to work on radio waves. He developed a short distance communication device without realizing that it was already invented[1]. This was used for light house communication at a New Zealand port for some time.

[1] See J C Bose issue, *Resonance*, Vol.3, No.2, 1998, and G Marconi issue, *Resonance*, Vol.7, No.1, 2002.

At this point Rutherford set his eyes on getting a scholarship of the Royal Commissioners for the Exhibition of 1851, which would enable him to study anywhere in the British-ruled countries. This was not easy as only one scholarship was given every two years to a New Zealand student who had to be on the roll in the University at the time of applying for it. Therefore Rutherford went back to Canterbury College in 1894 and completed BSc degree with geology, chemistry and some research work. For this scholarship there was another competitor, Maclaurin, who actually won it. But to Rutherford's luck, Maclaurin did not accept it as the terms of offer did not suit him. Thus Rutherford got the scholarship and one of the greatest scientific journeys began.

One of the greatest scientific journeys began when Rutherford got the only scholarship.

Rutherford at the time had three degrees (BA, MA and BSc) and two years of advanced research experience in the area of electrical technology. Rutherford's research was very much influenced by J J Thomson's work[2] on electromagnetic phenomena and guided by his book about advanced electricity. Rutherford decided to work with J J Thomson, who was then the Director of Cavendish Laboratory at Cambridge University.

[2] See *Resonance*, Vol.2, No.12, 1997.

At Cambridge – First Time

Rutherford left New Zealand in 1895 and joined J J Thomson. He became the first non-Cambridge graduate to be admitted for PhD at Cambridge University. From Rutherford's previous research achievements, Thomson recognised his skills and ability in experimentation, and assigned him to work on the electrical conduction of gases at low pressure. Rutherford's innovative ability came to light in 1896 when he passed Roentgen's X-rays and Becquerel's radioactive rays into the experimental gas chambers and found that insulating gases had turned into conducting media. From this he got interested in investigating the constituents of the radioactive rays and discovered alpha and beta rays in 1898. On further investigation beta rays were shown to be the same as the high energy cathode rays or high speed electrons, and the cathode rays were particles a thousand times lighter than a hydrogen atom. All this happened in quick succession, and from the results

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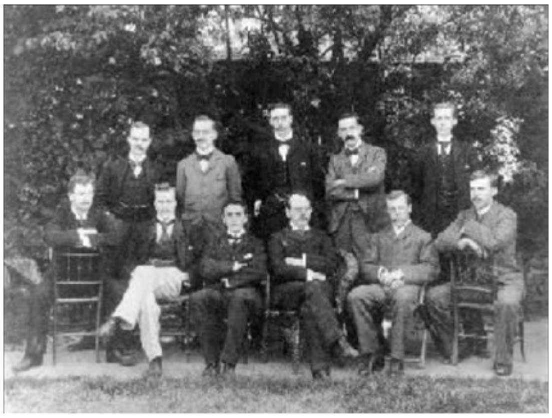

Figure 1.* (*left*) *Cavendish group in 1897. Sitting, from (R) 1st E Rutherford, 3rd J J Thomson.
Figure 2.* (*right*) *J J Thomson.

Rutherford recognised the existence of subatomic particles.

Despite these highly significant achievements, Rutherford knew that he had no chance of making a great career at Cambridge, as a non-Cambridge graduate was not permitted by the prevailing rules. Given this circumstance, Rutherford accepted an invitation to the Macdonald Chair of Physics at McGill University in Montreal, Canada, and moved there without completing the PhD degree.

At McGill, Canada

The laboratory at McGill was well equipped being generously financed by a tobacco millionaire for whom smoking was a dirty habit. Rutherford considered the laboratory to be the best of its kind in the world and resumed his work on radioactive emission. He became the world's centre of research on radioactivity and subatomic particles.

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The first important discovery of Rutherford at McGill in late 1899 was of the radioactive gas emanating from thorium compounds, later found to be radon, a noble element. The work was done with the assistance of his first research student H Brookes and Professor R B Owens of Electrical Engineering at McGill University. The credit for actually discovering radon is given to the German scientist F E Dorn. Frederick Soddy joined Rutherford (1900–1903) and together they proposed that radioactivity is due to the spontaneous disintegration of heavy atoms that decay into slightly lighter atoms. Rutherford with the assistance of Otto Hahn, who was at McGill in 1905–1906, measured the sequence of decay products.

In 1904, Rutherford published the book *Radioactivity* which was acclaimed as a classic and remained unsurpassed as a textbook and guide in the field. It contained essentially everything known till then about the radioactive substances and much of it was his and his students' work.

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Rutherford showed that a narrow beam of alpha rays in vacuum is deflected by magnetic and electric fields and that it becomes fuzzy if air is introduced or if it is passed through a thin sheet of mica. That is, he had discovered alpha scattering. He photographed the alpha particles scattered over a few degrees.

The other important achievements of Rutherford at McGill were the estimation of the earth's age by radiodating using the half-lives of the radioactive elements present in it, and the elucidation of the principle of smoke detector.

From McGill to Manchester

Being a leading figure in a field that was witnessing revolutionary discoveries, Rutherford got offers of good positions in institutions in America and elsewhere. However he wanted to be in England, which was a great centre for research and a source of excellent students. His desire was fulfilled by Professor Arthur Schuster of Manchester who gave up his Langworthy Chair of Physics with the condition that Rutherford be appointed in his position. Thus Rutherford could move back to England in 1907.

At Manchester, Rutherford continued his work on alpha particles. He, with his student Thomas Royds (*Box* 1), showed in 1907–09 that alpha particles are doubly ionized helium atoms.

The scattering of alpha particles was actively researched in several laboratories. The large-angle scattering of alpha particles was explained as the result of multiple small-angle scattering

Box 1.

Royds worked with Paschen in Tübingen and Rubens in Berlin on infrared radiation and spectroscopy, and became a solar physicist. He obtained the DSc degree from Manchester University and was appointed as Assistant Director of Kodaikanal Solar Physics Observatory. He was its Director between 1922 and 1937, and during the last one year of his service acted as the Director General of Observatories in India and returned to England. During this period he contributed significantly to the physics of the Sun.

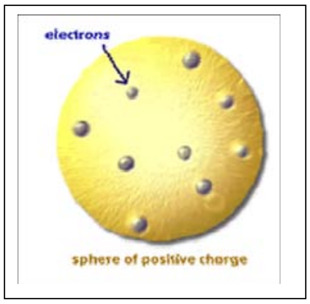


Figure 3. J J Thomson's plum pudding model.

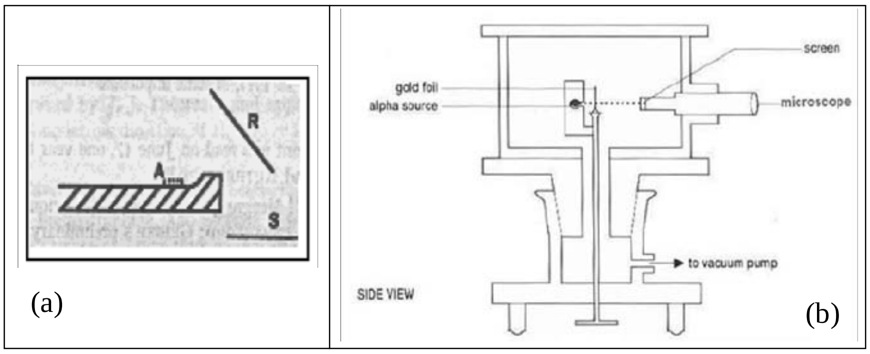
based on J J Thomson's 'plum pudding model' of the atom (*Figure* 3). But Rutherford did not believe in this. He had photographed, while in McGill, the alpha particles scattered over a few degrees. Now he wanted to measure their number in relation to the angle of deflection. For this purpose, he, with the assistance of Hans Geiger, who had joined him, developed the Rutherford–Geiger tube to record individual alpha particles. The principle of the tube was based on the fact that an alpha particle is capable of ionizing thousands of atoms in a gas, an observation made by John Townsend of Cambridge. The alpha particle count measured by this method of using a galvanometer was compared with that measured on the fluorescent screen of a spinthariscope[3]. Geiger used a vacuum tube with a metal foil in the middle and a fluorescing plate at the end. Alpha rays passed through the metal foil and on to the fluorescing plate. The flash was measured using a microscope. This was a tough task.

[3] A simple device that shows fluorescent flashes when alpha particles fall on a zinc sulphide screen, each flash indicates one alpha particle. The phenomenon was discovered accidentally by William Crooke in 1903, when he spilled a tiny quantity of radium on the zinc sulphide screen and tried to recover if using a microscope.

Atom's Mystery Uncovered

At this point, Ernest Marsden joined Rutherford as an undergraduate trainee. Geiger found Marsden interested in and suitable for this task and Rutherford assigned it to him. So Geiger and Marsden worked together. Marsden modified Geiger's tube to measure large-angle scattering by simply moving the screen from behind the metal (gold) foil to its front side (*Figure* 4). To prevent

Figure 4. (a) Marsden's scheme. A: alpha source on lead shield, R: foil, S: ZnS screen (microscope is not shown). (b) Schematic diagram of Marsden–Geiger counter. The microscope is fixed to a turntable which can be rotated to any angle.



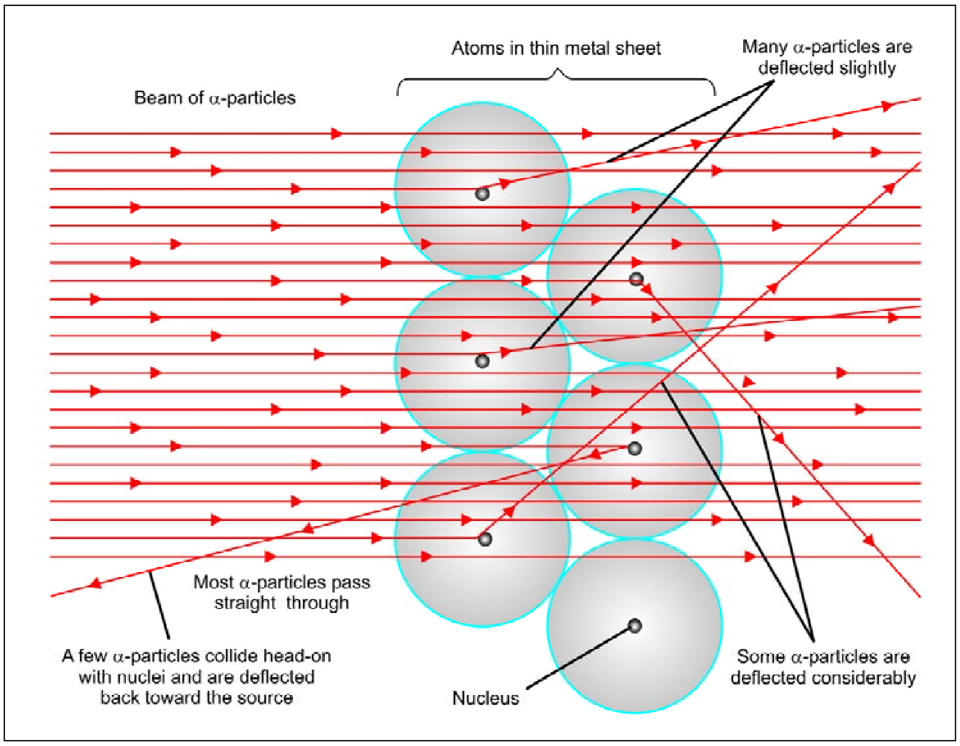


Figure 5. Rutherford's interpretation of Marsden's α-scattering results.

the alpha particles reaching the screen directly a lead shield was placed between the alpha source and the screen. Marsden found (1909) that about 1 in 8000 particles reached the screen after having deflected at a large angle. It was an astonishing result. Rutherford concluded that the positive charge must be concentrated at one point in the centre of the atom instead of diffused as proposed in Thomson's model, and the electrons are spread around in a comparatively large space which looked mainly empty (*Figure* 5).

It was the most important event in the history of the discovery of the atom and in understanding the nature of matter. About the observation Rutherford says "...It was as if you fired a 15-inch naval shell at a piece of tissue paper and it came back and hit you. I realized that this scattering backwards must be the result of a single collision, and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the mass of the atom was concentrated in

Rutherford says on his discovery of the nucleus, "It was as if you fired a 15-inch naval shell at a piece of tissue paper and it came back and hit you. I realized that this scattering backwards must be the result of a single collision."

Figure 6. Niels Bohr.

a minute nucleus". Though it was clear in 1909 to Rutherford about how the atom would look like, it took another two years to consolidate the experimental facts and develop the theory. In 1911 Rutherford proposed what is now known as the 'nuclear atom model'. Niels Bohr carried it forward in close consultation with Rutherford by placing electrons that go around Rutherford's nucleus in stable orbits. Rutherford attained the status of one of the most illustrious scientists of all time. John Campbell of the University of Canterbury, New Zealand, has described him thus: "He is to the atom what Darwin is to evolution, Newton to mechanics, Faraday to electricity and Einstein to relativity".

Post Nuclear Atom and WWI

Rutherford developed the radioactive tracer technique and the concept of isotopes with the assistance of Gyorgy Hevesy. Henry Moseley, working with Rutherford, investigated characteristic X-rays, and developed the concept and importance of atomic numbers.

In World War I, Rutherford participated in war related research which consisted of developing methods for detecting submarines by sound waves. He helped to mobilize scientists to contribute their mite in war efforts.

Back in Cambridge

After the war, in 1919, Rutherford moved to Cambridge University, succeeding J J Thomson, as Cavendish Professor of Physics and the Director of the Cavendish Laboratory. Soon, he found that nuclei can be disintegrated artificially by bombarding with alpha particles, and thus cause transmutations. By this means he converted nitrogen nuclei into oxygen nuclei. In the process he discovered the proton which was formed as the other product of the nuclear reaction. Later, with James Chadwick's assistance, Rutherford showed that any light atom could be disintegrated on striking with alpha particles. John Cockroft and Ernest Walton, working in Rutherford's group, developed the technique to produce accelerated particle beams for the disintegration of atoms.

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Awards and Honours

The scientific achievements of Rutherford are many and each had its impact on the scientific development. Naturally he was bestowed with many awards, honours, and prizes.

He was elected Fellow of the Royal Society of London in 1903, when he was 32 years. In 1904, he received Rumford Medal of the Royal Society. Twenty years later he served as the President of the Royal Society from 1925 to 1930. He won the 1908 Nobel Prize in Chemistry for his "investigations into the disintegration of the elements, and the chemistry of radioactive substances."

In 1914 he was knighted and became Sir Ernest. In 1931 he was made First Baron (Lord) Rutherford of Nelson, his native place in New Zealand, and of Cambridge of the County of Cambridge, England.

Rutherford received Bressera Prize of the Turin Academy of Science in 1910, Copley medal of the Royal Society in 1922, the Albert Medal of the Royal Society of Arts in 1928, and the Faraday Medal of the Institution of Electrical Engineers in 1930.

Rutherford was conferred with honorary doctorate degrees from several universities. Among them are the Universities of Birmingham, Bristol, Cambridge, Cape Town, Copenhagen, Dublin, Durham, Edinburgh, Giessen, Glasgow, Leeds, Liverpool, London, McGill, Melbourne, Oxford, Pennsylvania, Toronto, Wisconsin and Yale.

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Rutherford's Personality

Rudolf Peierls provides an impressive picture of Rutherford's personality. "Rutherford was outspoken, outgoing and direct. He liked his Physics and his experiments simple and described his work in simple and concise language. He had a booming voice, Rutherford made decisions easily and firmly, and once a matter was decided, did not give it any further thought.

and it is said that in the days when the counting circuits tended to be sensitive to noise, the performance of his collaborators' equipment went wrong whenever he entered their research rooms. He made decisions easily and firmly, and once a matter was decided, did not give it any further thought. He could be rude and even unreasonable on occasion, but when he had cooled off would put matters right with a handsome apology. He had enormous enthusiasm for a promising idea in physics and regarded mathematics as an important tool in formulating and applying the laws of physics, but never as an end in itself. He disparaged mathematicians who were too attached to formal mathematics."

Niels Bohr had close relationship with Rutherford throughout his lifetime. Bohr consulted Rutherford in all his research and took his help in improving and publishing his work. Bohr says that he felt greater admiration every year for the marvellous power with which Rutherford set an example to the world of untiring creative activity.

James Chadwick writes, "...He (Rutherford) had a volcanic energy, interest, enthusiasm and an immense capacity for work. He had the most astonishing insight into physical processes, and in a few remarks he would illuminate a whole subject. There is a stock phrase-'to throw light on a subject'. This is exactly what Rutherford did. To work with him was a continual joy and wonder. He seemed to know the answer before the experiment was made, and was ready to push on the irresistible urge to the next. (He was nicknamed 'crocodile', which cannot turn its head...must always go forward with all devouring jaws open.) He was indeed a pioneer - the word he often used - at his best exploring an unknown country, pointing out the really important features and leaving the rest for others to survey at leisure. He was, in my opinion, the greatest experimental physicist since Faraday." James Chadwick says, "In appearance Rutherford was more like a successful businessman or Dominion farmer than a scholar....he was of massive build, had a moustache and a ruddy complexion. He wore lose, rather baggy clothes, except on formal occasions. A little under six feet in height, he was noticeable but by no means

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impressive. It seemed impossible for Rutherford to speak softly. His whisper could be heard all over the room, and in any company he dominated through the sheer volume and nature of his voice, which remained tinged with antipodean flavour despite his many years in Canada and England. His laughter was equally formidable. Rutherford would not hesitate making fun of the Nobel Committee decision to choose him for the Chemistry Prize instead of the Physics Prize." During the award speech Rutherford said, "...I had dealt with many different transformations with various periods of time, but the quickest I met is my own transformation in one moment from a Physicist to a Chemist."

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Rutherford's way of talking seems to have been one of the subjects of reference to his personality by most people who had any contact with him. John Campbell says, "...At the end of 1911 Rutherford was the guest of honour at the Cavendish Annual Dinner, at which he was, not surprisingly, in fine form. The Chairman, while introducing him, stated that Rutherford had another distinction: of all the young Physicists who had worked at the Cavendish, none could match him in swearing at apparatus."

Such a great scientist was in appearance anything but that. Chaim Weizmann describes, "Rutherford was youthful, energetic and boisterous. He suggested anything but a scientist. He talked readily and vigorously on any subject under the Sun, often without knowing anything about it. He was quite devoid of any political knowledge or feelings, being entirely taken up with his epoch-making scientific work. He was a kindly person but did not suffer fools gladly." Though Rutherford was considered as politically ignorant, he was actively involved with many social organizations. He was a vice president of the Manchester Society for Women's Suffrage and of the Manchester branch of the Men's League for Women's Suffrage.

Scientific Publications

Rutherford published 189 papers. He wrote six books which were classics and are of great importance particularly in providing

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insight into the development in the major areas of physics and chemistry during that period. The first book *Radioactivity* published in 1904 remained as an important reference work for a long time. In 1906, *Radioactive Transformation*s was brought out. He co-authored *Radiation from Radioactive Substances* with J Chadwick and C D Ellis in 1919. It was a fine documentation of his many papers to learned societies and others. Its second edition was published in 1930. *The Electrical Structure of Matter*, *The Artificial Transmutation of Elements*, and *The Newer Alchemy* were published in 1926, 1933, and 1937, respectively.

Personal Life

In 1900, Rutherford married Mary Newton, only daughter of Arthur and Mary de Renzy Newton. They had only one daughter, Eileen, who married R H Fowler, a physicist. Rutherford had to suffer the sorrow of their daughter's death during the birth of her second child.

Rutherford liked playing golf and enjoyed riding the car he had bought with his Nobel Prize money.

Rutherford died on the 19th of October 1937, in Cambridge. His ashes were buried in Westminster Abbey close to the tombs of Sir Isaac Newton and Lord Kelvin.

Suggested Reading

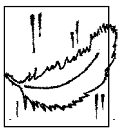
[1] J Campbell, *CERN Courier*, Vol.51, No.4, p.18–23, May 2011.

[2] I James, *Remarkable Physicists: from Galileo to Yukawa*, Cambridge University Press, 2005.

[3] M Kumar, *Quantum*, Hachette India, 2009.

[4] R Peierls, 'Rutherford and Bohr', *Resonance*, Vol.15, No.5, pp. 476-487, 2010.

Address for Correspondence
G Nagendrappa
Email:
gnagendrappa@gmail.com



On 3 Jan. 1938, the Jubilee Session of the Indian Science Congress, held jointly with the British Association, was opened by the Viceroy at Calcutta. Sir James Jeans as Chairman read the Presidential Address prepared by Rutherford but he first of all paid him this tribute:

Those of us who were honoured by his friendship know that his greatness as a scientist was matched by his greatness as a man. We remember, and always shall remembers, with affection his big, energetic, exuberant personality, the simplicity, sincerity and transparent honesty of his character, and, perhaps most of all, his genius for friendship and good comradeship. Honours of every conceivable kind had been showered upon him, so that he could not but know of the esteem in which he was held by the whole world, and yet he was always simple, unassuming and ready to listen patiently to even the youngest and most inexperienced of his pupils or fellow-workers, if only he were honestly seeking for scientific truth.