The centennial of the discovery of millimetre waves by Jagadis Chandra Bose (1858–1937)

In May 1885, Jagadis Chandra Bose produced for the first time electromagnetic waves having wavelengths of a few millimetres; and thus he opened up the fields of microwave physics and communication. On the centennial year, Bose Institute, Calcutta has brought out a charming 165-page book entitled 'J. C. Bose and Microwaves – A collection', edited by P. Bhattacharyya and M. H. Engineer. Most of the book is used for reproducing the classical original papers of J. C. Bose's wherein he studied the production of microwaves and their interaction with matter. The book has a foreword by P. K. Ray, Bose Institute (2 pages), an Introduction (3 pages), a historical note (4 pages), a copy of the patent application made by Bose (11 pages) and a chapter on the current status of microwave and millimeter waves (8 pages). The volume contains very interesting historical information. P. K. Ray says:

> *'I am sure (the book) will be useful not only as a historical document which will thrill and excite the minds of young researchers, but will also prove that, with firm conviction and considerable amount of faith and confidence how a scientist can come out with a miraculous scientific discovery.'*

This volume in a sense is a tribute (to quote P. K. Ray again):

> *'To the doyen of Indian science who for the first time instilled in the minds of a large number of young researchers the confidence that Indian scientists on Indian soil with even meagre resources can produce world class science.'*

The Director, Bose Institute has most graciously permitted us to use this book to write the following article. For producing a connected picture of J. C. Bose's discovery we have used many extracts from the book. We also quote from passages of the book how:

> *'the man who had brought modern physical science into India was thought of by the rest of the world in his time'*

It is gratifying to note that J. C. Bose's discovery of mm waves is being followed up in this country. A 10.4 metre dish antenna has been set up along with a millimetre wave laboratory in Bangalore to do mm wave radio astronomy (Figures 2 and 3). Many laboratories in India are also working on mm wave communication and on mm wave radar.

We reproduce in this section two of J. C. Bose's original articles which illustrate the genius he had for innovation and invention and the extraordinary insight he had for physics.

S. Ramaseshan

In May 1895 Jagadis Chandra Bose communicated a paper entitled 'On the polarization of the electric ray' to the physical section of the *Asiatic Society of Bengal* wherein he described how he had generated electromagnetic waves of about 5 millimetre wavelength. It was truly a great achievement. It is remarkable how in a small room (20 ft sq.) in the Presidency College, Calcutta he was able to fabricate the apparatus, generate these waves and study their properties. These studies made history as the appearance of this paper saw the dawn of physical science in India and it also created the new field of microwave research.

Apart from Bose's aesthetic appreciation of the science behind his discovery he realized its practical uses also. *In early 1895 he demonstrated at the Presidency College the possibility of sending messages over distances using his electromagnetic rays.* Perhaps the most spectacular demonstration he made was in the Town Hall of Calcutta in 1895. Before a large gathering he transmitted the waves 'through the body of the Chairman of the meeting, the Lieutenant Governor of Bengal'; the waves travelled over a fair distance in air, then through a solid wall, displaced a heavy weight, rang a bell and finally, to the surprise of everyone present, exploded a mine placed in a closed room!

The celebrated paper of James Clerk Maxwell (1831–1879) on the electromagnetic theory was published in 1853 (when Bose was only 5 years old). Maxwell unfortunately could not see the brilliant confirmation of his theory by the experiments of Heinrich Rudolf Hertz in 1888.

Hertz died at the young age of 37 in 1894. Shortly after Hertz's death, Oliver Lodge gave a commemorative lecture (1894) entitled 'The work of Hertz and some of his successors' at the Royal Institution. This lecture greatly influenced many young scientists like Bose, Rutherford (see Box 1), Righi, Marconi, Branly, Zehnder, Popov and serious work on the generation of electromagnetic waves was started in different countries. For example, Righi tried to obtain wavelengths of 3 cm to 10 cm while his pupil Marconi experimented with 25 cm waves. In 1897 using a pair of parabolic cylindrical reflectors separated by four miles, Marconi succeeded in convincing the British Post Office that wireless telegraphy was possible.

As said earlier Bose too was influenced by Lodge's lecture and started his researches in November 1894. Within six short months he succeeded in producing 5 mm to 25 mm waves. He sent his paper to *The Asiatic Society*. Bose made many innovations. Most of the previous investigators including Hertz himself faced the grave problem of the discharge stopping when the surface of the sphere became

Figure 1. J. C. Bose lecturing at the Royal Institution.

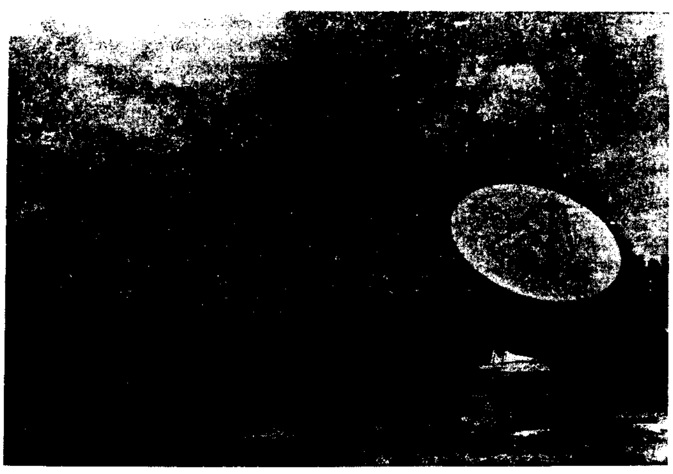

Figure 2. Millimetre Wave Telescope in Bangalore – A fitting memorial to J. C. Bose who discovered millimetre radio waves.

rough. Bose got over this problem by using platinum balls/beads.

'after some difficulty in obtaining the requisite high temperature I succeed in casting a solid ball and two beads of platinum'

He used for the first time a spiral spring coherer as receiver. He was also amongst the first to employ semi-conductors (like galena) as a self-recovering detector for his rays. For polariser and analysers, his use of jute fibres and the pages of a book are indeed masterpieces of innovation.

His apparatus was very compact:

'The radiating box was portable; the one I have been using for some time past is 7 inches in height, 6 inches in length and 4 inches in breadth. There is another which is still smaller.'

This he packed into a suitcase and exhibited the generation and transmission of 5 mm to 25 mm electromagnetic waves to many audiences.

Bose's apparatus was reproduced in many contemporary books and articles by J. J. Thomson, Poincaré and others. Cornu the President of the French Academy of Sciences acknowledged 'Bose's power for furthering the progress of science'. Lord Kelvin was 'literally filled with wonder and admiration'. After Bose's British Association lecture, old Lord Kelvin limped up the stairs to the ladies gallery to congratulate Mrs (Lady) Abala Bose.

We reproduce some passages written at that time:

News item from *The Englishman* of 13 December 1895 or *The Statesman* of 14 December 1895:

'Father Lafont informs us that Professor J. C. Bose, BA and B Sc, and old pupil of St. Xavier's College and Lecturer in physics in the Presidency College had the honour of receiving, by the last mail, a letter from Lord Rayleigh, the discoverer of argon, regarding a paper "On the indices of electric refraction" communicated by him to the Royal Society. So highly important were these researches regarded that the Royal Society has expressed a desire to make a grant in furtherance of them from the "Government Fund for the Encouragement of Original Research" annually voted to the Society by Parliament.'

The Electrician in its leading article (December 1895) was the first to foresee the possibilities of J. C. Bose's wireless receivers.

'His sensitive detector of electromagnetic radiation, perfectly prompt in its self-recovery, should serve to revolutionise the existing methods of telegraphy.'

Figure 3. The millimetre wave electronics laboratory at Raman Research Institute.

Box 1.

Also in 1895, a young physics student named Ernest Rutherford arrived in Britain from New Zealand with a scholarship for further study. The scholarship, awarded to a New Zealand student only once every few years, had initially been given to a young chemist, but who decided at the last minute to get married and stay in New Zealand. The scholarship passed to Rutherford, who, thanks to a change in regulations, was able to use it at the Cavendish Laboratory in Cambridge, under J. J. Thomson.

In New Zealand, Rutherford had carried out experiments on radio telegraphy. He took his transmitter to Britain and at Cambridge continued his pioneer investigations. In 1895. Guglielmo Marconi was carrying out his first experiments on radio telegraphy in Bologna, but according to J. J. Thomson, it was Rutherford who held the world record for radio telegraphy transmission at that time.

The Calcutta Newspaper, *The Englishman* (18 January 1896) quoted from that issue of *The Electrician* thus:

'The Electrician thinks that it would be a useful and remunerative work for some practically-minded man "to devise a practicable system of electromagnetic light-houses, the receivers on board ship being some electrical equivalent of the human eye. The evolution of a suitable generating apparatus would, we think present little difficulty; that of a suitable receiver on the other hand seems likely to give considerable trouble. In this connection we would draw attention to the substantial and workmanlike form of 'Coherer' devised by Professor Bose, described by him at the end of his paper which would appear to leave little to be desired, and it is certainly more likely to withstand, the thousand and one shocks at sea than any of the forms hitherto brought about . . . should Professor Bose succeed in perfecting and patenting his 'Coherer' we may in time see the whole system of coast lighting throughout the navigable world revolutionized by the discoveries made by a Bengali Scientist working single-handed in our Presidency College Laboratory."'

Another paper of his 'On the determination of the wavelength of electric radiation by a diffraction grating' was communicated to the Royal Society by Lord Rayleigh in 1896.

That this paper received approbation from the London University is evident from the letter Sir Alfred Croft, Director of Public Instruction wrote on 16 June 1896.

'The subject dealt with has long been regarded as of very great importance, attempting as it does the complete specification of the unknown forces involved, by determining the length of the invisible wave. . . . The problem was attempted by Hertz, and subsequently by many continental physicists, but the results obtained were very contradictory. Mr. Bose has recently succeeded in solving the problem with entirely satisfactory results; and a copy of the paper embodying his solution was sent to the University of London as a Thesis for the degree of Doctor of Science. I should explain that before being admitted to the examination for that degree a candidate has to produce a Dissertation embodying the results of original research in some branch of science. On the acceptance of the Dissertation by the University, the candidate has, in general, to undergo a further examination. There is, however, a provision in the D Sc regulations that a candidate may, at the discretion of the university, be exempted from further examination, provided the paper submitted is of special excellence. Mr. Bose received on the 27 May, a telegram from the Registrar informing him that his Thesis was accepted and his presence at the examination excused'.

This exemption was a great honour. And this thesis, in the form of a paper was communicated to the Royal Society for publication by Lord Rayleigh and accepted by the Society within a fortnight.

Such honours in recognition of his work convinced the Lt. Governor of Bengal, of the need of sanctioning a special annual grant of Rs 2500 for his own independent researches.

Lord Kelvin realized the conditions under which J. C. Bose worked and wrote to Lord George Hamilton, then Secretary of State of India.

'It would be conducive to the credit of India and the scientific education in Calcutta, if a well-equipped physical laboratory is added to the resources of the University of Calcutta in connection with the Professorship held by Dr. Bose.'

Following on this Lord George Hamilton wrote:

'To the great importance which we attach to the establishment in the Indian Empire of a Central laboratory for advanced teaching and research in connection with the Presidency College, Calcutta. We believe that it would be not only beneficial in respect to higher education, but also that it could largely promote the material interest of the country; and we venture to urge on you the desirability of establishing in India a Physical Laboratory worthy of that Great Empire.'

Among the memorialists were Lord Lister, then President of the Royal Society, Lord Kelvin, Prof. Clifton, Prof. Fitzgerald, Dr Gladstone, Prof. Poynting, Sir William Ramsay, Sir Gabriel Stokes, Prof. Silvanus Thompson, Sir William Ricker and others.

Regarding Bose's lecture, *Times* (London) on 5 October 1896 wrote:

'Among the most interesting features at the British Association this year was the paper on electrical waves by Professor J. C. Bose. The gentleman, an MA of Cambridge, Doctor of Science of London and a graduate of the Calcutta University, had already won the attention of the scientific world by his strikingly original researches on the polarization of electric ray. His later papers on the determination of the indices of electric refraction and the wave length of electric radiation were published, with high tributes, by the Royal Society.'

Daily Chronicle on 28 November 1896 reported:

'*Prof. Bose has transmitted signals to a distance of nearly a mile; and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel.* It is telegraphy without any kind of intervening conductor. Every reader, we are sure, will instantly see that if all this be true the great problem of transmitting signals from ship to ship or from lighthouse to ship through a fog, has been solved and this alone will be a priceless benefit to the human race.'

Bose addressed the Before-Easter session of the Royal Institution. This Friday Evening Discourse was welcomed by the press and the public. Referring to his discourse, *The Spectator* said:

'There is, however, to our thinking something of rare interest in the spectacle there presented, of a Bengali of the purest descent lecturing in London to an audience of appreciative European savants upon one of the most recondite branches of modern physical science. It suggests at least the possibility that we may one day see an invaluable addition to the great army of those who are trying by acute observation and patient experiment to wring from Nature some of her most jealously guarded secrets. The people of the East have just the burning imagination which could extort a truth out of a mass of apparently disconnected facts, a habit of meditation without allowing the mind to dissipate itself and a power of persistence – it is something a little different from patience – such as hardly belongs to any European. We do not know Professor Bose, but we venture to say that if he caught with his scientific imagination, a glimpse of a wonder-working "ray" as yet unknown to man . . . , and believed that experiment would reveal its properties and potentialities, he would go on experimenting ceaselessly through a long life, and, dying, and hand on his task to some successor. Nothing would seem to him laborious in his inquiry, nothing insignificant, nothing painful, any more than it would seem to the true Sanyasi in the pursuit of his inquiry into the ultimate relation of his own spirit to that of the Divine. Just think what kind of addition to the means of investigation would be made by the arrival within that sphere of inquiry of a thousand men with the Sanyasi mind, the mind which utterly controls the body and can meditate and inquire endlessly while life remains, never for a moment losing sight of the object, never for a moment letting it to be obscured by any terrestrial temptation.

. . . We can see no reason whatever why the Asiatic mind, turning from its absorption in insoluble, problems, . . . should betake itself ardently, thirstily, hungrily, to the research into Nature which can never end, yet is always yielding results, often evil as well as good. If that happened – and Professor Bose is at all events a living evidence that it can happen, that we are not imagining an impossibility – that would be the greatest addition ever made to the sum of the mental force of making in that one special and of course most profitable direction.'

Before leaving England, he was invited to deliver a lecture on electric ray by the Imperial Institute on 18 February 1897.

Referring to his work, Sir Henry Roscoe, the Vice Chancellor of the University of London, acknowledged that

'the Eastern mind was equally capable of making great scientific discoveries and producing experimentalists as eminent as those of the west.'

Lord Reay, the former Governor of Bombay who was present in the lecture representing the statesman's point of view, drew attention to the importance of India's contribution to science:

'For science was absolutely international, and any result obtained by Dr. Bose in India could at once be annexed by us without protest.'

We reproduce the summary of Bose's work by Kuntz:

Bose showed that these short electrical waves had same properties as a beam of light, exhibiting reflection, refraction and even total reflection, double refraction, polarization and rotation of the plane of polarization. The thinnest film of air is sufficient to produce total reflection of visible light because of its extremely short wavelengths; but in Bose's short electric waves, the critical thickness of the air-space was determined by the refracting power of the prism, and by the wave-length of the electric oscillations. He found a special crystal, Nemalite, (a fibrous form of Brucite) which exhibits the polarisation of electric waves in the very same manner as a beam of light is polarised by selective absorption in crystals like Tourmaline, which Bose found to be due to their different electric conductivity in two directions. The rotation of the plane of polarisation was demonstrated by means of a contrivance twisted like a rope, and the rotation could be produced to left or right, just as different sorts of sugar rotate the plane of polarisation of ordinary light towards one direction or the other. The index of refraction of these electrical waves was determined for different materials; and a difficulty was eliminated which presented itself in Maxwell's theory, as to the relation between the index of refraction of light and the dielectric constant of insulators. Bose also measured the wave-length of the various oscillations. In order to produce the short electrical oscillations, to detect them and to study their optical properties, he had to invent a large number of new apparatus and instruments; and he has indeed enriched physics by a number of apparatus distinguished by simplicity, directness, and ingenuity.

Another statement about Bose's process in instrumentation:

'His technical virtuosity was quite remarkable. Microwave generators, detectors, waveguides, horn antennas, lens antennas, mirrors, two prism directional couples, polarimeters, spectrometers, dielectrometers, recorders, all the paraphernalia for today's research, he designed and fabricated himself. He has been called the father of microwave analogue optics for very good reason. Nor was he less of a pioneer in making solid state detectors – to construct these he discovered the phenomenon of "doping".'

Clearly he was much ahead of his time.

ACKNOWLEDGEMENTS. We thank Prof. P. K. Ray, Director, Bose Institute and his colleagues in his Institute for permission to reproduce extended passages from the book – *J. C. Bose and Microwaves – A Collection* edited by P. Bhattacharyya and M. H. Engineer.