ACHARYA JAGADIS CHUNDER BOSE
(1858–1937)

ACHARYA JAGADIS CHUNDER BOSE—HIS LIFE AND WORK
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Acharya Jagadis Chunder Bose occupies a high, almost unique, place in the recent history of Indian science. He was an investigator of uncommon courage, resourcefulness and dedication. Bose's scientific work broadly falls under three periods. From 1894 to 1899 he was almost entirely concerned with the study of electric waves, between 1899 and 1902 he shifted from the physical to the biophysical field, and beyond 1903 he was occupied with the study of plant-responses under physical stimuli of various types. For these studies he developed and constructed his own instruments which were remarkable for their originality and extreme sensitivity. Bose founded the *Bose Institute* in Calcutta in 1917. He continued to be the Director of the Institute till his death in 1937. Bose visited Europe many times, and America twice, on lecture tours. He was elected a Fellow of the Royal Society in 1920, and Corresponding Member of the Academy of Sciences, Vienna, in 1929. He was the General President of the Indian Science Congress in 1927. He served on the Council for Intellectual Co-operation of League of Nations from 1926 to 1930.

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Bose was born on November 30, 1858, in the town of Mymensingh in East Bengal. (His father, Bhagwan Chunder Bose, was at the time Deputy Magistrate of the place.) He died on November 23, 1937, at the age of 79 years. (He was survived by his wife Mrs. Abala Bose. She was the daughter of Mr. Durga Mohan Das, a leading advocate of the Calcutta High Court.) He received his primary education at the local school at Faridpur: his father did not send him to the English school which was there in the same town. Later, he joined the St. Xavier's School in Calcutta, and the College, from which he graduated at the age of 20. He subsequently went to England and joined the London University to study medicine. He attended some lectures by the famous zoologist, Ray Lancaster. Due partly to reasons of health, he left London to join the Christ College at Cambridge. He studied for the Natural Science Tripos, and attended lectures, amongst others, by Lord Rayleigh (Physics). He took the Tripos (Cambridge) and B.Sc. (London) in 1884. On his return from England he was appointed Professor of Physics in the Presidency College, Calcutta, in spite of serious opposition from the then Education Department. Bose had to do as much as 26 hours of lecture and demonstration work per week. (This was much more than what was normal for his British colleagues in the same college.) He retired from the college in 1915.

It was probably at the age of about 35 that Bose seriously made up his mind to dedicate himself completely to the pursuit of science and scientific research. No grant at the time was available to him for research work. The laboratory in the Presidency College, Calcutta, was poorly equipped and sometimes Bose had to construct his apparatus from his own personal resources. It was several years later that the Government sanctioned for his work in the college an yearly grant of Rs.2,500. Bose's earliest research work was concerned with electric waves and their interaction with matter. Electric waves were first produced in the laboratory by Heinrich Hertz in 1888 in his epochal experiments. The existence of these waves had been predicted by Maxwell about 20 years earlier on the basis of his extremely far-reaching and extraordinarily fruitful (as later work showed) electro-magnetic theory. It has been sometimes said that Bose was led to the study of electric waves after reading a paper by Sir Oliver Lodge on 'Heinrich Hertz and his Successors' (1894). From the very beginning Bose's remarkable physical insight, and his superb ingenuity and resourcefulness in experimentation were apparent. He succeeded in generating waves of wave-lengths much smaller than what Hertz and others had done. He produced waves of about half-a-centimetre in wave-length. Because of this he was able to investigate in considerable detail the 'optical' properties of electric waves, such as refraction, polarization and double refraction. He determined the refractive indices of many substances, and also investigated the influence on total reflection of the thickness of the air-gap between two dielectric slabs. In the paper published in the *Proceedings of the Royal Society* in November, 1897, he observed: 'It is seen from the above, that as the thickness of the air-space was gradually increased, the reflected component increased, while the transmitted portion decreased. Minimum thickness for total reflection was found to be 8 mm.' He also verified that the thickness of the air-gap, for which total reflection disappeared, increased with the wave-length. It may be mentioned that Bose's first paper entitled 'On Polarization of Electric Waves by Double Refracting Crystals' (he tried beryl, rocksalt, etc.) was published in May, 1895, in the *Journal of the Asiatic Society of Bengal*. In 1897 Bose gave a lecture at the famed Royal Institution, London. It is interesting (and also instructive) to recall that the demonstration apparatus exhibited at the lecture, which in present-day terminology may be described as a (simple) microwave spectrometer complete with transmitter and receiver (improved type of coherer), was constructed in Calcutta and taken by Bose with him to London. The originality and simplicity of the apparatus employed by Bose in his experiments were most remarkable. For instance, he demonstrated the polarization of electric waves by the simple device of 'interleaving the pages of a Bradshaw railway time table with sheets of tin foil'. Again, to eliminate the undesirable reflections of electric waves in tubes employed to guide them (as in the case of spectrometer), he tried many different coatings—in other words, he was searching for an absorber of microwaves. He found that blotting-paper dipped in electrolyte gave the best results. 'Bose, in India between 1895–97, used hollow tubes of either circular or square section as waveguides and waveguide radiators on wave-lengths between 5 mm. and 2·5 cm. His adoption of hollow tubes was probably based on the use of metal tubes in telescopes and microscopes.'* Bose also employed conical horns—he called them collecting funnels—for concentrating the waves on the detectors. He studied the rotation of the plane of polarization, and found that a bundle of twisted jute fibres gave right or left-handed rotation depending on the right or left-handed twist of the fibres. This constituted a 'large-scale or *macro* demonstration' of the optical phenomenon of the rotation of the plane of polarization.

For the detector, Bose used the coherer discovered by Branly and Lodge. He made considerable improvements, particularly in sensitivity and reliability. He also experimented with the point-contact-type detector consisting of a metal wire in contact with a metal plate or semiconducting crystal. In the case of most substances, the resistance falls when the detector is exposed to electric waves but there is also a rise of resistance for some substances such as lead peroxide and potassium. Bose found that in the case of galena crystal the detector was not only sensitive to electric waves but also to light radiation extending from infra-red to violet. Here he was obviously dealing with what later came to be recognized as photovoltaic effect. These experiments dealing with the variations in contact resistances under the influence of electric waves—particularly the erratic behaviour of the system in many cases—brought to Bose's mind the phenomenon of electric response in animal muscles when subjected to stimuli. 'Bose enquires whether inorganic models may not also

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* J. F. Ramsay, 'Microwave Antennae and Waveguide Techniques before 1900', *Proc. I.R.E.*, Feb., 1958.

be devised which will satisfy this criterion. In this way he was able to construct models in which mechanical and light stimuli produce electrical responses. The proportionality which exists between intensity of stimulation and electrical response, the gradual appearance of fatigue in response after repeated stimulation, from which the system recovers after it is given sufficient rest, the increase of response on treatment with one set of chemicals and its inhibition by another set, are similar to what occurs in living tissues. We shall describe here only one of his models: it is made of two wires of pure tin, whose lower ends are clamped to an ebonite block; the upper ends pass through an ebonite disc, and are joined through binding screws to the two terminals of a sensitive galvanometer. The arrangement fits into a cylindrical glass vessel, filled with distilled or tap water. On giving one of the tin wires a sharp twist, an electric current flows from the wire through the galvanometer system. The amplitude of response is enhanced when a small quantity of sodium bicarbonate is added to the distilled water; on the other hand, if oxalic acid is added to the water the response is abolished. Many of the effects observed in animal tissues under stimulation, viz. of the opposite effects of small and large doses of a chemical poison, etc., could be obtained with this model of Bose.'* Mention here may also be made of the interesting analogy between the excitation of nerve and the passivity of iron dipped in strong nitric acid. This was investigated in great detail by Lillie (1920–36) and later by Bonhoeffer.† The first suggestion came from W. Ostwald in 1901. Another interesting model is due to Bredig (1903–1908) in which the oscillations of a mercury drop placed in a hydrogen peroxide solution appear (outwardly) to resemble the rhythmic pulsations of an animal heart.

These investigations gradually led Bose to the formulation of his fundamental concept (and in this context it is relevant to call attention to his early training in physiology and medicine) that basically the response, under stimulus, in the non-living (e.g. metal) and the living (e.g. animal muscle) is of the same nature, though they differ in their level of complexity. From about 1903 onwards Bose investigated with great ingenuity, vigour and perseverance the response phenomena in plants when exposed to various kinds of stimuli, e.g. mechanical, electrical and chemical, and also light radiation. He regarded that the response phenomena in plants lie between those exhibited in inorganic matter and in animals. He developed and constructed in his own laboratory special instruments for the purpose of measuring almost every type of plant-response. The rate of growth of plants is, crudely speaking, of the order of 0·1–0·01 mm. per minute, and to measure that he constructed many instruments which he named *Crescographs* (*crescere:* to grow). The high-magnification crescograph consisted of a combination of levers (in some cases mechanical and optical) giving a magnification of about 10,000. The magnetic crescograph, in which the small displacement of a magnet caused a large deflection in astatic magnetic system, produced a magnification of more than a million. Bose also developed several types of automatic recorders in which friction between the recording pan and the writing plate was eliminated by either vibrating the plate or the stylus. He constructed an instrument to record the liberation of oxygen during photosynthesis in plants. He also studied the variations, as a result of stimulations, in the electrical resistance of plant tissue. He was the first to use electric probes for the localization of actively metabolizing layers in plants.

Bose's plant work was largely carried out with the *Mimosa* plant and with *Desmodium gyrans* (telegraph plant, the Indian name is *Bon Chural*). He studied even such things as the effect of load (placed on the leaf) on response to stimulus. For instance, he observes: 'The effect of load on the response of *Mimosa* is similar

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* D. M. Bose, Jagadish Chandra Bose: Birth Centenary Series III. *Science and Culture*, **24**, 5 (1958), p. 215.

† K. F. Bonhoeffer, 'On the Passivity of Iron'. *Corrosion*, II (1955). *See also* R. Fatt, 'Physics of Nerve Processes'. *Reports on Progress in Physics*, XXI (1958), p. 112.

to that on the contractile response of muscle. With increasing load the height of response undergoes a progressive diminution with shortening of period of recovery. Within limits, the amount of work performed by a muscle increases with load. The same is true of the work performed by the pulvinus of *Mimosa*.' In the case of *Desmodium gyrans* he observed that the detached leaflet continued to show rhythmic pulsations, the period being of the order of two minutes. The pulsation occurs between the temperature of about 17° C. and 45° C. The pulsation is affected by chemical reagents and electric stimuli. Bose also investigated the problem of the ascent of sap in plants. He thought, contrary to the generally accepted view then and now, that this is brought about by peristaltic activity of the inner cortical cells in the plant stem, somewhat analogous to the activity of the animal heart.

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It may be observed that one of the most far-reaching concepts which has emerged from the biological and physiological researches during the present century is that all vital processes in living organisms can be (completely) understood in terms of physical and chemical laws governing material phenomena. (It appears—some think it is certain—that this is not likely to be the case in the realm of phenomena concerning the mind.) Towards this realization Bose made a pioneering and very important contribution. In one of the papers read (but not published) before the Royal Society in 1904 he observed: 'From the point of view of its movements a plant may be regarded in either of two ways: in the first place, as a mysterious entity, with regard to whose working no law can be definitely predicted, or in the second place, simply as a machine, transforming the energy supplied to it, in ways more or less capable of mechanical explanation. Its movements are apparently so diverse that the former of these hypotheses might well seem to be the only alternative. Light, for example, induces sometimes positive curvature, sometimes negative. Gravitation, again, induces one movement in the root, and the opposite in the shoot. From these and other reactions it would appear as if the organism had been endowed with various specific sensibilities for its own advantage, and that a consistent mechanical explanation of its movements was therefore out of the question. In spite of this, however, I have attempted to show that the plant may nevertheless be regarded as a machine, and that its movements in response to external stimuli, though apparently so various, are ultimately reducible to fundamental unity of reaction.'* And further, to quote from his book, 'Plant Response as a Means of Physiological Investigation' (1906): 'The phenomenon of life, then, introduces no mystical power, such as would in any way thwart, or place in abeyance, the action of forces already operative. In the machinery of the living, as in that of the non-living, we merely see their transformation, in obedience to the same principle of conservation of energy as obtains elsewhere; and it may be expected that, in proportion as our power of investigation grows, the origin of each variation of the living organism will be found more and more traceable to the direct or indirect action upon it of external forces, the element of chance being thus progressively eliminated, as the definite sequence of cause and effect comes to be perceived with an increasing clearness; and only, I venture to think, as this is worked out, can we learn to apprehend fully the true significance of the great Theory of Evolution.'

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In his papers and books Bose gives very few references to previous and contemporary workers. This is partly, no doubt, due to the fact that he was in most cases

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*'Plant Response as a Means of Physiological Investigation' by Sir Jagadis Chunder Bose (1906), p. viii.

exploring new ground. It should also be mentioned that 'the priority of many of Bose's observations, e.g. positive and multiple responses, alike electrical and mechanical, and transmission of death excitation, is seldom given the acknowledgement due, in current literature on plant physiology ... He has left behind nineteen volumes which form a record of the work carried out and directed by him over a period of nearly thirty-seven years'. Bose was truly a great man of science and his pioneering spirit and work have played a vital rôle in the revival of scientific research in our country. But for all this he was more in the nature of a lone worker—a towering but isolated peak—rather than a builder himself of a school of scientific research. To conclude we may quote his memorable words spoken at the end of the lecture at the Royal Institution (London) in January, 1897: 'The land from which I come did at one time strive to extend human knowledge, but that was many centuries ago. It is now the privilege of the West to lead in this work. I would fain hope, and I am sure I am echoing your sentiments, that a time may come when the East, too, will take her part in this glorious undertaking; and that at no distant time it shall neither be the West nor the East, but both the East and the West, that will work together, each taking her share in extending the boundaries of knowledge, and bringing out the manifold blessings that follow in its train.'

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Geddes in his 'Life of Bose' gives the following extract from the *Spectator* (London): 'We can see no reason whatever why the Asiatic mind, turning from its absorption in insoluble problems, should not 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, upon which yet deeper inquiries can be based. If that happened—and Professor Bose is at all events a living evidence that it can happen—that would be the greatest addition ever made to the sum of the mental force of mankind.'