SOME HISTORICAL ASPECTS OF JAGADIS CHANDRA BOSE'S MICROWAVE RESEARCH DURING 1895—1900

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The scientific research of Jagadis C. Bose, F. R. S. on radio waves during 1895-1900 was characterized by the fact that shortly after Hertz's pioneering discovery and study of these waves, Bose felt the need of devising radiators of millimetre waves for producing narrow pencils of radiation, so that the phenomena of polarization exhibited by crystals could be effectively studied. With great virtuosity and ingenuity Bose constructed simple but highly efficient and sensitive apparatuses. His attempt to construct a self-recovering coherer led him not only to the discovery of the first semiconductor detector of microwaves as well as visible radiation (galena detector patented with the US-Govt, in 1904 : No. 755840), but also to anticipate the promising science of solid-state physics. It is suggested that physicists and chemists should reperform some of his experiments in order to test the validity of his classification of metals into two oppositely behaving groups with reference to coherer action. One remarkable aspect of his research on polarization of microwaves is that he not only devised efficient polarizers and analyzers from vegetable fibres and books, but also contributed, in some way, to the microscopic explanation of optical activity by demonstrating a microwave analogue of this phenomenon caused by twisted 'macromolecules' of jute fibres. Despite his early success in demonstrating the usefulness of electric waves in wireless signalling, Bose did not go in for commercial follow-out of his investigations. Rather he allowed the galena-receiver patent to lapse. His interest of research shifted towards the borderland of physics and biology in the course of his observations of the response of non-living and living substances to electric radiation. That direction of research deserves to be dealt with in a separate paper.

§1. INTRODUCTION

If J. C. Bose's place in the world of science is to be described in one sentence, then he should be characterized as one of the pioneers of microwave physics and as one of those who anticipated the science of cybernetics that seeks to unify physics, biology and psychology with respect to the problem of automatic control systems. Indians with excessive patriotism go to the extreme of idolizing Bose as *the* inventor of wireless telegraphy and as a triumphant oriental savant who, through his biophysical researches, has convincingly vindicated the existence of a Supreme Consciousness that unifies all diversities. On the other hand, some critics—rather detractors—go to the other extreme; they underrate his contribution to microwave researches and also consider his biophysical researches as a metaphysical attempt at fitting empirical results into the Vedic doctrine of unity in diversity. The critics however forget that science *does* ultimately aim at consistent unifying principles that establish a comprehensible order in the manifoldness of natural phenomena and that it is through a discerning philosophical insight into Nature's diverse manifestations that Norbert Wiener has created the modern science of cybernetics. Both idolization and detraction are in fact rooted in ignorance of what Bose actually did. Hence my attempt to review his microwave researches.

Only a few years before 1927, i. e. the year of the inception of radio broadcasting in India, radio engineers freed themselves somewhat belatedly from the technological fixation of using long waves, and realized that they should return to the "short-wave" region of the radiofrequency spectrum, with which the pioneers of Hertzian waves had started their investigations. It is now well-known that in later decades this interest in the use of short waves extended into the microwave region up to the millimetre wave level.

It is interesting that when in 1890s the successors of Hertz like Lodge, Righi, Marconi, Popov were dealing with decimetre or centimetre waves, J. C. Bose chose to deal with millimetre waves, which he produced with his experimental ingenuity. Moreover, for the detection of these he constructed a new device that is acknowledged as the first semiconductor radio-wave detector. This fact alone justifies a review of Bose's early microwave researches, although his interest of research began to shift towards the borderland between physics and biology at the very time (1901) when he was persuaded by Sister Nivedita and Mrs. Bull[a] to patent his galena "detector of electrical disturbances" with the U. S. Government for establishing priority. Bose did not however care to renew his patent and allowed it to lapse.

And history has very quickly forgotten this achievement of Bose, as is evident from the fact that in the quite informative article on J. C. Bose in the *Dictionary of Scientific Biography* (Editor : C. C. Gillispie ; Charles Scribner's sons, New York, 1970-76) there is no reference to the galena detector.*

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*The author of that article is Charles Süsskind, Professor of Engineering Science, University of California, Berkeley and the Editor of the *Encyclopedia of Electronics*; at the

Even in the remarkable science-historical book *Syntony and Spark : the Origins of Radio* by Hugh G. J. Aitken (John Wiley 1976), Bose's name does not occur at all, although the author, in discussing different types of coherers, has written such a sentence as : "The coherer was, if we may stretch a point, the first solid-state device used in electronics, antedating the crystal detector." (p. 104). There is no mention of the person who pioneered the solid-state crystal detector. On the other hand, however, Bose's pioneering researches have been rightfully recognized in some purely technical papers in the *Proceedings of the Institute of Radio Engineers* by professional radio-engineers and solid-state physicists. At the same time I am yet to come across an Indian electronic engineer who is intersted in or knows what Bose actually did in the field of microwave physics.

§2. The Notable Lines of Research

In order to give briefly an idea of what J. C. Bose actually did, the best thing would be to quote, at the outset, from the foreword written by Sir J. J. Thomson in mid-1926 for the *Collected Physical Papers* (henceforth referred to as *CPP*) of Bose published by Longmans, Green & Co. in 1927 :

> This book contains a collection of the papers on Physical subjects written by Sir Jagadis Bose. A considerable number of these were written some thirty years ago, shortly after the publication of Hertz's experiments on Electric Waves when the study of the properties of electric waves was being pursued with great vigour. This study was facilitated by the method introduced by Bose, of generating electrical waves of shorter wave length than those in general use. By this method he obtained important results on coherence, polarization, double refraction and rotation of the plane of polarization which are described in the papers collected in this volume. In addition to the purely physical papers there are others which describe the beginnings of Sir Jagadis' application of physical methods to the study of living matter, a subjeet to which most of his work n recent years has been devoted. The papers... mark the dawn of the revival in India, of interest in researches in Physical Science ; this which has been so marked a feature of the last thirty years is very largely due to the work and influence of Sir Jagadis Bose.

XV International Congress of the History of Science, Edinburgh, August 1977, he presided over a session where I discussed J. C. Bose's microwave researches, and on that occasion I drew Prof. Süsskind's attention to Bose's US-Patent of the galena receiver. He intends to mention it in the possible future edition of the *DSB*. Thanks are however due to Süssskind for the fact that it was he who convinced the editorial board of the justification for including Bose's lifework in the *DSB*.

This short foreword sums up the salient facts that (i) Bose introduced notable improvemets in the investigation of wireless waves shortly after Hertz's discovery and study of these waves in 1880s, (ii) Bose's interest of research shifted subsequently towards the borderland between physics and biology, and (iii) his researches signalized the beginning of the Indian renaissance in science. And the following quotation from Bose's preface to the same book would explain why I confine my present discussion to the period 1895-1900 :

> A collection of papers mainly physical, dating from the year 1895, is published in the present volume. The first object of my inquiry was the optical properties of Electric Waves, brought down to within a few octaves of visible light. In the course of my investigations I was led to the discovery of electric response of non-living matter, such as metals, an account of which was published in 1900 by the International Congress of Science, Paris. The response, like that of living matter, was shown to exhibit fatigue under continuous stimulation, enhancement under chemical stimulants, and permanent abolition under poisons. These results indicated that the response of the more complex and unstable living matter is ultimately the expression of physico-chemical reactions[b]. —My subsequent investigations were directed towards the establishment of the generalisation of the essential unity of physiological mechanism in plant and animal life.

The discussion of Bose's post-1900 researches would require a separate article. Likewise the discussion of his pioneering work in the foregoing period deserves a special treatment.

When Lodge, Branly, Righi, Marconi, Fleming and others pursued Hertz's work on the electric waves, they designed new apparatuses for verifying his experimental findings on the quasioptical properties of the electric waves as well as for utilizing the electric waves for message transmission.

It is likely that J. C. Bose, Professor of Physics at the Presidency College, Calcutta, came across Lodge's *The Work of Hertz and Some of his Successors* (1894).[c] The first remarkable aspect of Bose's follow-up of microwave researches is that while Lodge reduced Hertz's decimetre waves (*c.* 66 cm) to centimetre waves (*c.* 8 cm), Bose reduced them to the millimetre level (*c.* 5 mm). Two decades back (1958) J. F. Ramsay reviewed[1] the contemporary position of the milimetre-wave research in the following terms : "Today millimetre waves research is in a similar position to that existing in the 1890's. ... Generation of the waves presents formidable difficulties, detectors are almost as crude as those of the early experimentalists." Evidently, however, the position in regard to *mm*-wave generation in the late 1970s is considerably changed, and the developments in laser optics have overtaken Ramsay's statement during the past 20 years.

Hertz had found that the sparks for producing electric waves ceased to be oscillatory as soon as the surface of the sparking balls got roughened, and therefore the balls required frequent repolishing. Lodge[1a] constructed his fairly persistent oscillator for centimetre-waves by interposing a hollow sphere in the spark gap and by providing a hollow cylinder as wave-guide. Bose constructed improved, persistently oscillating radiators of millimetre waves, in which the sparking took place (through an interposed platinum sphere) between two hollow hemispehres with two platinum beads attached to their middle. Bose desribed the advantages of his radiator, with which he had "no difficulty in obtaining an oscillatory discharge," in his first paper[2] on electric waves. He found the vibrating interrupter of the Ruhmkorff coil to be a source of trouble and therefore discarded it. "To obtain a flash of radiation I have only to press the stud and release it, and on an average, I require about fifty flashes for a day's work. For working an entire month it is therefore only necessary to have a little over a thousand breaks of the primary current. With the usual vibrating interrupter a larger number of breaks would have been necessary even for one hour's work" The sparking surfaces needed no polishing. His radiating box was very 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 one which is still smaller." This description gives an idea of the virtuosity with which Bose developed his compact short-wave radiators. He used a cylindrical lens of sulphur for rendering the beam parallel by making the spark-gap coincide with the focal line. He had determined[8] the index of refraction of sulphur, 1.734, for short electric waves by the method of total reflection. Incidentally it may be mentioned that Bose refracted electric waves through a cylindrical pillar of the Presidency College building[4].

The need of wave-guides or radiating tubes had been already felt by the early pioneers of electric–wave researches. Lodge's hollow cylindrical radiator or 'copper hat' testifies to the use of wave-guides. Lodge[1a] said ; "When definite radiation is desired, it is well to put the radiator in a copper hat, open in only one direction." Bose used both cylindrical and square wave-guides in his radiators and also employed pyramidal horns in the receivers as radiation-collecting antennae. J. F. Ramsay remarks[1] that at Bose's longest wave lengths (*c.* 2.5 cm) "his tubes would behave as slightly oversize wave-guides, as the width was around 1 inch. At 5 mm, however, the tube would act more as a shield, liable to produce higher order modes, whence Bose's search for absorbent material." Bose developed "lossy" artificial media in his search for a microwave absorber. The blotting paper soaked in electrolyte proved the best.

Although Bose knew that large electric waves were advantageous in view of their great penetrative power, he realized their disadvantage for electro-optical investigations, viz. they are unwantedly reflected from room surroundings, thereby disturbing all portions of the receiving circuit and they cannot be formed into a narrow pencil of radiation. He removed these drawbacks by constructing $\frac{1}{4}$, $\frac{1}{2}$ and 1 inch wave radiators, which demonstrated in his lecture before the Royal Institution on 29 January 1897. His radiators gave quite intense radiation, and the parallel pencil was only about one cm. in diameter. He remarked[5]:

> The production of such a narrow pencil became absolutely necessary for a certain class of investigations. Merely qualitative results for reflection or refraction may no doubt be obtained with gigantic mirrors or prisms, but when we come to study the phenomena of polarisation as exhibited by crystals, Nature imposes a limit, and this limitation of the size of the crystal has to be accepted in conducting any investigation on their polarising properties.

Already it had been felt by Hertz's immediate successors that "more interest attaches to polarisation, double refraction and dispersion experiments"[1a] than to interference and diffraction effects. And Bose seized upon, for investigation, the phenomenon of "polarisation of electric ray by double-refracting crystals" in his very first scientific paper[2] on electric waves communicated to the Asiatic Society of Bengal in 1895. He pursued his polarisation investigations in his subsequent papers with great meticulousness.

However, before dealing with that aspect of his researches it is necessary to discuss that just as, on the one hand, Bose devised short wave radiators, he developed, on the other hand, a new type of highly sensitive receiver. Lodge considered the then prevalent iron-filings tube *coherer* as the "most astonishingly sensitive detector of Hertz waves". He utilized the coherer action (i. e. the sudden diminution of resistance on receiving electric radiation), but he himself mentioned in his lecture[1a] at the Royal Institution in June 1894 : "I have not yet done any seriously metrical experiments." Up to a certain stage of investigations the conventional metal-filings coherer did serve well as a sensitive receiver. However, it required shaking or tapping (almost each time after exposure to electric radiation) for restoring it to sensitiveness. Moreover, Bose realized that there was a limit to its sensitivity. So he devised a spiral-spring receiver or coherer (with numerous points of contact) in series with a volatic cell and a dead-beat galvanometer. The spirals could be subjected to variable pressure by the action of a screw. The e. m. f. could be varied by a potentiometer-slide arrangement. The receiver, when exposed to long-continued radiation, lost some sensibility, which could be again maintained fairly uniform by slightly varying the e.m.f. "to keep pace with the fatigue produced"[6]. When Bose reported his description of the spiral-spring coherer in *the Electrician* (Dec. 1895), this journal readily reviewed : "The sensibility and range of this type of 'coherer' would appear to leave little to be desired". (Quoted in Geddes' book[6])[(d)]. In his Royal Institution lecture in 1897 Bose remarked[5] : "The sensitiveness, when necessary, can be exalted to almost any extent, and it is thus possible to carry out some of the most delicate experiments (specially on polarisation) with certainty. In my more recent apparatus I use a single-contact receiver made of steel, nickel, aluminium or magnesium. These receivers can not only be made extremely sensitive, but also highly reliable."

When Lodge developed his coherers, he utilized the usual behaviour of contact-sensitiveness of metals, i.e. diminution of resistance when subjected to electric radiation. He however made a brief remark[7] in his Friday Evening lecture on 'coherers' that "all metals do not behave in the same way, but the majority...show an increase of coherence [i.e. diminution of resistance]... A few metals (e.g. silver) appear to behave in an opposite direction." Lodge does not seem to have pursued an investigation of such exceptional behaviour of some metals. It is noticeable that just two months after this Friday Evening Discourse of Lodge, Bose presented his paper on "Self-recovering Coherer and the Study of the Cohering Action of Different Metals" at the Royal Society[8]. In this paper, there is no reference to Lodge's lecture. but Bose introduced this very aspect as a subject for persuing further investigation : "In the majority of metals, the normal tendency is towards a diminution of contact resistance by the action of electric waves. ...But... there is an interesting exception, where the normal state of things is just the reverse of what prevails in the majority of metals."

After working with many kinds of metals he concluded that "the most interesting and typically exceptional case ... is the receiver made with potassium, which not only exhibits an increase of resistance, but also a remarkable power of self-recovery." The problem of making self-recovering detectors attracted Bose's attention, and he pursued his investigation of this aspect in his subsequent paper*, where he concluded that the material of his detectors could be classified into two groups : the so-called ***positive*** type which on exposure to electric waves exhibits increase of conductivity or resistance diminution, and the ***negative*** type which exhibits resistance increase. Our interest in this line of investigation lies in the fact that Bose claimed that silver, when exposed to electric radiation, could undergo an allotropic change

* See *Reference 10.*

and thus yield a "radiation product" which belonged to the negative group. He even described a set of chemical experiments, by which he believed to have "chemically" poroduced a positive and negative "allotropic variety of silver", these two varieties, he claimed,[9] gave a P. D. of about 0.12 volt when made into a voltaic cell. ***Physicists as well as chemists would do well to reperform Bose's experiments for testing the validity of these inferences.*** Perhaps much of these results of Bose would prove irreproducible according to modern reliable experimental methods, but nevertheless for three reasons we may consider his efforts in this direction to be of special significance : (1) His work indicated that research concerning the action of electric waves "in modifying the molecular structure of matter" deserved greater attention, because it was "full of promise in many lines of inquiry in molecular physics"[9] ; (2) His search for a satisfactory self-recovering receiver led to his experimental finding that *galena* (PbS) was a highly effective self-recovering detector sensitive to short-wave electric radiation as well as to visible radiation[10] ; (3) In the course of these investigations Bose's interest shifted towards the borderland of physics and biology [10a]. This aspect is however beyond the scope of our present discussion.

As to the *galena detector,** Bose touched upon its importance in his above-mentioned paper[10] : "That light does produce conductivity variation is seen in selenium. I have also succeeded in detecting the effect of light in producing variation of contact resistance in a galena receiver. One and the same receiver responded in the same way when alternately acted on by visible and invisible (electric) radiation. The peculiarities of this ***universal radiometer*** were in every way similar to those of detectors for electric radiation." (Italics mine). Despite Bose's reluctance to give any part of his life for money-making purposes two of his friends, Miss Margaret Noble (later 'Sister Nivedita') and Mrs. Bull persuaded him to apply for patent with the U. S. Government, in 1901, to establish priority, and the patent was granted in 1904 (US Patent 755840).** However, Bose allowed the patent to lapse. Pearson & Brattain[11] clearly indicate Bose's priority in introducing a semiconductor rectifier as suitable radiowave-detector and also give the reason why interest in such detectors lagged :

> The demonstration of the existence of radio waves by H. Hertz in 1888 created a potential demand for a suitable detector, but it was not realized

*Referred to as *Tejometer* in his Friday Evening lecture at the Royal Institution on 10 May 1901 ; *see* "The Response of Inorganic Matter to Mechanical and Electrical Stimulus," p. 434 of the Elsevier—Vol. 5 referred to in *Ref. 5.* or *CPP,* p. 270. Also *see* U. S. Patent no. 755840, p. 3, line-85. (Thanks are due to the U. S. Patent Office for favouring me with a copy.)

**Application filed : Sept. 30, 1901 ; patented : March 29, 1904.

> until 1904 that semiconductor rectifiers were well suited for this purpose. J. C. Bose [11], H. H. C. Dunwoody [12], L. W. Austin [13], and G. W. Pierce [14] found that point contacts (cat whiskers) on galena, silicon carbide, tellurium, silicon, etc. were good detectors of radio waves. Silicon detectors were found by experience to be most stable, while galena detectors had the best sensitivity. It was G. W. Pierce, by the way, who went to a great deal of effort at this time to show that these devices did not operate on a thermal basis. With the advent of the vacuum tube at about this time, interest in the point contact detector lagged and little of scientific interest was contributed on such detectors for a number of years. (References : [11] US-Patent 755840, 1904 ; [12] US-Patent 837616, 1906 ; [13]......*Phys. Rev* **24** (June 1907), pp. 508-510 ; [14]... ..*Phys. Rev,* **25** (July 1907), pp. 31-60,... .).

It is now known that galena has a rectifier action on radio waves, while its detection of visible waves is a photovoltaic effect. In discussing the photovoltaic effects of PbS, PbTe and PbSe, Moss[12] refers to Bose's pioneering galena detector [6]

As already mentioned, Bose made an exhaustive study of polarization of of electric waves. Hertz had constructed a wire-grating polarizer (or analyzer) in a big 2m-octagonal frame for reflecting or polarizing 66 cm waves. Lodge, who dealt with shorter waves, used a similar type of wire grid "only on a much smaller scale, say an 18-inch octagonal frame of copper strip with a harp of parallel copper wires."[1a] Bose worked with many types of crystals, stratified rocks, etc. for studying polarization. He however found that "the most efficient polarising substances I have come across are the vegetable fibres. ... Common jute (*Corchorus capsularis*) exhibits the property of polarisation in a very marked degree".[13] He made compact cells (3 × 3 cm area and 5 cm thickness) of stretched parallel fibres, which could be used as polarizer and analyzer and also as a polarimeter with a graduated disc. He even found "locks of human hair to polarise the electric ray". He used also a Bradshaw time-table (interleaved with tin foils) as polarizer or analyzer. This he demonstrated in his Friday lecture of 1897 at the Royal Institution : "An ordinary book is thus seen to act as a perfect polariser of the ray ; the vibrations parallel to the pages are completly absorbed, and those at right angles transmitted in a perfectly polarised condition." Lord Rayleigh humorously remarked to Bose at the end of the lecture that nobody had been able to see any light through the complex tables of 'Bradshaw's Railway Guide', but Bose showed light through it by turning it through 90° ![4]

A noteworthy aspect of his polarization investigations is his study of "The rotation of plane of polarisation of electric waves by a twisted structure"[14]. It is not known whether Bose read Pasteur's lecture on optical activity delivered in 1860, where we find the earliest reference to the possibility of a helical arrangement of atoms [15]: "Are the atoms of the dextroacid grouped on the spiral of a right-handed helix, or are they situated at the apices of an irregular tetrahedron, or are they disposed according to some other asymmetric arrangement? We do not know." Pasteur was evidently unable to decisively identify the spatial arrangement of the atoms. Anyway, Bose in his above paper[14] did not refer to Pasteur's anticipation of helical arrangement of atoms, but quoted a passage from Preston's book on Light, 2nd edition (March 1895), in which Preston wrote : "It is, perhaps. not surprising that crystalline substances should, on account of ***some special molecular arrangement***, possess rotatory power.... ... It is just possible that the light, in traversing a solution in which the molecules are free to move, may, on account of some peculiarity of structure, cause the molecules to take up ***some special arrangement***, so that the fluid becomes as it were polarised by the transmission of light, in a manner somewhat analogous to that in which a fluid dielectric is polarised in a fluid of eletrostatic force." (Italics mine). It may be noted that Preston only referred to some unspecified "special arrangement" of molecules ; there was no reference to possible helicity. Therefore, it is unlikely that Bose had got some hint of such a a possibility. But Bose's scientific insight prompted him to conjecture that the "special arrangement" might be a twisted helical one which caused optical activity. Bose wrote : "In order *to imitate* the rotation produced by liquids like sugar solutions, I made small elements or 'molecules' of twisted jute, of two varietes, one kind being twisted to the right (positive) and the other twisted to the left (negative)." (Italics mine). These two 'molecules' individually produced right-and left-handed rotations of polarization plane of electric waves, but jointly counteracted one another. J. F Ramsay discussed[1] this remarkable aspect thus : "Here, according to Bose, was an analog to sugar rotations. The significant featur of this microwave technique was in its providing a macroscopic representation of the submicroscopic. Recently in 1955 quasi crystallographic reflections have been obtained from model crystal structures of macroscopic 'atoms' when irradiated by millimeter waves. The basic technique is, however, reminiscent of Bose's early experiments in microwave modeling."

§ 3. Bose's Work and the International Background

The history of the Hertzian-wave researches during 1890-95 is characterized by the fact that different physicists had different aims in researching into the electric waves. Edouard Branly, who published his experimental results on the metal-filings coherer in 1890-91, was chiefly interested in studying the nervous system and looked upon the 'imperfect contact' switches of the coherer as analogues of neurones. Alexander Popov constructed his receiver primarily as an aid to weather forecasting, although he was aware of its usefulness in wireless signalling in association with a suitable transmitter (1895). Augusto Righi, whose transmitter model (1894) was fully utilized by his pupil Marconi in his commercial venture, was chiefly interested in the microwave-frequency investigations of the quasioptical behaviour of the electric waves. Bose was likewise interested chiefly in such quasioptical investigations, as is evident from the description given above. However, as early as 1895 Bose demonstrated, at the physical laboratory of the Presidency College and also publicly in the Calcutta Town Hall in presence of the then Lt. Governor Sir William McKenzie, the mechanism of transmitting wireless messages at a distance. In the same year Ernest Rutherford too performed such a transmission experiment at Cambridge, but did not pursue that line of investigation further. (Rutherford's method of detecting electromagnetic waves was later improved and used by Marconi among others). Despite these experimental successes neither Bose nor Rutherford thought of a commercial follow-out. Although during this period Alexander Muirhead of the famous firm of telegraph instrument-makers and Oliver Lodge started considering the possibility of developing the new technology of wireless signalling, they did not seriously start racing for gaining commercial lead before the much-publicized arrival of Marconi in England and his application for a broad patent on radio signalling (application filed : 2 June 1896 ; patent granted : 2 July 1897).

The situation began to change during the period 1896-1900, when Marconi's success in winning the support of the British Post Office and Government (regarding his radio signalling project and patent) precipitated the race for patenting transmitters and receivers. We may recall that in January 1897, i.e. during this period, Bose demonstrated[5] his radiators, coherers and polarizing devices at the Royal Institution. It is interesting that Bose did not hesitate to put his cards on the table even at that time of incipient competition when the psychosis of trade-secrecy was affecting the minds of many scientists. After this Friday Evening Discourse of Bose the professional journal *Electric Engineer* expressed "surprise that no secret was at any time made as to its [Bose's coherer] construction, so that it has been open to all the world to adopt it for practical and possibly money-making purposes."*

Bose's indifference towards commercial success became more manifest in his Friday lecture at the Royal Institution on 10 May 1901[10a] as well as in his paper[1e] read at the Royal Society on 20 June the same year. In these lectures he openly demonstrated and discussed his so-called 'artificial retina' or *Tejometer* (universal radiometer), i.e. the galena detector. Bose had intended to describe this detector in greater detail in his Friday lecture,

*Quoted in Patrick Geddes Book on Bose (Ref. 6).

time permitting—as is clear from his own remark given as a footnote in the Elsevier reproduction (Vol. 5, p. 434) mentioned in Reference 5.*

However, that was the time when Marconi had already secured the famous 'Four-sevens' patent (No. 7777, patented : 26 April 1900) concerning a new tuning method. Marconi's lead in the race heightened the patenting psychosis even among such academicians as Lodge, who in association with Muirhead formed the Lodge-Muirhead Syndicate in 1901. Earlier, they had applied for (May 1897) patents after knowing of Marconi's application for the first wireless signalling patent in June 1896. In such a situation Bose's friends Miss Noble and Mrs. Bull must have felt that he should not lose the priority-race simply by default. That was the reason why they persuaded him to apply for the U. S.-patent in September 1901, i.e. within a few months after his lectures at the Royal Institution and Royal Society where he had described the galena receiver. However, Bose allowed the patent to lapse even after securing it. According to Bose's biographer Geddes : "His [Bose's] child memory had been impressed by the pure white flowers offered in Indian worships ; and it came early to him that whatever offerings his life could make should be untainted by any considerations of personal advantage." Bose's reluctance to renew the Patent may be explained in a simple way on the basis of Geddes' analysis of Bose's temperament. I do not attempt a deeper analysis of Bose's withdrawal from commercial competition. Let such an analysis be left to the social historians of science. However, in this connexion I simply quote a remark[16] of Forman, Heilbron and Weart.

> Physicists in all nations received fees for additional examining work, for special government service, for appearing as expert witnesses. and for consultation—or even collaboration—with industry. Anglo-Saxon physicists probably led the world in extracting money from this last source. Despite the close relations between German science and technology, the German professor of physics did not rush to make money from his research : 'It is well known throughout the world that the physical laboratories of Germany have no windows looking towards the patent office.' [Cited from Münsterberg, *Science*, Vol. 4(1896), p. 162, a propos of Röntgen's discovery]. German physicists who became involved in business often left their university positions for industrial jobs.
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> Not so the British physicist : Lord Kelvin, the holder of many lucrative patents, ran an instrument-making firm which, in many respects, was a branch of his laboratory, and which he visited for an hour or so every

*In the text of the Friday lecture reproduced in *CPP* (p. 269) the reference to galena is explicit : "I have been able to construct an artificial retina *constructed of galena.*" But in the Elsevier reproduction the italicized portion does not occur.

day. (...Compare the indifference of Pierre Curie to the commercial exploitation of his electrometer...). Other English academic physicists and many American ones often acted as consultants and expert witnesses for electrotechnical firms, electric streetcar companies, etc. An interesting illustration of national differences in this matter is afforded by the radium industry. Marie Curie prided herself on eschewing the commercial exploitation of radium ; F. Giesel manufactured it at the Braunschweig Quinine Works and sold it at cost ; W. Ramsay set up a corporation which hoped to refine and market it for profit We take it that the relative crassness of British and American physicists was related to their need to supply for themselves what the European received through his pension system.

In a letter to one of the above authors, Spencer Weart*, I drew his attention to Bose's reluctance to renew his patent. In his reply (October 5, 1976) Dr. Weart wrote : "The information about Bose was new to me. I've recently been doing some research into the scientists-and-patents question, which leads me to believe that the taboo against profiting from science slowly broke down, among Europeans, between 1900 and 1940, although many continued to give it lip service." Indian social historians of science may undertake a study for investigating whether most of the Indian pioneers of modern scientific education and research continued to cherish the ideal** of ancient Indian scholars and sages, who—though patronized by affluent kings—disliked the idea of making money beyond what plain living called for ; whether this national trait (in the academicians of renascent India) of eschewing commercial exploitation of inventions and discoveries is one of the many factors that have retarded the process of industrialization of our country.

NOTES

(a) Mrs. Bull, the widow of the famous Norwegian violinist Ole Bornemann Bull (1810-1880), was an American citizen who, like her Irish friend Miss Margaret Noble (later Sister Nivedita), became a follower of Swami Vivekananda and also came into close contact with the Bose couple during her visit to Calcutta in 1899. The Boses, during their visit to America in the first decade of this century, accepted the hospitality of Mrs. Bull.

(b) In his Friday Evening Discourse of 10 May 1901 at the Royal Institution of London [see *CPP*, p. 275 or *the Royal Instn. Library of Science*

* Director, Center for History of Physics, American Institute of Physics, New York.

** E.g., in his inaugural address on the occasion of the foundation of the Bose Institute on November 30, 1917 J. C. Bose said : "Through the regular publication of the Transactions of the Institute, these Indian contributions will reach the whole world. The discoveries made will thus become public property. No patents will ever be taken. The spirit of our national culture demands that we should ever be free from the desecration of utilising knowledge for personal gain."

—*Physical Sciences*, Vol. 5, p. 439 (Elsevier, 1970)], Bose had already expressed his belief in the fundamentality of physico-chemical reactions. It is very surprising that in the first page of the Acharya Jagadis Chandra Bose Birth Centenary brochure (1958, edited by A. Home) a portion of this Friday lecture was quoted with unexplainable 'emendations', among which the following is very glaring; the *CPP*-version is: "Do they [autographic response-records of living and non-living things] not show us that the responsive processes, seen in life, have been foreshadowed in non-life?—that the physiological is, after all, but an expression of the physico-chemical, and there is no abrupt break, but a continuity?" And the Centenary-brochure version is: "...—that the physiological is related to the physico-chemical? that there is no abrupt break, but a uniform and continuous march of law?" It should however be mentioned that Bose himself just put the more camprehensive term 'physico-chemical' in *CPP* (1927) in place of only 'physical', which he had used in the original lecture of 1901 (see Elsevier reproduction referred to above).

(c) It is well known that during the 1880s the German physicist Heinrich Hertz demonstrated the existence of electromagnetic waves or radio waves predicted theoretically two decades previously by Maxwell. Hertz's research papers were soon incorporated into his book *Untersuchungen ueber die Ausbreitung der Elektrischen Kraft*. And its authorized translation *Electric Waves, being Researches on the Propagation of Electric Action with Finite Velocity through Space* was published in 1893 (translated by D. E. Jones, with a preface by Lord Kelvin; Macmillan & Co.). Hertz died on 1 January 1894. A tribute was paid to him on 1 June the same year, in a Friday Evening Discourse at the Royal Institution, by the British physicist Oliver Lodge who during 1887-88 had been experimenting with propagation of electric waves along wires in connexion with his researches concerning lightning conductors. The topic of this lecture was the "Work of Hertz". Soon Lodge brought out a little book, the *Work of Hertz and some of his Successors*. The inspiring impact of Lodge's Friday lecture and the book has been described as follows by Charles Süsskind in his paper "Guglielmo Marconi (1874-1937)" in *Endeavour*, Vol. XXXIII, No. 119, May 1974, pp. 67-72:

> "On 1st June 1894, five months after Hertz's death, Oliver Lodge gave a commemorative lecture at the Royal Institution. Lodge must have felt deprived of the great discovery by Hertz, since Lodge had concentrated on demonstrating the existence of Maxwell's waves by transmission along wires rather than through space. Although the two methods are essentially equivalent, Hertz's demonstration of propagation across free space was of course incomparably more spectacular. A lecture at the Royal Institution, with its tradition of popular appeal, would serve a three-

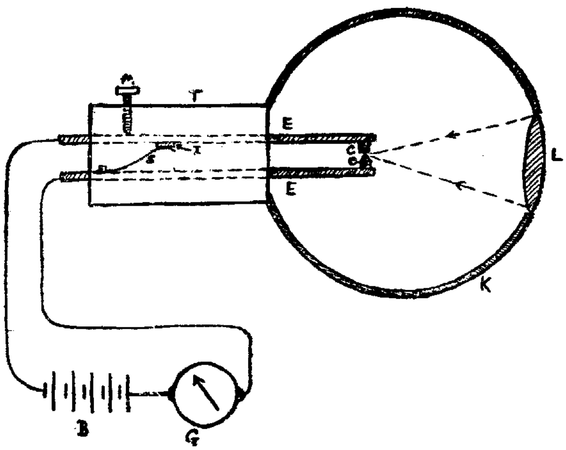
fold purpose: commemorate Hertz and his work, inform the public about more recent advances, and provide a strong *re'clame* for Lodge. His title was, 'The work of Hertz and some of his successors'; and the listeners (and readers, since the lecture was reprinted verbatim, with diagrams, in *The Electrician*) were left in no doubt who was the most important amongst Hertz's successors. ...Lodge's 1894 lecture was widely reported (for instance, in *Nature* and in *Engineering*, both journals that enjoyed worldwide distribution) and found a ready echo througout the world. It inspired further work in England, in Germany, even in Russia: in faraway Kronstadt, headquarters of the Czar's navy, a physics instructor A. S. Popov went to work on the related practical problem of detecting approaching electrical storms by connecting Lodge's apparatus to a meteorological recorder. He gave a couple of lectures that ultimately were to elevate him to the status of a national hero as the inventor of radio—posthumously, sinee he died in 1905. In Italy, professor of physics at the University of Bologna, Augusto Righi (1850-1921), made preparations to incorporate the work of Hertz in his lectures. He also had constructed an oscillator... It was Lodge's lecture that caught young Marconi's eye during the summer holidays of 1894."

Surely Bose too learnt of Hertz's work from Lodge's book.

(d) Sir Patrick Geddes (1854-1932), British biologist and sociologist and a modern pioneer of urban and regional planning, was professor of sociology and civics at the Bombay University during 1919-1924. For furthur information, see Lewis Mumford's article on Geddes in the *International Encyclopedia of the Social Sciences*, Vol. 6 (ed. David L. Sills; Macmillan Co. & the Free Press 1968) and *Patrick Geddes in India* edited by Jacqueline Tyrwhitt (London: Humphries 1947).

(e) About 1950 the phenomenon of photoconductivity of semiconductors began to receive great attention in technology and research in connexion with the production of photoconductive infrared detectors. In photoconductors (unlike photoemissive cells), electrons, on being irradiated with photons, are not emitted, but they absorb sufficient energy from the quanta to go over from a *bound* state to a *free* state where they become current-carriers. Thus 'photoconductivity' is an increase in conductivity in a partial or semi-conductor under the action of radiation. The lead salt photoconductors: lead-sulphide or galena (PbS), lead-telluride (PbTe), and lead-selenide (PbSe) are highly sensitive infrared detectors over the wave-length region 1·5 micron to 7 micron (1 micron = 10^{-6} m). Photovoltaic effects are observable in all these substances, and therefore cells can be made with them which generate voltages under the action of infrared radiation. J. C. Bose pioneered the construction of the galena detector by utilizing photovoltaic effect of this lead salt.

The text of the Patent which describes the galena receiver gives three explanatory figures. The heading of the text reads thus : "United States Patent Office. Jagadis Chunder Bose, of Calcutta, India, Assignor of One-half to Sara Chapman Bull, of Cambridge, Massachusetts.—*Detector for Electrical Disturbances*. Specification forming part of Letters Patent No. 755, 840, dated March 29, 1904. Application filed September 30, 1901. Serial No. 77,028 (No model)". Bose signed the five-page Patent in the presence of two subscribing witnesses : R. E. Ellis and T. L. Whitehead.



Simplified diagram for the galena detector

CC —Sensitive contacts (galena),
M —Micrometer-Screw for adjusting pressure on the Spring (*S*) in order to adjust the force of contact between *CC*.
EE —Electrically conducting arms, movable through the tube (*T*) for focussing *CC* with respect to the lens employed (*L*).
I —Insulating surface.
K —Casing.
B —Battery
G —Dead-beat d'Arsonval galvanometer

In describing the detector, Bose wrote :—

> By placing an ordinary glass lens···in the opening in the wall of the case-section...opposite the sensitive contacts...of the instrument and by throwing light upon this lens an immediate response is observed in the galvanometer, the needle of which is deflected in accordance with the spectral properties of the light thrown upon the sensitive contacts or artificial retina. With a glass lens the instrument will detect and record lights not only some way beyond the violet, but also in regions far below the infra-red in the invisible regions of electric radiation. We may thus style the apparatus a 'tejometer' (Sanscrit *tej*=radiation) or

universal radiometer. ...By removing the metallic and wooden casings and lens the instrument may be used as a detector or so-called 'coherer' for wireless or other telegraphy. ...What I claim, and desire to secure by Letters Patent is—.. a coherer or detector of electrical disturbances, Hertzian waves, light waves, or other radiations, comprising a pair of galena contacts....

In this connexion the Friday Evening Discourse of C. W. Siemens on February 18, 1876 on the *Action of Light on Selenium* is worth reading [The Royal Institution Library of Science: Physical Sciences (Elsevier 1970), Vol. 2, pp. 466-477]. Bose's "artificial retina" of galena resembles in some way Siemens' "artificial eye" of selenium.

REFERENCES :

(Bose's papers published till 1925 are included in his *CPP* with minor modifications. The reproduced papers do not however bear the volume numbers of the journals but only the months and years of publication. The numbers within the { }-brackets indicate the page numbers of the *CPP*. For the papers published in *Proc. Roy. Soc.* the parenthesized words *Rc.* and *Rd.* mean respectively 'received' and 'read' at the Royal Society).

1 Ramsay, J. F. "Microwave Antenna & Waveguide Techniques before 1900," *Proc. IRE*, Feb. 1958, **46** : p. 405,

1a Lodge, O. Friday Evening Discourse, June 1, 1894, "The Work of Hertz," *Royal Institution Library of Science : Physical Sciences* (Elsevier. 1970), Vol. 4, p. 321.

2 Bose, J. C. "On Polarisation of Electric Rays by Double-Refracting Crystals," Asiatic Society of Bengal, May 1895 {1}.

3 ——"On the Determination of the Index of Refraction of Sulphur for the Electric Ray", *Proc. Roy. Soc.*, 1895, **59** : p. 160 {21}. [*Rc.* : 20 Oct. 1895; *Rd.* : 12 Dec. 1895].

4 ——*Adṛśya Ālok* (Invisible Light), in *Avyakta* (the Unmanifest), a collection of popular Bengali essays. (Vaṅgīya Vijñān Pariṣad, Calcutta-9).

5 ——Friday Evening Discourse, January 29, 1897, "Electromagnetic Radiation and the Polarisation of the Electric Ray", *Royal Institution Library of Science : Physical Sciences* (Elsevier, 1970), Vol. 5, p. 11 {77}. Vide the Manager's Minutes XV of the Royal Institution of Great Britain, May 1893—July 1903 :—Meeting of Dec. 7, 1896, item—27, pp. 213, 214. According to the printed notice for the Fri. Ev. Disc., the Lord Bishop of London was to deliver his lecture "The Picturesque in History" on January 29, 1897 and J. C. Bose, "The Polarisation of the Electric Ray" on Feb. 5, 1897. Eventually however J. C. Bose delivered his lecture on January 29, 1897. (Thanks are due to Mrs. I. M. McCabe of the Royal Institution Library for allowing me to consult the above Minutes.)

6 Geddes, Patrick, *The Life and Work of Sir Jagadis C. Bose* (Longmans, Green & Co., 1920), p. 63.

7 Lodge, O. Fridary Evening Discourse, Feb. 24, 1899, "Coherers", *Royal Institution Library of Science : Physical Sciences* (Elsevier, 1970), Vol. 5, p. 233.

8 Bose, J. C., "On a self-recovering Coherer and the Study of the Cohering Action of Different Metals", *Proc. Roy. Soc.*, 1899, **65** : p. 166. {116}.
[*Rc.* : 6 March 1899 ; *Rd.* : 27 April 1899].

9 ——"On Electric Touch and the Molecular Changes Produced in Matter by Electric Waves" *Proc. Roy. Soc.*, 1900, **66** : p. 452. {127},
[*Rc.* : 29 January 1900 ; *Rd.* : 8 Feb. 1900].

10 ——"On the Continuity of Effect of Light & Electric Radiation on Matter", *Proc. Roy Soc.*, 1901, **70** : p. 154. {163}.
[*Rc.* : 18 April 1901 ; *Rd.* : 20 June 1901].

10a ——"On the Similarity of Effect of Electrical Stimulus on Inorganic and Living Substances", *International Congress of Science*, Paris 1900. {253}.

11 Pearson, G. L. and Brattain, W. H. "History of Semiconductor Research", *Proc. IRE*, Dec. 1955, **43** : p. 1794.

12 Moss, T. S. "Lead Salt Photoconductors", *ibid.* : p. 1869.

13 Bose, J. C. "On a New Electro-polariscope", *Electrician*, 27 Dec. 1895. {11}

14 Bose, J. C. "On the Rotation of Plane of Polarisation of Electric Waves by a Twisted Structure", *Proc. Roy. Soc.*, 1898, **63** : p. 146. {102}.
[*Rc.* : 14 Feb. 1898 ; *Rd.* : 10 March 1898]

15 Pasteur, Louis *Lecons de chimie Professe's en 1860*, Paris 1861, translated and printed as Alembic Club Reprint No. 14.
Thanks are due to Dr. O. Ramsay, Dept. of Chemistry, Michigan University for drawing my attention to this early suggestion of Pasteur.

16 Forman, P., Heilbron, J. L. and Weart, S. R. "Physics circa 1900", *Historical Studies in the Physical Sciences—5* : pp. 48-49 (ed. R. McCormmach : Princeton Univ. Press 1975).

[For references to Bose's other papers concerning electric waves published in *Proc. Roy. Soc.*, see *Index to the Proceedings of the Royal Society of London (Old Series)* volumes 1-75 (1800-1905), London : Harrison & Sons, St. Martin's Lane, 1913].