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J.C. BOSE'S VIEWS ON BIOLOGICAL RHYTHMS

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J.C. Bose, even though a physicist by training, performed extensive experiments on the responses of non-living and living objects, especially plants. His extremely fascinating findings and landmark publications deserve to be more widely known in India and elsewhere. Here we give a brief account of J.C. Bose's views on biological rhythms. He first reported short term (1 min.) lateral leaflet rhythms and endodiurnal rhythms of the terminal leaves in the same plant - the Indian telegraph plant *Desmodium gyrans*. His was the first experimental demonstration of the persistence of the endodiurnal leaf movements in continuous light and continuous darkness in 1919. Bose's report was confirmed by the Dutch lady botanist Antonia Kleinhoonte working with leaf movements of the large jack bean *Canavalia ensiformis*. His plant physiological researches are contained in 1122 pages in four monograph volumes. His pioneering investigations on the comparative biophysics of plant and animal behaviour strangely did not activate other Indian biologists to undertake similar research. Bose's tradition of going back to nature to understand living processes has practically vanished in India.

Key Words : Diurnal rhythms of water lily; Effect of light on plants; Endodiurnal rhythms; Midday sleep of plants; Nyctitropic recorder; Photonastic responses; Plant autographs.

INTRODUCTION

Jagadish Chandra Bose (1858-1937) was Professor of Physics at Presidency College, Calcutta and retired as Senior Professor in 1915. He founded the Bose Institute in 1917 to enable him to continue his Plant physiological investigations.

J.C. Bose was a very orderly and systematic scientist and has himself summarized his extensive researches in physics and on the topics of responses of living and non-living objects and plant physiological investigations in several erudite monographs[1] written in simple scientific and terse English prose. His research findings were world class when he made them and have remained classics to our day. We learn[1] that his science was well appreciated by contemporary physicists such as Lord Kelvin (1824-1907), J.J. Thomson (1856-1940), J.W. Rayleigh (1842-1919) and J.H. Poincare (1854-1912). There is little evidence that his landmark publications on plant physiology,

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movements and tropisms of plants and diurnal rhythms attracted the attention of contemporary Indian or even western biologists. J.C. Bose's contributions to biological (circadian) rhythms (Fig. 1) were acknowledged, however, in the first monograph[2] on the subject, published interestingly in the birth centenary year of J.C. Bose, in 1958. J.C. Bose was a keen observer of nature and the myriad responses of plants to the balancs specings various environmental factors such as light/darkness, changes in temperature and humidity etc. fascinated him and kindled his scientific curiosity. He thus observed and experimentally investigated, using simple and self-fabricated recorders and monitors the tropic movements in plants, twining of tendrils, thermonastic phenomena, photonastic responses, geotropism and night and day movements of petals and leaves of plants. Here we wish to give a brief account on J.C. Bose's views on biological rhythms which he had himself admirably described in four monographs published in 1918[3], 1991[4], 1923[5] and 1927[6].

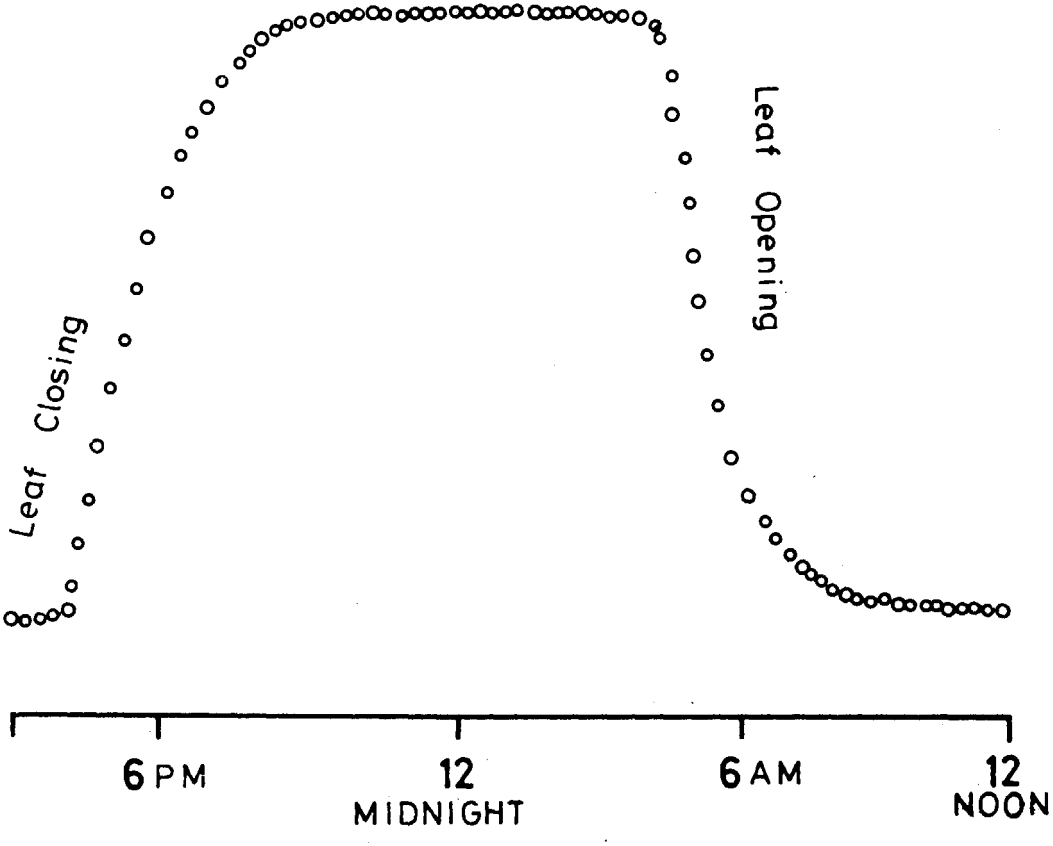

Fig. 1 Diurnal movement of the leaflet of *Cassia alata*.

Diurnal (Circadian) Rhythms in Plants

In volume II of a monograph *Life Movements in Plants*[4] J.C. Bose typically had 128 illustrations. The diurnal movements in plants, concedes Bose, "has long been a perplexing one, and its literature is copious". The literature was copious indeed and contained contradictory claims. The big question, which developed into a controversy which persisted into the present era[7], was whether diurnal rhythms were responses of organisms to external stimuli (exogenous) or intrinsic to organisms (endogenous) and therefore, by implication, genetic. The phenomenon of sleep movements of leaves was first experimentally established as early as in 1729 by the French astronomer Jean Jacques de Mairan. He observed that the diurnal movements of leaves "were not restricted to the sunset or to the open air, it is only a little less marked when one maintains the plant continually enclosed in a dark place" which was the interior of a cave[8]. Bose writes "after a good many years of experimental investigation, I have succeeded in analysing the main factors concerned in the many phenomena which have been described as Nyctitropism". He wrote five papers on:

1. Daily movements in relation to light and darkness.
2. Daily movements due to variations of temperature affecting growth.
3. Daily movements due to variations of temperature affecting geotropic curvature.
4. The immediate and after-effect of light.
5. Diurnal movements of the leaf of *Mimosa* due to combined effects of various factors.[4]

Bose writes: "The difficulties of the experimental reinvestigation here called for towards clearing up and explanation of the subject are sufficiently great, they are further increased by the fact that these diurnal movements may be brought about by different agencies independent of each other. Thus in *Crocus* and in *Tulip*, the movement of opening during rise of temperature has been shown by Pfeffer to be due to differential growth in the inner and outer halves of the perianth. I shall in this connection show that a precisely opposite movement of closing is induced in *Nymphaea* under similar rise of temperature ..... Again certain leaflets open in light, and close in darkness in the so-called sleep position. Intense light, however, produces the 'mid-day sleep' - an effect which is apparently similar to that of darkness[4]. This 'mid-day sleep' is to our knowledge, in the context of plants, first reported here by J.C. Bose. This phenomenon may also be found only in plants in the tropics which do get to be exposed to very high intensities of sunlight >1,20,000 lux. In the case of the leaflets of the groundnut plant *Arachis hypogea*, during mid-day sleep the leaves fold upward i.e. in a direction opposite to the

movement during hours of darkness. Bose correctly concludes, "The determining factor of these movements is the variation of light". The mid-day sleep position is obviously to lessen the intensity of light at the level of the blade of the leaflets.

J.C. Bose was also the first scientist to report the autonomous short term (of 1 min.) movements of the lateral leaflets of the Indian telegraph plant *Desmodium gyrans*. He could modify the autonomous movements or even arrest them by applying appropriate intensities of light from above. Normal activity (pulsations) resumed on stoppage of light. Bose remarked on the overriding influence of light and darkness in entraining the diurnal rhythms thus: "Turning first to the case where light exerts a predominant influence, the obvious test of keeping the plant in continuous darkness or continuous light is not practicable. One would think that if the movement was due to periodic variation of light such movement would disappear under constant light or darkness. *But owing to the persistence of after-effect, the periodic movement previously acquired is continued for a long time*" (emphasis added)[4]. (p. 523-534). This is to our knowledge the first experimental demonstration of the persistence of circadian rhythms under

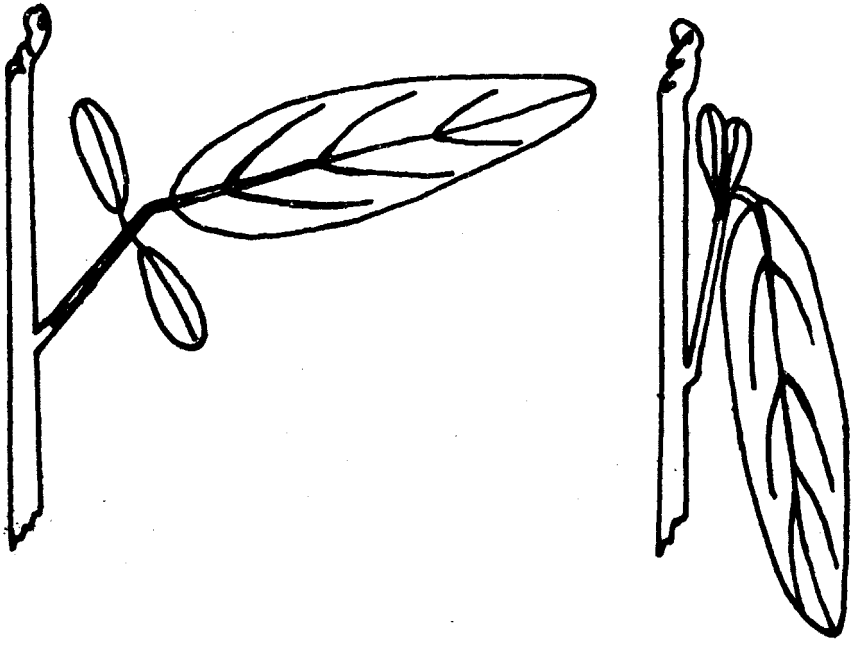

Fig. 2 The day and night positions of the petiole and terminal leaflet of the Indian telegraph plant *Desmodium gyrans*.

constant conditions, today we would describe such rhythms as being "circadian and free running in LL (continuous light) and DD (continuous darkness)". This finding of Bose based on experiments carried out in the period 1914-1919 and reported in 1919, was confirmed by the Dutch botanist A. Kleinhoonte working with leaf movements of the large jack bean *Canavalia ensiformis*, in 1929[9]. Bose wrote, "I commenced my investigations on nyctitropism (Bose's term for diurnal leaf/petal movements) (Fig. 2) five years ago, after having perfected an apparatus for continuous record of the movements of plants throughout day and night. A contrivance, described further on, has been devised for obtaining a record of diurnal variation of temperature. I have also succeeded recently, in perfecting a device for automatic record of variation of intensity of light ..... I have in this way collected several hundred *autographs* (emphasis added) of different plants throughout all seasons of the year[4]. Some of the contrivances alluded to by Bose are *not* available even today in some of the better departments of Botany in Indian universities.

J.C. Bose considered with consummate care all factors that may interact with the diurnal rhythms. He notes that there is little twilight in the tropics and that the "light-dawn" and the "thermal-dawn" are more or less coincident in Calcutta, and so on.

We wish to reproduce a very engaging account J.C. Bose gave of "The Night-Watch of Nymphaea", "Why does the Water-Lily keep awake all night and close her petals during the day? Because, say they, the Water-Lily is the lover of the moon, and as the human soul expands at the touch of the beloved, so the Lily opens out her heart at the touch of the moonbeam and keeps watch all night along, she shrinks affrighted from the rude touch of the sun and closes her petals during the day ..... This phenomenon, recurring every day, has not only been observed by the poets, but an explanation has been offered for it: the Lily loves the moon and is frightened by the Sun.".

"Had the poet taken out a lantern in the dark night he would have noticed that the Lily opened even in the total absence of light from the moon! But the poet is not expected to carry a lantern and peer about in the dark, that inordinate curiosity is characteristic only of the man of science. "A French dictionary-maker consulted Cuvier, the Zoologist, upon his definition of a crab as a little red fish which walks backwards". 'Admirable' said Cuvier; 'only the crab is not necessarily little, nor is it red till boiled, it is not a fish, and it cannot walk backwards with these exceptions, your definition is perfect. And so with the poet's description of the movement of the Lily, it does not open to the moonlight nor yet close to the sun".

"The sleep and waking of the Water-Lily is by no means an isolated occurrence. My attention was first drawn to another remarkable floral display by the folksong which begins:

Our days' work is over,
Like life's span but an hour!
For now behold the gold-starred fields
Of opening *Jhinga* flower

Now I witness, every evening, a glorious transformation in my experimental garden at Sijbaria on the Ganges. The gardener has planted a large plot with Jhinga (*Luffa acutangula*). The flowers when closed in the day-time are very inconspicuous, the outer floral leaves being dull green, in my afternoon walk, I can hardly recognize the old familiar field, yet a little later, it is covered with masses of flowers in their golden glory. They remain open throughout the night, but close early in the morning, the fairy field of cloth of gold seems suddenly to have vanished".

A description of biological rhythms has not had more poetry and romance packed into it, as in these anecdotes of J.C. Bose. The extracts cited here are a mere sampling of the plant physiological researches of Sir Jagadish Chandra Bose which are contained in 1122 printed pages in four monograph volumes. Bose's approach to the problems of plant responses was biophysical. His pioneering investigations on the comparative biophysics of plant and animal behaviour strangely did not activate biologists to undertake similar research. The point we highlight is that J.C. Bose was endowed with that happy blend of mindset which could analyse natural phenomena with complementary perspectives of a philosopher, physicist and naturalist. He went to nature to observe and record natural phenomena and further experimentally verify in the laboratory the observed phenomena with the aid of self-fabricated instruments of elegance and simplicity. An example, his Nictitropic Recorder employed in recording leaf movements, is given in Fig. 3. D.M. Bose[13] has pointed out that "when Bose passed over to the investigation of problems of response to various kinds of stimuli in plants, it was as a physicist introducing new physical techniques and new concepts to the study of plant responses. He was intruding into a compartmentalized branch of science, which was then passing through a phase of stagnation - under such circumstance his intrusion was resented by a certain group, who did not like new fangled theories and techniques". This, and the fact that he was far ahead of his times, might have been the reason why his contributions on the responses of living and non-living objects may have been neglected by his contemporaries in India and in the west.

J.C. Bose's tradition of going back to nature to understand living processes has practically vanished in India. In fact there is much resistance among an older generation of botanists to any kind of work which alluded to plants behaving[10,11] even though Darwin had written a whole book[12] on the subject. J.B.S. Haldane wrote, in an article to commemorate J.C. Bose's contributions, "Finally, some activities of plants may

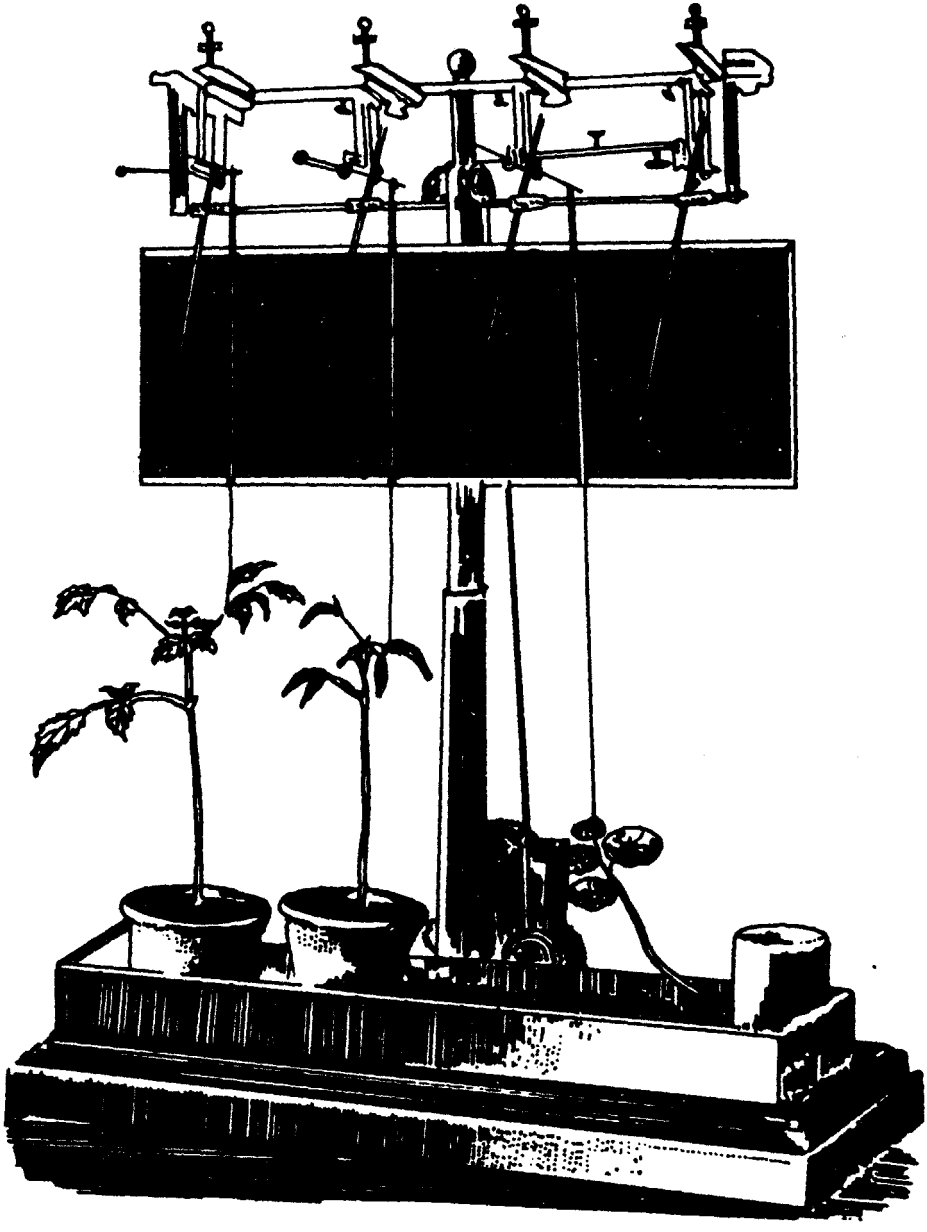

Fig. 3 The Nyctitropic recorder with four writing levers. The flower pots are placed in a trough filled with water to a constant height. The first two levers are shown in the figure to record movements of leaves, the third to record movements of leaves, the third to record movement of a horizontally laid shoot, the fourth lever attached to a differential thermometer records diurnal variations in temperature.

perhaps be called behaviour. We do not think J.C. Bose would have objected to this work. Darwin studied climbing and insectivorous plants in much the same way as one might study an animal, and accumulated statistics."

REFERENCES

1. Bose J.C. Birth Centenary. *Trans Bose Inst. Vol. XXII* 1958; p. 230.
2. Bunning E. *Die Physiologische Uhr.* Springer Verlag Berlin. New York, 1958.
3. Bose J.C. *Life Movements in Plants.* Trans Bose Inst *Vol I*: 1918; p. 254.
4. Bose J.C. *Life Movements in Plants.* Trans Bose Inst *Vol II*: 1919; pp. 255-597.
5. Bose J.C. *Life Movements in Plants.* Trans Bose Inst *Vol. III and Vol. IV.* Longmans, Green and Co. London and New York 1923; pp. 598-902.
6. Bose J.C. *Plant Autographs and their Revelations.* Bose Institute, Calcutta, 1955.
7. Chandrashekaran M.K. *Curr Sci* 1990; 59: 182.
8. De Mairan. Observation botanique. *Histoire de L'Academie Royale des Sciences Paris*, 1729; p. 35.
9. Kleinhoonte A. *Arch Neerl. Sci ex et nat III* 1929; 65: 1-110.
10. Ganeshaiah K N, Uma Shankar. *Curr. Sci.* 1993, 65: 371.
11. Chandrashekaran M.K. *Curr. Sci.* 1993, 65: 805.
12. Darwin C. *The movements and habits of climbing plants.* Murray London, 1882.
13. Bose D M. Jagadish Chandra Bose (1858-1937) in J.C. Bose Birth Centenary Vol. XXII Trans Bose Inst. 1958 pp. v-xv.