J C Bose's Contributions to Chronobiology

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J C Bose, even though a physicist, performed extensive experiments on the responses of plants to light, temperature and other stimuli. His plant physiological researches fill 1122 printed pages of four monograph volumes. Reproduced here are his contributions to chronobiology in his own language.

M K Chandrashekaran has studied biological rhythms in plants, fruitflies, crabs, mice, bats, squirrels and humans. Having established an active school of research in chronobiology at the Madurai Kamaraj University, he has now moved to the Jawaharlal Nehru Centre for Advanced Scientific Research at Bangalore and plans to focus his attention on rhythms in social insects.

Chronobiology is the subject of the scientific study of biological rhythms of *circadian*, *lunar/tidal* (see Repert and Weaver in Suggested Reading) and *circannual* frequencies. Of these biological rhythms the circadian rhythms are ubiquitous and occur in organisms from fungi through fruit flies to humans. It is now widely recognized that circadian rhythms are a fundamental property of life. Just as *ecology* is the subject that examines the adaptations of organisms to the *spatial* order of their environment, *chronobiology* is the subject that examines the adaptations of organisms to the *temporal* order of our earthly environment. It may interest students of sociology and history of scientific ideas that until about 1960 it was considered unscientific to proclaim the very existence of biological rhythms even by some erudite biologists. It was with the symposium on Biological Clocks held at Cold Spring Harbour in New York in 1960 with Erwin Buenning in the Chair, that an era of intensified experimental work was ushered in. And 1997 has been called 'party time' for chronobiology since it marks the twentyfifth anniversary of the discovery of the *supra chiasmatic nuclei* (SCN) in the brain of mammals by two independent groups working in the east coast and west coast of the USA as being the pacemaker of circadian organization, and the identification and cloning of the first circadian clock gene in a mammal in 1997.

In our own country, Jagadish Chandra Bose had made very early and very important contributions to the field of chronobiology

and circadian rhythms at a time when neither of the two technical terms had been coined. This author had come across references to J C Bose's work in the first monograph written on the subject of circadian clocks in German in 1958, interestingly in the Bose birth centenary year. An excellent account of the life and researches of J C Bose has been given by D M Bose, his successor as Director of Bose Institute, on the occasion of the former's birth centenary in 1958.

Jagadish Chandra Bose (1858–1937) was Professor of Physics in Presidency College, Calcutta and retired as Senior Professor in 1915. He was a very orderly and systematic scientist and has himself summarized his extensive researches in physics and the topics of responses of living and non-living objects and plant physiological investigations in several erudite monographs. We learn on the authority of D M Bose that his science was well appreciated by contemporary physicists such as Lord Kelvin (1824–1907), J J Thomson (1856–1940), J W S Rayleigh (1842–1919) and H Poincare (1854–1912). There is little evidence that his landmark publications on plant physiology, photosynthesis, movements and tropisms in plants, diurnal sleep movements in leaves of *Mimosa pudica* and the Indian telegraph plant *Desmodium gyrans* attracted the attention of Indian or even western biologists. J C Bose was a keen observer of nature, and the myriad responses of plants to the environmental stimuli such as light/darkness, changes in temperature and humidity etc fascinated him and kindled his scientific curiosity. He thus elaborately observed and experimentally investigated, using simple yet elegant, self-fabricated recorders and monitors, the tropic movements of plants (which had similarly fascinated Charles Darwin), like twining of tendrils, thermonastic phenomena [1], photonastic [2] responses, geotropism and day/night diurnal sleep movements of petals and leaves of plants. It would need today, not one biologist like me, but several of us even to write meaningful summaries of the biological contributions of J C Bose. Therefore with abundant precaution I restrict myself to giving a brief account from his many passages in his inimitable English prose,

[1] Movements induced by temperature.

[2] Movements induced by light.

his contributions to chronobiology, described in four monographs published in 1918, 1919, 1923 and 1927.

Diurnal (Circadian) Rhythms in Plants

In volume II of a monograph *Life movements in plants*, J C Bose typically has 128 illustrations. It is important to remember that when J C Bose carried out experiments on diurnal rhythms *(Figures 1a, 1b)* in plants the subject was still considered the *soft underbelly* of biology. Wilhelm Pfeffer (1845–1920), on the basis of extensive experiments on the sleep movements of bean plants, had at last in a 1915 paper, concluded that the rhythms may be of endogenous origin; since Pfeffer published in German his papers were not known to scientists working in English speaking countries. Pfeffer was often even misquoted and had to be explained in an English translation of some of his key passages. Some of the key passages of the chronobiology experiments of J C Bose are being reproduced in this article *in the original.* J C Bose was aware of the fact that the literature on the subject of diurnal rhythms was copious, contentious and contradictory. The big question was whether biological rhythms were caused by *external* factors or were they expressions of *internal* factors and (by implication) genetic.

Bose writes "...after a good many years of experimental investigation, I have succeeded in analysing the main factors

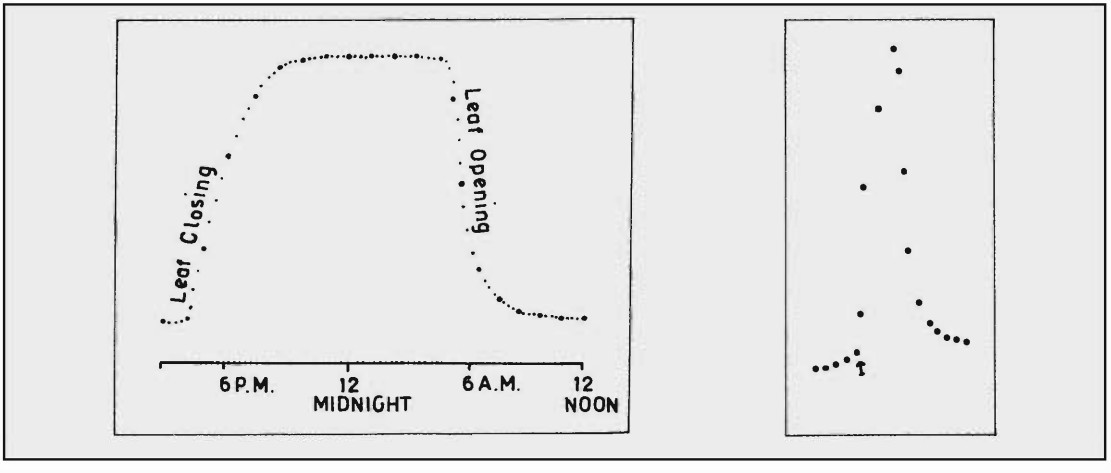

Figure 1. (a) Diurnal movement of the leaflet of Cassia alata. (b) Effect of sudden darkening (at arrow) produces movement of closure (up-curve). Restoration of light induces opening movement (down-curve). Successive dots at intervals of 15 minutes.

[3] A term then in vogue for diurnal leaf/petal movements.

concerned in the many phenomena which have been described as Nyctitropism [3]". He wrote five papers on:

- Daily movements in relation to light and darkness.
- Daily movements due to variations of temperature affecting growth.
- Daily movements due to variations of temperature affecting geotropic curvature.
- The immediate after-effect of light.
- Diurnal movements of the leaves of *Mimosa* due to combined effects of various factors.

Bose further 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 '*mid-day sleep*' (*emphasis added*) – an effect which is apparently similar to that of darkness" (*Figure 1b*). This 'mid-day sleep' is, to my personal knowledge, in the context of plants, first reported here by J C Bose. This phenomenon may also be restricted only to plants occurring in the tropics, which do get to be exposed to very high light intensities of sunlight of ca 1,20,000 to 1,40,000 lux. In the case of the leaflets of the groundnut plant *Arachis hypogea*, during mid-day the leaves fold upwards i.e. in a direction opposite to the movement during darkness hours. Bose correctly concludes, "The determining factor of these movements is the variation of light". The mid-day position of the leaves of *Arachis hypogea* is possibly an adaptation to lessen the intensity of light at the level of the blades of the leaflets.

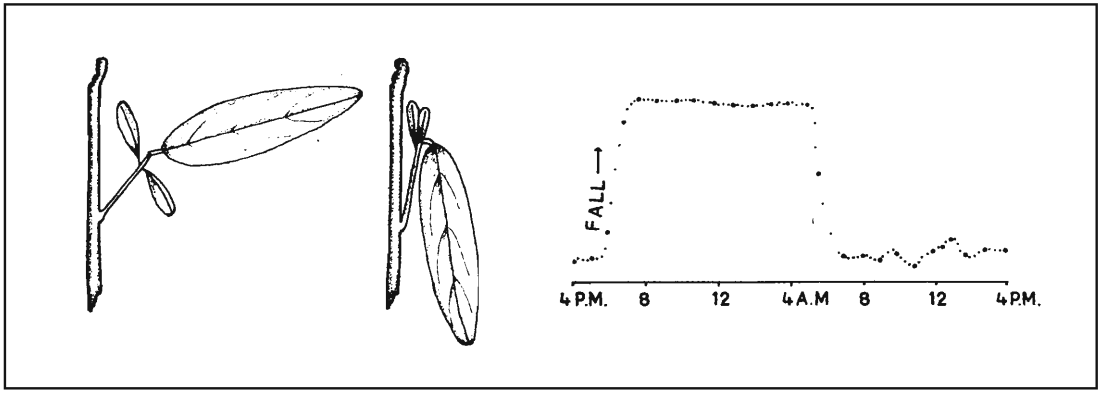

Figure 2. (a) The day and night positions of the petiole and terminal leaflet of the Indian telegraph plant Desmodium gyrans. (b) Diurnal record of the terminal leaflet of Desmodium gyrans. Up-curve represents movement of closure.

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* (*Figures 2a,b*). He could manipulate, modify and even stop the autonomous movements 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)". 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 were confirmed by the Dutch lady botanist Antonia Kleinhoonte working with the leaf movements of the large jack bean *Canavalia ensiformis* ten years later in 1929. Bose wrote: "I commenced my investigations on nyctitropism five years ago, after having perfected an apparatus for continuous record of the movements of plants (*Figure 3*) throughout day and

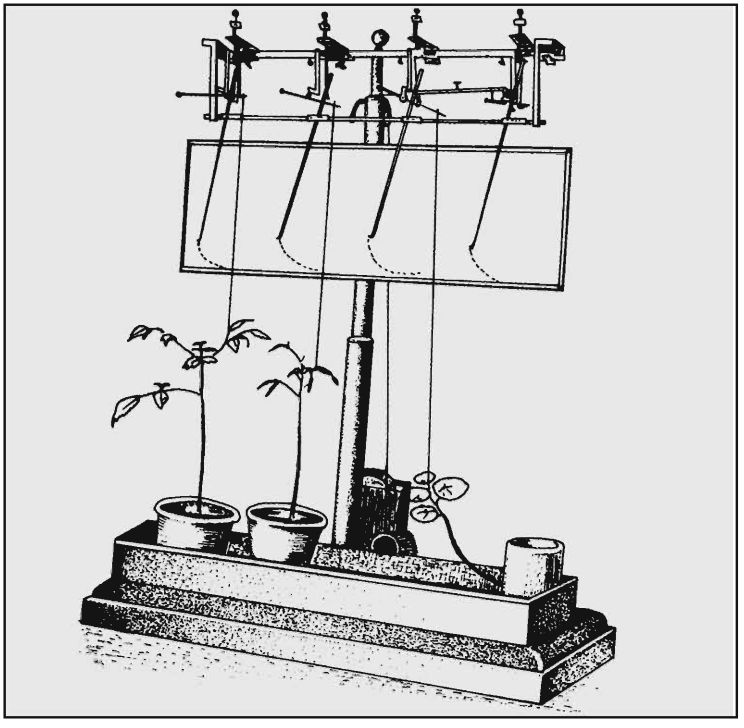

Figure 3. The Nyctitropic recorder with four writing levers. The flower pots are placed in a trough filled with water to a constant height. The first two levers shown in the figure are to record the movements of leaves, the third to record the movements of a horizontally laid shoot, the fourth lever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

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". J C Bose is the only scientist to have achieved this, since in Calcutta, unlike in Pfeffer's Germany and Kleinhoonte's Holland, severe winters do not exist. Some of the contrivances alluded to by J C Bose are still *not available* in some of the better departments of botany in the universities of India. 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. Contrast this with the present day M Sc students in biology who have not heard of long day and short day plants and have no knowledge whatsoever of the duration of local civil twilight–dawn or dusk.

Reproduced below is an engaging account J C Bose gave of "The Night-Watch of *Nymphaea*" and is illustrative of his style of writing and humour: "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 moon beam 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 everyday, 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".

He continues "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" (*Figure 4*).

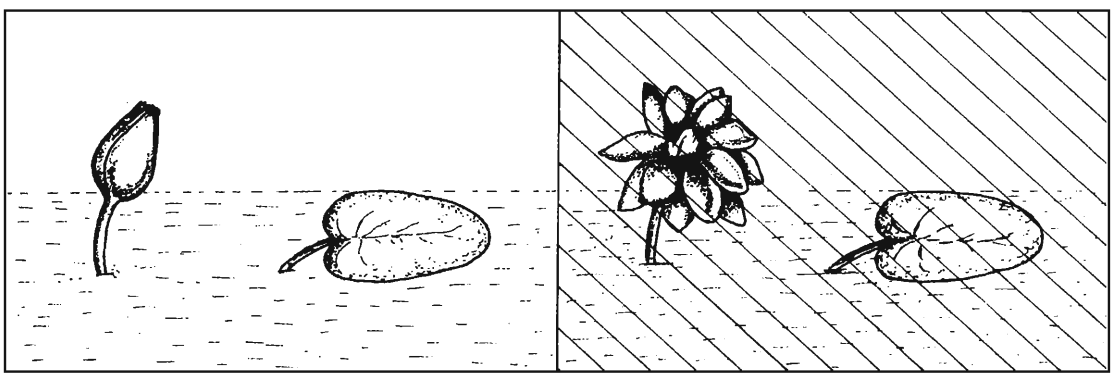

Figure 4. Nymphae–closed at daytime and opened at night.

"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 a 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. These extracts are made from over 1122 printed pages on the theme of responses of plants to environmental and experimental stimuli contained in four volumes. As a physicist Bose's approaches to the problems of plant responses was biophysical. His pioneering investigations on the comparative biophysics of plant and animal behaviour strangely left biologists cold and indifferent. Jagadish Chandra Bose was endowed with that happy blend of mindset which could analyse natural phenomena with the complementary perspectives of a philosopher, physicist and naturalist. He went to nature to observe and record natural phenomena and further experimentally verified in the laboratory the observed phenomena employing in the process self-fabricated instruments of elegance and simplicity. As an example the Nyctitropic recorder he used for recording leaf movements is shown in *Figure 3*. D M Bose 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 stage of stagnation – under such circumstances 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, far ahead of his times, might have been the reason why his contributions, such as to chronobiology highlighted in this essay, were 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 even today among an older generation of botanists to any kind of work alluding to behaviour in plants even though Darwin wrote a whole book on the subject. J B S Haldane wrote, in an article to commemorate J C Bose's contributions, "Finally, some activities of plants may perhaps be called behaviour. We do not think J C Bose would have objected to this word. Darwin studied climbing and insectivorous plants in much the same way as one might study an animal, and accumulated statistics".

Acknowledgements

I am thankful to the Librarian, Bose Institute, for sending me against nominal payment all the available books of Sir J C Bose. This article is based on an earlier write up on the subject with minor modifications (see Chandrashekaran and Subbaraj in Suggested Reading).

Suggested Reading

- **D M Bose. Jagadish Chandra Bose (1858–1937) in J C Bose Birth Centenary. Vol. XXII. *Trans. Bose Inst.* Pp. V–XV. 1958.**
- **E Buenning and M K Chandrashekaran. Pfeffer's views on rhythms. *Chronobiologia.* 2: 160–167, 1975.**
- **M K Chandrashekaran and R Subbaraj. J C Bose's views on biological rhythms. *Indian J. Hist. Sci.* 31: 375–382, 1996.**
- **S M Reppert and D R Weaver. Forward genetic approach strikes gold: Cloning of a mammalian clock gene. *Cell.* 89: 487–490, 1997.**

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