The non-exponential decay pattern of the weak luminescence from seedlings of *Cicer arietinum* L. stimulated by pulsating electric fields

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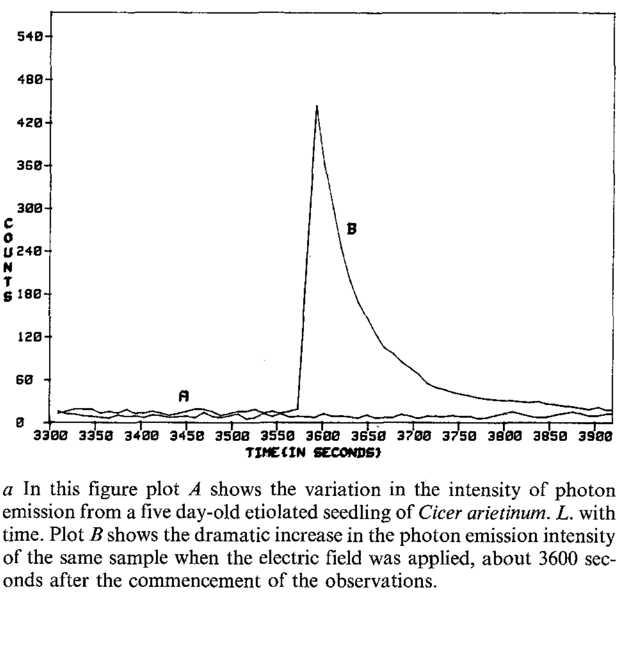
Abstract. Our experiments have shown that the response of etiolated seedlings of *Cicer arietinum* L. to an externally applied pulsating electric field involves a weak luminescence, the intensity of which follows a non-exponential decay pattern.
Key words. Etiolated seedlings; external electric fields; weak luminescence; non-exponential decay; coherence in biological systems.

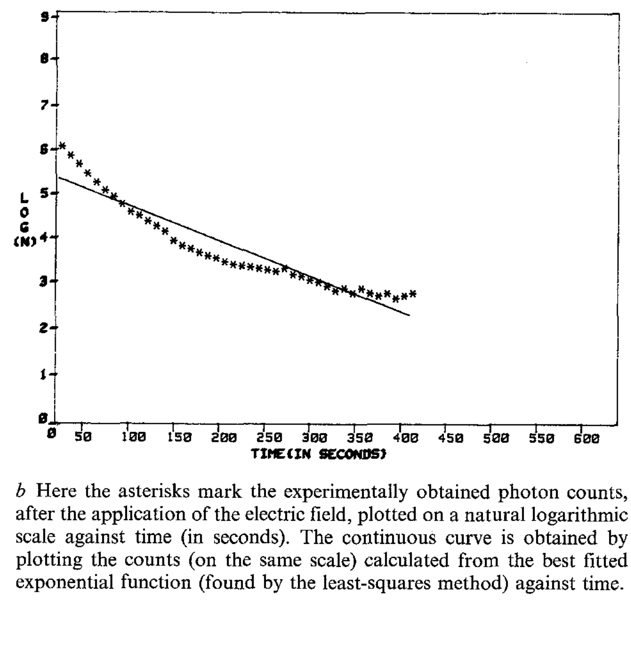
In recent years there has been much interest in the biological effects of electromagnetic fields[2-7]. There have also been reports of ultraweak photon emission from living systems[8-13]. Recent investigations[14] on different biological systems have revealed that the relaxation of the photon-emitting system after excitation by light is non-exponential[15]. In this context it appeared to be of interest to investigate the effects of external pulsating electric fields on biological systems and observe the relaxation behaviour. For this purpose we conducted several experiments to monitor the intensity of weak photon emission from whole seedlings of *Cicer arietinum* L. after the application of external pulsating electric fields. Seedlings of *Cicer arietinum* L. were grown on moist cotton wool for up to five days at a controlled temperature of 25 ± 1 °C, under conditions where the plants became completely etiolated.

All measurements were performed with a low-level photon counting system[16]. This comprises a 9558 B Thorn EMI photo-multiplier tube (PMT) with a quartz window which is maintained at − 30 °C. This PMT is sensitive in the wavelength range of 250–800 nm. It is coupled with an EG & G ORTEC 974 model counter display system with a timer which can be pre-set. The assembly measures the emitted photons as counts per specified time interval. The background of the PMT remains in the range of 15–20 counts per 10-s interval throughout the experiment. To register the maximum number of photons emitted we used a silver-plated reflector. The sample chamber is air-tight and impervious to light. The electric pulser that we used was placed outside the sample chamber and two coils were employed to apply the field, one on each side of the quartz cuvette containing the sample.

All the current-carrying wires inside the sample chamber were covered with black polyethylene tape to check the possibility of any photons from a current-carrying conductor being counted. We verified that the coils and the current-carrying conductor did not contribute anything significant towards the photon count statistics. No significant variation was noticed in the PMT dark current on application of the field in the absence of the sample. The field produced at the centre of the cuvette was 0.0008



a In this figure plot *A* shows the variation in the intensity of photon emission from a five day-old etiolated seedling of *Cicer arietinum*. *L.* with time. Plot *B* shows the dramatic increase in the photon emission intensity of the same sample when the electric field was applied, about 3600 seconds after the commencement of the observations.



b Here the asterisks mark the experimentally obtained photon counts, after the application of the electric field, plotted on a natural logarithmic scale against time (in seconds). The continuous curve is obtained by plotting the counts (on the same scale) calculated from the best fitted exponential function (found by the least-squares method) against time.

tesla and the rate of change of the field was 6.5 tesla per second as the current was rising, and 10.6 tesla per second as the current was falling.

Plot A in figure *a* shows the variation in the intensity of photon emission with time for a seedling of *Cicer arietinum* L. grown for five days under conditions that caused complete etiolation. As is evident from this figure, the photon emission intensity of the seedling in the absence of the field (plot A) is statistically insignificant as compared to the background. Figure *a* also shows the abrupt increase (plot B) in the intensity of emission as the field was applied. We note that the intensity of the field-induced photon emission follows some non-exponential decay law.

To see the deviation from exponential behaviour we calculated the best fit of our data to an exponential function, using the method of least squares. In figure *b* we plotted counts on a logarithmic scale against time. The asterisks represent the experimental points, and the continuous line is the curve obtained from the best least-squares fitted exponential function. The obvious disagreement between the two curves in fig. *b* clearly demonstrates the non-exponential behaviour of the decay pattern. Similar results were reported from the studies on light-excitation of biological systems [15].

In this paper we have described the results from a single plant. However, we conducted experiments with nearly a dozen plants grown under identical conditions and subjected to similar experimental treatment. In all cases the results followed the same decay pattern, irrespective of the intensity of the emitted radiation.

Our experiments show that externally-applied electric fields can generate coherent excited states in the samples tested. The externally-applied field appears to interact with endogeneous high voltage electric fields within biological microstructures [8], exciting the system to higher energy states, the subsequent relaxation of which generates photons. Our results are in full conformity with the assertion that there is a connection between deviation from exponential relaxation and coherence [14,15] in biological systems. It has already been proposed [17] that radiating systems with coherent re-scattering might follow a non-exponential decay law. There are theoretical models giving rise to the possibility of coherence in biological systems [18,19]. Our observations further strengthen the concept of coherence in biological systems.

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