High-Speed, Time-Resolved Spectrum of a Lightning Stroke

Abstract. *The first time-resolved spectrum of a return stroke between the cloud and ground has been obtained with a slitless spectrograph. The time for luminosity to rise from zero to its peak in a section of the channel is 10 microseconds or less, and the intense emission lines are attributed to singly ionized nitrogen atoms. Several faint lines persisting for approximately 150 microseconds are due to neutral nitrogen and oxygen atoms.*

Interest has been revived recently in slitless spectroscopy of lightning, a technique suitable for studying the physical characteristics of individual lightning strokes. Salanave (*1*) presented an extensive review of the literature, in which he reported the first spectrum of a lightning flash time-resolved into its component strokes on a time scale measured in *milliseconds*. This spectrum and all lightning spectra obtained since have consisted of the time-integrated light from an individual return stroke, a phenomenon lasting on the order of 100 μsec. The technique of time-resolving the spectrum of the flash into its component strokes, with a slitless spectrograph, has been extended to obtain the first time-resolved spectrum of an individual return stroke. Thus, we now have the spectrum-of-a-stroke versus time in *microseconds*.

A model 104 high-speed camera, on loan from Los Alamos Scientific Laboratory, was converted to a high-speed slitless spectrograph by addition of a Bausch and Lomb replica grating. The grating is blazed for 5500 Å and has 600 lines per millimeter. An Aero Ektar *f*/2.5 field lens with a focal length of 178 mm is mounted behind the grating to focus the spectrum on a horizontal slit with a vertical width of 0.5 mm. The slit can isolate a 10-m section of a cloud-to-ground stroke at a distance of 3.56 km for time-resolution of the spectrum. A three-faced mirror driven by a turbine produces the time axis in the streaked spectrum. Compressed air drives the turbine. Although the turbine is capable of 4000 rev/sec, it was found that 50 rev/sec was sufficient to give 5-μsec resolution. The spectral dispersion is 143 Å/mm.

On 14 July 1965 this system was used for the first time during an intense storm over the city of Tucson. Laboratory tests had indicated that a high-speed film would be required, and therefore Agfa Isopan Record was selected and overdeveloped 100 percent in D-19. Several time-resolved spectra of single-stroke flashes were obtained. The best of these is reproduced in Figs. 1 and 2. Two prints from the same negative, differing only in exposure, are presented to show the full exposure latitude of the film.

An intense discharge occurs within the first 5 or 10 μsec and then decreases with time. The extension of the intense lines to the left of zero time is due to overexposure. In Fig. 2, several weak lines at 4650, 6158, and 6456 Å persist for approximately 150 μsec. All the intense lines are attributed to the nitrogen atoms in the singly ionized state (N II), with several persistent faint lines from neutral nitrogen (N I) and oxygen (O I). Emission species were identified by comparison with time-integrated spectra previously published by Salanave *et al.* (*2*). Most of the emission is from unresolved multiplets, and so the strongest line in the multiplet is used to establish the wavelength. Calibrated spectra from a xenon flash tube of known spectral emittance were developed with these films. Physical parameters derived from relative intensity measurements have not yet been calculated.

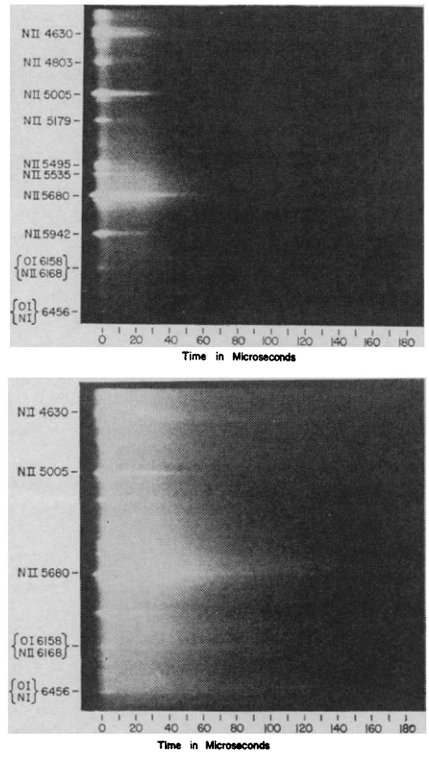

Fig. 1 (top). Time-resolved spectral components of a lightning stroke. Intense, unresolved multiplets are identified by the strongest line in the multiplet. Fig. 2 (bottom). The same negative used in Fig. 1 has been printed with less exposure to show the persistence of several lines for approximately 150 μsec.

The first attempt to record the time-resolved spectral emissions from individual return strokes was recently reported by Krider (*3*). He used a photoelectric system with narrow passband interference filters to monitor spectral regions of interest. A curious feature of these data is the long period required for intensity of various spectral features to rise from zero to peak. For example, N II required approximately 40 μsec to reach its peak value. Krider correctly suggested that the length of this period depends on the apparent time required for the leading edge of the return stroke to traverse the particular length of channel section under observation. In these latest data, the lightning stroke was approximately 3 km or less from the observation point. Therefore, less than 10 m of the stroke channel were isolated by the horizontal slit. If return stroke velocity is 3.5×10^9 cm/sec (Malan, *4*), the leading edge of the return stroke is propagated across the section of the channel under study in about 0.3 μsec. Therefore, the contribution to the rise time by the propagation of the return stroke is considered negligible in these more recent data. A time of 10 μsec or less for intensity to rise from zero to its peak is consistent with the average times for currents to rise from zero to peak that were reported by Schonland (*5*). It can only be concluded that Krider examined a large section of the channel and consequently found long times for intensity to rise from zero to its peak, the long times being due to the propagation of the return stroke.

Time-resolved spectra of flashes consisting of more than one stroke have not been obtained. It appears that sufficient light is available to record the time-resolved spectral components in the pre-discharge phase, or the period before the return stroke reaches peak luminosity.

RICHARD E. ORVILLE
Institute of Atmospheric Physics, University of Arizona, Tucson

References and Notes

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6. I thank Drs. Herman Hoerlin and Milton Peek of the Los Alamos Scientific Laboratory for arranging the loan of the model 104 high-speed camera. Supported by the Office of Naval Research contract Nonr 2173(06).

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Hormone-Induced Repression of a Peroxidase Isozyme in Plant Tissue

Abstract. *Young stem sections of dwarf peas (Progress No. 9) grown in light contain at least seven peroxidase isozymes separable by electrophoresis on starch gel. An eighth isozyme appears as the tissue elongates and ages, on or off the plant. The appearance of this isozyme in excised sections is repressed by application of the plant growth hormone, indole-3-acetic acid.*

Peroxidase catalyzes the oxidation of the plant growth hormone, indole-3-acetic acid (IAA) (*1*). Conversely, the fact that IAA alters the activity of peroxidase in plant tissues (*2*) suggests that this mutual interaction between hormone and enzyme may be important in the regulation of growth. Although the molecular heterogeneity of plant peroxidases has been known for some time (*3*), no effect of IAA on this heterogeneity has yet been described. We now report one specific peroxidase band whose appearance is repressed by treatment of the tissue with IAA.

Excised 5-mm sections from the sixth internode of light-grown (24-hour photoperiod) *Pisum sativum* 'Progress No. 9' cv. were used. The following basic experiment was conducted four times. Ten sections were incubated in a basal medium consisting of 0.025*M* potassium phosphate, *p*H 6.1, and 1 percent sucrose with or without $5 \times 10^{-5}M$ IAA. Such a concentration is on the ascending limb of the growth versus IAA concentration curve for this tissue (*4*). The sections were treated for 2-, 6-, 12-, 18-, or 24-hour periods in either basal medium or medium supplemented with IAA. The design of the experiment was such that all sections were harvested immediately before an electrophoretic separation of the plant proteins (see *5*).

Prior to electrophoresis the sections were rinsed in distilled water, weighed, and measured. Three sections from each treatment were then macerated onto a rectangle of Whatman No. 1 filter paper (8 by 5 mm). The cell debris was removed with forceps, and the paper was inserted immediately into a starch gel (15.5 by 11.5 by 0.5 cm). The gel was prepared according to the method of Smithies (*6*), with 15 g of hydrolyzed starch (Connaught) per 150 ml of buffer. The gel buffer was made by diluting 46 ml of borate buffer concentrate (Fisher), *p*H 9.0, to 1 liter. The bridge buffer, was composed of 0.3*M* H_3BO_3 and 0.05*M* NaOH, *p*H 8.3. A constant voltage of 400 volts with a variation of 40 ± 5 ma was delivered (Beckman Duostat) giving 10 volt/cm through the starch matrix. The matrix was chilled during the 90-minute run, and after electrophoresis the gel was slieed transversely. The interior surfaces were flooded with $5 \times 10^{-3}M$ guaiacol and $5 \times 10^{-3}M$ H_2O_2 in 0.2*M* phosphate buffer, *p*H 5.8. The zymogram patterns, which appeared within a few minutes, were photographed on Polaroid film with transmitted light within 15 minutes.

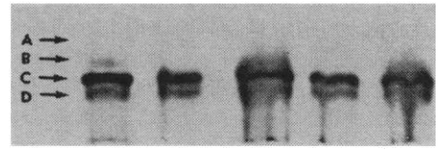

Fig. 2. Starch gel stained with guaiacol-H_2O_2, showing resolution of peroxidases. The bands correspond with the cathodic peroxidases of the first five columns beginning at the extreme left in Fig. 1.

The freshly excised young sections have seven visible peroxidase isozymes (A, C, D, E, F, G, and H, Fig. 1). Between 2 and 6 hours after the sections were removed from the plant, an additional actively migrating cationic peroxidase (band B) appeared in those sections incubated in basal medium alone. The intensity of this band increases progressively with time. The 12- and 18-hour-treated sections possess enough of this isozyme to be clearly photographed, and by 24 hours it is a major peroxidase band (Fig. 2). Sections that have been incubated in medium containing IAA show no signs of this band even after 24 hours. Tissue that has aged normally on the plant (left column, Figs. 1 and 2), shows detectable amounts of band B, whereas freshly cut sections from young sixth intermodes do not have this band.

Thus, isoperoxidase B appears to be a normal component of stem tissue developing *in situ*. Once this peroxidase has appeared in the sections, treatment with IAA directly before and during maceration and electrophoresis does not lead to its disappearance. Band A becomes more intensely staining within the first 2 hours, but is unaffected by IAA treatment.

Analysis of the medium in which the sections were incubated revealed that leakage of peroxidase from the tissue (*7*) was much greater with con-

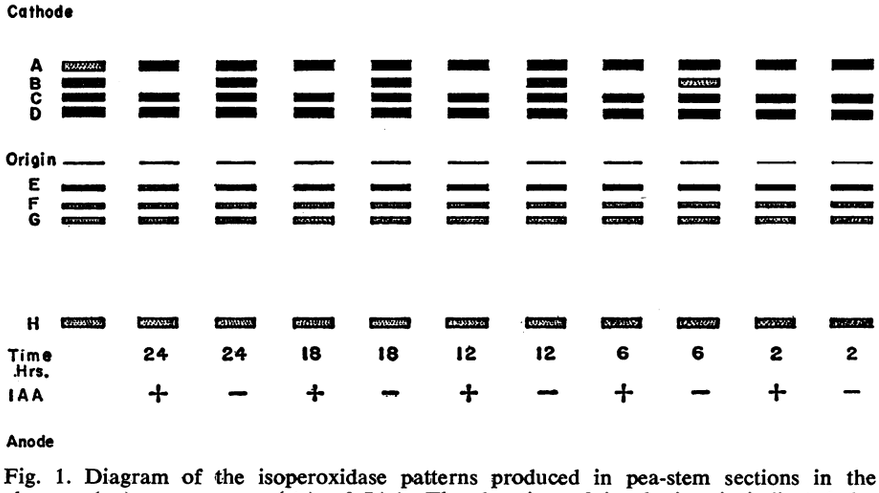

Fig. 1. Diagram of the isoperoxidase patterns produced in pea-stem sections in the absence (−) or presence (+) of IAA. The duration of incubation is indicated for each treatment. The degree of stippling approximates the staining intensity. The column at the extreme left refers to mature stem tissue homogenized directly after excision, without incubation.