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12. Amplitudes of seismic waves recorded at a given station vary as a function of both the earthquake source orientation and location. Since we were looking for small changes in orientation, it was necessary to minimize the effects of location. For this reason, we compared foreshock amplitude ratios to amplitude ratios from aftershocks at the same approximate location. In practice, events were used from a cube a few kilometers on a side.
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14. The averages shown are estimates of the logarithmic mean, $(\overline{P/S})_{\log}$; the uncertainties shown are estimates of the fractional standard deviation $\sigma_{\log}/(\overline{P/S})_{\log}$. They were obtained as follows: $R = \ln (P/S)$, $\delta R^2 = \delta P^2/P^2 + \delta S^2/S^2$, where P and S are the amplitudes measured for a given event, and δP and δS are estimates of their respective uncertainties. $\bar{R} = \Sigma wR/\Sigma w$, where $w_i = (\delta R_i)^{-2}$, and $\sigma_R{}^2 = (\Sigma wR^2 - \bar{R}\Sigma wR)/\Sigma w$; then $(\overline{P/S})_{\log} = \exp (\bar{R})$ and $\sigma_{\log} = \bar{R}\sigma_R$. The uncertainties shown are thus estimates of the standard deviation of the data. If one wished to estimate the significance of the changes in the mean, he could obtain the standard deviation of the mean by dividing by the square root of the number of observations. We have not attempted such a calculation here, primarily because the data do not have a true log-normal distribution. Fortunately, in at least some of the cases shown, the change is large enough to not require statistics.
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18. We thank B. Raleigh and W. Thatcher for help and encouragement with this work; D. Boore, T. Hanks, and B. Bakun for critical reading of the manuscript; B. Bolt for a preprint of his paper and permission to use data from the Berkeley Seismograph Station; P. Morrison for his help and cooperation with data from stations operated by the California State Department of Water Resources; and R. Eis and D. Barton for expert technical assistance. Conversations with I. L. Nersesov, D. Lockner, and J. Byerlee provided much of the incentive for this work.

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Daylight Time-Resolved Photographs of Lightning

Abstract. *Lightning dart leaders and return strokes have been recorded in daylight with both good spatial resolution and good time resolution as part of the Thunderstorm Research International Program. The resulting time-resolved photographs are apparently equivalent to the best data obtained earlier only at night. Average two-dimensional return stroke velocities in four subsequent strokes between the ground and a height of 1400 meters were approximately 1.3 × 10⁸ meters per second. The estimated systematic error is 10 to 15 percent.*

Time-resolved photographs of lightning leaders and return strokes in the daytime are practically nonexistent. However, photographs of the entire lightning flash in the daytime are well documented (*1, 2*). They have been used primarily to obtain channel characteristics, such as shape, number of branches, and ground contact point, and have necessarily integrated all the light from the flash. Successful experiments to time-resolve the leaders and return strokes in a flash have been restricted to nighttime observations (*3, 4*). These data have typically yielded leader and return stroke velocities, which are among the fundamental physical characteristics of lightning.

Recent interest in the return stroke velocity has been stimulated by the realization that another physical characteristic of lightning, the electric current, can be remotely determined in the first few tens of microseconds in a straight, vertical cloud-to-ground return stroke if the electric radiation field and return stroke velocity are known (*5*). The electric radiation field is now routinely measured at the National Aeronautics and Space Administration (NASA) Kennedy Space Center as part of the summer Thunderstorm Research International Program (TRIP). Velocity measurements correlated with these measurements of the electric radiation field will help to verify that the computational techniques used to obtain the current are valid. The thunderstorm activity typically peaks in the early afternoon in July and August (*6*). Unfortunately, because thunderstorms tend not to occur during the nighttime, reliable return stroke velocities have not yet been reported in these experiments. Consequently, the remote determination of electric current in return strokes in the TRIP experiments depends upon recording in the daytime the luminous components in a flash and subsequently measuring their velocities. We present here the first daytime recordings of dart leaders and return strokes with both good spatial resolution and good time resolution.

Our equipment consists of a streaking camera (Beckman and Whitley model 351) and a data-back still camera (Nikon), both loaded with Kodak 2476 Shellburst film. Excess fogging during the exposure is prevented by the use of a conventional No. 92 gelatin filter, a deep red filter which passes only light of wavelength greater than approximately 620 nm (*1*). Each camera is equipped with a 55-mm objective lens, and the shutters are triggered by an electronic circuit which is activated by light from the first return stroke. The light is detected by a solar cell consisting of 2 cm² of silicon on a ceramic base and mounted with a field of view of approximately 35°. The resulting amplified current signal is used to trigger the streaking camera, the still camera, and a digital timer for sight-sound measurements of the distance to the flash. The amplified signal for the streaking camera is used to trigger a silicon-controlled rectifier which discharges a capacitor across a solenoid, opening the leaf shutter in 10 msec. The exposure is typically set for 0.1 second and *f*/2 to record, on the average, at least two subsequent strokes in a multistroke flash composed of three or more strokes. The drum in the streaking camera is rotated at 50 rev/sec to produce a writing rate of 4.3×10^{-2} mm/μsec. The amplified signal for the still camera is used to close a contact and open the focal plane shutter in approximately 55 msec. We can vary the exposure by monitoring a through-the-lens meter, but typically the exposure is 0.5 second at *f*/32. This system will not record the first stroke but is adequate for recording and time-resolving subsequent strokes in most multistroke flashes. The resulting photographs and distance measurements can be used to calculate the velocity of the luminous events in a flash.

Figure 1 shows a flash recorded in the afternoon at approximately 1831 U.T. on 22 July 1977 from the top of the Opera-

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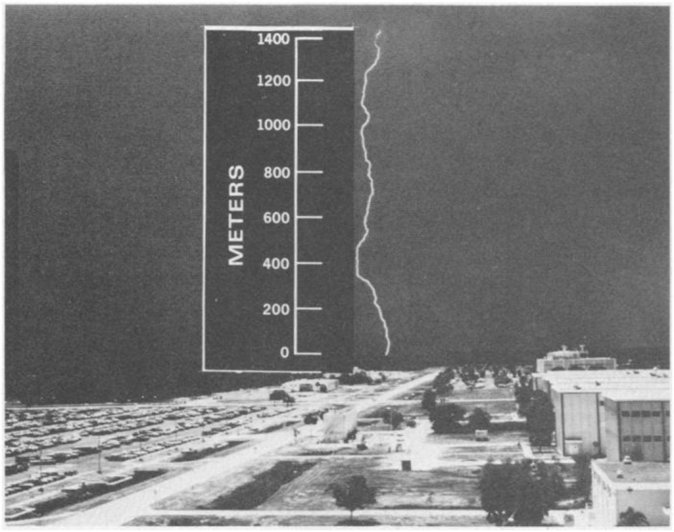

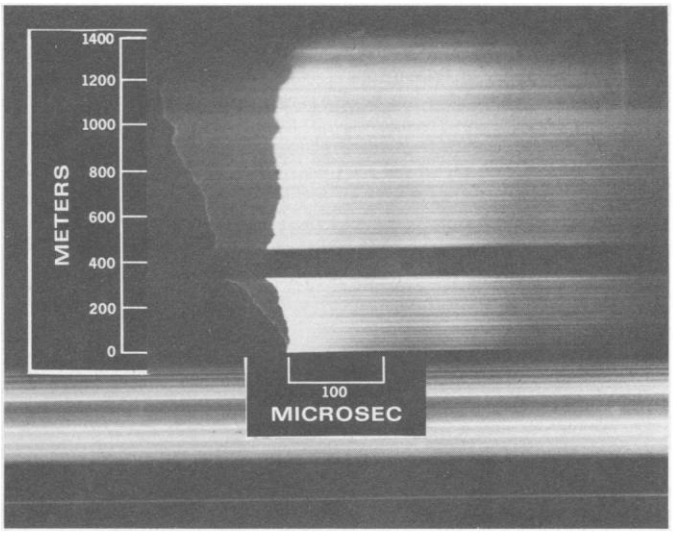

Fig. 1 (left). Flash recorded at approximately 1831 U.T. on 22 July 1977 at the NASA Kennedy Space Center. Fig. 2 (right). Streaked recording of one stroke that occurred in the flash reproduced in Fig. 1.

tions and Checkout Building at the Kennedy Space Center. The dark sky results from the use of the deep red filter, and the bright sunlight is apparent from the shadows cast by objects in the foreground. The time to thunder from our site was approximately 15 to 16 seconds, providing a distance estimate between 5 and 6 km. Another time-to-thunder measurement of 24 seconds was obtained from the University of Florida experimental site (*7*). The two circles produced by these independent measurements intersect at a distance of 5.8 km from our site on an azimuth consistent with the direction of the flash in Fig. 1. The error in this distance determination is probably less than 10 percent. Assuming a range of 5.8 km, we have calculated a height scale and superimposed it next to the channel. In Fig. 1, it is apparent that the channel enters the cloud base at approximately 1400 m. From a rawinsonde sounding of the atmosphere taken from the Cape Canaveral Air Force Station at 1900 U.T., we estimate a cloud base height of 1400 to 1500 m, in good agreement with the apparent cloud base in Fig. 1.

Figure 2 shows the same lightning discharge with one of the subsequent strokes time-resolved into its dart leader and return stroke. Four of the return strokes in this flash were recorded by the streaking camera. The gap in the recorded data between approximately 350 and 450 m is the result of the fact that the objective lens imaged a vertically straight section of the lightning channel on a thin opaque line in the focal plane that was used for focusing tests. Luminous emissions from the dart leader persist until the bright return stroke occurs. The quality of this photograph, recorded in bright daylight (Fig. 1), is surprisingly good. A literature survey of available data (*3, 8*) suggests that these data are similar in quality to earlier data obtained at night.

Velocity measurements are obtained in the following way. The still and moving film negatives are enlarged to the same size to obtain photographic prints with a magnification of approximately ×13. Thus a ground-to-cloud time of 10 μsec for a return stroke, which corresponds to a displacement of 0.43 mm on the moving film, is enlarged to 5.6 mm. Similarly, a dart leader transit time from cloud to ground of 100 μsec, which corresponds to a displacement of 4.3 mm on the moving film, is enlarged to 56 mm. The still and moving film images are then digitized (accuracy, 0.01 inch or 2.5×10^{-2} cm) by means of a minicomputer system. The horizontal displacement is calculated between the two images at identical heights in the channel. We are, in effect, overlaying the still and moving lightning channels within the computer, calculating the displacement, and solving for the velocity. A detailed analysis of the systematic errors indicates that the major error is associated with determining the distance to the flash (10 percent); smaller errors are associated with the digitization of the still channel length (3 percent) and the measured separation between the still and streaked image in the channel (4 percent). Negligible errors are associated with determining the drum speed (0.1 percent) and the magnification factors in the still and streaked photographs (1 percent each). Since the errors are independent, the total systematic error is approximately 11 percent. We therefore estimate the systematic error, in general, to be 10 to 15 percent. The drum speed error is negligible because the time between strokes is known to within a few microseconds (*9*). Thus, the measured distance between images on the negative can be used to determine a drum rotation rate that is more accurate than our counter reading.

Analysis of Figs. 1 and 2 indicates that the dart traveled the 1400 m from the cloud base to ground in approximately 113 μsec at a two-dimensional velocity that was nearly constant at 1.2×10^7 m/sec. The return stroke luminosity propagated from the ground to the cloud base in 10.0 μsec at an average velocity of 1.3×10^8 m/sec. Three other return strokes recorded in this flash have average velocities in a narrow range from 1.2×10^8 to 1.4×10^8 m/sec. Their associated dart leaders have velocities ranging from 1.2×10^7 to 2.6×10^7 m/sec. All return stroke velocities reported in the literature range from 2×10^7 to 1.4×10^8 m/sec, an order of magnitude variation (*4*). If subsequent return stroke velocities are nearly constant and narrowly distributed in thunderstorms as suggested by Radda and Krider (*10*), it will simplify the calculation of electric currents in remote lightning strokes (*11*).

These results indicate that optical experiments on lightning can now be done in the daytime. Thus, optical studies which include the measurements of leader and return stroke velocities and spectroscopic measurements of the lightning channel temperature can be correlated with measurements of the electric and magnetic fields, the charge transferred in each stroke, the return stroke current, and the precipitation echo with fast scanning radars and conventional radars (*12*). These cooperative observations should lead to a better understanding of the physical and meteorological characteristics of lightning.

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β-Adrenergic Receptors in Aged Rat Brain: Reduced Number and Capacity of Pineal Gland to Develop Supersensitivity

Abstract. *The density but not the affinity of β-adrenergic receptors declined significantly with age in rat pineal gland, corpus striatum, and cerebellum, as determined by the binding of tritiated dihydroalprenolol. Exposing rats to light for 12 hours increased the binding of this radioligand in 3-month-old but not in 24-month-old rats. The reduced responsiveness to catecholamines seen in aging may be due to a decrease in the number of β-adrenergic receptors which, in turn, may be caused by an impaired capacity of receptors in aged animals to adapt to changes in adrenergic neuronal input.*

The aging process is associated with reduced biochemical and physiological responses to various hormones (*1*). In the case of steroid hormones, decreased responsiveness is accompanied by a decline in the number but not in the affinity of steroid receptors in target tissues (*2*). Diminished β-adrenergic responsiveness to catecholamine hormones has also been reported in tissues from senescent rodents and humans (*3, 4*). Since many of the physiological effects that result from the interaction of catecholamines with β-adrenergic receptors are mediated through activation of adenylate cyclase (E.C. 4.6.1.1) (*5*), in aging there may be an alteration of this receptor-enzyme complex. In fact, decreased sensitivity of adenylate cyclase to norepinephrine and isoproterenol has been reported in brain (*6*), liver (*7*), vascular smooth muscle (*3*), erythrocytes (*8*), and adipocytes (*9*) isolated from aged rats. The reason for the age-related loss of β-adrenergic responsiveness has yet to be elucidated. An understanding of the mechanisms responsible for these changes may provide greater insight into the aging process and may ultimately suggest a new rationale for treating geriatric patients.

The recent development of a potent β-adrenergic receptor antagonist with high affinity and specificity for β-adrenergic receptors. [^{3}H]dihydroalprenolol ([^{3}H]-DHA) (*10*), permitted us to characterize these receptors in the brain of rats of various ages. In the work reported here we found an age-related decrease in the density but not in the affinity of β-adrenergic receptors in several areas of the rat brain. We also found that aged rats have a decreased ability to produce adaptive changes in these receptors.

Male rats (Fischer 344, Charles River), ranging in age from 1 to 24 months, were used in these experiments. These rats have a maximum life-span of 33 months, with 50 percent mortality at approximately 28 months of age. They were acclimatized for 2 weeks on a 12-hour light-dark cycle and were decapitated 5 to 7 hours after initiation of the light cycle, unless otherwise specified. Direct labeling of β-adrenergic receptor sites in homogenates of pineal gland, corpus striatum, and cerebellum was carried out according to procedures described previously (*11*). The assay was conducted in 150 μl of 50 m*M* tris-HCl buffer containing 3 m*M* Mg^{2+}, 0.6 to 40 n*M* of [^{3}H]DHA (New England Nuclear; specific activity, 32 to 48 Ci/mmole), and tissue homogenate (0.4 to 2 mg of tissue). To determine nonspecific binding, incubation mixtures also contained 20 μ*M* of (±)-propranolol, which selectively displaces [^{3}H]DHA from β-adrenergic sites. Specific binding of [^{3}H]DHA is defined as the total [^{3}H]DHA binding minus the nonspecific binding determined in the presence of excess propranolol. Protein concentration was determined by the method of Lowry *et al.* (*12*).

Specific [^{3}H]DHA binding was saturable at approximately 20 n*M* [^{3}H]DHA in pineal gland and striatum and 10 n*M* in cerebellum. At these concentrations specific binding represented more than 80 percent of total binding in pineal gland, but only about 40 to 60 percent of total binding in cerebellum and striatum, respectively. In confirmation of previous reports (*11, 13*), specific [^{3}H]DHA binding in these brain areas was stereospecific and of high affinity and was displaced by unlabeled β-adrenergic agonists and antagonists. For example, (−)-alprenolol was nearly two orders of magnitude more potent than (+)-alprenolol in displacing specific [^{3}H]DHA binding, and (−)-isoproterenol was five to ten times as potent as (−)-norepinephrine.

Using saturating concentrations of [^{3}H]DHA, we found that specific binding in the three brain areas varied significantly with age (Fig. 1). Specific binding in pineal gland (Fig. 1A) was maximal at approximately 1 month of age. By 3 months the specific binding declined significantly and then remained at the reduced level through 24 months of age. Specific binding in cerebellum and striatum, on the other hand, increased significantly between 1 and 6 months of age and then decreased significantly through 24 months of age (Fig. 1, B and C). In striatum and cerebellum the decline in specific binding sites with age was accompanied by an increase in nonspecific binding sites (of approximately 24 fmole of [^{3}H]DHA bound per milligram of protein), suggesting that other types of binding sites may be developing with age. Such sites may be associated with glial cells, since the glia/neuron ratio has been shown to increase with age (*14*).

To determine whether the decline in specific [^{3}H]DHA binding was due to a

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