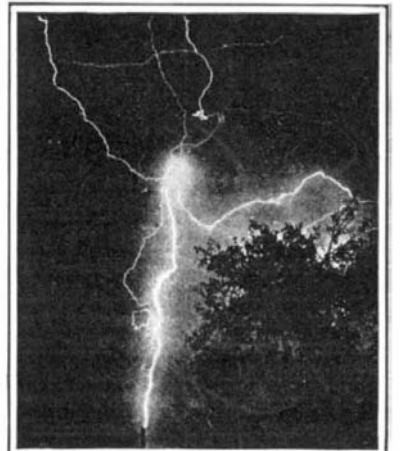




New Ideas About Lightning

A Postscript to the Schoolbooks and Encyclopædias

By C. Fitzhugh Talman



ELEMENTARY text-books still generally follow Arago in classifying the visible electrical discharges of the atmosphere under three distinctive headings: zigzag lightning, sheet lightning, and ball lightning.

The term zigzag lightning is a misnomer, and like other misnomers tends to perpetuate a mistaken idea.

In ancient paintings and sculptures the lightnings grasped in the hand of Jove or clutched in the talons of his eagle bristled with sharp angles. Exactly the same

kind of lightning is still represented by artists. Arago and his contemporaries firmly believed in angular lightning. Its existence was first denied by James Nasmyth, in 1856, and his contention that so-called zig-zag lightning is really sinuous was soon after confirmed by photography. Nasmyth's drawings illustrating the contrast between the lightning of art and the lightning of nature are reproduced in Fig. 1. The need of reiterating his announcement at this late date is shown by the fact that lightning flashes still zig-zag their way through the drawings of many contemporary illustrators of story books. It is not so long ago that they were definitely banished from the school books.

The camera has solved many problems concerning the forms of lightning, but has also raised a number of new ones. The use of a moving camera, which analyzes the lightning flash by revealing its structure at successive moments of time, introduced by Weber and Hoffer in 1889, and further applied by Walter in 1901 and Larsen in 1902 revolutionized our knowledge of this subject. This method has been further improved by Walter during the past two years.¹ He now uses two cameras, installed side by side, one of which is fixed, while the other is turned slowly on a vertical axis by clockwork. Two photographs are thus taken, one of which shows the relative positions of all the flashes occurring within a certain field, while the other analyzes the flashes that have a sensible duration; and a comparison of the two pictures shows the relations in time of the various phases of the phenomenon. (See Fig. 2.)

Briefly stated, the camera has given us the following information in regard to lightning:

Visible lightning is due to the incandescence of the air along the path of an electric discharge—which may be sinuous, spiral or looped (disregarding the sheet and globular forms for the present) and is usually accompanied by numerous branches. The flash as a rule consists of several sparks (i. e., separate discharges) following the same path. Each spark is generally instantaneous, in the ordinary sense of the term (sometimes lasting less than one five-thousandth second, according to Schmidt), but the intervals be-

tween the sparks may average one tenth second, so that the total duration of the flash is often half a second or more. These successive discharges along the same path give lightning its flickering appearance.

The electric discharge does not, as a rule, immediately bridge over the whole space between cloud and

warmly advocated by W. J. S. Lockyer, among others.² Those who accept this view call the phenomenon an "afterglow." According to K. E. F. Schmidt³, the glow is due to phosphorescence. An analogous phenomenon seen in Geissler tubes containing air has recently been similarly explained by Prof. Strutt as a phosphorescent flame, due to the reaction of nitric oxide and ozone formed in the discharge. According to Walter the afterglow has no objective existence. He claims that the horizontal trails seen in the moving-camera

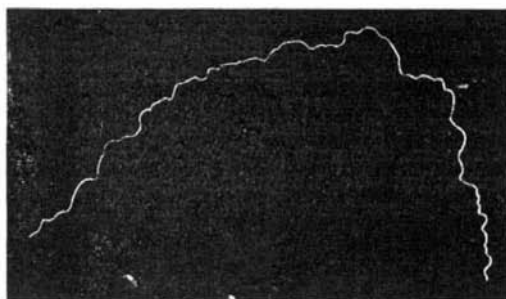
photographs are chiefly due to the superposition of those portions of the path of the discharge that run parallel with the motion of the camera. Lastly, we must suppose that the diffuse glows seen about all the brighter features of a lightning photograph are at least partly the result of internal reflections in the camera and other defects in the technique of the photographic process.

"Ribbon" lightning is common in lightning photographs; i. e., the photograph very often shows a band, rather than a line of light; but this is, in most cases, simply due to an accidental or intentional movement of the camera transversely to the direction of the flash, or sometimes to the same inherent defects of the camera that account in part for the afterglow. Walter finds that with a perfectly stationary camera the apparent breadth of an average stream of lightning would, if real, indicate that the path was over three feet in diameter. In these cases he believes that the breadth of the path is illusory; the imperfect definition of the objective for bright objects having spread the image as much as tenfold. The same effect is seen in astronomical photographs; the brighter stars appearing on the negative not as points, but as broad disks. The human retina is subject to the same defect; and we may thus account for the frequently reported occurrence of so-called "ribbon" lightning, as seen with the naked eye.

In some cases a flash of lightning, as recorded by a stationary camera, or as seen by the eye, may be more or less broadened owing to a lateral shifting by the wind, of the air channel along which the successive discharges occur; but that there should be anything like a *uniform* shifting all along the path of a flash of average length—i. e., several thousand feet—is, in the nature of things, extremely unlikely. The wind effect might cause an irregular thickening or twisting of the image impressed on the photographic plate, or the retina, but hardly anything similar to the tape-like stream of light commonly shown in pictures of so-called ribbon lightning. Lockyer, in the examination of many hundred photographs of lightning, was able to find only one—viz., that made by Kayser, at Berlin, July 16th, 1884—in which some-



Artists Lightning



Natural Lightning

Fig. 1.—Nasmyth's drawings of lightning, real and unreal. *Quarterly Journal of the Royal Meteorological Society*

earth or cloud and cloud. It builds up its path gradually; the electric current feels its way, so to speak. The first feeble discharges extend only part way along the ultimate path, and end as brush discharges in the air. Then comes a sudden and powerful discharge along the whole path. This may completely equalize the potential between the two bodies connected by the flash; or, after a brief pause, a series of discharges may occur along the same path, as described in the preceding paragraph. Some of the remarkable photographs taken by Walter, at Hamburg, show these three classes of phenomena very clearly; and they have been named by this investigator the "preliminary," "primary," and "after" discharges, respectively. ("Vorentladungen," "Anfangsentladung," "Nachentladungen.") The time occupied by the preliminary discharges has been found to vary between 0.001 and 0.02 second. The after-discharges may continue for half a second, or more, as stated above.

In a photograph of a lightning flash made with a camera moved across the direction of the flash so as to reveal its successive phases (see Fig. 2b), the successive sparks are usually easy to distinguish, but are not separated by intervals of complete darkness. The whole band has a more or less blurred effect, apparently indicating that the illumination persisted from one spark to the next. Often this glow is stronger at

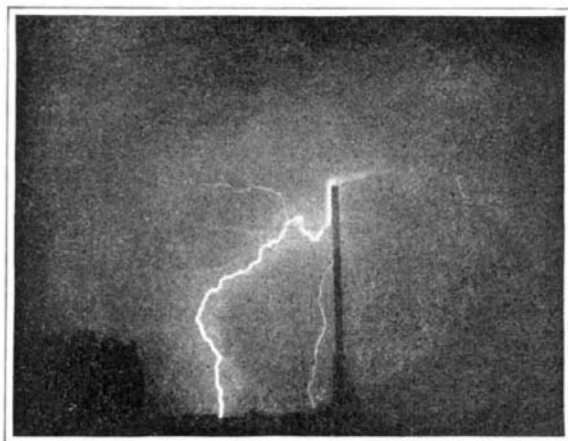


Fig. 2a

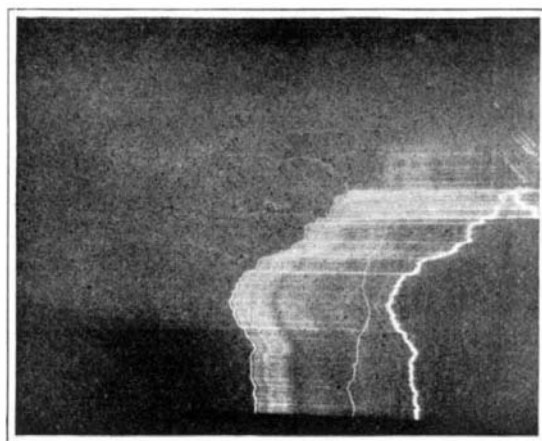


Fig. 2b

Fig. 2.—Lightning photograph with double camera.—(Walter.)

a was taken with a stationary, and b with a camera moving toward the left, so that the order of the phenomena, in time, proceeds from left to right. The black vertical bar shown distinctly in a and faintly in b is a distant chimney. The most brilliant flash in a is shown in b to have been made up of a large number of successive discharges along an identical path; while all the other flashes were sensibly instantaneous.

certain points in the path of the discharge than others, so that the moving camera gives the appearance of horizontal striation to the broadened image of the flash.

The true nature of this glow has not yet been settled beyond dispute. The most obvious explanation is that the incandescence of the air persists for a time after the discharge is passed. This explanation was offered by Touchet some years ago, and has been

¹ B. Walter, "Ueber Doppelaufnahmen von Blitzen," *Jahrb. Hamb. Wiss. Anstalten*, 27, 1909. 5 Beiheft. Hamburg, 1910.

² *Comptes rendus*, 140, 1905, p. 1031.
³ *Elektrotechn. Zeitschr.*, 26, 1905, p. 903.

thing approaching the ribbon form was registered by an absolutely motionless camera; and even in this case the "ribbon" is so irregular in width as to hardly deserve this name. I think, moreover, it is safe to assume that the flash photographed by Kayser was rather near the camera, so that the portion of it shown in his picture had not a great absolute length.

"Beaded" lightning—also known as "chapleted" or "pearl" lightning—has several times been drawn but

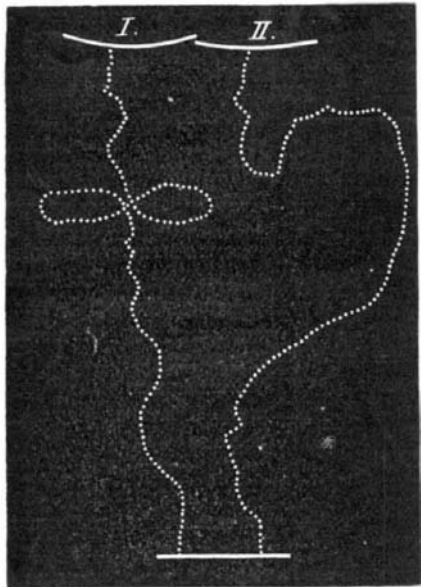


Fig. 3.—Drawing of two flashes of "beaded" lightning.

(After Endemann, *Meteorologische Zeitschrift*, 1888.)

very rarely photographed. It is described as consisting of a series of bright points giving more or less the effect of a string of pearls. (See Fig. 3.) In several cases an ordinary linear flash is said to have resolved itself into this beaded form before fading out of sight. Lockyer³ thinks that in all cases it is simply a discontinuous afterglow; though, as stated above, the existence of the afterglow has been denied. Photographs with a moving camera appear to show that the afterglow is strongest at the points along a lightning flash where the direction of the flash changes. This is illustrated in Fig. 4. It will be seen that the lateral streaks of light, which are, according to Lockyer, the trails impressed upon the moving photographic plate by the afterglow, are most pronounced at the bends and loops in the path of the discharge. It is evident that if these bright spots persisted long enough after the original flash to be perceptible to the naked eye, they would produce exactly the effect described as beaded lightning. Unfortunately, this phenomenon has been rarely observed, and we are not able to say positively whether the "beads" sometimes appear without a previous continuous flash, in which case we should have to seek another explanation. It may be that in some cases what is seen is simply several portions of a continuous flash visible through interstices in the clouds. "Stellar" lightning (often seen in connection with volcanic eruptions) is explained by Prinz as probably an effect of perspective. Suppose the branching flash shown in Fig. 6 to be seen by an observer at either A or B, i. e., in the line of the flash. It will present the appearance shown in Fig. 5.

"Black" lightning—a common feature of lightning photographs, generally in connection with ordinary bright flashes—is often explained as a reversal due to over-exposure. (See *SCIENTIFIC AMERICAN*, 1910, p. 463.) This explanation hardly seems to account for the fact that the small, and presumably relatively faint, lateral branches of a bright flash are so often of this character. Since the discovery by A. W. Clayden, in 1889, of what is now known as the "Clayden effect," it has been generally believed that after relatively faint flashes have been impressed on the plate, a subsequent general illumination of the field by light reflected from clouds causes these flashes to print dark, or under some conditions to be entirely obliterated.⁶

"Sheet" lightning is the name applied to diffuse, and usually noiseless discharges. Common usage extends this term to include diffuse reflections of ordinary linear discharges, which are themselves hidden by clouds or below the horizon; especially the "heat" lightning that plays along the horizon on summer evenings, and is merely the reflection of a thunder-

storm too far distant to be audible. It is a mistake, however, to suppose that sheet lightning is always the effect of a diffuse reflection; the electric discharge itself sometimes takes a sheet-like form, and an analogous phenomenon is the glowing of so-called "incandescent" or self-luminous clouds, the occurrence of which is probably much commoner than is generally supposed.⁷

"Ball" lightning is still a baffling subject, and we cannot here enter into the many speculations concerning it. There is, indeed, considerable doubt as to the propriety of regarding this luminous meteor as a form of lightning, in the ordinary sense of the term.

The Cause of Lightning.

It is doubtful whether any other discovery in the whole history of science has wrought so many changes in conceptions deemed fundamental and irrefragable as has that of ions and the phenomena connected therewith. In the light of the knowledge acquired during the past decade the science of electricity needs to be, but has not been, rewritten; and to-day physicists, in dealing with this subject, are using a terminology based upon obsolete notions, and therefore often extremely misleading.

Without, however, attempting to set forth the modifications that the new views concerning the nature of electricity have brought about in every branch of atmospheric electricity, and without attempting a rigid definition of the terms employed, let us consider for a moment the hypothesis now most plausibly advanced to account for the fact that, at certain times, the potential gradient of the atmosphere becomes so great that the resistance of the air is broken down, and an electrical discharge occurs. This hypothesis is a little over two years old, and is due to a brilliant young English physicist, George Simpson, attached to the meteorological service of the Government of India.⁸

Simpson's hypothesis is based upon the fact, well attested by laboratory experiments, that the breaking up of drops of water involves a separation of positive from negative electricity; in other words, a production of both positive and negative ions. In this process the drops become positively charged; i. e., they retain a greater number of positive than of negative ions, the latter being set free in the air. About three times as many negative as positive ions are thus released.

Now a thunderstorm is accompanied by a strong upward movement of the air; so strong that small drops cannot fall through it, while large drops, which would be heavy enough to fall through such a vertical current if they could retain their integrity, are broken up by the air and then carried aloft, where they tend to accumulate, recombine and fall again. This process may be repeated over and over again, so that the positive charge of the drops is continually increasing, and at the same time negative ions are being set free, which are carried by the ascending air current to the upper part of the cloud, where they unite with the cloud particles and give them a strong negative charge. Thus a continuous separation of electricity is in progress. Ultimately the positively charged drops accumu-

lated rain, leaving the cloud strongly charged with negative electricity.

According to this hypothesis the heavy rain of a thunderstorm should be positively charged, and that such is the case was shown by extensive observations made by Simpson in India. However, within the highly electrified cloud there must be a rapid combination of the negatively charged water drops, which would fall as a more gentle rain; and this assumption is

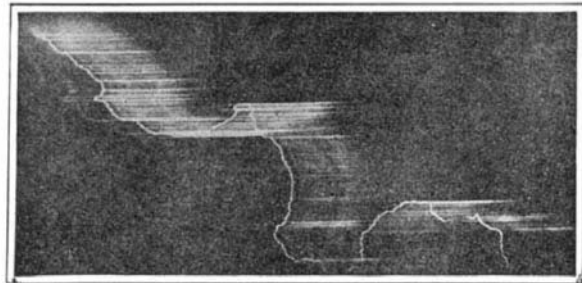


Fig. 4.—Lockyer's explanation of "beaded" lightning. (Photograph by Walter.)

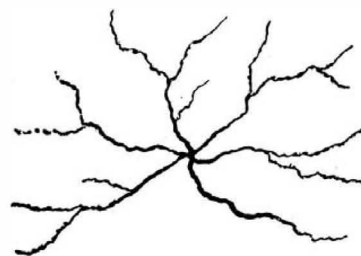


Fig. 5.—"Stellar" lightning. (After Prinz.)



Fig. 6.—Explanation of "stellar" lightning. (After Prinz.)

also confirmed by observation. Simpson's hypothesis may be said to have supplanted that of Wilson and Gerdien, according to which the separation of the positive from the negative ions was due to the fact that the latter more readily become the nuclei of aqueous condensation. It was supposed that, in an ascending air current, the dust was sifted out by condensation upon it in the lower strata; as the air, thus freed of its dust, continued to rise, it was cooled until it had reached such a degree of supersaturation that condensation could occur upon the negative ions, which would thus be sifted out in their turn. The objections raised to this hypothesis are chiefly quantitative rather than qualitative, and it is still an open question whether it may or may not account in part for the potential gradients observed in the atmosphere.

Lightning Recorders.

Even a hasty survey of recent progress in the study of lightning should take note of the ingenious use of the methods of wireless telegraphy in observing and recording electrical discharges in the atmosphere.

A flash of lightning sets up electromagnetic waves in the ether. These may be received, at great distances from their source, by a suitable antenna, and sent through a coherer (using this term in the generic sense), which thus becomes conducting to a galvanic current; the latter actuates a relay, which closes a secondary circuit, and brings into play the recording apparatus, which is usually a pen tracing a record on a revolving drum. The forms of lightning recorder that thus make a continuous registration on a sheet of paper are called generically *ceraunographs* (a term introduced by Odenbach in 1891). Several forms of the *ceraunograph* have been devised by Boggio-Lera, Fenyl, Schreiber, Lancetta, Odenbach, Garcia Mollà and others. Their radius of action is several hundred miles. By the use of several relays Boggio-Lera and Turpain have produced instruments that record not only the occurrence, but also approximately the distance, of an electrical discharge. There are also thunderstorm recorders that make an audible record, by ringing a bell or otherwise. In the ingenious instrument invented by Tommasina—known as the *electro-radio-phone* or *ceraunophone*—the observer uses a telephone receiver, whereby he is enabled to listen to a thunderstorm far beyond the range of the unaided ear, and to gain some idea of the movement of the storm by noting the variations in the intensity of the sound.

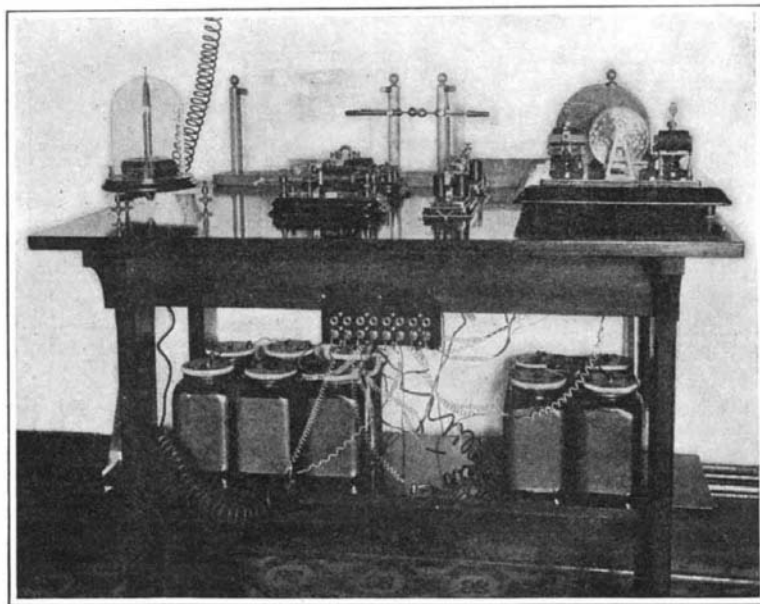


Fig. 7.—Odenbach's *ceraunograph* as installed at St. Ignatius College Observatory, Cleveland, Ohio.

This instrument formerly recorded thunderstorms as far distant as Fort Smith, Ark. Since wireless telegraph stations have been installed at Cleveland this range is much reduced, but the inventor is now at work on a device to cut out the wireless. On the table are seen two sets of receiving apparatus, one with a 1,000-ohm relay, the other 150 ohms, each with a sounder serving as a decoherer. To the left is a galvanometer which indicates the amount of current passing over the coherer. The recording apparatus is shown on the right.

late to such an extent, or they reach a place where the updraft is so weakened that they fall as positively

⁴ *Knowledge*, n. s. 5, 1908, p. 118.

⁵ *Knowledge*, n. s. 4, 1907, pp. 146-147.

⁶ *Phil. Mag.*, 5th ser., 28, 1889, p. 92.

⁷ *Meteorologische Zeitschrift*, 17, 1900, pp. 448-457; *Monthly Weather Review*, 29, 1901, p. 466.

⁸ *Proc. Roy. Soc.*, ser. A, 82, 1909, p. 169, fig.