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# LIGHTNING RESEARCH IN SWITZERLAND

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It is common knowledge that most of the fortunately rare failures in the supply of electric energy can be traced to atmospheric discharges. With a view to eliminating these failures and improving the service given to users of electric energy, operators of large power companies and manufacturers of high tension plant in various countries undertook to promote systematic research on the different phenomena due to lightning discharges.

A glance at a map of Switzerland will show that the topography of that country is rather favourable to the formation of local thunderstorms which, owing to the closely interlinked distribution systems have far-reaching effects. To cope with these troubles, Swiss power companies and other interested parties appointed a committee in 1926 to investigate lightning. At that time no suitable apparatus was available on the market and the opinions of the experts as to the proper methods to be used differed widely. Therefore it was left to the engineers of that committee to design their own apparatus and to develop methods for recording and interpreting lightning phenomena.

Early in 1928 work had advanced sufficiently to start the investigations of voltage surges on transmission lines. As a result of 10 years' research, it was definitely established that direct lightning strokes are the most important source of troubles.

In the United States similar investigations had been carried out long before the outbreak of the war. A station was installed on the tower of the Empire State Building in New York City and a large number of direct strokes to the tower has been recorded and carefully analysed (McEachron, *Journal of the Franklin Institute*, February 1939). In the course of three years 68 lightning strokes striking the spire of this building at a height of 1,250 ft. above the ground have been secured. The shape and the dimensions of this building resemble a needle-shaped electrode and, as similar conditions would hardly be met in other places, it was deemed necessary to carry out investigations under conditions more likely to prevail in territories served by continental power companies.

A suitable location exposed to frequent thunderstorms was found on Monte San Salvatore near Lugano in the southern part of Switzerland. In the latter part of 1942 a wooden structure fitted with a lightning rod has been installed on the top of this hill, at about 915 m. (3,000 ft.) above sea-level, facing Lake Lugano 274 m. (900 ft.) above sea-level, leaving a difference in height of 641 m. (2100 ft.).

## MEASURING EQUIPMENT

The *lightning rod* (Plate I) consists essentially of a wooden structure about 60 m. (197 ft.) in height on the top of which an iron pipe of 10 m. (33 ft.) length is fitted. The structure is stayed in four directions by means of steel cables (Plate I). The point of the tower as well as the stay-cables are connected to a conductor which, about 15 m. (50 ft.) above ground, leads to a shunt and from there to the ground. To prevent leakage of discharge currents to the ground wooden beams about 12 m. (40 ft.) long are inserted in the stay-cables. These beams are protected by means of arcing horns adjusted to a spark gap of 3 m. (10 ft.). The currents are measured by a *calibrated shunt*. Originally it consisted of a metal resistor with three elements of 0·02, 0·5 and 10 ohms respectively with carborundum resistances in parallel for the protection of the last two stages. Owing to their small thermal capacity they are likely to fail when discharge currents persist for a certain time. Therefore the shunt had to be modified and since 1946 it has been provided with only two metallic elements, having values of 0·02 ohms and 1·0 ohms, and the whole of the discharge current has to flow through both. From the 1·0 ohm resistance the calibration current of about 100 milliamperes is branched off and the high-sensitivity stage, giving full-scale reading at a discharge current of 50 amperes, is protected against overload by means of a vacuum tube, combined with spark-gaps. By this shunt arrangement the accuracy of measurement has been improved considerably.

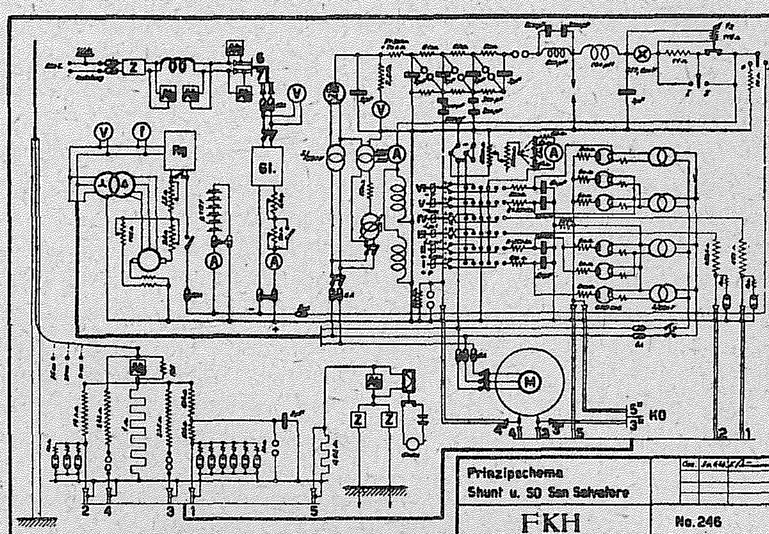
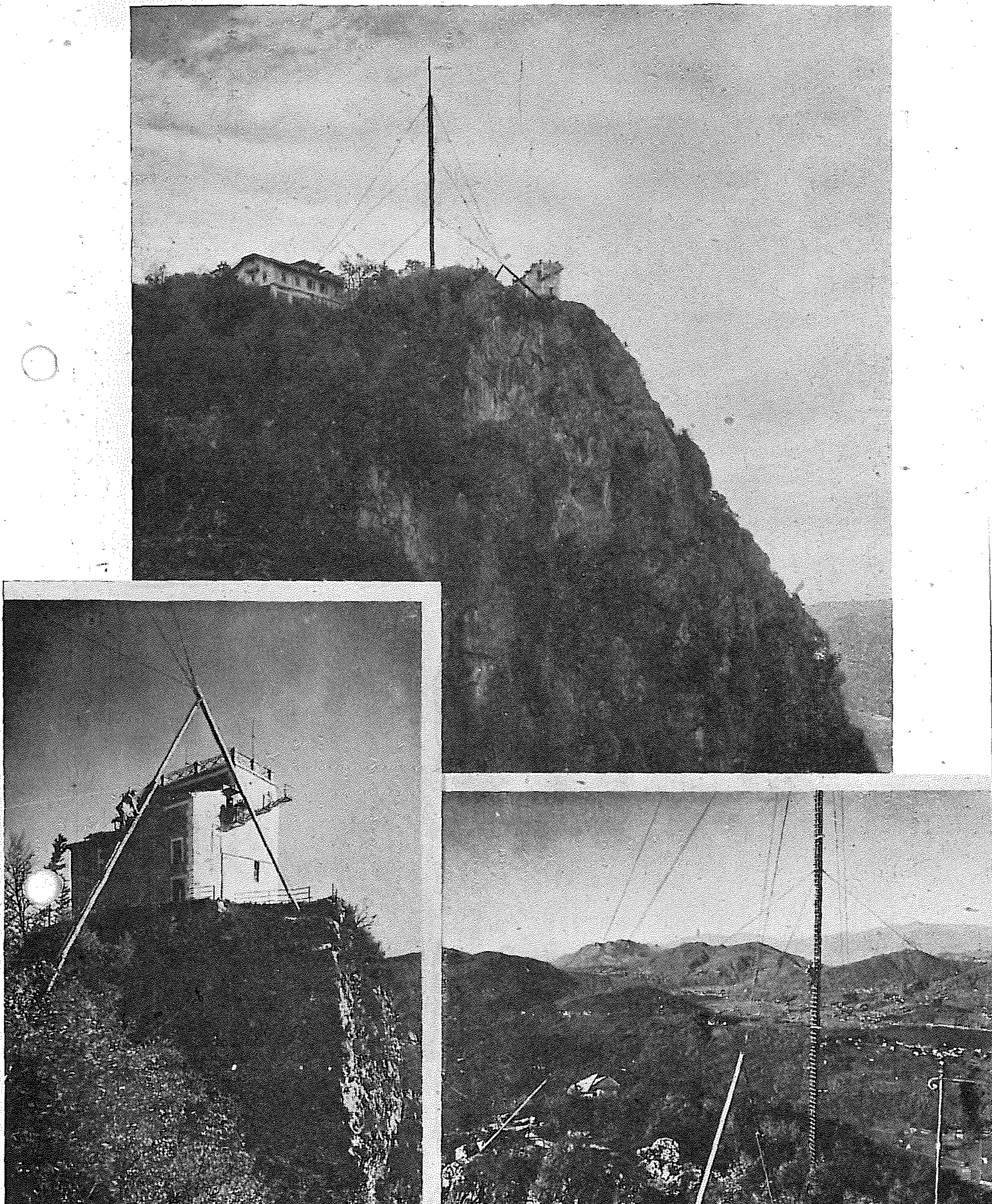



Fig. 1. Diagram of connexions of the complete recording outfit.

Figure 1 is the circuit-diagram of the complete recording outfit, showing at the left the measuring shunt which is now mounted on a wooden frame (see Plate II) at a distance of about 15 m. (50 ft.) from the recording room, the connexion between them being made by means of shielded cables.

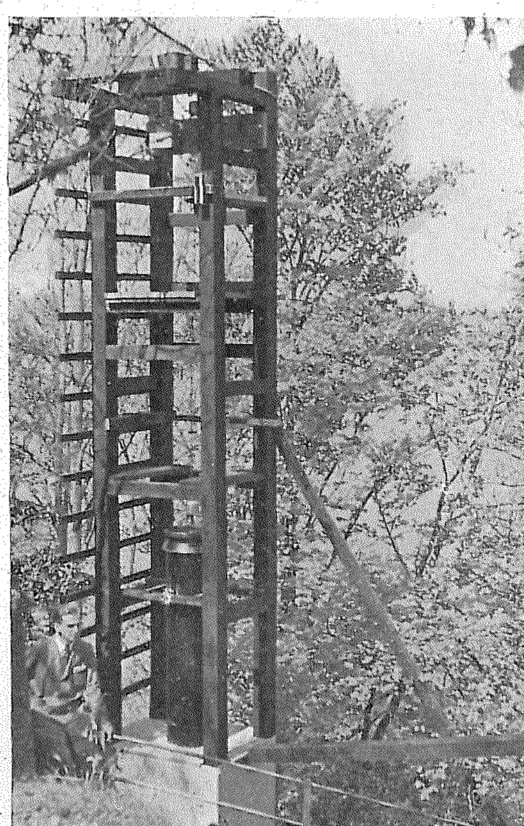
The oscillographs and auxiliary apparatus are installed in an old dwelling available for this purpose. The first records in the spring of 1943 were made by means of a *loop-type oscillograph* adapted for the present purpose. Discharge currents lasting from a few thousands of a second to about one second can be recorded directly, but owing to the inertia of the moving parts it is not possible

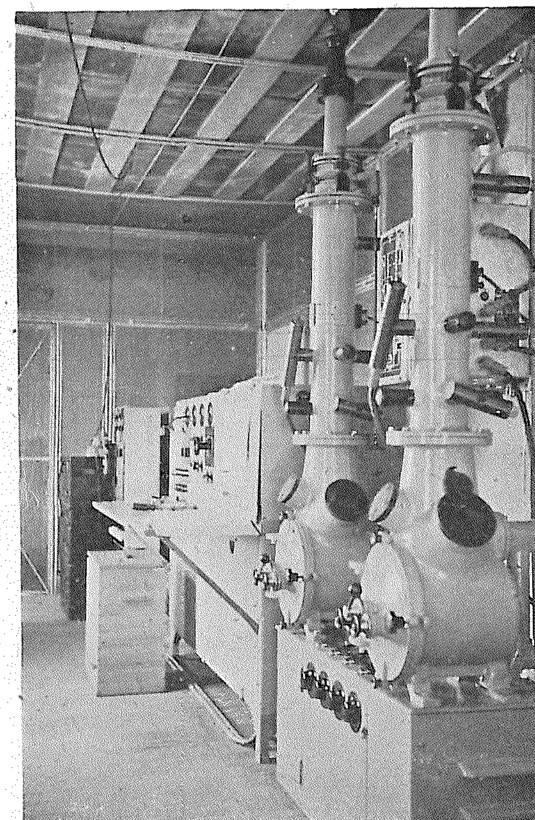


Lightning rod on Mount San Salvatore.

The wooden structure is 60 m. high with an iron pipe of 10 m. length on top. Note the wooden beams at the lower ends of the stay-cables.

PLATE I





Measuring equipment at Mount San Salvatore.

The left-hand photograph shows the timber frame with shunt and wooden duct containing lead to the Faraday cage. The right-hand photograph shows the interior of the Faraday cage with two cathode-ray oscillographs in front and the loop oscillograph in the rear.

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to record surges of shorter duration. To determine current peaks of very short duration, and especially the crest values and the amount of charge of a lightning stroke by means of a loop-type oscillograph, hot cathode valves are used to charge static condensers. One condenser is charged to the maximum voltage drop across the shunt caused by the discharge current, while the other, of larger capacity, is fed through an ohmic resistance. In the first the voltage across the terminals of the condenser indicates the crest value of the stroke current. The charge of the second one, on the other hand, is proportional to the amount of charge of the stroke.

Even an extremely short time is sufficient to charge these condensers through the valves. Their discharge through the elements of the oscillograph is sufficiently delayed to overcome the inertia of the moving coil and thus to give an accurate reading of the initial deflections, which indicate the current peak and charge of the stroke.

The six moving coils of the oscillograph have been used to record the following quantities :

(1) positive charge of each surge ;

(2) crest value of positive surges within the range of 3,000 to 100,000 amperes ;

(3) tail of a discharge of long duration within a range of 1 to 50 amperes ;

(4) tail of a discharge of shorter duration within a range of 50 to 2,000 amperes ;

(5) crest value of a negative surge within a range of 3,000 to 100,000 amperes ;

(6) negative charge of each surge.

In order to avoid delays in operating the moving-coil oscillograph the recording film rotates continuously in the dark and the beam of light is controlled by the lightning stroke. The arc lamp has tungsten electrodes and the arc is ignited by means of a small four-stage surge generator for $4 \times 3{,}000$ volts which is triggered by the stroke itself. During the discharge of the condensers direct current is supplied from a storage battery and by means of a time-delay device, cut off again after an interval of about one second. By this arrangement it is possible to obtain, within the first thousandth of a second, an arc sufficiently intense to record the initial, and often the most important part, of a lightning stroke.

Early in 1945 a *cathode-ray-oscillograph* became available to record fast current variations and in 1946 a second outfit was provided. One records the discharge current during 1/50th of a second and the other during 1/5000th of a second, both oscillographs being automatically cut in by means of a special time base which operates on the occurrence of a stroke of a certain intensity.

The complete equipment is mounted in the interior of a *Faraday cage* (see Plate II) in which the operator is working. Due to the inductive voltage drop of the current flowing to earth the potential of the whole cage, when lightning strikes the tower, is raised to a few hundred thousand volts.

As the 100 ampere-hour capacity of the storage battery is not sufficient to ensure continuous recording during thunderstorms, the recording equipment is (even during storms) connected to the 220-volt local supply system of the town of Lugano. A choke coil of a few millihenries with the turns bifilarly wound for the supply current, acts as a trap for lightning strokes and prevents them reaching the local network.

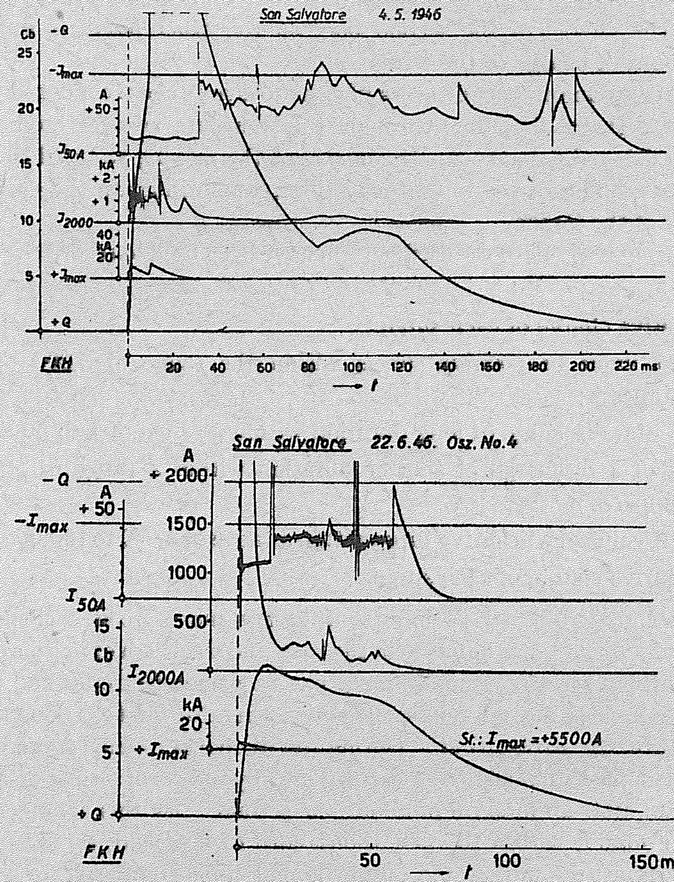


Fig. 2. Typical oscillograms of positive strokes.

Apart from the oscillograph a number of *magnetic links* are provided along the lead from the lightning rod to the shunt. These links provide a means of checking the *crest-value* of the strokes. Recently two loops have been fitted to the point of the tower. The discharge currents induce voltages in these loops which cause Lichtenberg figures recorded by a klydonograph. As the induced voltages are governed by the rate of rise of the lightning current, these Lichtenberg figures indicate the *rate-of-rise* of the stroke current. A device acting on the release of the capacitively-bound charges in the lightning rod serves to sound *an alarm* by which the attention of the operator is drawn to the impending lightning strokes. By this device, which operates on near clouds only, better results have been obtained than is possible by the use of a radio receiving set which sounds an alarm also on the occurence of more distant thunderstorms.

## RESULTS OF INVESTIGATIONS

During 1943–1946 about 25 oscillograms of lightning strokes have been obtained. Of these, Figure 2 shows examples of positive strokes and

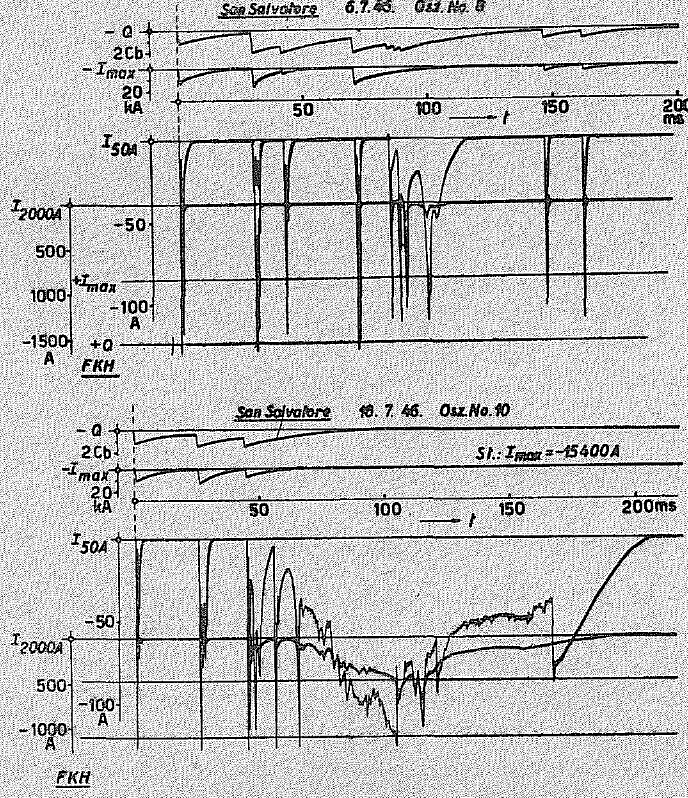


Fig. 3. Typical oscillograms of negative strokes.

Figures 3 and 4 of negative strokes. Before discussing the records a few definitions should be remembered viz. :

A *partial stroke* is the stroke current between two consecutive zero values. According to Schonland each partial stroke is made up of a *leader stroke* and a *main stroke* (*Proceedings of the Royal Society*, A, Vol. 143, Jan 1934 and Vol. 152, Oct./Nov. 1935).

An *impulse current* is a current of less than 0·01 second duration.

A *continuing current* is a discharge of a duration exceeding 0·01 second.

Detailed results or probability curves cannot be given here, but the most important results are summarized below :

Of 23 records secured, 12 come from clouds having a negative charge, 10 from clouds having a positive charge, while only 1 stroke contained a small negative charge, followed by a larger positive charge.

Of 12 negative strokes, 3 were of a very low intensity, having crest values of only 10 to 40 amperes.

All the positive strokes were simple, i.e. they consist of only one partial stroke.

Most of the negative strokes are composed of up to 17 partial strokes, with a mean of 3 to 4 partial strokes.

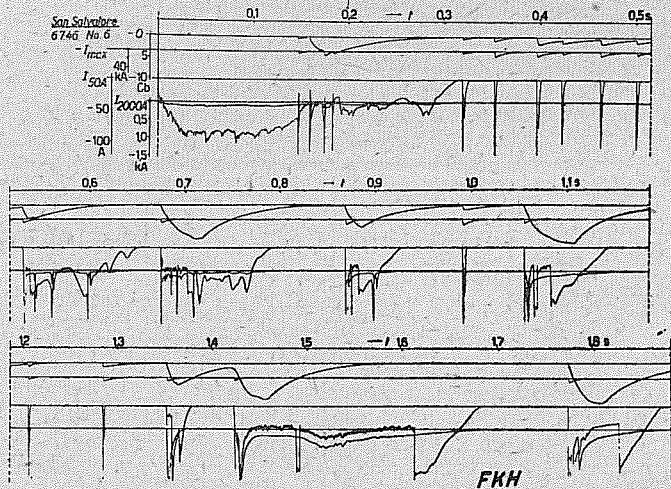


Fig. 4. Oscillograms of a multiple negative stroke of long duration—1·85 second.

Of the 23 strokes, 12 begin with a continuing current, 11 with an impulse current (4 with positive and 7 with negative current).

The later partial strokes always begin with an impulse current even when the initial partial stroke began with a continuing current.

The longest of the 23 strokes secured amounted to 1·85 second.

The intervals between two consecutive partial strokes are in general of a duration of a few hundredths of a second.

The electric charge of a stroke is smaller in the impulses than in the continuing currents. Impulse currents have a charge of about 1 coulomb; continuing currents have charges up to 70 coulombs.

The largest charge of a stroke recorded was about 160 coulombs (in 17 partial strokes).

The impulse currents of a stroke have a time to half-value of 30 to 100 micro-seconds with a mean value of about 50 micro-seconds.

The impulse currents of the partial strokes of one and the same stroke often have the same time to half-value; they differ only in their crest values.

The rate-of-rise of the impulse currents of a stroke is veiy high, especially with negative currents; their front is often less than 1·5 micro-seconds.

A comparison of the records from the Empire State Building by McEachron with those from Monte San Salvatore shows that with the former all the strokes come from clouds having negative charges while with the latter about the same number of positive and negative charges have been observed. The total charge in both cases was of the same order, with a maximum of about 160 coulombs. The maximum number of partial strokes observed is 12 on the Empire State Building and 17 on Monte San Salvatore. The total duration of the longest stroke was 1·5 and 1·85 seconds respectively. Unfortunately there was no Boys camera available on Monte San Salvatore, so that no comparison with the records secured on the Empire State Building could be made.

Of special interest is the fact that all the strokes on the Empire State Building are initiated by negative clouds while the Swiss records show that about half of them are from positive clouds. This seems to be due to the fact that the Empire State Building acts as a lightning rod of about 1,250 ft. Such a point electrode has the effect of giving longer sparks with positive than with negative charges leaving it, a fact well known in high-voltage engineering. The Lichtenberg figures produced by the klydonograph show the same phenomenon. McEachron definitely established that the first leader stroke starts from the tower towards the negative cloud. As there are no records of positive strokes, their nature can only be surmised. In the plains, according to optical observations in South Africa by Schonland, and contrary to those made in the United States, practically all the strokes are initiated by the clouds and are propagated downwards. From the oscillograms of Monte San Salvatore, it is concluded that continuing currents are originated when the leader stroke grows upwards and that impulse currents are originated when a leader stroke grows from the cloud downwards and then strikes a lightning rod. The same may happen also if partial strokes grow towards and strike an existing lightning channel. This could be confirmed or disproved by comparing records taken with the Boys camera with oscillograms of stroke current.

If the above surmises are correct, the oscillograms show that the conditions for the initiation of the strokes on Monte San Salvatore are between those of the plains and of the sky-scraper. It would seem therefore that strokes may be obtained on San Salvatore of a nature which would never occur on sky-scrapers, and the conclusions drawn from the San Salvatore investigations are more nearly applicable to the usual case of lightning strokes to the ground.

The existence of " fulgurites ", i.e. tubular pieces of sintered sand, seems to prove that strokes of long duration also occur in the plains. A further proof of the occurrence of such currents lies in the fact that wooden structures are often burned by strokes, which is possible only where the currents are of long duration.

From records taken by the magnetic links on transmission lines it can be assumed that in the plains of Switzerland most of the strokes are from negative clouds to earth. According to our records, negative clouds cause multiple strokes of long duration and therefore are of greater danger.

It is still to be decided how the nature of strokes to objects less exposed than the tower on San Salvatore, such as chimneys or spires, could be determined without making use of oscillographs and other complicated recording equipment in each of the very many points exposed to lightning. A possible solution would be to use a large number of very simple instruments for certain details of the stroke current, such as charge, crest value of current, duration, number of partial strokes etc. The results thus obtained could be compared with the data derived from the complete current curves from Monte San Salvatore. On the other hand the author believes that the detection of the complete wave form of stroke currents by oscillographic recording of remote lightning strokes, for instance by aerials, involves very difficult problems, so that at present this method should not be used for complete stroke current measurements.

The results of the observations now available show a surprising variety and great differences in lightning strokes. Some strokes have been observed with an intensity of only 10 amperes, others with crest values of 30,000 amperes, with charges of less than one to more than 160 coulombs, and with durations of 0·0015 to 1·8 seconds. It is obvious that a very large number of observations will be required to study all the different aspects of lightning strokes, their behaviour and their effect on the daily life.