

the density of the earth. The gravitation pull on it is 42,000 times the radiation pressure.

Now, let us see the effect of size on the radiating body. Let us halve the diameter of the sun. He would then have one-eighth the mass and one-quarter the surface. Or, while his pull was reduced to one-eighth, his radiation push would only be reduced to one-quarter. The pull would now be only 21,000 times the push. Halve the diameter again, and the pull would be only 10,500 times the push. Reduce the diameter to  $1/42,000$  of its original value, that is, to about 20 miles, and the pull would equal the push.

In other words, a sun as hot as ours and 20 miles in diameter would repel bodies less than 1 cm. in diameter, and could only hold in those which were larger.

But it is, of course, absurd to think of such a small sun as this having so high a temperature as  $6000^{\circ}$ . Let us then reduce the temperature to  $1/20$ , say  $300^{\circ}$  absolute, or the temperature of the earth. Then the radiation would be reduced to the fourth power of  $1/20$ , or  $1/160,000$ , and the diameter would have to be reduced to  $1/160,000$  of 20 miles, or about 20 cm., say, 8 inches, when again radiation would balance gravitation.

It is not very difficult to show that if we had two equal spheres each of the density and temperature of the earth they would neither attract nor repel each other—their radiation pressure would balance the gravitation pull—when their diameters were about 6.8 cm., when in fact these were about the size of cricket balls.

It must be remembered that this is only true for spheres out in space receiving no appreciable radiation from the surrounding region.

It would appear that we have arrived at a result of some importance in considering the aggregation of small meteorites. Imagine a thinly scattered stream of small meteorites at the distance of the earth from the sun. Then, even if they be as large as cricket balls, they may have no tendency to move together. If they are smaller they may even tend to move apart and scatter.

In conclusion, let me mention one more effect of this radiation pressure. You will remember that radiation presses back against any surface from which it issues. If, then, a sphere at rest in space is radiating equally on all sides it is pressed equally on all sides, and the net result is a balance between the pressures. But suppose that it is moving. It is following up the energy which it pours forth in front, crowding it into a smaller space than if it were at rest, making it more dense. Hence, the pressure is slightly greater, and it can be shown that it is greater the greater the velocity and the higher the temperature. On the other hand, it is drawing away from the energy which it pours out behind, thinning it out, as it were, and the pressure at the back is slightly less than if the sphere were at rest.

The net result is a force opposing the motion, a force like viscous friction, always tending to reduce the speed.

Thus calculation shows that there is a retarding force on the earth as it moves along its orbit amounting in all to about 20 kgm., say, 50 lbs. Not very serious, for in billions of years it will only reduce the velocity by one in a million, and it will only have serious effects if the life of the earth is prolonged at its present temperature to hundreds of billions of years.

But here again size is everything. Reduce the diameter of the moving body, and the retarding effect increases in proportion to the reduction. If the earth were reduced to the size of a marble, the effect would be appreciable in a hundred thousand years. If it were reduced to a speck of dust a thousandth of a centimeter in diameter, the effect would be appreciable in a hundred years.

Note what the effect would be. Imagine a dust particle shot out from the earth and left behind to circulate on its

own account round the sun. It would be heated by the sun and would be radiating out on all sides. As it journeyed forward there would be a resisting force tending to stop it. But instead of acting in this way the resistance would enable the sun to pull the particle inward, and the fall inward would actually increase the velocity. This increase in velocity would increase the resistance, and at the same time the approach to the sun would raise its temperature, increase the radiation, and so increase the resistance still further. The particle would therefore move in a more and more rapid spiral orbit, and ultimately it would fall into the sun. Small marble-sized meteorites would fall in from the distance of the earth probably in a few million years. Small particles of dust would be swept in in a few thousand years.

Thus, the sun is ever at work keeping the space round him free from dust. If the particles are very minute he drives them forth into outer space. If they are larger he draws them in. It is just possible that we have evidence of this drawing in in the zodiacal light, that vast dust-like ring which stretches from the sun outward far beyond the orbit of the earth, and is at once the largest and the most mysterious member of the solar system.

#### A SIMPLE, EFFECTIVE, AND INEXPENSIVE LIGHTNING RECORDER.

By HENRY F. ALCIATORE, Observer. Dated November 22, 1904.

In the latter part of August, 1902, the writer, at his own expense, constructed and erected in the local office of the United States Weather Bureau in New Orleans, La., a lightning recorder which has proved fairly satisfactory. Our object was to obtain automatic records of the hundreds of electric discharges, visible and invisible, that usually precede and accompany thunderstorms, and to study the same with a view to increasing the accuracy and value of local weather forecasts.

The action of the instrument is based upon the effect that high-tension electric waves in free air, such as lightning, have upon metal filings suitably arranged in a glass or other insulating tube between two metal electrodes, one of which is connected to a collector above the ground and the other to the earth. In their normal state the filings rest loosely at the bottom of the tube between two electrodes about  $1/16$  inch apart, and their electrical resistance is comparatively high. Now, when lightning occurs in the vicinity of the filings some of the electric waves traveling through the air pass through the filings from one electrode to the other; this causes the filings to stick together and their electrical resistance is greatly reduced, thereby rendering it possible for the current from a local battery to operate a relay in circuit with the filings, which in turn operates a device that separates the filings and restores them to their original condition, and at the same time records the passage of the electric waves.

Two years' experience with the lightning recorder described below has demonstrated that lightning records can be used to some advantage in making local forecasts. If, for instance, the recorder ticks frequently on a clear summer morning when there are no visible signs of an impending thunderstorm (each tick represents an electric discharge somewhere near the station, may be only a mile distant and may be 50 miles away) we conclude that the condition of the atmosphere is unstable, and that some time during the day there will be a thunderstorm. On July 3, 1903, for example, the first signal occurred at 5:21 a. m., and the first audible thunder at 12:40 p. m., or seven hours and nineteen minutes later. The last thunder occurred at 3:00 p. m., and the last signal at 3:53 p. m. About 180 signals were recorded by the instrument before the first audible thunder. In its present crude condition our recorder can not tell us from what direction the storm is approaching the station, nor with what speed and intensity, but by improving it such information may some day be obtained.

Among those most interested in forecasts of thunderstorms are the owners of extensive electric light and power plants, wherein thousands of dollars' worth of electric machinery are at the mercy of a stroke of lightning. While a lightning recorder can do nothing, directly, to prevent the coming of the destructive bolt, yet if a superintendent knew some hours in advance that a storm was coming he could prepare himself, and would have certain advantages over one taken unawares. This information the United States Weather Bureau may some day be able to give.

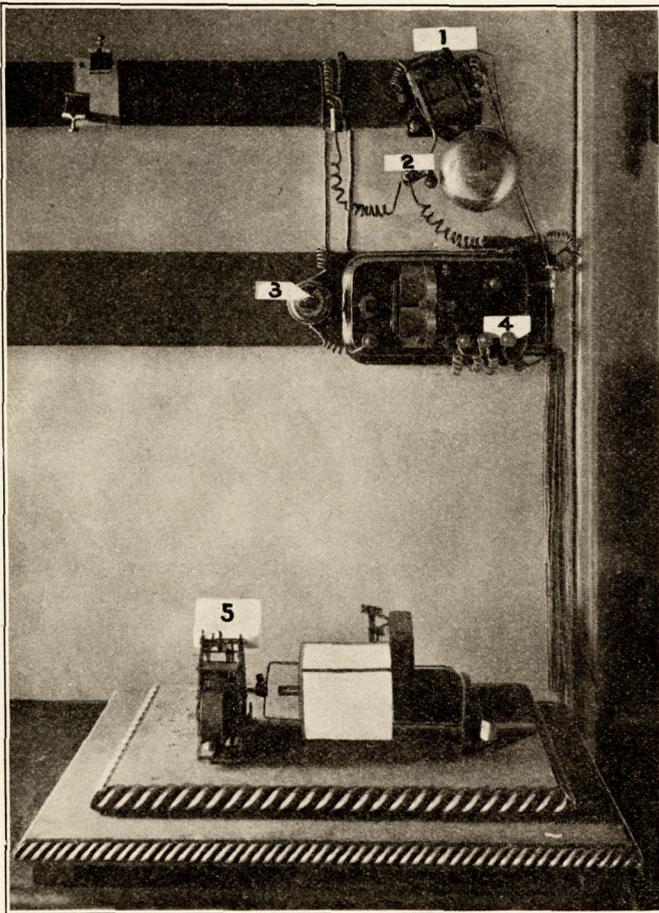


FIG. 1.—Lightning recorder. 1, decoherer; 2, coherer; 3, cut-out; 4, relay; 5, recorder.

For the benefit of those who desire to take up this interesting work the writer gives below a description, with approximate cost, of a simple, practical, and inexpensive lightning recorder, which can be made and installed by any one having an ordinary knowledge of electricity, and which will give warning of approaching thunderstorms anywhere from a few minutes to several hours in advance of the first peal of audible thunder. The instrument at New Orleans consists of—

#### THE COLLECTOR.

The collector is a hollow cylinder fourteen feet long and eleven inches in diameter, made of two sheets of commercial zinc nailed to three disks of wood, one at each end and the third in the middle. The edges of the zincs are soldered. There is an eye hook at the top of the guy lines and a  $\frac{1}{4}$ -inch bolt, about two inches long, at the bottom, which fits into an ordinary telegraph glass insulator, fixed to a six by six wooden board one inch thick nailed to the floor of the platform, upon which the collector stands in an upright position. The top of the collector is about 110 feet above the ground. Cost, about \$3.00

#### THE COHERER.

The coherer consists of a piece of thick glass tube, one-quarter inch inside diameter, two inches long, into which are closely fitted two silver electrodes each one-quarter inch in diameter and three-eighths of an inch long, with a piece of copper wire soldered to each. The electrodes are about one-sixteenth of an inch apart. In the space between them are placed a few filings filed from a 10-cent piece of money with a coarse file. A dime piece will give enough filings for a dozen receivers. The spaces back of the electrodes are filled with plaster of Paris, to keep the moisture out. This coherer can be refilled at a cost of about two cents. Cost, about \$1.00.

#### THE DECOHERER.

The decoherer is an ordinary  $3\frac{1}{2}$ -inch doorbell, to the hammer of which is soldered a stout piece of wire, two inches long, at right angles with the axis of the hammer, and to which the coherer is attached by a piece of insulating tape. When the bell rings, the filings are shaken and separated. Cost, about \$1.50.

#### THE RELAY.

The relay is of the ordinary kind used in telegraphy and has a resistance of about 150 ohms. Cost, about \$5.00.

#### THE FUSE.

This is a piece of 2-ampere fuse, about three inches long, such as is used in electric light circuits. Cost, about five cents.

#### THE GROUND.

A sewer, gas, or water pipe, of metal, under the ground, or a small piece of metal buried in the earth will answer for a ground.

#### THE CUT-OUT AND DOUBLE CONNECTORS.

A small cut-out, with ebony handle, such as is used in electric light wiring, and two double connectors of the kind used in telegraphy are used. Cost, about fifty cents.

#### THE BATTERIES.

Two batteries are used, one of two dry cells for the coherer and one of four dry cells for the decoherer and recorder circuits. Cost, about \$1.80.

#### THE WIRES.

A piece of No. 10 weather-proof, electric-light wire, to lead from the collector to the coherer, and a supply of office bell wire for office connections. Cost, about \$1.00 for ordinary installations.

#### THE RECORDER.

The recorder consists of a strong clockworks; a hollow wooden cylinder, three and a quarter inches in diameter and three and a quarter inches long, mounted on an endless screw fixed to an upright iron support at one end; and a small doorbell magnet, on whose armature is soldered a self-inking pen made of a hollow brass cone about one-quarter of an inch in diameter at the base and one inch long. The cylinder carries a sheet of paper divided into hour and 5-minute spaces and makes a complete revolution once every hour. A fresh sheet is placed upon the cylinder every twenty-four hours. Every time the recorder ticks, the pen, which is suspended over the cylinder about one-sixteenth of an inch therefrom, strikes the paper and imprints thereon a dot. Cost, about \$15.00.

#### ARRANGEMENT OF CIRCUITS.

The collector is on the roof of the building; the rest of the apparatus is in the office room.

*Collector circuit.*—Run a wire from the lower end of the collector to the fuse box; thence to double connector No. 1; thence to coherer; thence to double connector No. 2; thence to the ground.

*Relay circuit.*—Run a wire from double connector No. 1 to the cut-out; thence to relay post No. 1, also a wire from relay post No. 2 to battery No. 1; thence to double connector No. 2.

*Decoherer and recorder circuit.*—These instruments are in series. Run a wire from relay post No. 3 to the decoherer; thence to the recorder; thence to battery No. 2; thence to relay post No. 4.

The wire leading from the collector should be nailed to the lower end of the collector and soldered thereto. The wires leading to the coherer—about one foot on each side—should be flexible, so that they will not interfere with the movements of the decoherer. The decoherer should be tilted to one side—the side away from the hammer. As there is a small current passing through the coherer constantly, sooner or later it will “stick”—that is, refuse to work. Therefore it should be given a rest as often as possible by cutting it out or putting in one of the extras. Sometimes the decoherer bell will ring once and sometimes it will ring several times, according to the intensity of the lightning discharges. Closed-circuit batteries will last longer than open-circuit ones.

Dr. Lee DeForest, of the American DeForest Wireless Telegraph Company, during a recent visit to New Orleans, suggested to the writer the advisability of thoroughly insulating the coherer wires from the walls of the building.

dicare that a thunderstorm will occur later in the day. In some of the thunderstorms of which we have obtained records, the first peal of thunder heard at station was preceded by an hundred or more signals.

5. The collector described above is not an element of danger to the station. It will not attract lightning any more than an ordinary smokestack similarly exposed.

6. The cost of operating the lightning recorder need not exceed that of operating two large-sized doorbells.

7. Generally speaking, the higher the collector stands above the ground the larger will be its range of action.

In working out the mechanical details of the recorder the writer received valuable assistance from Mr. F. W. Ax, of the New Orleans office force.

**THE INTRODUCTION OF METEOROLOGY INTO THE COURSES OF INSTRUCTION IN MATHEMATICS AND PHYSICS.**

By PROF. CLEVELAND ABBE.

[Read November 26, 1904, at Chicago, before the Central Association of Science and Mathematics Teachers.]

The study of meteorology has acquired a new and vivid interest since the establishment of fairly successful weather forecasts in this country and Europe. The civilized world now knows that the weather and the climate, the winds and storms are controlled by rigorous laws of nature. We may not understand these laws as yet, but they are in control of the universe and we are to discover them and utilize them for the benefit of mankind. We have not yet found any limit to the attainments of the human intellect, and what the mind can do in the way of thinking the hand will find some means to attain in the way of doing. We must think out our work before we can do it.

The ultimate object of all your systems of education, elementary, collegiate, and postgraduate, is to train the mind to think and then train the hand to do. In old times the schools crammed the brain with the results of work already done, memorizing a multitude of facts; but now, while not neglecting the memory, we seek to develop the reasoning faculties, or the reasoning habit of thought, and then to perfect our methods of doing. Our schools pay much attention to mathematics, mechanics, chemistry, and science in general, because these have an important practical bearing on our lives. In this new progress, the professional side of education, meteorology has not been neglected altogether. I have been greatly pleased to see the enthusiastic reception accorded it in every part of the Union and its growing popularity in both graded and high schools. I suppose that we owe this specifically to the general success of the Weather Bureau, but more particularly to Prof. Wm. M. Davis, who established a school of meteorology about 1878 as a division of the school of geology at Harvard University. His students and text-books, his “Elementary Meteorology,” the “Climatology” of his successor, Prof. R. DeC. Ward, and their methods of teaching have awakened teachers and professors alike to new possibilities. Other schools and other text-books have come into existence and the elements of the subject are now so well provided for that I do not need to say more about this; but I do feel the need of further advances.

I regard meteorology not so much as a matter of observation and generalization as a matter of deductive reason. Our studies have approached the limit of what we are likely to discover by inductive processes. We stand where astronomy stood in the days of La Place. We have had our Galileo and Newton, but we still need other leaders, and you will all agree with me that these must be trained in the schools. They must get their first lessons from you. Twenty or thirty years hence our future masters in meteorology will tell how their feet were turned in the right direction by the teachers of to-day.

In every school I find several boys and girls that have taken

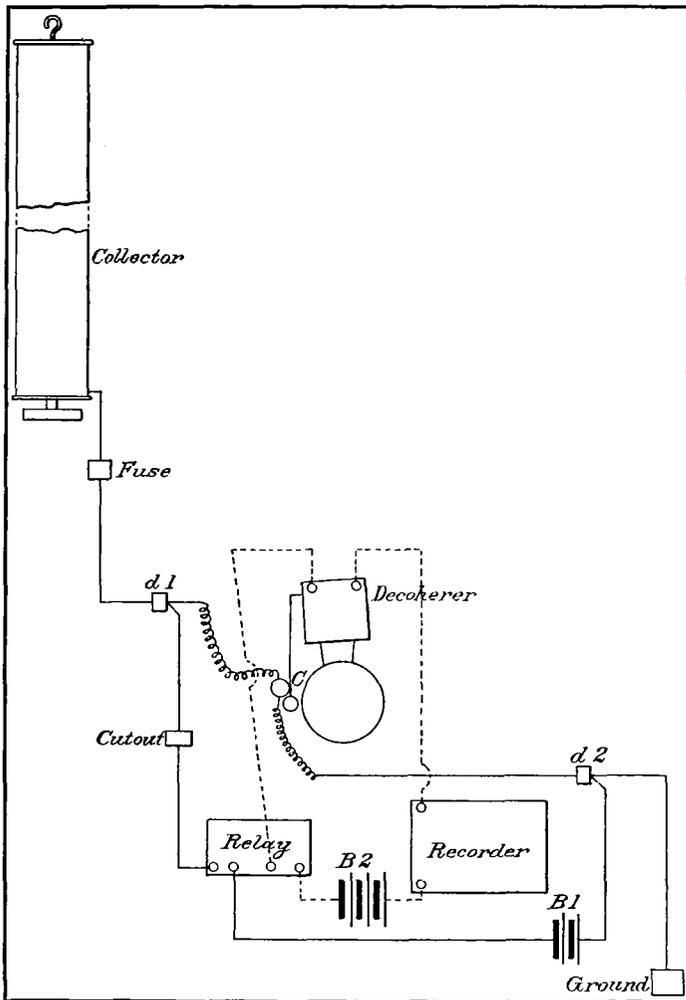


FIG. 2.—Diagram of the lightning recorder at New Orleans, La. *d*, double connector; *B*, battery; *C*, coherer.

Summarizing the results obtained so far it may be said that :

1. A practical lightning recorder can be made at small cost that will give results fully warranting the cost of construction.
2. Where written signals are not required, the bell on the decoherer can be utilized for giving audible signals; and the cost of the apparatus greatly reduced.
3. The recorder will not tick merely because the sky is cloudy and threatening; in cloudy weather it will give signals only when barometric and other atmospheric conditions favor the formation of thunderstorms. In storms coming from a great distance signals were recorded with a clear sky.
4. In most cases, frequent signals in the early forenoon in-