THE ELECTRIFICATION OF AIR.[1]

§ 1. THAT air can be electrified either positively or negatively is obvious from the fact that an isolated spherule of pure water, electrified either positively or negatively, can be wholly evaporated in air.[2] Thirty-four years ago it was pointed out by one of us[3] as probable that in ordinary natural atmospheric conditions, the air for some considerable height above the earth's surface is electrified,[4] and that the incessant variations of electrostatic force which he had observed, minute after minute, during calms and light winds, and often under a cloudless sky, were due to motions of large quantities of positively or negatively electrified air in the immediate neighbourhood of the place of observation.

§ 2. It was proved[5] by observations in the Old College of Glasgow University that the air was in general negatively electrified, not only indoors, within the old lecture room[6] of Natural Philosophy, but also in the out-of-doors space of the College Court, open to the sky, though closed around with high buildings, and between it and the top of the College Tower. The Old College was in a somewhat low situation, surrounded by a densely-crowded part of a great city. In the new University buildings, crowning a hill on the western boundary of Glasgow, similar phenomena, though with less general prevalence of negative electricity in the air, have been observed, both indoors, in the large Bute Hall, and in many other smaller rooms, and out-of-doors, in the court, which is somewhat similar to the courts of the Old College, but much larger. It is possible that the negative electricity found thirty years ago in the air of the Old College, may have been due to its situation, surrounded by houses with their fires, and smoking factory chimneys. In the New College much of the prevalence of negative electricity in air within doors has, however, been found to be due to electrification by the burning lamp[7] used with the quadrant electrometer; and more recent observations with electrification by flame absolutely excluded, throw doubt on the old conclusion, that both in town and country negative electrification is the prevailing condition of natural atmospheric air in the lower regions of the atmosphere.

§ 3. The electric ventilation found in the Old College, and described in § 299 of "Electrostatics and Magnetism," accord-

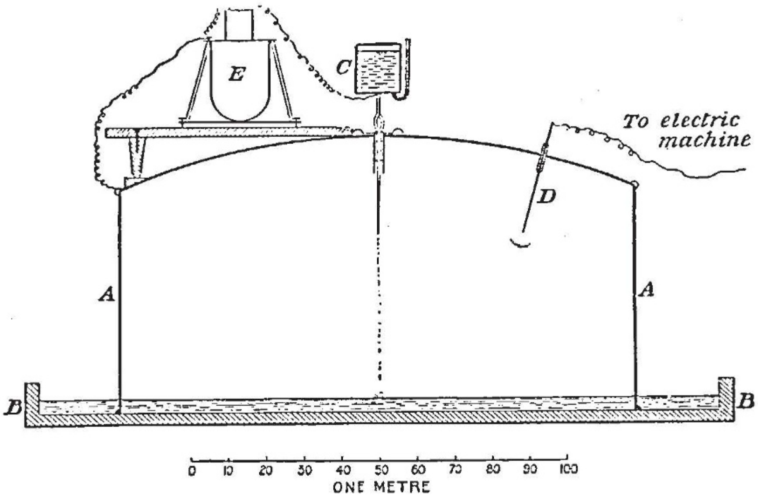


FIG. 1.

ing to which air drawn through a chink, less than ½-inch wide, of a slightly open window or door, into a large room, showed the electrification which it had on the other side of the chink, whether that was the natural electrification of the open air, or positive or negative electrification produced by aid of a spirit lamp and electric machine in an adjoining room, has been tried again in the New College with quite corresponding results. It has also been extended to the drawing in of electrified air through a tube to the enclosure represented in Fig. 1 of the present paper; with the result that the water-dropping test indicated in the sketch, amply sufficed to show the electrification, and verify that it was always the same as that of the air outside. When the tube was filled with loosely packed cotton-wool the electrification of the entering air was so nearly annulled as to be insensible to the test.

§ 4. The object proposed for the experiments described in the present communication was to find if a small unchanged portion of air could be electrified sufficiently to show its electrification by ordinary tests, and could keep its electrification for any considerable time; and to test whether or not dust in the air is essential to whatever of electrification might be observed in such circumstances, or is much concerned in it.

§ 5. The arrangement for the experiments is shown in the diagram, Fig. 1. A A is a large sheet-iron vat inverted on a large wooden tray B B, lined with lead. By filling the tray with water the air is confined in the vat. There are two holes in the top of the vat: one for the water-dropper C, and one for the charging wire D. Both the water-dropper, and the charging wire, ending with a pin-point as sharp as possible, are insulated by solid paraffin, which is surrounded by a metal tube, as shown in half size in Fig. 2. To start with they were supported by pieces of vulcanite embedded in paraffin. But it was found that after the lapse of some days (possibly on account of ozone generated by the incessant brush discharges), the insulation had utterly failed in both of them. The vulcanite pieces were then taken out, and solid paraffin, with the metal guard-tube round it to screen it from electrically influencing the water-dropper, was substituted. This has proved quite satisfactory: the water-dropper, with the flow of water stopped, holds a positive or a negative charge for hours.

§ 6. A quadrant electrometer E (described in "Electrostatics and Magnetism" §§ 346-353) was set up on the top of the vat near the water-dropper, as shown in Fig. 1. It was used with lamp and semi-transparent scale to indicate the difference of potential between the water-dropper and the vat. The sensibility

1 A Paper by Lord Kelvin, P.R.S., and Mr. Magnus Maclean, read at the Royal Society on May 31.

2 This demonstrates an affirmative answer to the question, Can a molecule of a gas be charged with electricity? (J. J. Thomson, "Recent Researches in Electricity and Magnetism," § 36, p. 53) and shows that the experiments referred to as pointing to the opposite conclusion are to be explained otherwise.

Since this was written, we find in the *Electrical Review* of May 18, on p. 571, in a lecture by Elihu Thomson, the following:—"It is known that as we leave the surface of the earth and rise in the air, there is an increase of positive potential with respect to the ground. . . . It is not clearly proven that a pure gas, rarefied or not, can receive and convey a charge. If we imagine a charged drop of water suspended in air and evaporating, it follows that, unless the charge be carried off in the vapour, the potential of the drop would rise steadily as its surface diminished, and would become infinite as the drop disappeared, unless the charge were dissipated before the complete drying up of the drop by dispersion of the drop itself, or conveyance of electricity by its vapour. The charge would certainly require to pass somewhere, and might leave the air and vapour charged."

It is quite clear that "must" ought to be substituted for "might" in this last line. Thus the vagueness and doubts expressed in the first part of the quoted statement are annulled by the last three sentences of it.

3 "Even in fair weather the intensity of the electric force in the air near the earth's surface is perpetually fluctuating. The speaker had often observed it, especially during calms or very light breezes from the east, varying from 40 Daniel's elements per foot to three or four times that amount during a few minutes, and returning again as rapidly to the lower amount. More frequently he had observed variations from about 30 to about 40, and back again, recurring in uncertain periods of perhaps about two minutes. These gradual variations cannot but be produced by electrified masses of air or cloud, floating by the locality of observation."—Lord Kelvin's "Electrostatics and Magnetism," art. xvi. § 282.

4 The out-of-doors air potential, as tested by a portable electrometer in an open place, or even by a water-dropping nozzle outside, two or three feet from the walls of the lecture room, was generally on these occasions positive, and the earth's surface itself therefore, of course, negative—the common fair weather condition—which I am forced to conclude is due to a paramount influence of positive electricity in higher regions of the air, notwithstanding the negative electricity of the air in the lower stratum near the earth's surface. On the two or three occasions when the in-door atmospheric electricity was found positive, and, therefore, the surface of the floor walls and ceiling negative, the potential outside was certainly positive, and the earth's surface out-of-doors negative, as usual in fine weather."—*Ibid.* § 300.

5 *Ibid.* Q. 2, § 283.

6 *Ibid.* §§ 296-300.

7 "Electrification of Air by Combustion," Magnus Maclean and Makita Goto, Philosophical Society of Glasgow, November 20, 1889; "Electrification of Air by Water Jet," Magnus Maclean and Makita Goto, *Philosophical Magazine*, August 1890.

of the electrometer was 21 scale divisions (half-millimetres) per volt, and as the scale was 90 centimetres long, difference of potentials up to 43 volts positive or negative, could be read by adjusting the metallic zero to the middle of the scale. A frictional plate-electric machine was used, and by means of it, in connection with the pin-point, the air inside the vat could be electrified either positively or negatively.

§ 7. The vat was fixed in position in the Apparatus Room of the Natural Philosophy Department of the University of Glasgow on December 13, 1893, and for more than three months the air inside was left undisturbed except by discharges from the pin-point through the electrifying wire, and by the spray from the water-dropper. Thus the air was becoming more and more freed of dust day by day. Yet at the end of the four months we found that the air was as easily electrified, either positively or negatively, as it was at the beginning; and that if we electrify it strongly by turning the machine for half an hour, it retains a considerable portion of this electrification for several hours.

§ 8. Observations were taken almost daily since December 13; but the following, taken on February 8, March 12, and April 23, will serve as specimens, the results being shown in each case by a curve. At all these dates the air must have been very free

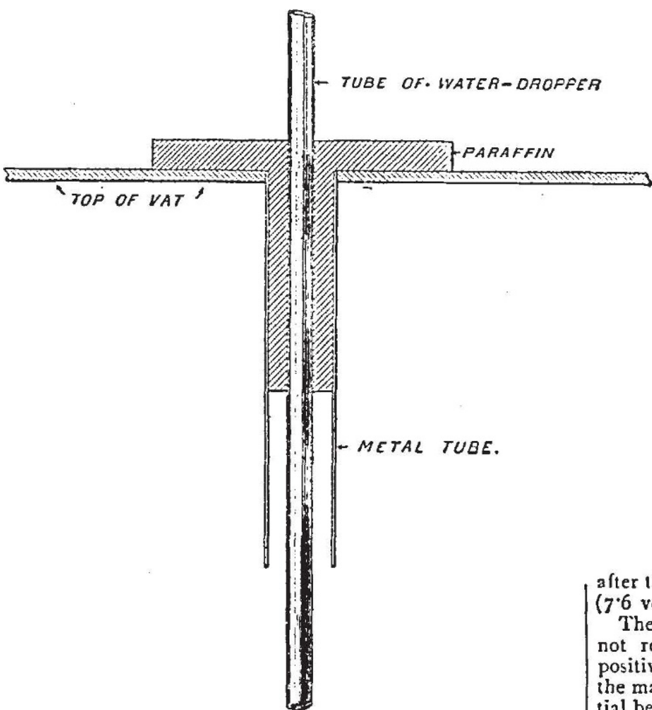


FIG. 2.

from dust. Both during the charging and during the observations the case of the electrometer and one pair of quadrants are kept metallically connected to the vat. During the charging the water-dropper and the other pair of quadrants were also kept in connection with the vat. Immediately after the charging was stopped the charging-wire was connected metallically to the outside of the vat, and left so with its sharp point unchanged in its position inside the vat during all the observations.

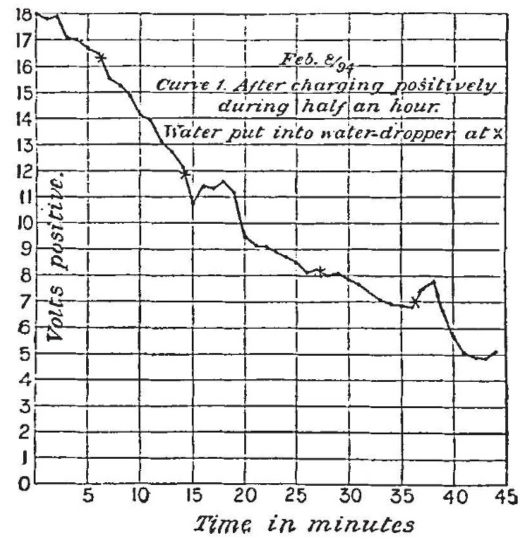
§ 9. *Curve* 1. *February* 8, 1894.—The friction-plate machine was turned positive for half an hour. Ten minutes after the machine stopped the water-dropper was filled and joined to one pair of quadrants of the electrometer, while the other pair was joined to the case of the instrument. The first reading on the curve was taken four minutes afterwards, that is, fourteen minutes after the machine stopped running (18 volts).

Curve 2. *March* 3, 1894.—The friction-plate machine was turned positive for five minutes. The water-dropper was filled and joined to the electrometer immediately after the machine stopped turning. The spot was off the scale, and nine minutes elapsed before it appeared on the scale. The first reading on the curve was taken one minute afterwards, or ten minutes after the machine stopped turning (35·25 volts).

Curve 3. *March* 12, 1894.—A Voss induction machine was joined to the charging wire, and run by an electric motor for four hours nineteen minutes. A test was applied at the beginning of the run to make sure that it was charging negatively; and a similar test when it was disconnected from the charging wire in the vat showed it to be still charging negatively. The water-dropper was joined to the electrometer, and the spot appeared on the scale immediately. The first reading on the curve was taken half a minute after the machine was disconnected (30·65 volts).

Curve 4. *April* 23, 1894.—The friction-plate machine was turned positive for thirty seconds, with water-dropper running and joined to the electrometer. Twenty seconds after the machine stopped the spot appeared on the scale, and the reading one and a half minutes after the machine stopped turning is the first point on the curve (7·3 volts).

Curve 5. *April* 23, 1894.—The friction-plate machine was turned negative for thirty seconds, with the water-dropper running and joined to the electrometer. Ten seconds afterwards the spot appeared on the scale, and the reading seventy seconds



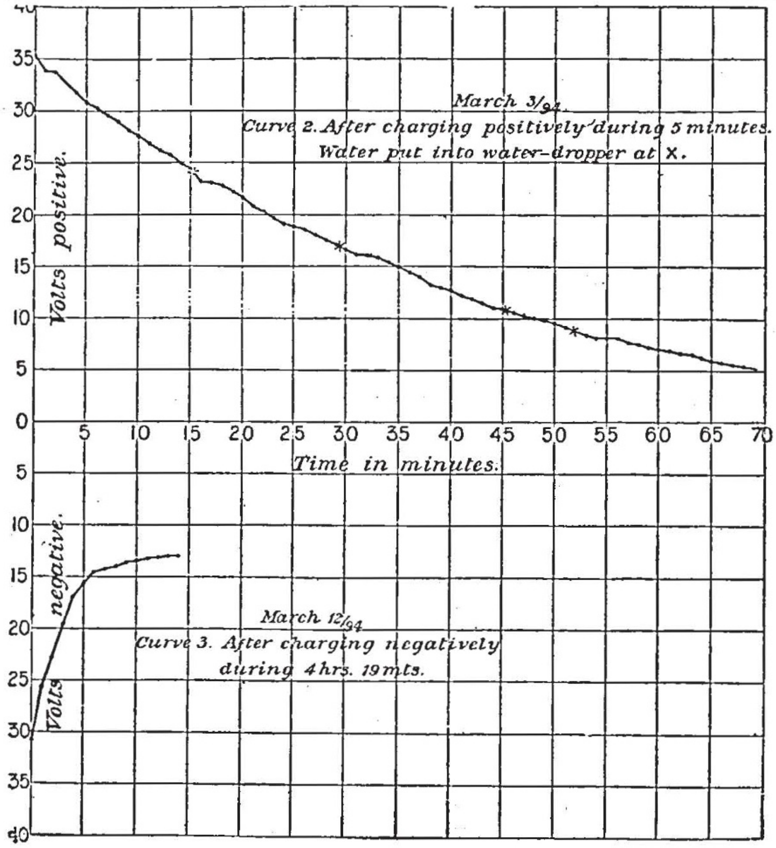
after the machine stopped turning is the first point on the curve (7·6 volts).

The curves show, what we always found, that the air does not retain a negative electrification so long as it retains a positive. We also found, by giving equal numbers of turns to the machine, that the immediately resulting difference of potential between the water-dropper and the vat was greater for the negative than for the positive electrification; though the quantity received from the machine was probably less in the case of the negative electrification, because the negative conductor was less well-insulated than the positive.

§ 10. On March 21, two U-tubes were put in below the edge of the vat, one on either side, so that it might be possible to blow dusty, or smoky, or dustless air into the vat. To one tube was fitted a blowpipe bellows, and by placing it on the top of a box in which brown paper and rosin were burning, the vat was filled with smoky air. Again, several layers of cotton-wool were placed on the mouth of the bellows, so as to get dustless air into the vat. The bellows were worked for several hours on four successive days, and we found no appreciable difference (1) in the ease with which the air could be electrified by discharges from the wire connected to the electric machine, and (2) in the length of time the air retains its electrification.

But it was found that, as had been observed four years ago with the same apparatus,[1] with the water-dropper insulated and connected to the electrometer, and no electrification of any kind to begin with, a negative electrification amounting to four, five, or six volts gradually supervened if the water-dropper was

[1] Maclean and Goto, *Philosophical Magazine*, August 1890.



kept running for 60 or 70 minutes, through air which was dusty, or natural, to begin with. It was also found, as in the observations of four years ago, that no electrification of this kind was produced by the dropping of the water through air purified of dust.

The circular bend of the tube of the water-dropper shown in the drawing was made for the purpose of acting as a trap to prevent the natural dusty air of the locality from entering the vat when the water-dropper ran empty.

§ 11. The equilibrum of electrified air within a space enclosed by a fixed bounding surface of conducting material presents an interesting illustration of elementary hydrostatic principles. The condition to be fulfilled is simply that the surfaces of equal electric "volume-density" are surfaces of equal potential, if we assume that the material density of the air at given temperature and pressure is not altered by electrification. This assumption we temporarily make from want of knowledge; but it is quite possible that experiment may prove that it is not accurately true; and it is to be hoped that experimental investigation will be made for answering this very interesting question.

§ 12. For stable equilibrium it is further necessary that the electric density, if not uniform throughout, diminishes from the bounding surface inwards. Hence, if there is a portion of non-electrified air in the enclosure it must be wholly surrounded by electrified air.

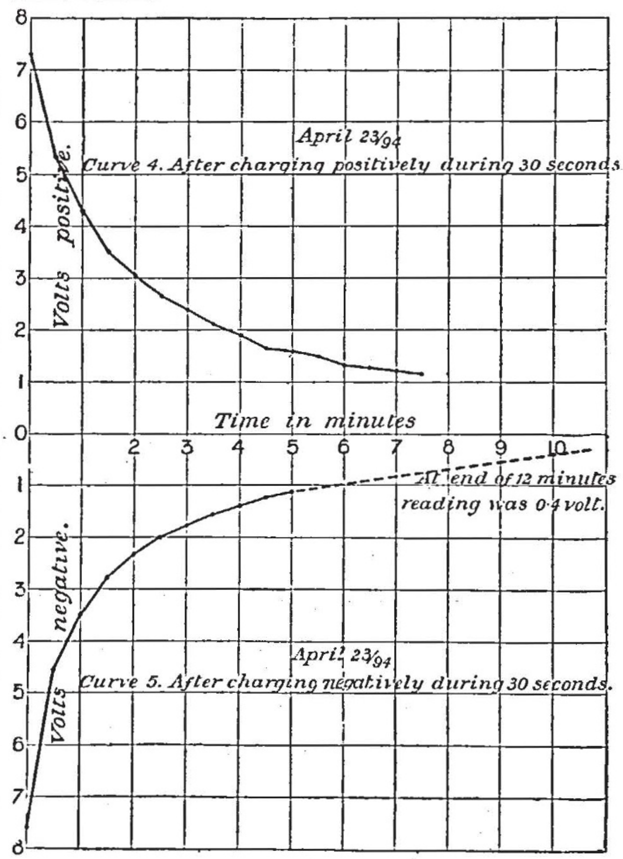
§ 13. We may form some idea of the absolute value of the electric density, and of the electrostatic force in different parts of the enclosure, in the electrifications found in our experiments, by considering instead of our vat a spherical enclosure of diameter intermediate between the diameter and depth of the vat which we used. Consider, for example, a spherical space enclosed in metal of 100 cm. diameter, and let the nozzle of the water-dropper be so placed that the stream breaks into drops at the centre of the space. The potential shown by the electrometer connected with it, being the difference between the potentials of the air at the boundary and at the centre, will be the difference of the potentials at the centre due respectively to the total quantity of electricity distributed through the air and the equal and opposite quantity on the inner boundary of the enclosing metal; and we therefore have the formula:—

$$V = 4\pi \int_0^a \rho \left(\frac{r^2}{r} - \frac{r^2}{a} \right) dr,$$

where V denotes the potential indicated by the water-dropper, a the radius of the spherical hollow, and ρ the electric density of the air at distance r from the centre. Supposing now, for example, ρ to be constant from the surface to the centre (which may be nearly the case after long electrification as performed in our experiments), we find $V = \frac{2}{3}\pi\rho a^2$; whence $\rho = 3V/2\pi a^2$.

To particularise further, suppose the potential to have been 38 volts or 0·127 electrostatic c.g.s. (which is less than the greatest found in our experiments) and take $a = 50$ cm.: we find $\rho = 2{\cdot}4.10^{-5}$. The electrostatic force at distance r from the centre, being $\frac{4}{3}\pi\rho r$, is therefore equal to $10^{-4}r$. Hence a small body electrified with a quantity of electricity equal to that possessed by a cubic centimetre of the air, and placed midway ($r = 25$) between the surface and centre of the enclosure experiences a force equal to $2{\cdot}4.10^{-9}.25$, or 6×10^{-8}, or approximately 6.10^{-5} grammes weight. This is 4·8 per cent. of the force of gravity on a cubic centimetre of air of density 1/800.

§ 14. Hence we see that, on the supposition of electric density uniform throughout the spherical enclosure, each cubic centimetre of air experiences an electrostatic force towards the boundary in simple proportion to distance from the centre, and amounting at the boundary to nearly 10



per cent. of the force of gravity upon it; and electric forces of not very dissimilar magnitudes must have acted on the air electrified as it actually was in the non-spherical enclosure used in our experiments. If natural air or cloud, close to the ground or in the lower regions of the earth's atmosphere, is ever, as in all probability it often is, electrified to as great a degree of electric density as we have found it within our experimental vat, the natural electrostatic force in the atmosphere, due as it is, no doubt, to positive electricity in very high regions, must exercise an important ponderomotive force quite comparable in magnitude with that due to difference of temperatures in different positions.

It is interesting to remark that negatively electrified air over negatively electrified ground, and with non-electrified air above it, in an absolute calm, would be in unstable equilibrium; and the negatively electrified air would therefore rise, probably in large masses, through the non-electrified air up to the higher regions, where the positive electrification is supposed to reside. Even with no stronger electrification than that which we have had within our experimental vat, the moving forces would be sufficient to produce instability comparable with that of air warmed by the ground and rising through colder air above.

§ 15. During a thunderstorm the electrification of air, or of air and the watery spherules constituting cloud, need not be enormously stronger than that found in our experiments. This we see by considering that if a uniformly electrified globe of a metre diameter produces a difference of potential of 38 volts between its surface and centre, a globe of a kilometre diameter, electrified to the same electric density, reckoned according to the total electricity in any small volume (electricity of air and of spherules of water, if there are any in it), would produce a difference of potential of 38 million volts between its surface and centre. In a thunderstorm, flashes of lightning show us differences of potentials of millions of volts, but not perhaps of many times 38 million volts, between places of the atmosphere distant from one another by half a kilometre.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

THE Council of the Owens College has, on the recommendation of the Senate, made the following appointments to Fellowships in the College:—Bishop Berkeley—Dr. A. W. Crossley in Chemistry, A. H. Jameson in Engineering; Honorary Research—Wilmot Holt, junr., in Chemistry.

MR. ANDREW J. HERBERTSON, of Edinburgh, has been appointed Lecturer on Geography at the Owens College, Manchester, in succession to Mr. Yule Oldham.

SCIENTIFIC SERIALS.

American Journal of Mathematics, vol. xvi. 3. (Baltimore: July 1894.)—A class of uniform transcendental functions, by Dr. T. Craig (pp. 207-220), gives another mode of forming a certain transcendental function first introduced by M. Picard (*Comptes Rendus*, 1878), and which does not seem to have been subsequently discussed. M. G. Humbert (pp. 221-253), writing "Sur les surfaces de Kummer elliptiques," after mentioning that Cayley's *tetrahedroid* is a particular case of a Kummer surface with six double points, applies himself to the problem of determining whether any other of these surfaces possess similar properties.—Mr. Basset contributes a memoir on the deformation of thin elastic plates and shells (pp. 254-290). The origin of the investigation appears to be the dissatisfaction Mr. Basset has felt with Mr. Love's treatment of the theories of thin plates, shells, and wires in the second volume of his book on "Elasticity."

Jahrbuch der k. k. geolog. Reichsanstalt Wien. Bd. xliii. Heft 3 and 4, March 1894.—Although Graz is one of the few localities in the Central Alps in which palæozoic strata are present containing good fossils, the exact age of these strata and their parallelism with the Silurian and Devonian strata of extra-Alpine regions have remained uncertain. The richly fossiliferous Coral-limestone of the Graz succession was determined as mid-Devonian by Suess, Stache, and others. Hoernes, on the other hand, thought it Lower Devonian. Now, for the first time, the Corals have been made the subject of a detailed study.—Dr. K. A. Penecke contributes a paper to the *Jahrbuch*, "On the Devonian strata of Graz," in which he proves that the "Coral limestone" and the "Calceola horizon" immediately above it are the uppermost bed of the *Lower Devonian* series. The age of the palæozoic strata of Graz ranges, according to Dr. Penecke, from the oldest Silurian to the youngest Devonian, and may possibly include a part of the Lower Coal Measures.—The monograph of the Raibl strata, by Baron von Wöhrmann, marks a considerable advance in our knowledge of Alpine Trias. The author's previous papers on the Raibl fauna in North and South Tyrol, have paved the way for this general paper. All the Raibl facies known in the Alps are described, the species contained in them reviewed, the indications of the geographical conditions discussed, and comparative references made to extra-Alpine seas in the same period. The subject is one of the most complex, but its treatment is searching, concise, and exhaustive. We note, almost with relief, the entire absence of the speculative method and wordy argument too frequently seen of late in matters concerning the Alps.

Bd xliv. Heft 2, June 1894.—"On the newer literature of the Alpine Trias," by Dr. A. Bittner. The personal and polemical tone of this paper renders it somewhat remarkable. By way of reviewing the terminology and literature of the Alpine Trias, Dr. Bittner exposes scathingly the fashion of new name-giving on insufficient grounds, the prejudice and obstinacy with which a name once given is apt to be retained, and the danger to science of subsequent attempts to modify the original meaning of a name, and prop a deservedly falling fabric. The writings of Mojsisovics are those which specially come under the whip. We are told, for example, that in studying "the Cephalopoda of the Hallstadt Limestone," one of the greatest works of Mojsisovics, we must read everywhere—instead of Mediterranean Trias, Alpine Trias; instead of Juvavic horizon, Noric horizon; instead of Noric horizon, Ladinian horizon; the author of the work himself having entirely departed from the geological conceptions for which the names were created! Dr. Bittner's paper is, to say the least, breezy; but, on the principle of the old proverb, "It's an ill wind, &c.," there is no doubt it will have a healthful effect in blowing away some of the cobwebs of tradition from a study which nature had already made so difficult and so fascinating.

SOCIETIES AND ACADEMIES.

LONDON.

Royal Society, May 10.—"The Composition of Atmospheres which Extinguish Flame." By Dr. Frank Clowes, Professor of Chemistry, University College, Nottingham.

The statements usually published, as to the proportion of carbon dioxide in air necessary to extinguish a candle flame, vary widely. The present investigation was undertaken with the object of fixing the minimum proportion of carbon dioxide and of nitrogen gas, which, when mingled with air, will extinguish flame; and with the further object of ascertaining also the minimum proportion of each of these gases, which is necessary to extinguish the flames of different combustible substances, including those of certain gases.

The method of experimenting, which was devised, prevented the introduction of errors arising from the incomplete mixture of the gas with the air, from the solubility of carbon dioxide in water, and from the effect of carbonic dioxide produced from the flame during its combustion. The proportions of gas and air in the mixtures used were checked by analysis and were shown to be accurate, and duplicate experiments agreed in their results closely.

A preliminary series of experiments proved that, within the wide limits selected, the extinctive proportion of carbon dioxide was independent of the *size* of the flame of any particular combustible which was introduced into the mixture.

An extended series of experiments was then made to ascertain the minimum extinctive proportion of carbon dioxide for flames of very various description. The results arrived at showed that the flames of very different combustibles which were burnt from wicks, required a strikingly similar proportion of carbon dioxide in the air for their extinction. Thus the percentage of carbon dioxide necessary for the extinction of the flames of the following combustibles were: for absolute alcohol, 14; for methylated alcohol, 13; for paraffin oil, 15; for mixed colza and petroleum, 16; and for a candle, 14.