XI. "On Allotropic or Active Nitrogen, and on the Complete Synthesis of Ammonia." By GEORGE STILLINGFLEET JOHNSON, King's College. Communicated by Professor G. JOHNSON, F.R.S. Received October 8, 1881.

[Publication deferred.]

XII. "Researches on Chemical Equivalence. Part IV. Manganous and Nickelous Sulphates." By EDMUND J. MILLS, D.Sc., F.R.S., and J. H. BICKET. Received October 25, 1881.

[Publication deferred.]

XIII. "Researches on Chemical Equivalence. Part V." By EDMUND J. MILLS, D.Sc., F.R.S., and BERTRAM HUNT. Received October 27, 1881.

[Publication deferred.]

November 24, 1881.

THE PRESIDENT in the Chair.

In pursuance of the Statutes, notice was given from the Chair of the ensuing Anniversary Meeting, and the list of Officers and Council nominated for election was read, as follows:—

President.—William Spottiswoode, M.A., D.C.L., LL.D.

Treasurer.—John Evans, D.C.L., LL.D.

Secretaries.— { Professor George Gabriel Stokes, M.A., D.C.L., LL.D.
Michael Foster, M.A., M.D., LL.D.

Foreign Secretary.—Professor Alexander William Williamson, Ph.D., LL.D.

Other Members of the Council.—Francis Maitland Balfour, M.A., LL.D.; I. Lowthian Bell, F.C.S.; Sir Risdon Bennett, M.D.; Professor Thomas George Bonney, M.A.; Professor Heinrich Debus, Ph.D.; Alexander John Ellis, B.A.; Sir John Hawkshaw, M.I.C.E.; Thomas Archer Hirst, Ph.D.; William Huggins, D.C.L., LL.D.; Professor Thomas Henry Huxley, LL.D.; Professor Joseph Lister, M.D.; Pro-

fessor Daniel Oliver, F.L.S.; Professor Henry Enfield Roscoe, B.A., LL.D.; Warington W. Smyth, M.A.; Henry Tibbats Stainton, F.G.S.; Edward James Stone, M.A.

The Presents received were laid on the table, and thanks ordered for them.

THE BAKERIAN LECTURE—"Action of Free Molecules on Radiant Heat, and its Conversion thereby into Sound," was delivered by J. TYNDALL, F.R.S.

The following is an abstract:—

The lecture opens with a brief reference to the researches of Leslie, Rumford, and Melloni. The labours of Tyndall and Magnus, as far as they bear upon the present subject, are then succinctly sketched, their points of difference being signalised and briefly discussed. This preliminary sketch is wound up by a reference to a recently published paper by Lecher and Pernter, who, while supporting the lecturer in the matter of gases, dissent from him in the matter of vapours. These investigators are especially emphatic in affirming the neutrality of aqueous vapour to radiant heat. Following Magnus, they refer Tyndall's results to what Magnus calls "vapour-hesion," that is to say, to the condensation of the vapours on the surfaces of the plates of rock-salt used to close the experimental tube, and on the interior surface of the tube itself.

In November, 1880, the lecturer's investigations in this field were resumed. Former experiments were repeated and verified with divers sources of heat, and with various experimental tubes—some polished within, and others coated inside with lampblack. The results obtained with the one class of tubes are substantially the same as those obtained with the other.

But even a coating of lampblack may be supposed to reflect a certain amount of heat, hence the desirability of an arrangement whereby internal reflection should be entirely abolished. This was accomplished in the following manner:—A spiral of platinum wire, rendered incandescent by a voltaic current of measured strength, was chosen as source of heat. An experimental tube 38 inches long and 6 inches in diameter had two circular apertures at its ends, closed by transparent plates of rock-salt, 3 inches in diameter. The tube was furnished with three cocks—one connected with a large Bianchi's air-pump; another with a purifying apparatus; while through the third vapours and gases could be admitted. Prior to entering the tube, the calorific rays were sent through a very perfect rock-salt lens, by means of which an image of the spiral was formed on the

most distant plate of rock-salt. To obtain the image with clearness, the spiral was first rendered highly luminous, and afterwards reduced, by the introduction of resistance, to the required temperature. In this way a calorific beam was sent along the axis of the experimental tube without at all impinging upon its interior surface. No reflection came into play; no absorption by hypothetical liquid films, coating the internal surface, could occur; and yet experiments made with this arrangement entirely confirmed the preceding ones, wherein by far the greater quantity of heat which reached the pile had undergone reflection.

When the source of heat was changed to a carefully worked cylinder of lime, a portion of which was rendered incandescent by an ignited stream of coal-gas and oxygen, the results were confirmatory of those obtained with the spiral. The order of absorption in bot cases was the same, the only difference being that the fractional part of the total radiation absorbed in the case of the lime-light was less than that absorbed in the case of the spiral.

To condense the radiation from the lime-light, concave mirrors were sometimes employed, and sometimes rock-salt lenses. The results in both cases were identical.

An experimental tube of the dimensions here given was employed by the lecturer to check his results more than ten years ago. Its interior surface was rough and tarnished, and when warmed dynamically by the entrance of a gas its power as a radiator enabled it to disturb, to some slight extent, the purity of the results. To obviate this, the experimental tube recently employed was provided with an internal silver surface, deposited electrolytically and highly polished. By this arrangement the radiation of the tube itself, as well as its absorption, was rendered quite insensible.

The rock-salt plates used to close the experimental tube, and on which liquid films are alleged to be deposited, remain to be examined. In this case also an *experimentum crucis* is possible. If the observed absorptions be due to such liquid films, then the separation of the salts more widely from each other, the space between them being copiously supplied with vapour, ought to produce no effect; but if the absorption, as alleged by the lecturer, be the act of the vapour molecules, then the deepening of the absorbing stratum ought to produce an augmented effect. For many gases and some vapours this problem was solved as far back as 1863. By means of an apparatus then described, polished plates of rock-salt could be brought into contact with each other, and then gradually separated, until the gaseous stratum between them was some inches in depth. With sulphuric ether vapour the distance between the plates being $\frac{1}{20}$ of an inch, an absorption of 2 per cent. was observed. With a thinner stratum, or a weaker vapour, even this small absorption vanished; while in passing from

$\frac{1}{20}$ of an inch to 2 inches the absorption rose from 2 per cent. to 35 per cent. of the total radiation. Such experiments, recently verified, entirely dispose of the hypothesis that liquid films were the cause of the observed absorption.

The "vapour-hesion" hypothesis involves the assumption that liquids exert on radiant heat an absorbent power which is denied to their vapours. It assumes, in other words, that the seat of absorption is the molecule considered as a whole, and not the constituent atoms of the molecule. For were the absorption intra-molecular, the passage from the liquid to the vaporous condition, which leaves the molecules intact, could not abolish the absorption. So far back as 1864 the lecturer had proved that when vapours, in quantities proportional to the densities of their liquids, were examined in the experimental tube, the order of their absorptions was precisely that of the liquids from which they were derived. This result has been recently tested and verified in the most ample manner by means of the apparatus in which internal reflection never comes into play. It furnishes, therefore, the strongest presumptive evidence that the seat of absorption in liquids and in vapours is the same.

As a problem of molecular physics it was, however, in the highest degree desirable to compare together *equal* quantities, instead of proportional quantities, of liquids and vapours. Highly volatile liquids alone lend themselves to this experiment, for only from such liquids can vapours be obtained sufficient, when caused to assume the liquid form, to produce layers of practicable thickness. Two cases, however, have been very fully worked out, the substances employed being the hydride of amyl and sulphuric ether. Careful and exact experiments, many times repeated, lead to the result that when the number of molecules traversed by the calorific rays in the vapour is the same as that traversed in the liquid, the absorptions are identical. In the silvered experimental tube, which, as stated, is 38 inches long, hydride of amyl vapour, at a mercury pressure of 6·6 inches, is equivalent to a liquid layer 1 millim. in thickness, while a vapour column of sulphuric ether, of the same length, and 7·2 inches pressure, would also produce a liquid layer 1 millim. thick. The experiment has been made with the utmost care, both with the lime-light and the incandescent platinum, with the result that it is impossible to say that there is any difference between the vapour absorption and the liquid absorption. In the face of such facts the "vapour-hesion" hypothesis, as an explanation of the results published by the lecturer, cannot be sustained.

On the 29th of November, 1880, he had the pleasure of witnessing, in the laboratory of the Royal Institution, the experiments of Mr. Graham Bell, wherein a concentrated luminous beam, rendered intermittent by a rotating perforated disk, was caused to impinge upon

various solid substances, and to produce musical sounds. Mr. Bell's previous experiments upon selenium naturally led him to conclude that the effect was produced by the luminous rays of the spectrum. The contemplation of these experiments produced in the lecturer the conviction that the results were due to the intermittent absorption of radiant heat. He was experimenting on vapours at this time. Substituting in idea gaseous for solid matter, he clearly pictured the sudden expansion of an absorbent gas or vapour at every stroke of the calorific beam, and its contraction when the beam was intercepted. Pulses far stronger than those obtainable from solid matter would probably be thus produced, which, when rapid enough, would generate musical sounds. The intensity of the sound would, of course, be determined by the absorptive power of the gas or vapour.

This idea was tested on the spot. Placing sulphuric ether in a test-tube, and connecting the tube with the ear, the intermittent beam was caused to fall upon the vapour above the liquid. A feeble musical sound was distinctly heard. Formic ether was tried in the same way, and with the same result. Bisulphide of carbon was then tried, but the vapour of this liquid proved incompetent to generate a musical sound. These results, which were in perfect accordance with those previously enunciated by the lecturer, were first made public during a discussion at the Society of Telegraph Engineers on the 8th of December, 1880.*

It was obvious, however, that the arrangement of Mr. Bell—a truly beautiful one—was not suited to bring out the maximum effect. He had employed a series of lenses to concentrate his beam, and these, however pure, would, in the case of transparent gases, absorb a large portion of the rays most influential in producing the sound. The lecturer, therefore, resorted to lenses of rock-salt and to concave mirrors silvered in front. He employed various sources of heat, including that of the electric lamp. The lime-light he found very convenient. With the lime-light and concave mirror, sounds of surprising intensity were produced by all the highly absorbent gases and vapours. Among gases chloride of methyl was loudest. Conveyed directly to the ear by a tube of india-rubber, the sound of this gas seemed as loud as the peal of an organ. Abandoning the ear-tube, and choosing a suitable recipient for the gas, the sounds were heard at a distance of 20 feet from their origin. As regards intensity, the order of the sounds, in gases, corresponds exactly with the order of their absorptions of radiant heat.

Among vapours sulphuric ether stands highest, this result being in part due to the great volatility of the liquid. But the intensity of the sound is by no means wholly dependent on volatility. The specific

* "Journal of Telegraph Engineers," vol. 9, p. 382.

action of the molecules on radiant heat is as clearly shown in these experiments as in those previously conducted with the experimental tube and thermopile. Upwards of eighty vapours have been tested in regard to their sound-producing power.

With regard to aqueous vapour, whose action upon radiant heat even the latest publications on this subject describe as *nil*, it was especially interesting to be able to question the vapour itself as to its absorbent power, and to receive from it an answer which did not admit of doubt. A number of bulbs about an inch in diameter were placed under the receiver of an air-pump, with a vessel containing sulphuric acid beside them. When thoroughly dry they were exposed to an intermittent beam. The well-dried air within the bulbs proved silent, while the slightest admixture of humid air sufficed to endow it with sounding power. Placing a little water in a thin glass bulb, and heating it nearly to its boiling point, the sounds produced by the developed vapour are exceedingly loud. The bulbs employed in these experiments are usually about a cubic inch in volume. They may, however, be reduced to one-fiftieth or even one one-hundredth of a cubic inch. When a minute drop of water is vaporised within such little bulbs, on their exposure to the intermittent beam loud musical sounds are produced.

It is to be borne in mind, that the heat employed in these experiments, coming as it did from a highly luminous source, was absorbed in a far smaller degree than would be the heat from bodies under the temperature of incandescence.

To render the correlation of sound-producing power and adiathermancy complete, all the gases and vapours which had been exposed to the intermittent beam were examined as to the augmentation of their elastic force through the absorption of radiant heat. A glass cylinder, 4 inches long and 3 inches in diameter, had its ends closed with transparent plates of rock-salt. Connected with this cylinder was a narrow U-tube, containing a coloured liquid which stood at the same level in the two arms of the U. The cylinder could be exhausted at pleasure or filled with a gas or vapour. When filled, the sudden removal of a double silvered screen permitted the beam from the lime-light to pass through it, the augmentation of elastic force being immediately declared by the depression of the liquid in one of the arms of the U-tube and its elevation in the other. The difference of level in the two arms gave, in terms of water-pressure, a measure of the heat absorbed. With the stronger vapours it would be easy with this instrument to produce an augmentation of elastic force corresponding to a water-pressure of a thousand millimetres. As might be expected, the intensity of the sounds corresponded with the energy of the absorption, varying from "exceedingly strong," "very strong," "strong," "moderate," "weak," to

"inaudible." In this connexion reference was made to the interesting experiments of Professor Röntgen, an independent and successful worker in this field.

In conclusion, the lecture draws attention to the bearing of its results upon the phenomena of meteorology. The views of Magnus regarding the part played by mist or haze, are referred to and attention is directed to various observations by Wells which are in opposition to these views. The observations of Wilson, Six, Leslie, Denham, Hooker, Livingstone, Mitchell, Strachey, and others are referred to and connected with the action of aqueous vapour upon solar and terrestrial radiation. Many years ago the lecturer sought to imitate the action of aqueous vapour on the solar rays by sending a beam from the electric light through a layer of water, and afterwards examining its spectrum. The curve representing the distribution of heat resembled that obtained from the spectrum of the sun, the invisible calorific radiation being reduced by the water from nearly eight times to about twice the visible. Could we get above the screen of atmospheric vapour, a large amount of the ultra-red rays would assuredly be restored to the solar spectrum. This conclusion has been recently established on the grandest scale by Professor Langley, who on the 10th of September wrote to the lecturer from an elevation of 12,000 feet on Mount Whitney, "where the air is perhaps drier than at any other equal altitude ever used for scientific investigation." An extract from Professor Langley's letter will fitly close this summary:—"You may," he says, "be interested in knowing that the result indicates a great difference in the *distribution* of the solar energy here from that to which we are accustomed in regions of ordinary humidity, and that while the evidence of the effect of water vapour on the more refrangible rays is feeble, there is, on the other hand, a systematic effect, due to its absence, which shows, by contrast, its power on the red and ultra-red in a striking light. These experiments also indicate an enormous extension of the ultra-red rays beyond the point to which they have been followed below, and being made on a scale different from that of the laboratory—on one indeed as grand as nature can furnish—and by means wholly independent of those usually applied to the research, must, I think, when published, put an end to any doubt as to the accuracy of the statements so long since made by you, as to the absorbent power of water-vapour over the greater part of the spectrum, and as to its predominant importance in modifying to us the solar energy."