ON SPECTRUM PHOTOGRAPHY*

THOSE of you who know best how the Society of Arts always places itself in the forefront of any movement which is likely to benefit mankind by the application of the various sciences to the practical affairs of life, may recollect that, as nearly as may be thirty years ago, the dawn of a new science was brought before an audience in this room. If I look, no longer to the Journal, but to the "Transactions," of the Society of Arts, Manufactures, and Commerce, as far back as the year 1843,† I find a paper there by the late Mr. Claudet, who then gave an account of the progress which had been made up to that time in an art and a science which is now pefectly familiar to all of you; I refer to photography. It is exceedingly curious that his lecture on the origin of this science, and my present lecture on the application of photography to spectrum analysis are complementary to each other, so much so that one may almost say that Mr. Claudet's lecture, admirable though it was, was incomplete, because he did not show in it, as of course he could not, how certain matters which he referred to in that lecture have been dealt with in the light of modern science.

If you carry yourselves back to the year 1839, some four years before the lecture to which I refer was delivered, you will recollect Mr. Nièpce had at that time brought photography to a more practical realisation than it had been by any of his predecessors. He had then for some years allied himself with Daguerre, and the daguerrotype was already in existence. The action of iodine on silver, first discovered by Fox Talbot, had been fixed by the vapour of mercury.‡ Now, in the daguerrotype we had not the action of light in its ordinary sense; and men's minds were very much exercised as to what could be the real cause of the effects which were then being revealed. Mr. Claudet, in his lecture, points this out in a most admirable way, and I will summarise, if you will allow me, some of the principal points to which he alludes. You had a beam of light falling on a plate. On this plate was a certain chemical compound. What part of the sunlight, or was it sunlight at all, which so acted upon this compound, that you got an image more or less permanent? What more natural than that this question should be investigated by means of various tinted glasses? The solar beam which the experimenters then used they made to pass through glass, now of one colour, and now of another. I can show you, by means of this electric lamp, nearly what they did. Imagine the lamp to be the sun; in the path of the beam differently coloured glasses are placed. We have now the action of a red glass; we now change the red glass for another one, and now we have the action of a green glass. There was an immense deal of difference of opinion concerning the action of light as investigated in this way. In fact, I shall have shortly to show that Mr. Claudet and a very distinguished French physicist, M. Becquerel, were considerably at variance with regard to one particular point which came out from this kind of investigation. But we had not long to wait. Sir J. Herschel, in the year 1839, pointed out that it was not a question of investigating these new qualities of light at all by means of coloured glasses; they should be investigated by means of the spectrum. In three papers, communicated to the Royal Society in the years 1839, 1840, and 1842, he showed that the only philosophic way of investigating this problem was really by obtaining a pure spectrum, such a one as I now throw upon the screen. You see that we have, at once, in different parts of this spectrum, exactly what we get at different times when we deal with red glass, yellow glass, orange glass, green glass, blue glass, and so on. And having such a spectrum as this to deal with, and supposing such a spectrum thrown on to the photographic plate, it is quite clear to all of you that if there were something magical or unknown in the red rays which gave us this new action on the molecules of the particular chemical compound employed, or whether this magic really resided in the blue rays, that we should at once have this pointed out to us in the most unmistakeable manner, by action in the part of the plate on which the red rays fell, or in the part of the plate on which the blue rays fell.

Now, although Sir John Herschel was the first, in this country, to point out the extreme importance of this point of view, he was by no means the only one. Then, as now, there were distinguished Americans who were well to the front, and among them was Dr. Draper, the father of another Dr. Draper whom I shall have to speak of by and by. Those of you who are familiar with the enormous step in advance which was taken in spectroscopic investigations by Wollaston, who substituted a slit for a round hole, will perhaps be somewhat surprised to find that the first observations were conducted by throwing a converging beam of sunlight, giving an achromatic image of the sun, on the plate, through a prism. This method of procedure of course did not go so far as a better one might have gone, but it went a considerable way. Sir J. Herschel, from his observations made in this manner, stated that he had found a new kind of light—a new prismatic colour, "lavender grey," altogether beyond the blue end of the spectrum, such as you have seen it on the screen—altogether beyond the *blue* end of the spectrum, not the *red* end. Prof. Draper, on his part, also came in the main to the same conclusion, stating that he had discovered a "latent light."

When we have come from the year 1839 to the years 1842 and 1843, we find a great advance—an advance, just the same as far as photography goes, as Wollaston's advance on Newton was with regard to spectroscopic observation. Both Becquerel and Draper introduced, instead of this achromatic image of the sun, the simple arrangement of throwing sunlight through a slit and a proper combination of lenses on to a plate. The result was that on June 13, 1842, Becquerel did what I may venture to call a stupendous feat.* He did what has never been done since, so far as I know. He photographed the whole solar spectrum wi h nearly all the lines registered by

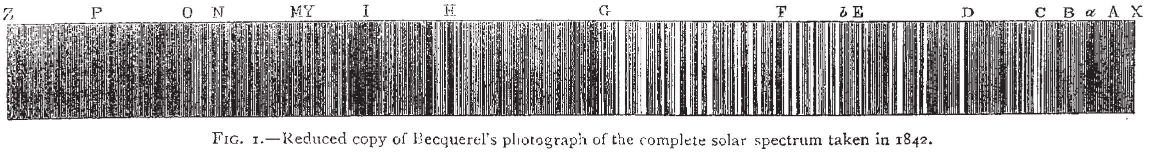


FIG. 1.—Reduced copy of Becquerel's photograph of the complete solar spectrum taken in 1842.

the hand and eye of Fraunhofer. I do not mean merely the blue end of the spectrum, as you may imagine, but the complete spectrum, from the "latent light"—the ultra-violet rays of Draper—to the extreme red end. Draper also did something like the same thing, but not quite the same thing, in what he calls a "tithonographic representation" of the solar spectrum. He gives certain lines in the extreme visible blue part of the spectrum,§ certain other lines, which none but Becquerel had ever seen before (Draper's work being done nearly a year later), and in the extreme red—beyond the visible red of the spectrum—he gives other lines which even Becquerel had not photographed. This of course was such a tremendous revelation to both these men that as you can imagine a considerable discussion arose. Becquerel found, from an absolute comparison between the Fraunhofer lines which he had photographed and the Fraunhofer lines which Fraunhofer himself had registered, evidence in favour of the fact that this new chemical agent which was astonishing the world, whatever it was, was not something absolutely and completely independent of the visible rays. Draper, on the other hand, in his "tithonographic representation," had, for some photographic reason or other, not succeeded in registering the lines in the yellow, orange, and green part of the spectrum, although he had fixed the lines in the blue, in the extreme violet, and in the extreme red; and he considered himself justified by his experiments in coming to exactly the opposite conclusion to that at which Becquerel had arrived, namely, that the light, whatever kind of light it might be, which was at work in effecting this chemical change which rendered photography possible, was something absolutely and completely independent of the ordinary light which the retina receives.

This was in the year 1843. I need not tell you that by the year 1845, in which year Mr. Claudet read another paper before this Society, further investigations by means of the spectrum had

* A Cantor Lecture delivered at the Society of Arts, Nov. 24, 1873, by J. Norman Lockyer, F.R.S.
† Vol. lv. p. 89.
‡ Fox Talbot, *Philosophical Magazine*, vol xxii. p, 97.
§ *Philosophical Magazine*, vol. xxii. p. 360, 1843. For his earliest work see Journal of the Franklin Institute for the year 1837.

* "Bibliothèque universelle de Genève," t xxxix.-xl., 1842, p. 341.]

shown that Dr. Draper's idea was heretical, and at the present moment you know it is the general opinion of physicists, an opinion founded upon the work which has been done to advance photography, and other researches since that time, that the radiations which you get from any light source, from the extreme violet to the extreme red, differ only in the rate and in the magnitude of the vibrations which are at work, so that I claim for the application of photography to spectroscopy, as a first result, the establishment of a great fact, that the visible, the chemical, and the heat rays are really part and parcel of the same thing, that thing being a system of undulations varying in rate and wave-length from one end of the spectrum to the other, whether you consider the visible portion or the invisible rays—those outside the blue in one case, and outside the red in the other. But this is not all: I claim another thing for the application of photography to spectroscopy. Sir J. Herschel, so soon as he applied the prism, stated, in a communication to the Royal Society, that it was no longer possible to proceed with that branch of research under the best possible conditions, unless opticians would construct lenses which would bring the visible and the chemical rays into absolute coincidence. This is now done by our Rosses and Dallmeyers in the camera-lenses, and that is the second great feature which I claim for the application of photography to spectroscopy.

The next step brings us down to the year 1852. In this year a paper † was communicated to the Royal Society, by Prof. Stokes, who had already announced his discovery of what has since been called "fluorescence;" "on the long spectrum of the electric light." Prof. Stokes dealt in his first paper with the "change of refrangibility," or, as Sir William Thomson proposed to call it, "degradation of light," by virtue of which, light, which was generally invisible to us, could, under certain circumstances, be made visible. It is no part of my present purpose to go into this magnificent paper, one of the crowning glories of the work of this century, at any great length; but you will see in a moment that, if it were a question of the *degradation* of light, then the invisible light to which Prof. Stokes referred as being capable of being rendered visible, must have been light outside the blue end of the spectrum, and not outside the red. Prof. Stokes, in his investigations, in order to get at this invisible light under better conditions, if possible, than those with which he commenced operations, tested the transparency of the substances through which the light with which he experimented passed, and the transparency of glass was passed under review by him,* when he found that this invisible light, or whatever it was, could only get through glass with extreme difficulty. Continuing his investigations, he found that quartz on the other hand allowed this invisible light to pass. If you will allow me, I will read an extract from Prof. Stokes's paper of the extremest importance to our subject. After referring to these experiments on glass and quartz, he proceeds to say:†—"I have little doubt that the solar spectrum" (which you recollect had already been photographed to a certain extent both by Becquerel and Draper beyond the visible blue end of the spectrum), "would be prolonged, though to what extent I am unable to say, by using a complete optical train, in every member of which glass was replaced by quartz." He then adds that other substances which suggested themselves to him were not equally good. Then further, that if this invisible light does get through quartz, and does become visible to the eye, it does not at all follow that it will be capable of being photographed. Because already Prof. Stokes, in order to continue his researches in fluorescence, had been, as it were, driven to photograph some of the results which he had thus obtained. I am sorry to say that, so far as I can find out, none of those photographs have ever been published.

Before I go further, I think it will be convenient to throw on the screen some photographs of the solar spectrum, showing exactly what I mean by the "invisible rays;" and you will then see the enormous advance which Prof. Stokes made the moment he introduced his quartz train, and enabled both the eye and the photographer to take advantage of a new region of the spectrum in its entirety, in order to investigate it.

In a note to his paper communicated to the Royal Society, he shows that his anticipations, so far as the eye was concerned, were perfectly justified by the facts. ‡ He says:—"I have since ordered a complete train of quartz, of which a considerable portion, comprising, among other things, two very fine prisms, has been already executed for me by Mr. Darker; with these I have seen the lines of the solar spectrum to a distance beyond H, more than double that of *p*. So that the length of the spectrum, reckoned from H (the outside line in the portion originally visible), was more than double the length of the part previously known from photographic impressions." I will now throw on the screen the spectrum of the extreme part of the visible portion. The eye

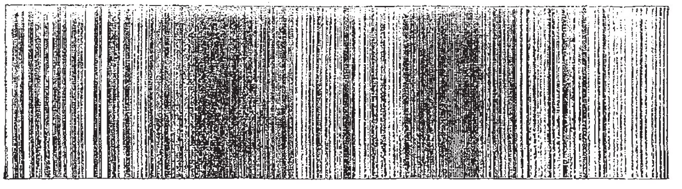


Fig. 2.—The H-lines in the blue end of the solar spectrum, from a photograph by the author.

generally can see the two dark bands which you see in the middle of the screen called H 1 and H 2. The least refrangible part of the spectrum lies to the right. When Prof. Stokes, therefore, stated that the solar spectrum was prolonged, he means that the part of the spectrum visible either to the unassisted eye or on a photographic plate after impression extends to a certain distance beyond these two dark lines. The part which Prof. Stokes rendered visible by means of his quartz train extended a considerable distance to the left beyond the part of the spectrum which you now see on the screen.

So much for the solar spectrum. Now let me carry you on another ten years, to the year 1862. Prof. Stokes, in a paper communicated to the Royal Society in this year,† refers to his former paper, and to what he had been enabled to do by means of it. He states: "A map of the new lines [the lines thus observed by him] was exhibited at an evening lecture before the British Association, at their meeting in Belfast in the autumn of the same year, and I then stated that I conceived we had obtained evidence that the limit of the solar spectrum in the more refrangible direction had been reached. In fact, the very same arrangement which revealed, by means of fluorescence, the existence of what were evidently rays of higher refrangibility coming from the electric spark, failed to show anything of the kind when applied to the solar spectrum;" and then he goes on to say that, in making observations by means of the electric spark, he had found that in the case of a spark taken between the poles of an induction coil like this on the table, or between the poles of an electric lamp such as you see there, that the visible spectrum which was revealed and rendered visible to him by means of fluorescence was no less than six or eight times longer than the whole of the visible part of the spectrum. That you see, was a revelation of the first order. He was so astonished at this, that he at first thought there was some mistake. "I could not help suspecting that it was a mistake, arising from the reflection of stray light." In fact, so astonished was he, so many methods did he try in order to break down the impossibility, if it existed, that he adds, in a subsequent part of the paper, "I tried different methods, without being able to satisfy myself as to the accuracy of the observations, and frequently thought of resorting to photography."

Prof. Stokes thought of resorting to photography, but at the moment that Prof. Stokes was thinking of this, Dr. Miller, of King's College (unknown to Prof. Stokes), was not only thinking of resorting to photography, but had actually resorted to it, and was taking photographs of the so-called invisible part of the spectrum, in which the spectrum in the case of some substances was

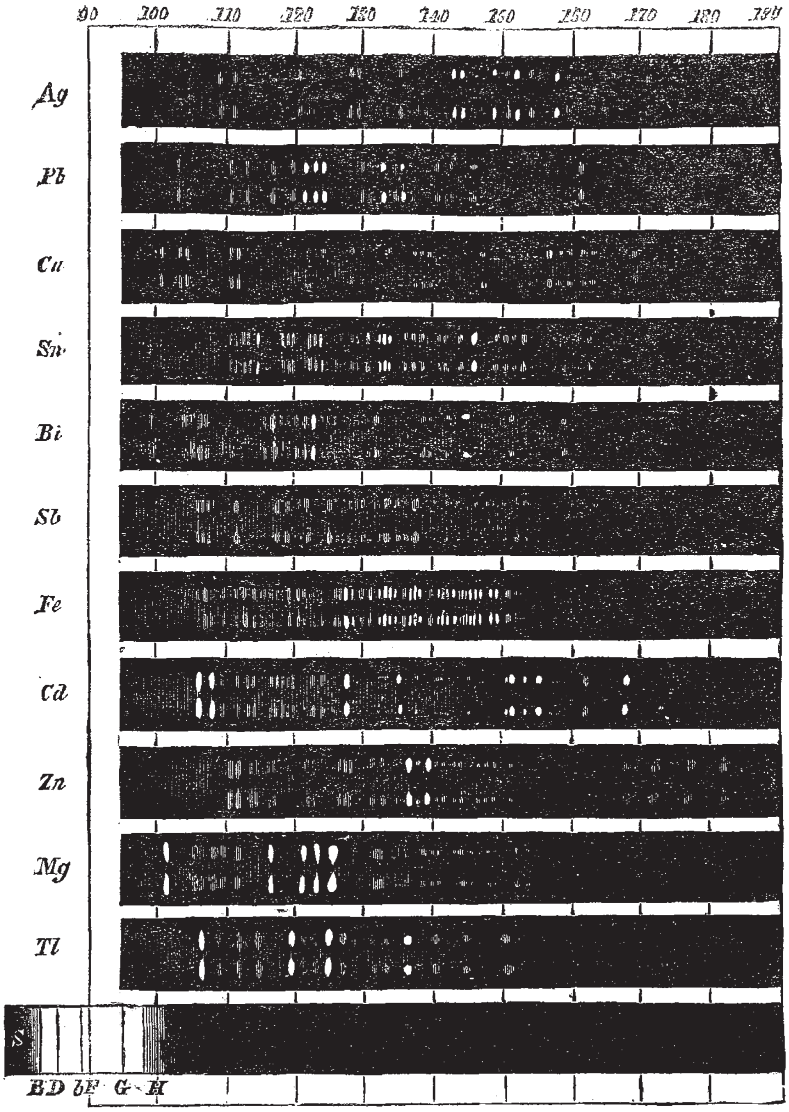
* *Philosophical Transactions*, vol. clxii., 1852.
† On the long spectrum of the electric light. Phil. Trans., vol. clii. p. 599.

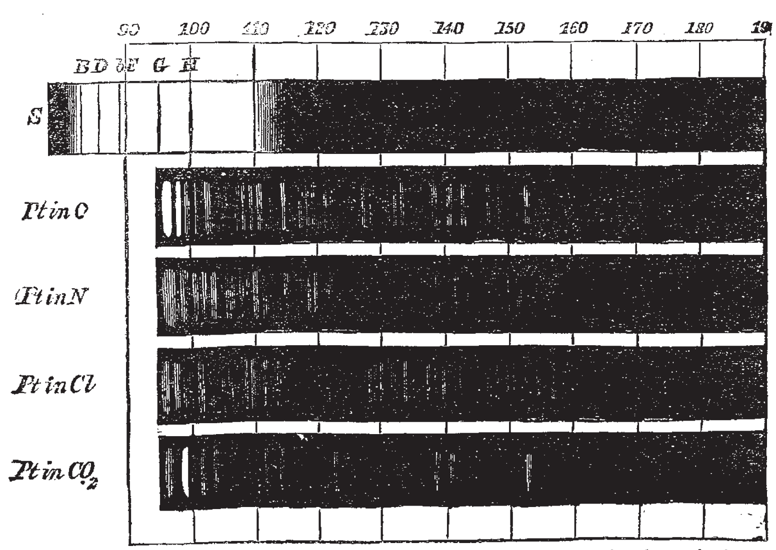
* Op. cit. Art. 202. † Art. 204. ‡ Page 559.

five or six times, and in the case of silver one might say almost seven times, as long as the spectrum ordinarily visible through glass prisms. Prof. Miller goes very nearly over the same ground that Prof. Stokes had done before him. He also investigated the transparency of quartz, and comes to the conclusion that quartz is almost the only substance that can be employed. Prof. Miller, in this paper, which you will find in the *Philosophical Transactions*,* also gives for the first time a detailed account of the way in which such work is done. Permit me to give you a rough notion of this method of work. We have here a spark from an induction coil, exactly such a spark as Dr. Miller wished to examine. He had a spectroscope something like this on the table, with two important differences. The first important difference was that instead of having two glass prisms he had prisms of quartz; and again, instead of having an observing telescope adapted for use by the eye, he inserted a camera, or what was to all intents and purposes a camera, in the same place. So that he had, first of all, a light source by which you get an intense illumination, due, as is generally imagined, to the extremely high temperature of the spark. Then you have a quartz lens, and quartz prisms, and then simply the photographic plate. Having therefore an entire absence of the non-transparency of glass, Prof. Miller was delighted to find that, on taking this spark in this way, between electrodes of different substances, he not only photographed what could be seen, namely, a spectrum ranging from red to blue, but one extending as a rule six times the length of the visible spectrum beyond the blue; although, in some cases, it is true it is only four times as long on the more refrangible side of H, as H is from the red end of the spectrum, that is to say the line which is generally called A. In this paper of Dr. Miller's we have the germ of all the applications of photography to spectroscopic inquiry which have been carried on since; and I am sorry to say that altogether too little has been carried on. Not only did Dr. Miller investigate in this way the radiation of different vapours, and give photographs for the first time of the bright lines of a very large number of chemical substances, but he went further than this, and dealt with the absorption of different substances.

He commences his paper with the absorption of chemical rays by transmission through different media,—through solids (transparent, of course), through liquids, and through gases and vapours, the only alteration he made in his general mode of experimentation being that in the case of the absorption of gases and vapours he placed the instrument farther from the light source, and in the path of the ray inserted a tube containing the gas or vapour to be experimented with, as I am doing now, so that the light which passed from the spark to the telescope was compelled to traverse a thickness of vapour according to the length of the tube employed. In that way he not only determined the absorption of equal lengths of different vapours amongst themselves, but the absorption of different lengths of the same vapour; his paper is thus one of the most important contributions to spectroscopic knowledge that I am acquainted with, and I hold that the chief importance of it is the application of

* Vol. cit. p. 801.





FIGS. and 4*.—Copies of Dr. Miller's maps of the ultra-violet spectrum of the chemical element showing the length of the visible and ultra-violet spectrum.

* These have been obligingly placed at my disposal by Messrs. Longmans.—J. N. L.

photography to spectroscopic observations. There are few things so difficult, I think, as to make a proper spectroscopic observation, while from the little experience I have had at present I should think there is nothing more easy than to produce passable spectroscopic photographs.

That, then, was in the year 1862. In the year 1863 we have another equally distinct advance to chronicle, but this time the work is done in France. M. Mascart—a name very well known to physicists—undertook a tremendous work, which he has not yet completed, namely, a complete investigation of the ultra violet solar spectrum.* Instead of using a quartz prism, as Dr. Miller had done before him, M. Mascart uses a diffraction

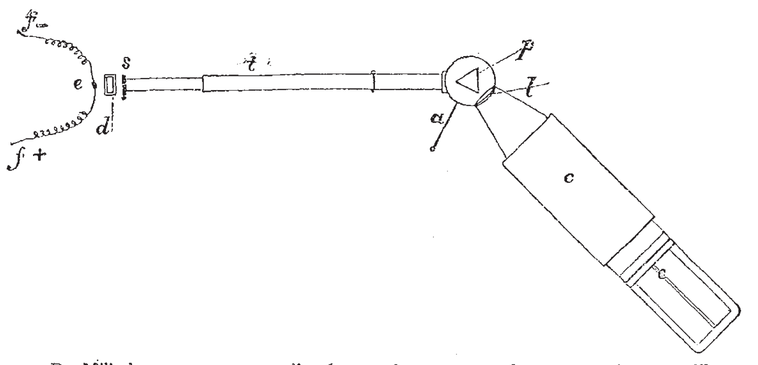


FIG. 5.—Dr. Miller's arrangements,—*s*, slit; *l*, quartz lens; *c*, camera; *p*, quartz prism; *t*, collimator.

grating, that is to say an instrument by means of which the light is not refracted, as in the case of the prism, but diffracted by an effect of interference of fine lines ruled on glass. M. Mascart has shown it to be possible, by means of reflecting light from the first surface of the diffraction gratings, to get light diffracted without its going through the glass at all. In this way, therefore, you avoid altogether the imperfect transparency of the glass. Prof. Mascart has gone on advancing every year, until now he has completed a photographic map, not only of the solar spectrum extending about as far as the line R., by means of photography, but he has been able to observe as far as the line called T. There he finds the solar spectrum ends; but in the

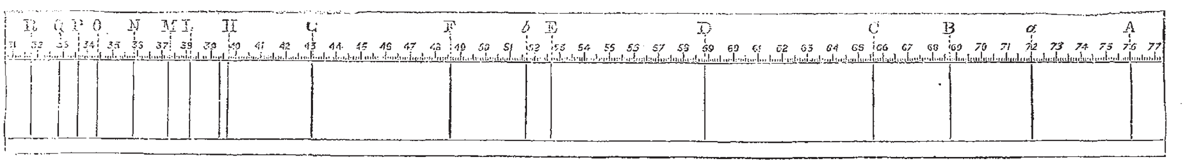


FIG. 6.—Wave-length solar spectrum showing the lines (from L to R) the positions of which have been determined by Mascart, and showing also how short the ultra-violet spectrum of the sun is as compared with that of the chemical elements.

case of a great many vapours, such, for instance, as that of cadmium and other metals of the same nature, he finds he can go on photographing very much farther, and has been able to photograph almost as far as the eye can see, that is to say, to a distance, as I have already told you, five or six, or even seven times as far from the line H as H is from A. So that you see, thanks to photography, we can now photograph six times more of the spectrum than we can see of it with the eye ordinarily.

J. NORMAN LOCKYER

(*To be continued.*)

THE CENTRAL PARK OF NEW YORK AND MR. WATERHOUSE HAWKINS

SOME time ago (NATURE, vol. vi. p. 70) we copied from the *American Naturalist* an account of the destruction "by order of Mr. Henry Hilton" of Mr. Waterhouse Hawkins' restorations of *Hadrosaurus* and other extinct animals, in the Central Park of New York. We have lately received some further correspondence on this subject, from which it appears that in April last Mr. Hawkins addressed to the Board of Commissioners of the Central Park a memorial, setting forth the manner in which he had been treated, and claiming compensation for his losses. It is not very easy to understand the origin of the affair, which appears to have occurred through some change in the government of the city of New York, produced by the notorious "Ring." But it is quite evident that Mr. Hawkins has the sentiments of all the leading scientific men of the United States in his favour.

Prof. Henry, of the Smithsonian Institution, speaks of the destruction of Mr. Hawkins' models as a "disgrace to the country, which nothing can wipe out, save a renewal of the work on a more liberal scale." Prof. Newbury, and other *savants*, write in a similar strain. There can therefore, we suppose, be no doubt that Mr. Hawkins will ultimately receive ample compensation for the treatment which he has received from Mr. Hilton and his subordinates.

EUCALYPTUS GLOBULUS IN MAURITIUS

THE subject of the introduction of the Eucalyptus as a sanitary agency in fever-stricken countries has of late been so much talked about that some authoritative preliminary inquiries have been made with the view of planting *Eucalyptus globulus* on a large scale in the Mauritius. From these inquiries, directed chiefly as to the possible success of the plant in the island, it appears that it does not thrive in any part, and still less in the warmer parts. The tree, moreover, is unsuited to resist the violent winds or hurricanes with which the Mauritius is so frequently visited. In 1865 twelve plants were planted in the Botanic Gardens at Pampelmousses, and though they were secured to strong stakes, eleven of them were destroyed in the hurricane of 1868; the remaining one also was blown over, but met with some support by falling into the branches of another tree, where it still remains.

Though it appears at one time thousands of young plants were planted in the lower parts of the island very few at the present time exist; there are, however, several

* "Annales scientifiques de l'Ecole normale Supérieure." Vol. for 1864, p. 219.