

SOLAR PHYSICS<sup>1</sup>

I.

I HAVE to address you in this course of lectures on what we know of the infra-red end of the spectrum and its relation to solar physics. I will commence by asking a question, and endeavour to answer it in such a way as will, I hope, be understood. The question I propound is, How do we know that there are any rays below the red rays of the spectrum? In answering the question I would beg you to remember that every body in motion possesses what we call energy, or a capacity for doing work, be the motion a wave motion or a direct motion. Let us take one or two examples of waves: first, that of water, which is familiar to us. I need scarcely point out that a wave of the sea is capable of doing an immense amount of work, not to say mischief; there is no doubt, then, that it is capable of doing work, and this we may take as the true definition of energy, existing in a body, viz. the capacity of doing work. Whence, then, does a wave derive its energy? Perhaps we may have to travel many miles from the place where we find our wave. Travelling to the origin of the waves, we shall no doubt find that a wind has generated them, and in reality it is the energy possessed by the wind which is carried by the waves to the distant shore. The energy possessed by the wind has not been directly expended on our coast, but when transmitted by the waves this same energy is applied in different manner, and by this difference in application it becomes effective. We all know, for instance, that a child may ring a church bell if he give a pull at the right intervals of time, and so, by timing the impact of waves correctly, it is possible for them to do work which in any other way would be impossible. Another example of the energy of waves is the tuning-fork, as in the experiment which Mr. Lockyer showed you. You will recollect that he demonstrated that if one tuning-fork was brought near another of the same pitch the second took up the vibration of the air. The tuning-fork which was struck, or bowed, generated waves in the air carrying some part of the energy of the vibrating prongs to be expended on the second tuning-fork, and as this tuning-fork vibrated in the same period as the first one, each blow of the air-waves was essentially well-timed, and the fork was thus set in motion. You will also recollect that a fork not of the same pitch—that is, not sounding the same note—was unable to cause vibration in the second fork; and this was simply because the energy was applied at wrong intervals of time. In the case of the tuning-fork, then, the air is the medium through which this energy was conveyed.

With light we have the same kind of motion in the luminiferous ether: the motions of the molecules swinging in the source of light may, for the sake of illustration, be looked upon as composed of an infinite number of tuning-forks, the ether, instead of the air, carrying their energy in all directions. How can the energy in the ether show itself? In the first place it must meet with some obstruction, and secondly that obstruction must be capable of vibrating with it, and thus damp or destroy the waves. The destruction of the wave motion in the ether is known as the absorption, and thus we see that where there is absorption there work of some kind must be done. The work, then, that light can perform is this. [When I say light, I say it with a definite object. It has been said that it is nonsense to talk about dark light; but it is no more nonsense to talk about dark light than to talk of a white violet, a yellow rose, and so on. Therefore, I prefer to call the whole ether vibrations with which we are acquainted, light, until we get a more authoritative definition.] The work that light may perform then is this, it may cause certain appliances in our eye to vibrate (and perhaps also cause chemical decomposition on the colouring matter of some membrane which is placed near the retina), which gives us the sensation of vision. Secondly, it may cause the molecules of the material body on which it falls to vibrate more freely than they do when in a normal state of vibration, and thus raise the temperature of the body. (It must be recollected that physicists suppose the molecules of all matters to be in active vibration, and a rise of temperature simply means an increase of those molecular motions). In the third place it may cause the atoms which compose the molecules to vibrate more energetically than they do under ordinary circumstances, and cause one or more of the atoms to swing off, as it were, and thus create a new molecule; in other words, cause a dissociation of the molecule. We may sum up our definition by saying that the presence of light can be known

<sup>1</sup> Lecture delivered on May 25, 1881, at the Lecture Theatre, South Kensington Museum, by Capt. Abney, R.E., F.R.S.

by three distinct kinds of work. It may be known by its causing the sensation of vision; it may be known by a rise in temperature of the body on which it falls; and it may be also known by the chemical action which it induces. I think, then, we have an answer to the question which I propounded, How can we tell that there are rays which exist below the visible red of the spectrum? If they exist, they must be shown by a rise in the temperature of any body which may absorb those rays when placed in their path, or by their chemical effect. That they do not give rise to the sensation of vision I need scarcely say.

The dark rays were discovered in the years 1800 and 1801 by Sir William Herschel, who was investigating the solar surface with a telescope. Finding that the heat sent to the eye was unbearable, he wished to obtain some medium to cut off those particular rays which gave the heating effect. In order to do that he undertook a series of investigations of the spectrum, in what we should now call perhaps a rough kind of way, in a manner which I will show you on the screen. A beam of light was passed through a prism fixed horizontally against a slit in a wall, being bent so that the spectrum fell upon a table beneath, on which he ruled lines marking the boundaries of the colours. On a sloping board turning on castors he placed three thermometers in a line, two of which he caused to lie within the spectrum, the third remaining outside it. He then noted the height of the mercury in all three of the thermometers, and thus compared the two in the spectrum with that lying beyond it (I may say that the diameters of the bulbs of the two thermometers in the spectrum, which is rather an important point, were one-eighth of an inch and half an inch respectively). Not only did Sir William Herschel use thermometers, but he also used the principle of absorption to increase their indications, for he blackened those thermometers with China black. He found he got a greater effect by using lampblack than by using the bare bulbs of the thermometers. He commenced by placing his two thermometers in the violet, and he found he got a certain rise of mercury. Having made a scale in accordance with the ruled lines on his table, he set up at the point indicating the violet an ordinate also to scale, showing the number of degrees of rise in the thermometer at that particular point. Then in the indigo he set up another ordinate indicating the degrees of rise there, and so on at all these different points; so that he was able to construct, as it were, a mountain of the heat effect due to the spectrum in all parts (Fig. 1). Having gone in this way over the

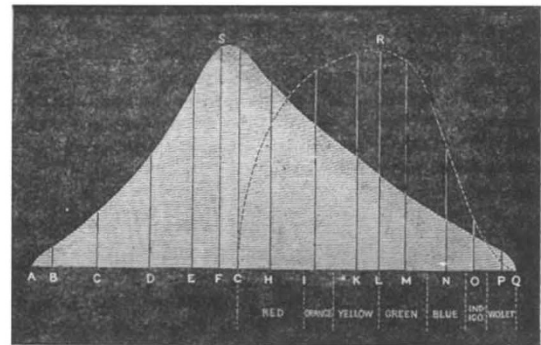


FIG. 1.

whole of the visible solar spectrum, he found there was a rise in the two thermometers, as he approached the red from the violet. (It must be recollected that before his time there was no knowledge of any rays which existed below the red). He therefore ruled lines on his table beyond the red, and having reached the limit of the luminous spectrum, he shifted his thermometers beyond, and found that they rose even higher than in the red. This led him to continue the experiment, and he found by going a long way beyond the red he still got a slight trace of rise in the mercury of his thermometers. By this means he was able to construct his well-known curve (which answers to a curve of energy) in the very simple manner shown in Fig. 1. I shall have to refer to this curve in another lecture, and I want you to fully bear in mind that the heights of every part of this curve answered to a comparative measure of the energy of the particular parts of the spectrum—

in other words, to the comparative heating effect of different parts of the solar spectrum. Thus you see that Sir William Herschel, by the use of thermometers, was able to discover that there were rays existing below the red, and this he did by the second method, viz. by noting the rise of temperature in the absorbent body, lampblack, placed in the path of the rays. There are other modes of showing a rise in temperature in lampblack, amongst others by the thermopile, and to that I shall have to refer more at length in a subsequent lecture, and therefore I pass on at once to the chemical effect of the different rays of the spectrum.

In order to show you how we can arrive at a knowledge of the existence of energy in the different parts of the spectrum by their doing chemical work, I must take you through one or two very simple experiments, experiments which I dare say you may have heard of before, but the sight of which perhaps may impress your minds more than if you merely read of them. The first experiment will show the effect upon chloride of silver. I have in this frame a piece of paper impregnated with chloride of silver, and behind this screen, which I have had erected to save your eyes, is a Siemens electric lamp, which gives out a very intense light indeed. A lens placed at a proper distance from the points will cause an image of them to fall on this paper. After a few seconds' exposure you see that where the image fell we shall have a darkening effect; in fact we have an image of the arc printed on the chloride of silver paper. Now this paper apparently to all casual observation is white; what rays of the spectrum are they then that cause this blackening effect? By and by we shall have to find out to what this blackening is due. I have here some chloride of silver in collodion, and with this I think we shall be able to see what rays they are which affect the chloride of silver. In front of the slit of this spectroscopic arrangement we place this chloride of silver, and you will remark that the image of the slit cast by the prism on yonder white wall is of a lemon colour, and that the violet of the spectrum is much subdued in intensity. The true colour of chloride of silver in that particular state in which it exists in the paper then is that which absorbs the violet, and from what has been said on the principle of work being done where absorption takes place, we should expect to find that it is the violet rays which discolour that chloride of silver, and not the yellow rays, which, as we saw, passed freely through it. We will prove that. I have here a blue glass, and we will see whether we can print through the blue glass in the same satisfactory manner that we can when the light is unshaded. Placing a yellow glass in front of the light, first you see that there is no action whatever—the paper remains perfectly white. Now, taking the blue glass, and trying to print through it, you see we have a print of the arc—not perhaps quite so deep as where the unshaded light acted on the paper, but still sufficiently so to show that the blue and violet light are effective. The proposition enunciated then in this case is correct, that the rays active in the dissociation of chloride of silver are the rays it absorbs. But we may consult the spectrum still further, and, by placing such a piece of paper directly in it, and allowing it to print, we shall find that the chloride of silver is only attacked by the blue and violet rays, and not at all by the yellow. Such, you see, is the case in the photograph before you. There is an invisible part of the spectrum beyond the violet by which the silver chloride is even more affected, but that is a region of the spectrum with which I will not trouble you, as it is beyond the scope of my lectures. It will be seen then that we have a specimen of the chemical decomposition of a solid body. Now I should like to show you what is the cause of that darkening; namely, how the chloride of silver is changed. I am obliged to use chemical symbols, because they are short, but I will try to explain them. In ordinary chemistry the chloride of silver is designated  $\text{AgCl}$ ,  $\text{Ag}$  meaning one atom of silver, and  $\text{Cl}$  meaning one atom of chlorine, which are joined together. But in order to explain phenomena which are met with in photography, silver really requires two atoms of chlorine to be combined with it to form chloride of silver; that silver is a *diad* element. This I have expressed by this symbol which I have here,  $\text{Ag}^{\prime}\text{Cl}_2$ ; that is two equivalents of chlorine are obliged to be combined with one equivalent of silver. I will give the reason why the old formula is not perfectly correct: when you have light acting on chloride of silver, work of some description is done amongst the atoms of the molecules forming it, and we have one atom of chlorine thrown off by the vibrations of the blue part of the spectrum, and the new molecule  $\text{Ag}^{\prime}\text{Cl}$  is what is formed, which will grasp any

other unsatisfied atom or molecule which may come in its way. In chloride of silver, then, we have an example of the decomposition of a solid body by the action of light. I have here two bottles, both containing ethyl iodide, a body which we will say roughly is composed of ethyl and iodine combined together; the action of light on this is to cause the iodine to separate from the ethyl, and the iodine liberated colours the liquid, as we have it in one bottle. The other bottle is ethyl iodide unaltered by light. So that you see we are obliged to shield this liquid from the light in order to prevent it from decomposing into ethyl and iodine. Here we have decomposition of a liquid by light.

I will now endeavour to show you the decomposition, or dissociation, which is perhaps a better term, of the molecules of a gas, and its combination with something else. I have here a jar of chlorine, and I think you will see by holding it in the rays of the spectrum that we have certainly the violet cut off, and a good deal of the blue. Therefore, if we find any work can take place within this chlorine it must be by those rays which are absorbed or cut off. I have here a jar of hydrogen which is perfectly colourless, and were I to put that in the spectrum I should teach you nothing, because the whole of the rays would pass through it. If then I have a mixture of hydrogen and chlorine together, and allow light to act upon them, it is quite evident that the only matter which can be acted upon is the chlorine. Now, in these small glass bulbs which are covered with yellow paper, are equal volumes of chlorine and hydrogen. When chlorine and hydrogen are combined together we have what is known as hydrochloric acid, a gas of the same tenuity as a mixture of the two. It has been found by practical experiment that if you have an intense source of light acting upon chlorine and hydrogen a combination between these two at once takes place, and we have the hydrochloric acid formed with a violent explosion—not enough to do any harm, but one which will make the room echo. Now our conception of the matter is this, that no hydrogen atom can exist by itself; that there must be two atoms to form hydrogen molecules; and that there must be at least two atoms of chlorine to form a chlorine molecule, perhaps more. Anyhow, you cannot have less than two atoms to form one molecule of chlorine, or less than two of hydrogen to form a molecule of hydrogen. If then we have these two mixed together, and cause light to act upon them, what is the physical result? The physical result is that the atoms of chlorine will swing violently apart from one another, they will be dissociated, and in their swing will catch up one of the atoms of hydrogen, and hydrochloric gas will be formed. Now you saw that the mixture of chlorine and hydrogen, or rather that the chlorine itself cut off the blue; in other words, it was the blue light which would have any chemical effect upon the mixture. I will now get Mr. Greening to allow the Siemens light to act through red glass, and you will see, I think, that there will be no effect whatever. Now, directly he takes it away there is a violent combination of the two with an explosion. To show that it is the blue light that is the effective light we will cause those two gases to explode by means of white light filtered through blue glass. I may say that the arrangement is very simple. We have the Siemens light; a lens brings the rays from that Siemens light to a focus on the centre of the bulb, and the vibration of the ether proceeding from those points causes those two molecules to combine in the way that you saw just now. We will put the blue and yellow glasses together first, and start the Siemens machine; when we draw away the yellow glass we have the same result as before.

For photographic purposes silver salts are the most convenient; if, however, we had to wait until the silver salts visibly darkened before we obtained a photograph, we should have to wait much longer than it is in the experience of all that we have to do. I will try and explain what happens when a very short exposure is given to a silver salt. For certain reasons silver chloride is not used, but we have recourse to silver iodide or silver bromide, and in some cases where both are used together a better result is obtained. What happens to these salts by a short exposure? What happens to silver chloride when acted upon by light? You will remember I told you that (with our notation for silver) after light had acted on silver chloride we had one atom of silver combined with one atom of chlorine. In the same way, if we replace the chlorine by iodine we have sub-iodide of silver formed. The visible image and the image impressed by a very short exposure are identical except in the quantity of matter altered. We will suppose, for instance, according to the modern theory that each of these molecules are charged with electricity,

with one kind of electricity. These sub-molecules, the sub-iodide and the sub-chloride, are unsaturated compounds, and are ready to join hands with any body for which they have the least affinity. Suppose then we have a solution of a silver salt, say of silver nitrate, and that we introduce some body which will precipitate that silver in a metallic state, and suppose again that one atom of silver as it is precipitated is charged with one kind of electricity, it is quite within the range of probability that the silver atom, as it is precipitated in the solution, may be attracted by the sub-iodide of silver when charged with another kind of electricity, and so form a new molecule as it were. This built-up molecule will not be fully satisfied, but probably have an excess of the opposite kind of electricity, with which the sub-iodide was charged, and the silver atoms which were oppositely charged to those first attracted would in their turn be attracted, and so on until the image is, as it were, built up on the small quantity of sub-iodide first formed by the action of light. In the case of silver bromide we have the same thing happening. We have sub-bromide of silver formed, which is represented by one atom of silver, and one of bromine,  $Ag^+Br^-$ , and it is quite within the range of possibility that another body may be brought in contact with that, which, being charged with electricity opposite in polarity to that with which this molecule is charged, may attract away, as it were, the bromine, and thus leave the metallic silver itself behind. This is what happens really in the case of what we call alkaline development. In the first case we had acid development, or an image built up by the deposition of silver from silver nitrate, and in the other abstraction of bromine from the small quantity of sub-bromide of silver which is formed by the action of light. The image so built up, however, would scarcely be apparent, since the metallic silver thus formed would be inappreciable to the eye. Another phenomenon seems, however, to present itself, and that is, that the atoms of metallic silver, and of the unaltered bromide of silver, are oppositely charged with electricity, and combine to form fresh sub-bromide of silver; these new molecules of sub-bromide are reduced, and so the action goes on till an image is built up, each molecule of sub-bromide originally formed by the action of light forming a nucleus for the reduction. If instead of forming the iodide and bromide of silver in collodion films, as is usually the case now, we form iodide and bromide of silver on a metallic silver plate by allowing iodine and bromine vapour to have access to it, and if, after exposure to light, we allowed mercury vapour to act upon it, then the same kind of action would take place, the condensed mercury vapour would be attracted to those points which had been acted upon by light. That is the earliest form of photography, and was known as daguerrotype.

I now propose to show you a practical demonstration of the two methods of development of which I have shown you the outlines by diagrams. First, I will ask you to notice the part of the spectrum which the silver iodide plate cuts off. I have placed such a plate in front of the slit of the lamp, and you will see the blue is cut off. Iodide like chloride cuts off the blue rays, but with more intensity than the chloride. Where there is absorption there alone can work be done, the blue rays are therefore most effective in altering iodide of silver. I have a photographic spectrum apparatus placed in position. We have the Siemens light as before, a collimating lens (about which I need not enter into details), a prism through which the light has to pass from the slit, and here we have a lens and an ordinary camera. I propose to place a plate coated with silver iodide in the spectrum of the arc, and another coated with bromide, and then develop them if possible on the screen before you by the two methods of development. The first plate we expose is an ordinary wet plate, *i.e.* we have a collodion film which covers the plate, and this collodion film contains iodide of silver, and it is moistened with nitrate of silver. We will expose that to the spectrum for a second. I have in front of the slit at present a solution of bichromate of potash, which cuts off the blue, and therefore the light passing through would have no effect on the plate. I withdraw the front of the slide, and give a very short exposure. Now we will take a cell, *F*, containing what we call a developing solution, that is, something which will precipitate metallic silver from the soluble nitrate of silver; we will place it upon the stand of the lantern, *B*, and by means of the lens *G* we shall see a reversed image of part of the cell on the screen. I next place a piece of yellow glass, *E*, in front of the lantern lens. I take the plate and simply immerse it in the solution, and by degrees you will see a blackening take

place. I am afraid the film is a little too intense—it is now coming out more rapidly and more vigorously; and here we have the image of the blue end of the spectrum perfectly developed. I will get my assistant to take charge of this, and in the meanwhile I will throw on the screen another spectrum which was taken in a similar manner.

Now we will try the other mode of development, which I hope will be more visible to the audience than the one we have tried. We will use the Siemens light again to form the spectrum. We will keep the yellow solution in front to cut off the blue rays whilst focussing it, and then I am perfectly safe. Then we will remove the yellow solution, and give a very short exposure, and we will develop by the alkaline process. We will use the same apparatus as before for developing. We have here a cell containing the liquid which has a great affinity for bromine, and I have no doubt we shall find that the solution will take away the bromine and leave metallic silver behind. It will probably be rather slower than the other in appearing. The plate is now placed in the cell, and we see the lines of the spectrum are appearing, and finally the image is fully out. I now withdraw the yellow glass.

You may ask how it is I can afford to let the light fall on the plate without causing a further deposition. The fact is, this solution

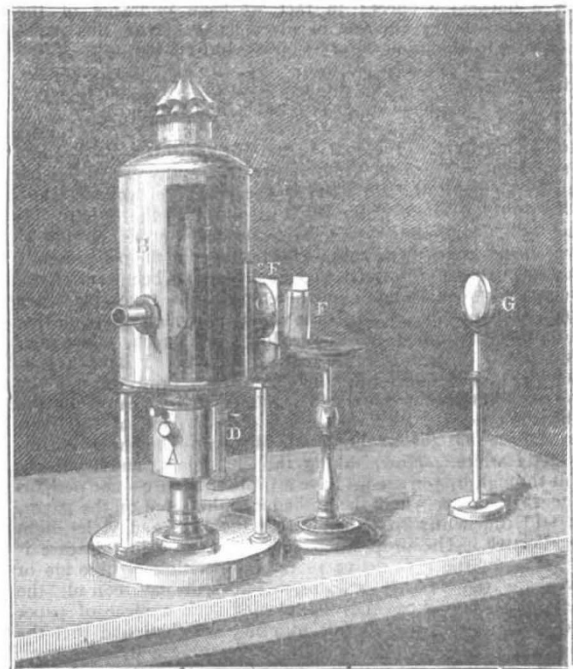


FIG. 2.

itself is coloured red,<sup>1</sup> and therefore the light passing through it has no effect on the bromide. I daresay by and by, when those pictures are thrown on the screen, you will be able to see what kind of spectrum we have got. You will remember, then, that we have in these methods of development which I have endeavoured to bring before you two kinds of chemical action—one a physical action of attraction exercised by sub-iodide of silver, the other a chemical one by the taking away of bromine from the silver salt.

The first mention that we have of a photographic spectrum in the red or below the red was in the year 1839, when Dr. Draper published a paper saying that he had been able to observe certain lines in the solar spectrum below the limit of the red. I propose to show you on the screen a copy of his photograph, and explain how it was taken. Dr. Draper proceeded in this way. He took a daguerrotype plate, exposed it to light first, then exposed it to the spectrum. In Dr. Draper's spectrum we have the whole of the blue and violet part of the spectrum delineated, but in part of the green and all of the yellow there is a blank, but be-

<sup>1</sup> The plate was developed by ferrous oxalate.

low these the lines in the red A and B in the red are shown; but still lower down there are three lines delineated, which he calls  $\alpha$ ,  $\beta$ ,  $\gamma$ . Recollect the way he proceeded. He exposed the daguerrotype to light, and he allowed the spectrum to fall upon it. What was the meaning of that? The meaning of that was he altered the iodide of silver to begin with. I have here a piece of iodide of silver paper. One half has been exposed to light, and the other has not been exposed to light at all, and you will see the difference in colour. One has a greenish brown tint, and

the other a decided yellow. The yellow you saw cut off the blue; the brown tint, if you put that in the spectrum, would allow the yellow to pass, but would cut off not only the blue but also some of the red too. How then do we explain this action? It is true he found that these lines, A, B,  $\alpha$ ,  $\beta$  and  $\gamma$ , had impressed themselves, but he found they were what we call reversed lines, that is to say, what ought to be black before were white, and what ought to be white before were black. How can this be explained? The spectrum was the same, the iodide of silver

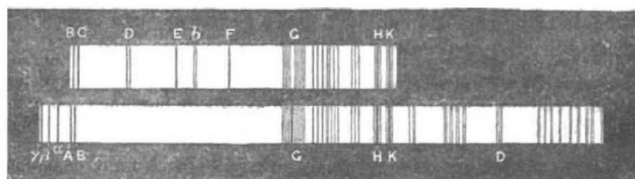


FIG. 3.

plate was the same. All was the same except the previous exposure to light. Now, this remained unexplained for a long time. It was supposed there was a certain antagonism between the rays, that is to say, that the red rays were able to undo the work which the blue had done, and that the yellow remained neutral. But was this an explanation? There can be no such thing as antagonism of energy in this matter, and therefore it required some further explanation.

In investigating the subject it fell to my lot to try experiments on the constitution of the photographic image, and my experiments led me to find that what was supposed to be antagonism of rays in the red part of the spectrum to those of the blue was nothing else but another chemical action which was called into play.

I have here a negative of a line drawing. I place a collodion plate containing iodide of silver in contact with it, but before I develop it I will place half of it in a solution of peroxide of hydrogen, which is an oxidising solution, and on developing I find only half the image has appeared, viz. the part which was not placed in the oxygen peroxide; to adopt the old explanation, there is an antagonism of the peroxide of hydrogen to the action of light! This gave a clue to Dr. Draper's reversal of the image which he got in the red rays of the spectrum. I will show you what it occurred to me did happen. Dr. Draper's plate after it had been exposed to light contained molecules of sub-iodide of silver, and when he allowed the spectrum to play upon it the sub-iodide of silver was anxious to obtain anything it could to satisfy itself, and so took up oxygen from the air and formed an oxy-iodide of silver,  $\text{Ag}_2\text{I}$ , combined with oxygen, and that oxide of silver was totally incapable of development. Why? Simply because its energy of attraction was satisfied; there was nothing to attract the mercury condensed from the mercury vapour by which his image was developed. This then might be an explanation of Draper's photograph which should be capable of proof, and in order to prove it I will show the way I proceeded. I will take a plate of iodide of silver and expose it to light before you; then I propose to immerse it in a cell containing an oxidising solution of very delicate peroxide of hydrogen, which, as we know, is a very strong oxidiser, in fact one which will give up oxygen very freely to anything brought in contact with it. I have an arrangement by which I can do that, consisting of a dark slide in which I can put the cell and the silver plate. Here you see the prepared plate in its normal state. The electric light is allowed to act upon it, and of course the iodide of silver will be reduced to sub-iodide. I shall next allow the spectrum to play on the plate whilst immersed in this oxidising solution, and see if we cannot get the same results that Draper did in his reversed spectrum. If the theory that I give of the production of Draper's oxidising photograph is correct, then the red light ought to aid the oxidation of the photograph, or rather of the subiodide, forming that oxyiodide of silver which I mentioned to you. I will leave the bichromate cell in front of the slit in order that you may see the blue rays have nothing at all to do with the matter. I will give rather a longer exposure than I did before, and in that way I think I shall be able to get a result. I will give it to my assistant to develop, and then throw it on the screen as soon as he has finished with it. Now what shall we expect to find in this photograph? If the red rays help the oxidation of the

iodide we shall expect to find that where the red rays are active no development whatever will have taken place, and as a fact that is really what we find. This method of Draper's, of photographing the ultra-red part of the spectrum, is exceedingly inconvenient, as it requires a long exposure, and, I may say, is unsatisfactory, because it gives very bad definition. You have to use a very open slit in order to get it.



FIG. 4.

I now throw on the screen a portion of the solar spectrum taken in the way I have just carried out before you. In it you will see a facsimile almost of Draper's photograph. The question arises, what would happen suppose the plate was immersed in a de-oxidising solution such as potassium nitrite? We have the answer at hand in the shape of a photograph so exposed. The reversal, you see, is entirely absent.

Now the question comes, Is it possible to show the existence of the ultra-red rays of the spectrum by visible means? In other words, by the exposure of any surface to the light? I think I can show you that it is possible by Balmain's phosphorescent paint. If I expose this to the light of the electric lamp we shall find that of course it will become very luminous indeed. Now when I expose this luminous surface to the action of the spectrum something ought to happen, perhaps which will give us an idea of Draper's photographs. I will try, and then I must pass round this luminous plate, because you will not be able to see it at a distance. I bring the light to a focus on the slit of the spectroscope, and place the surface of the paint, which is still luminous, in the spectrum for a short period, and now I will pass it round, and you will be able to see the phenomena; first of all a bright patch, and then a black patch beyond. The bright patch is caused by the blue rays; the black patch beyond is caused by the ultra-red rays, the red rays and the yellow rays; in other words, these rays have the property of quenching the vibrations of the phosphorescent particles, so that you see we have a means of showing visibly the existence of the ultra-red rays of the spectrum.

Our knowledge of the value of the photography of the spectrum, as regards its most refrangible portion, was very limited indeed until Mr. Lockyer took up the subject of spectrum photography with earnestness. In the year 1872 at Chatham we also began our researches in this matter, and we hoped that what we had found to be so immensely valuable in the violet and the blue regions of the spectrum—we might also be able to accomplish for the red and ultra-red rays of the spectrum as well. In the year 1872 Vogel made an important announcement, which, if it had proved everything one could have wished, would have left no need for further experimentation. He said if you took a bromide of silver plate or iodide of silver plate

and covered it with a dye, that in the spectrum, where the dye absorbed, there a photographic action, although beyond the usual boundary of photographic action, would be seen. We followed up this very carefully, hoping to find some dye by which we might be able to photograph the ultra-red rays of the spectrum. Had I known as much then as I do now I should not have followed any such chimerical idea. But what Vogel stated was perfectly correct, viz. that in that regions of the spectrum which certain dyes absorbed, a photographic action would take place. Suppose I take a plate prepared with some silver salt, and flow over it a dye, and then expose it to the spectrum; I find where the dye absorbed there a photographic image was formed. What was the meaning of this? This required investigation as well. The first dye that was taken up was that of cyanin blue. I have here a plate covered with cyanin blue, and when this plate was placed in the spectrum it was found that it bleached in the yellow, No. II. Fig. 5. Now what was the meaning of that bleaching in the yellow? Let us consult the absorption spectrum of cyanin blue, to see whether it absorbs in that particular part of the spectrum; for if it absorbs in that particular part there work must be done as I have already shown you. I will throw the spectrum on the screen, and then introduce a solution of cyanin blue in front of the slit of the lantern, No. I. Fig. 5. We do this, and it will be seen that there is great absorption in the yellow, so that that particular portion of spectrum bleached the cyanin blue which the cyanin blue cut off. So that work and absorption went hand in hand: when the action was investigated more closely, it was found

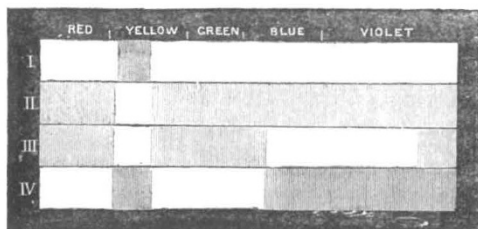


FIG. 5.—I., absorption spectrum of cyanin blue; II., bleaching effect of spectrum on paper stained with cyanin blue; III., bleaching effect of spectrum on a silver bromide film stained with cyanin blue; IV., photographic impression of spectrum prepared as in III. The shaded parts show metallic silver on development.

that the work performed was an oxidation; in other words, that bleaching took place through the effect of oxidation. So much for cyanin blue, *per se*; when, however, we took a plate covered with bromo-iodide of silver in collodion, and dyed with cyanin blue, exposing it for some time to the spectrum, it was found not only that the cyanin was bleached in the yellow, but it was also bleached in the blue, No. III. Fig. 5. It should be remembered that the only factor of difference was in the first case we had cyanin blue, in the collodion by itself, and in this last the dye and iodide and bromide of silver. What then was the explanation of this? That required a further investigation, and I think, perhaps, I shall be able to show you what really did happen. I will take that same cell of cyanin blue used before, and place it in front of the slit of the lantern, and we have the cyanin absorption spectrum on the screen. Now I have told you that when bromide of silver or iodide of silver is exposed to light, one atom of iodine or bromine is given off, and if the exposure be prolonged the amount is measurable, therefore it is possible that the bleaching action in the blue might be due to the action of bromine, and if so, bromine ought to be able to bleach cyanin blue. If we take bromine water and drop it into the cell, I think you will find that the whole spectrum will appear again in its usual brilliancy; we drop the bromine water in, and the whole spectrum does appear on the screen. Our question then is answered. The bromine liberated from the bromide of silver by the action of light when the dyed film was placed in the spectrum, was able to bleach it in the blue part of the spectrum in the same way that the oxygen in the air was able to bleach it under the influence of the yellow rays.

Now I will show you what the action of oxidised matter on silver is. Here we have a glass plate on which was written "May 25th" with an oxidised solution of albumen. This was coated with a collodion film containing bromide and iodide of

silver, and developed in the usual way. You will see that where the oxidisable matter is placed, there we have a deposition of silver upon those particular portions. Apply this to the spectrum developed on a plate stained with cyanin blue; where it is bleached in the yellow, the oxidised dye will cause a deposit of silver to be formed,<sup>1</sup> whilst where the blue rays have acted we shall have a deposition of silver due to ordinary development, as already explained. I throw upon the screen a spectrum showing this. The film of collodion containing the silver salts was dyed, and then the bromide of silver dissolved away. You see we have a bleaching in the yellow and also a bleaching in the blue, one being due to the oxidising action of the yellow rays on the plate, the other due to the action of the bromine upon the dye itself. Next I will show you a photograph (No. IV. Fig. 5) of the spectrum taken on such a dyed plate. We have the part impressed by the blue rays, and a deposition of silver as before, and also we have the yellow where there is another strong deposition of silver. For convenience' sake I have photographed the absorption spectrum of cyanin and placed it below the spectrum photographed on the silver stained with cyanin. You will thus see that the band in the yellow impressed on the latter plate corresponds exactly with the absorption of the cyanin blue itself.

Carrying the investigation a little further, it was found that the same took place with eosin. I have an eosin solution here, and here is an absorption-spectrum of eosin which cuts off a great deal of the green—we have the yellow, but the green is cut out and the blue is damped. The green is the principal portion which is absorbed; in other words, the work which has to be done on the dye will be done in that part of the spectrum. In the photograph of the spectrum of eosin taken with bromide of silver dyed with eosin, you see as a result that we have the plate impressed by the blue rays, and also the plate impressed by the green. The deposition of silver on the two parts is due to different causes: that in the green is due to the work done on the dye; the work was not done on the silver directly, but on the dye first. That on the blue was due to the work done on the silver bromide itself. I may say that all dyes which I have found useful in the photographic sense are what we call fugitive dyes; in other words, dyes which fade in the light. Ladies are perfectly well acquainted with the fact that some dyes will not stand well; those which fade most rapidly give the best results in spectrum photography.

(To be continued.)

#### UNIVERSITY AND EDUCATIONAL INTELLIGENCE

CAMBRIDGE.—The Clothworkers' Exhibition for proficiency in Physical Science, tenable for three years by an unattached student at Oxford or Cambridge, has been awarded to J. Davies. The next Clothworkers' Exhibition will be awarded for Physical Science by means of the examination for certificates to be held next July by the Oxford and Cambridge Schools Examination Board. Candidates must be non-collegiate students of one term's standing at Oxford or Cambridge, or non-residents who are prepared to enter as such.

The oral and practical examinations in the second part of the Natural Sciences Tripos concluded on Monday last (12th).

Prof. Stuart has now thirty-eight pupils in mechanism and engineering, and more space and new machinery are needed to meet their growing requirements. A new room measuring thirty-six by twenty-five feet is asked for, with motive power, a heavy lathe, a slotting machine and larger forge. Messrs. Greenwood and Batley will present a slotting machine when there is a place to put it in. The building will cost 225*l*.

Mr. D. MacAlister, Fellow and Medical Lecturer of St. John's College, will lecture on Methods of Physical Diagnosis three times a week next term, beginning February 2.

#### SOCIETIES AND ACADEMIES LONDON

Linnean Society, December 3.—Sir John Lubbock, Bart., president, in the chair.—Mr. J. Harris Stone exhibited specimens of the dried plant and made remarks on *Lychnis viscaria* as a

<sup>1</sup> It has been objected by Dr. Vogel that the bleaching action requires time to effect it, and that the phenomenon is visible after a short exposure. The simple answer to the question is, When does the bleaching commence? The merest trace of reduced dye would act as a nucleus for development, as does the merest immeasurable trace of subiodide or bromide.