RICHARD A. PROCTOR

PLEASANT WAYS IN SCIENCE

Richard A. Proctor

Pleasant Ways in Science

Sharp Ink Publishing
2022
Contact: info@sharpinkbooks.com

ISBN 978-80-282-3269-6

Table of Contents

PREFACE.

Table of Contents

It is very necessary that all who desire to become really proficient in any department of science should follow the beaten track, toiling more or less painfully over the difficult parts of the high road which is their only trustworthy approach to the learning they desire to attain. But there are many who wish to learn about scientific discoveries without this special labour, for which some have, perhaps, little taste, while many have scant leisure. My purpose in the present work, as in my “Light Science for Leisure Hours,” the “Myths and Marvels of Astronomy,” the “Borderland of Science,” and “Science Byways,” has been to provide paths of easy access to the knowledge of some of the more interesting discoveries, researches, or inquiries of the science of the day. I wish it to be distinctly understood that my purpose is to interest rather than to instruct, in the strict sense of the word. But I may add that it seems to me even more necessary to be cautious, and accurate in such a work as the present than in advanced treatises. For in a scientific work the reasoning which accompanies the statements of fact affords the means of testing and sometimes of correcting such statements. In a work like the present, where explanation and description take the place of reasoning, there is no such check. For this reason I have been very careful in the accounts which I have given of the subjects here dealt with. I have been particularly careful not to present, as established truths, such views as are at present only matters of opinion.

The essays in the present volume are taken chiefly from the *Contemporary Review*, the *Gentleman's Magazine*, the *Cornhill Magazine*, *Belgravia*, and *Chambers' Journal*. The sixth, however, presents the substance (and official report) of a lecture which I delivered at the Royal Institution in May, 1870. It was then that I first publicly enunciated the views respecting the stellar universe which I afterwards more fully stated in my "Universe of Stars." The same views have also been submitted to the Paris Academy of Science, as the results of his own investigations, by M. Flammarion, in words which read almost like translations of passages in the above-mentioned essay.

RICHARD A. PROCTOR.

PLEASANT WAYS IN SCIENCE.

OXYGEN IN THE SUN.

Table of Contents

The most promising result of solar research since Kirchhoff in 1859 interpreted the dark lines of the sun's spectrum has recently been announced from America. Interesting in itself, the discovery just made is doubly interesting in what it seems to promise in the future. Just as Kirchhoff's great discovery, that a certain double dark line in the solar spectrum is due to the vapour of sodium in the sun's atmosphere, was but the first of a long series of results which the spectroscopic analysis of the sun was to reveal, so the discovery just announced that a certain important gas—the oxygen present in our air and the chief chemical constituent of water—shows its presence in the sun by bright lines instead of dark, will in all probability turn out to be but the firstfruits of a new method of examining the solar spectrum. As its author, Dr. Henry Draper, of New York, remarks, further investigation in the direction he has pursued will lead to the discovery of other elements in the sun, but it was not "proper to conceal, for the sake of personal advantage, the principle on which such researches are to be conducted." It may well happen, though I anticipate otherwise, that by thus at once describing his method of observation, Dr. Draper may enable others to add to the list of known solar elements some which yet remain to be detected; but if Dr. Draper should thus have added but one element to that list, he will ever be regarded as the physicist to whose acumen the method was due by which all were detected, and to whom, therefore, the chief credit of their discovery must certainly be attributed.

I propose briefly to consider the circumstances which preceded the great discovery which it is now my pleasing duty to describe, in order that the reader may the more readily follow the remarks by which I shall endeavour to indicate some of the results which seem to follow from the discovery, as well as the line along which, in my opinion, the new method may most hopefully be followed.

It is generally known that what is called the spectroscopic method of analyzing the sun’s substance had its origin in Kirchhoff’s interpretation of the dark lines in the solar spectrum. Until 1859 these dark lines had not been supposed to have any special significance, or rather it had not been supposed that their significance, whatever it might be, could be interpreted. A physicist of some eminence spoke of these phenomena in 1858 in a tone which ought by the way seldom to be adopted by the man of science. “The phenomena defy, as we have seen,” he said, “all attempts hitherto to reduce them within empirical laws, and no complete explanation or theory of them is possible. All that theory can be expected to do is this—it may explain how dark lines of any sort may arise within the spectrum.” Kirchhoff, in 1859, showed not only how dark lines of any sort may appear, but how and why they do appear, and precisely what they mean. He found that the dark lines of the solar spectrum are due to the vapours of various elements in the sun’s atmosphere, and that the nature of such elements may be determined from the observed position of the dark lines. Thus when iron is raised by the passage of the electric spark to so intense a degree of heat that it is vaporized, the light of the glowing vapour of iron is found to give a multitude of bright lines along the whole length of the spectrum—that is, some red, some orange, some yellow, and so on. In the solar spectrum corresponding dark lines are found along the whole length of the spectrum—that is, some in the red, some in the orange, yellow, etc., and precisely in those parts of these various spectral regions which the bright lines of glowing iron would occupy. Multitudes of other dark lines exist of course in the solar spectrum. But those corresponding to the bright lines of glowing iron are unquestionably there. They are by no means lost in the multitude, as might be expected; but, owing to the peculiarity of their arrangement, strength, etc., they are perfectly recognizable as the iron lines reversed, that is, dark instead of bright. Kirchhoff's researches showed how this is to be interpreted. It means that the vapour of iron exists in the atmosphere of the sun, glowing necessarily with an intensely bright light; *but*, being cooler (however intensely hot) than the general mass of the sun within, the iron vapour absorbs more light than it emits, and the result is that the iron lines, instead of appearing bright, as they would if the iron vapour alone were shining, appear relatively dark on the bright rainbow-tinted background of the solar spectrum.

Thus was it shown that in the atmosphere of the sun there is the glowing vapour of the familiar metal, iron; and in like manner other metals, and one element (hydrogen) which is not ordinarily regarded as a metal, were shown to be present in the sun’s atmosphere. In saying that they are present in the sun’s atmosphere, I am, in point of fact, saying that they are present in the sun; for the solar atmosphere is, in fact, the outer part of the sun himself, since a very large part, if not by far the greater part, of the sun’s mass must be vaporous. But no other elements, except the metals iron, sodium, barium, calcium, magnesium, aluminium, manganese, chromium, cobalt, nickel, zinc, copper, and titanium, and the element hydrogen, were shown to be present in the sun, by this method of observing directly the solar dark lines. In passing, I may note that there are reasons for regarding hydrogen as a metallic element, strange though the idea may seem to those who regard hardness, brightness, malleability, ductility, plasticity, and the like, as the characteristic properties of metals, and necessarily fail to comprehend how a gas far rarer, under the same conditions, than the air we breathe, and which cannot possibly be malleable, ductile, or the like, can conceivably be regarded as a metal. But there is in reality no necessary connection between any one of the above properties and the metallic nature; many of the fifty-five metals are wanting in all of these properties; nor is there any reason why, as we have in mercury a metal which at ordinary temperatures is a liquid, so we might have in hydrogen a metal which, at all obtainable temperatures, and under all obtainable conditions of pressure, is gaseous. It was shown by the late Professor Graham (aided in his researches most effectively by Dr. Chandler Roberts) that hydrogen will enter into such combination with the metal palladium that it may be regarded as forming, for the time, with the palladium, an alloy; and as alloys can only be regarded as compounds of two or more metals, the inference is that hydrogen is in reality a metallic element.

Fourteen only of the elements known to us, or less than a quarter of the total number, were thus found to be present in the sun's constitution; and of these all were metals, if we regard hydrogen as metallic. Neither gold nor silver shows any trace of its presence, nor can any sign be seen of platinum, lead, and mercury. But, most remarkable of all, and most perplexing, was the absence of all trace of oxygen and nitrogen, two gases which could not be supposed wanting in the substance of the great ruling centre of the planetary system. It might well be believed, indeed, that none of the five metals just named are absent from the sun, and indeed that every one of the forty metals not recognized by the spectroscopic method nevertheless exists in the sun. For according to the nebular hypothesis of the origin of our solar system, the sun might be expected to contain all the elements which exist in our earth. Some of these elements might indeed escape discovery, because existing only in small quantities; and others (as platinum, gold, and lead, for example), because but a small portion of their vaporous substance rose above the level of that glowing surface which is called the photosphere. But that oxygen, which constitutes so large a portion of the solid, liquid, and vaporous mass of our earth, should not exist in enormous quantities, and its presence be very readily discernable, seemed amazing indeed. Nitrogen, also, might well be expected to be recognizable in the sun. Carbon, again, is so important a constituent of the earth, that we should expect to discover clear traces of its existence in the sun. In less degree, similar considerations apply to sulphur, boron, silicon, and the other non-metallic elements.

It was not supposed, however, by any one at all competent to form an opinion on the subject, that oxygen, nitrogen, and carbon are absent from the sun. It was perceived that an element might exist in enormous quantities in the substance of the sun, and yet fail to give any evidence of its presence, or only give such evidence as might readily escape recognition. If we remember how the dark lines are really caused, we shall perceive that this is so. A glowing vapour in the atmosphere of the sun absorbs rays of the same colour as it emits. If then, it is cooler than the glowing mass of the sun which it enwraps, and if, notwithstanding the heat received from this mass, it remains cooler, then it suffers none of those rays to pass earthwards.[1] It emits rays of the same kind (that is, of the same *colour*) itself, but, being cooler, the rays thus coming from it are feebler; or, to speak more correctly, the ethereal waves thus originated are feebler than those of the same order which *would* have travelled earthwards from the sun but for the interposed screen of vapour. Hence the corresponding parts of the solar spectrum are less brilliant, and contrasted with the rainbow-tinted streak of light, on which they lie as on a background, they appear dark.

In order, then, that any element may be detected by its dark lines, it is necessary that it should lie as a vaporous screen between the more intensely heated mass of the sun and the eye of the observer on earth. It must then form an enclosing envelope cooler than the sun within it. Or rather, some part of the vapour must be thus situated. For enormous masses of the vapour might be within the photospheric surface of the sun at a much higher temperature, which yet, being enclosed in the cooler vaporous shell of the same substance, would not be able to send its light rays earthwards. One may compare the state of things, so far as that particular element is concerned, to what is presented in the case of a metallic globe cooled on the outside but intensely hot within. The cool outside of such a globe is what determines the light and heat received from it, so long as the more heated mass within has not yet (by conduction) warmed the exterior shell. So in the case of a vapour permeating the entire mass, perhaps, of the sun, and at as high a temperature as the sun everywhere except on the outside: it is the temperature of the outermost part of such a vaporous mass which determines the intensity of the rays received from it—or in other words, determines whether the corresponding parts of the spectrum shall be darker or not than the rest of the spectrum. If the vapour does not rise above the photosphere of the sun in sufficient quantity to exercise a recognizable absorptive effect, its presence in the sun will not be indicated by any dark lines.

I dwell here on the question of quantity, which is sometimes overlooked in considering the spectroscopic evidence of the sun’s condition, but is in reality a very important factor in determining the nature of the evidence relating to each element in the solar mass. In some cases, the quantity of a material necessary to give unmistakable spectroscopic evidence is singularly small; insomuch that new elements, as thallium, cæsium, rubidium, and gallium, have been actually first recognized by their spectral lines when existing in such minute quantities in the substances examined as to give no other trace whatever of their existence. But it would be altogether a mistake to suppose that some element existing in exceedingly small quantities, or, more correctly, existing in the form of an exceedingly rare vapour in the sun’s atmosphere, would be detected by means of its dark lines, or *by any other method depending on the study of the solar spectrum*. When we place a small portion of some substance in the space between the carbon points of an electric lamp, and volatilize that substance in the voltaic arc, we obtain a spectrum including all the bright lines of the various elements contained in the substance; and if some element is contained in it in exceedingly small quantity, we may yet perceive its distinctive bright lines among the others (many of them far brighter) belonging to the elements present in greater quantities. But if we have (for example) a great mass of molten iron, the rainbow-tinted spectrum of whose light we examine from a great distance, and if a small quantity of sodium, or other substance which vaporizes at moderate temperatures, be cast into the molten iron so that the vapour of the added element presently rises above the glowing surface of the iron, no trace of the presence of this vapour would be shown in the spectrum observed from a distance. The part of the spectrum where the dark lines of sodium usually appear would, undoubtedly, be less brilliant than before, in the same sense that the sun may be said to be less brilliant when the air is in the least degree moist than when it is perfectly dry; but the loss of brilliancy is as utterly imperceptible in the one case as it is in the other. In like manner, a vapour might exist in the atmosphere of the sun (above the photosphere, that is), of whose presence not a trace would be afforded in the spectroscope, for the simple reason that the absorptive action of the vapour, though exerted to reduce the brightness of particular solar rays or tints, would not affect those rays sufficiently for the spectroscopist to recognize any diminution of their lustre.

There is another consideration, which, so far as I know, has not hitherto received much attention, but should certainly be taken into account in the attempt to interpret the real meaning of the solar spectrum. Some of the metals which are vaporized by the sun's heat below the photosphere may become liquid or even solid at or near the level of the photosphere. Even though the heat at the level of the photosphere may be such that, under ordinary conditions of pressure and so forth, such metals would be vaporous, the enormous pressure which must exist not far below the level of the photosphere may make the heat necessary for complete vaporization far greater than the actual heat at that level. In that case the vapour will in part condense into liquid globules, or, if the heat is considerably less than is necessary to keep the substance in the form of vapour, then it may in part be solidified, the tiny globules of liquid metal becoming tiny crystals of solid metal. We see both conditions fulfilled within the limits of our own air in the case of the vapour of water. Low down the water is present in the air (ordinarily) in the form of pure vapour; at a higher level the vapour is condensed by cold into liquid drops forming visible clouds (cumulus clouds), and yet higher, where the cold is still greater, the minute water-drops turn into ice-crystals, forming those light fleecy clouds called cirrus clouds by the meteorologist. Now true clouds of either sort may exist in the solar atmosphere even above that photospheric level which forms the boundary of the sun we see. It may be said that the spectroscope, applied to examine matter outside the photosphere, has given evidence only of vaporous cloud masses. The ruddy prominences which tower tens of thousands of miles above the surface of the sun, and the sierra (or as it is sometimes unclassically called, the chromosphere) which covers usually the whole of the photosphere to a depth of about eight thousand miles, show only, under spectroscopic scrutiny, the bright lines indicating gaseity. But though this is perfectly true, it is also true that we have not here a particle of evidence to show that clouds of liquid particles, and of tiny crystals, may not float over the sun's surface, or even that the ruddy clouds shown by the spectroscope to shine with light indicative of gaseity may not also contain liquid and crystalline particles. For in point of fact, the very principle on which our recognition of the bright lines depends involves the inference that matter whose light would *not* be resolved into bright lines would not be recognizable at all. The bright lines are seen, because by means of a spectroscope we can throw them far apart, without reducing their lustre, while the background of rainbow-tinted spectrum has its various portions similarly thrown further apart and correspondingly weakened. One may compare the process (the comparison, I believe, has not hitherto been employed) to the dilution of a dense liquid in which solid masses have been floating: the more we increase the quantity of the liquid in diluting it with water, the more transparent it becomes, but the solid masses in it are not changed, so that we only have to dilute the liquid sufficiently to see these masses. *But* if there were in the interstices of the solid masses particles of some substance which dissolved in the water, we should not recognize the presence of this substance by any increase in its visibility; for the very same process which thinned the liquid would thin this soluble substance in the same degree. In like manner, by dispersing and correspondingly weakening the sun’s light more and more, we can recognize the light of the gaseous matter in the prominences, for this is not weakened; but if the prominences also contain matter in the solid or liquid form (that is, drops or crystals), the spectroscopic method will not indicate the presence of such matter, for the spectrum of matter of this sort will be weakened by dispersion in precisely the same degree that the solar spectrum itself is weakened.

It is easy to see how the evidence of the presence of any element which behaved in this way would be weakened, if we consider what would happen in the case of our own earth, according as the air were simply moist but without clouds, or loaded with cumulus masses but without cirrus clouds, or loaded with cirrus clouds. For although there is not in the case of the earth a central glowing mass like the sun’s, on whose rainbow-tinted spectrum the dark lines caused by the absorptive action of our atmosphere could be seen by the inhabitant of some distant planet studying the earth from without, yet the sun’s light reflected from the surface of the earth plays in reality a similar part. It does not give a simple rainbow-tinted spectrum; for, being sunlight, it shows all the dark lines of the solar spectrum: but the addition of new dark lines to these, in consequence of the absorptive action of the earth’s atmosphere, could very readily be determined. In fact, we do thus recognize in the spectra of Mars, Venus, and other planets, the presence of aqueous vapour in their atmosphere, despite the fact that our own air, containing also aqueous vapour, naturally renders so much the more difficult the detection of that vapour in the atmosphere of remote planets necessarily seen through our own air. Now, a distant observer examining the light of our own earth on a day when, though the air was moist, there were no clouds, would have ample evidence of the presence of the vapour of water; for the light which he examined would have gone twice through our earth’s atmosphere, from its outermost thinnest parts to the densest layers close to the surface, then back again through the entire thickness of the air. But if the air were heavily laden with cumulus clouds (without any cirrus clouds at a higher layer), although *we* should know that there was abundant moisture in the air, and indeed much more moisture then there had been when there had been no clouds, our imagined observer would either perceive no traces at all of this moisture, or he would perceive traces so much fainter than when the air was clear that he would be apt to infer that the air was either quite dry, or at least very much drier than it had been in that case. For the light which he would receive from the earth would not in this case have passed through the entire depth of moisture-laden air twice, but twice only through that portion of the air which lay above the clouds, at whose surface the sun's light would be reflected. The whole of the moisture-laden layer of the air would be snugly concealed under the cloud-layer, and would exercise no absorptive action whatever on the light which the remote observer would examine. If from the upper surface of the layer of cumulus clouds aqueous vapour rose still higher, and were converted in the cold upper regions of the atmosphere into clouds of ice-crystals, the distant observer would have still less chance of recognizing the presence of moisture in our atmosphere. For the layer of air between the cumulus clouds and the cirrus clouds would be unable to exert any absorptive action on the light which reached the observer. All such light would come to him after reflection from the layer of cirrus clouds. He would be apt to infer that there was no moisture at all in the air of our planet, at the very time when in fact there was so much moisture that not one layer only, but two layers of clouds enveloped the earth, the innermost layer consisting of particles of liquid water, the outermost of particles of frozen water. Using the words ice, water, and steam, to represent the solid, liquid, and vaporous states of water, we may fairly say that ice and water, by hiding steam, would persuade the remote observer that there was no water at all on the earth —at least if he trusted solely to the spectroscopic evidence then obtained.[2]

We might in like manner fail to obtain any spectroscopic evidence of the presence of particular elements in the sun, because they do not exist in sufficient quantity in the vaporous form in those outer layers which the spectroscope can alone deal with.

In passing, I must note a circumstance in which some of those who have dealt with this special part of the spectroscopic evidence have erred. It is true in one sense that some elements may be of such a nature that their vapours cannot rise so high in the solar atmosphere as those of other elements. But it must not be supposed that the denser vapours seek a lower level, the lighter vapours rising higher. According to the known laws of gaseous diffusion, a gas or vapour diffuses itself throughout a space occupied by another gas or several other gases, in the same way as though the space were not occupied at all. If we introduce into a vessel full of common air a quantity of carbonic acid gas (I follow the older and more familiar nomenclature), this gas, although of much higher specific gravity than either oxygen or nitrogen, does not take its place at the bottom of the vessel, but so diffuses itself that the air of the upper part of the vessel contains exactly the same quantity of carbonic acid gas as the air of the lower part. Similarly, if hydrogen is introduced, it does not seek the upper part of the vessel, but diffuses itself uniformly throughout the vessel. If we enclose the carbonic acid gas in a light silken covering, and the hydrogen in another (at the same pressure as the air in the vessel) one little balloon will sink and the other will rise; but this is simply because diffusion is prevented. It may be asked how this agrees with what I have said above, that some elements may not exist in sufficient quantity or in suitable condition above the sun’s photospheric level to give any spectroscope evidence of their nature. As to quantity, indeed, the answer is obvious: if there is only a small quantity of any given element in the entire mass of the sun, only a very small quantity can under any circumstances exist outside the photosphere. As regards condition, it must be remembered that the vessel of my illustrative case was supposed to contain air at a given temperature and pressure throughout. If the vessel was so large that in different parts of it the temperature and pressure were different, the diffusion would, indeed, still be perfect, because at all ordinary temperatures and pressures hydrogen and carbonic acid gas remain gaseous. But if the vapour introduced is of such a nature that at moderate temperatures and pressures it condenses, wholly or in part, or liquefies, the diffusion will not take place with the same uniformity. We need not go further for illustration than to the case of our own atmosphere as it actually exists. The vapour of water spreads uniformly through each layer of the atmosphere which is at such a temperature and pressure as to permit of such diffusion; but where the temperature is too low for complete diffusion (at the actual pressure) the aqueous vapour is condensed into visible cloud, diffusion being checked at this point as at an impassable boundary. In the case of the sun, as in the case of our own earth, it is not the density of an element when in a vaporous form which limits its diffusion, but the value of the temperature at which its vapour at given pressure condenses into liquid particles. It is in this way only that any separation can be effected between the various elements which exist in the sun’s substance. A separation of this sort is unquestionably competent to modify the spectroscopic evidence respecting different elements. But it would be a mistake to suppose that any such separation could occur as has been imagined by some—a separation causing in remote times the planets supposed to have been thrown off by the sun to be rarest on the outskirts of the solar system and densest close to the sun. The small densities of the outer family of planets, as compared with the densities of the so-called terrestrial planets, must certainly be otherwise explained.

But undoubtedly the chief circumstance likely to operate in veiling the existence of important constituents of the solar mass must be that which has so long prevented spectroscopists from detecting the presence of oxygen in the sun. An element may exist in such a condition, either over particular parts of the photosphere, or over the entire surface of the sun, that instead of causing dark lines in the solar spectrum it may produce bright lines. Such lines may be conspicuous, or they may be so little brighter than the background of the spectrum as to be scarcely perceptible or quite imperceptible.

In passing, I would notice that this interpretation of the want of all spectroscopic evidence of the presence of oxygen, carbon, and other elements in the sun, is not an *ex post facto* explanation. As will presently appear, it is now absolutely certain that oxygen, though really existing, and doubtless, in enormous quantities, in the sun, has been concealed from recognition in this way. But that this might be so was perceived long ago. I myself, in the first edition of my treatise on "The Sun," pointed out, in 1870, with special reference to nitrogen and oxygen, that an element "may be in a condition enabling it to radiate as much light as it absorbs, or else very little more or very little less; so that it either obliterates all signs of its existence, or else gives lines so little brighter or darker than the surrounding parts of the spectrum that we can detect no trace of its existence.” I had still earlier given a similar explanation of the absence of all spectroscopic evidence of hydrogen in the case of the bright star Betelgeux.[3]

Let us more closely consider the significance of what we learn from the spectral evidence respecting the gas hydrogen. We know that when the total light of the sun is dealt with, the presence of hydrogen is constantly indicated by dark lines. In other words, regarding the sun as a whole, hydrogen constantly reduces the emission of rays of those special tints which correspond to the light of this element. When we examine the light of other suns than ours, we find that in many cases, probably in by far the greater number of cases, hydrogen acts a similar part. But not in every case. In the spectra of some stars, notably in those of Betelgeux and Alpha Herculis, the lines of hydrogen are not visible at all; while in yet others, as Gamma Cassiopeiæ, the middle star of the five which form the straggling W of this constellation, the lines of hydrogen show bright upon the relatively dark background of the spectrum. When we examine closely the sun himself, we find that although his light as a whole gives a spectrum in which the lines of hydrogen appear dark, the light of particular parts of his surface, if separately examined, occasionally shows the hydrogen lines bright as in the spectrum of Gamma Cassiopeiæ, while sometimes the light of particular parts gives, like the light of Betelgeux, no spectroscopic evidence whatever of the presence of hydrogen. Manifestly, if the whole surface of the sun were in the condition of the portions which give bright hydrogen lines, the spectrum of the sun would resemble that of Gamma Cassiopeiæ; while if the whole surface were in the condition of those parts which show no lines of hydrogen, the spectrum of the sun would resemble that of Betelgeux. Now if there were any reason for supposing that the parts of the sun which give no lines of hydrogen are those from which the hydrogen has been temporarily removed in some way, we might reasonably infer that in the stars whose spectra show no hydrogen lines there is no hydrogen. But the fact that the hydrogen lines are sometimes seen bright renders this supposition untenable. For we cannot suppose that the lines of hydrogen change from dark to bright or from bright to dark (both which changes certainly take place) without passing through a stage in which they are neither bright nor dark; in other words, we are compelled to assume that there is an intermediate condition in which the hydrogen lines, though really existent, are invisible because they are of precisely the same lustre as the adjacent parts of the spectrum. Hence the evanescence of the hydrogen lines affords no reason for supposing that hydrogen has become even reduced in quantity where the lines are not seen. And therefore it follows that the invisibility of the hydrogen lines in the spectrum of Betelgeux is no proof that hydrogen does not exist in that star in quantities resembling those in which it is present in the sun. And this, being demonstrated in the case of one gas, must be regarded as at least probable in the case of other gases. Wherefore the absence of the lines of oxygen from the spectrum of any star affords no sufficient reason for believing that oxygen is not present in that star, or that it may not be as plentifully present as hydrogen, or even far more plentifully present.

There are other considerations which have to be taken into account, as well in dealing with the difficulty arising from the absence of the lines of particular elements from the solar spectrum as in weighing the extremely important discovery which has just been effected by Dr. H. Draper.

I would specially call attention now to a point which I thus presented seven years ago:—“The great difficulty of interpreting the results of the spectroscopic analysis of the sun arises from the circumstance that we have no means of learning whence that part of the light comes which gives the continuous spectrum. When we recognize certain dark lines, we know certainly that the corresponding element exists in the gaseous form at a lower temperature than the substance which gives the continuous spectrum. But as regards that continuous spectrum itself we can form no such exact opinion.” It might, for instance, have its origin in glowing liquid or solid matter; but it might also be compounded of many spectra, each containing a large number of bands, the bands of one spectrum filling up the spaces which would be left dark between the bands of another spectrum, and so on until the entire range from the extreme visible red to the extreme visible violet were occupied by what appeared as a continuous rainbow-tinted streak. “We have, in fact, in the sun,” as I pointed out, “a vast agglomeration of elements, subject to two giant influences, producing in some sort opposing effects—viz., a temperature far surpassing any we can form any conception of, and a pressure (throughout nearly the whole of the sun's globe) which is perhaps even more disproportionate to the phenomena of our experience. Each known element would be vaporized by the solar temperature at known pressures; each (there can be little question) would be solidified by the vast pressures, did these arise at known temperatures. Now whether, under these circumstances, the laws of gaseous diffusion prevail where the elements *are* gaseous in the solar globe; whether, where liquid matter exists it is in general bounded in a definite manner from the neighbouring gaseous matter; whether any elements at all are solid, and if so under what conditions their solidity is maintained and the limits of the solid matter defined—all these are questions which *must* be answered before we can form a satisfactory idea of the solar constitution; yet they are questions which we have at present no means of answering." Again, we require to know whether any process resembling combustion can under any circumstances take place in the sun's globe. If we could assume that some general resemblance exists between the processes at work upon the sun and those we are acquainted with, we might imagine that the various elements ordinarily exist in the sun's globe in the gaseous form (chiefly) to certain levels, to others chiefly in the liquid form, and to yet others chiefly in the solid form. But even then that part of each element which is gaseous may exist in two forms, having widely different spectra (in reality in five, but I consider only the extreme forms). The light of one part is capable of giving characteristic spectra of lines or bands (which will be different according to pressure and may appear either dark or bright); that of the other is capable of giving a spectrum nearly or quite continuous.

It will be seen that Dr. H. Draper’s discovery supplies an answer to one of the questions, or rather to one of the sets of questions, thus indicated. I give his discovery as far as possible in his own words.

“*Oxygen discloses itself*,” he says, “*by bright lines or bands in the solar spectrum*, and does not give dark absorption-lines like the metals. We must therefore change our theory of the solar spectrum, and no longer regard it merely as a continuous spectrum with certain rays absorbed by a layer of ignited metallic vapours, but as having also bright lines and bands superposed on the background of continuous spectrum. Such a conception not only opens the way to the discovery of others of the non-metals, sulphur, phosphorus, selenium, chlorine, bromine, iodine, fluorine, carbon, etc., but also may account for some of the so-called dark lines, by regarding them as intervals between bright lines. It must be distinctly understood that in speaking of the solar spectrum here, I do not mean the spectrum of any limited area upon the disc or margin of the sun, but the spectrum of light from the whole disc.”

In support of the important statement here advanced, Dr. Draper submits a photograph of part of the solar spectrum with a comparison spectrum of air, and also with some of the lines of iron and aluminium. The photograph itself, a copy of which, kindly sent to me by Dr. Draper, lies before me as I write, fully bears out Dr. Draper’s statement. It is absolutely free from handwork or retouching, except that reference letters have been added in the negative. It shows the part of the solar spectrum between the well-known Fraunhofer lines G and H, of which G (an iron line) lies in the indigo, and H (a line of hydrogen) in the violet, so that the portion photographed belongs to that region of the spectrum whose chemical or actinic energy is strongest. Adjacent to this lies the photograph of the air lines, showing nine or ten well-defined oxygen lines or groups of lines, and two nitrogen bands. The exact agreement of the two spectra in position is indicated by the coincidence of bright lines of iron and aluminium included in the air spectrum with the dark lines of the same elements in the solar spectrum. “No close observation,” as Dr. Draper truly remarks, “is needed to demonstrate to even the most casual observer” (of this photograph) “that the oxygen lines are found in the sun as bright lines.” There is in particular one quadruple group of oxygen lines in the air spectrum, the coincidence of which with a group of bright lines in the solar spectrum is unmistakable.

“This oxygen group alone is almost sufficient,” says Dr. Draper, “to prove the presence of oxygen in the sun, for not only does each of the four components have a representative in the solar group, but the relative strength and the general aspect of the lines in each case is similar.[4] I shall not attempt at this time,” he proceeds, “to give a complete list of the oxygen lines, ... and it will be noticed that some lines in the air spectrum which have bright anologues in the sun are not marked with the symbol of oxygen. This is because there has not yet been an opportunity to make the necessary detailed comparisons. In order to be certain that a line belongs to oxygen, I have compared, under various pressures, the spectra of air, oxygen, nitrogen, carbonic acid, carburetted hydrogen, hydrogen, and cyanogen.

“As to the spectrum of nitrogen and the existence of this element in the sun there is not yet certainty. Nevertheless, even by comparing the diffused nitrogen lines of this particular photograph, in which nitrogen has been sacrificed to get the best effect for oxygen, the character of the evidence appears. There is a triple band somewhat diffused in the photograph belonging to nitrogen, which has its appropriate representative in the solar spectrum, and another band of nitrogen is similarly represented.” Dr. Draper states that “in another photograph a heavy nitrogen line which in the present one lies opposite an insufficiently exposed part of the solar spectrum, corresponds to a comparison band in the sun.”

But one of the most remarkable points in Dr. Draper’s paper is what he tells us respecting the visibility of these lines in the spectrum itself. They fall, as I have mentioned, in a part of the spectrum where the actinic energy is great but the luminosity small; in fact, while this part of the spectrum is the very strongest for photography, it is close to the region of the visible spectrum,

> “Where the last gleamings of refracted light
> Die in the fainting violet away.”

It is therefore to be expected that those, if any, of the bright lines of oxygen, will be least favourably shown for direct vision, and most favourably for what might almost be called photographic vision, where we see what photography records for us. Yet Dr. Draper states that these bright lines of oxygen can be readily seen. “The bright lines of oxygen in the spectrum of the solar disc have not been hitherto perceived, probably from the fact that in eye-observation bright lines on a less bright background do not make the impression on the mind that dark lines do. When attention is called to their presence they are readily enough seen, even without the aid of a reference spectrum. The photograph, however, brings them into greater prominence.” As the lines of oxygen are not confined to the indigo and violet, we may fairly hope that the bright lines in other parts of the spectrum of oxygen may be detected in the spectrum of the sun, now that spectroscopists know that bright lines and not dark lines are to be looked for.

Dr. Draper remarks that from purely theoretic considerations derived from terrestrial chemistry, and the nebular hypothesis, the presence of oxygen in the sun might have been strongly suspected; for this element is currently stated to form eight-ninths of the water of the globe, one-third of the crust of the earth, and one-fifth of the air, and should therefore probably be a large constituent of every member of the solar system. On the other hand, the discovery of oxygen, and probably other non-metals, in the sun gives increased strength to the nebular hypothesis, because to many persons the absence of this important group has presented a considerable difficulty. I have already remarked on the circumstance that we cannot, according to the known laws of gaseous diffusion, accept the reasoning of those who have endeavoured to explain the small density of the outer planets by the supposition that the lighter gases were left behind by the great contracting nebulous mass, out of which, on the nebular hypothesis, the solar system is supposed to have been formed. It is important to notice, now, that if on the one hand we find in the community of structure between the sun and our earth, as confirmed by the discovery of oxygen and nitrogen in the sun, evidence favouring the theory according to which all the members of that system were formed out of what was originally a single mass, we do not find evidence against the theory (as those who have advanced the explanation above referred to may be disposed to imagine) in the recognition in the sun's mass of enormous quantities of one of these elements which, according to their view, ought to be found chiefly in the outer members of the solar system. If those who believe in the nebular hypothesis (generally, that is, for many of the details of the hypothesis as advanced by Laplace are entirely untenable in the present position of physical science) had accepted the attempted explanation of the supposed absence of the non-metallic elements in the sun, they would now find themselves in a somewhat awkward position. They would, in fact, be almost bound logically to reject the nebular hypothesis, seeing that one of the asserted results of the formation of our system, according to that hypothesis, would have been disproved. But so far as I know no supporter of the nebular hypothesis possessing sufficient knowledge of astronomical facts and physical laws to render his opinion of any weight, has ever given in his adhesion to the unsatisfactory explanation referred to.