SPECTRAL ANALYSIS.

BY

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Explanation of the coloured engraving.

The whole of the Spectra, which are there represented are so placed one above the other, that for every perpendicular line in every spectrum, light of the same refrangibility and consequently of the same colour is inserted.

Fig 1 is a representation of a solar spectrum, in which only the strongest Frauenhofer's lines are inserted and designated by the letters A. a. B. C. D. E. b. F. G. H.

Fig. 2. Spectrum of the bluish green light of the inner cone of the flame of Bunsen's gas-burner.

Fig. 3. Spectrum of the light of sodium steam in the flame of the gas-burner.

Fig. 4. Spectrum of Potassium.

Fig. 5 Spectrum of a ray of the sun, which has passed through a rather strong diluted solution of Chlorophyll. A very dark sharply defined absorptive stripe beginning from the line B and extending above C, the 3 remaining stripes are not so dark and much less sharply defined.

Fig. 6. Spectrum of a ray of the sun after it has passed through a diluted solution of the pigment of the blood.

Fig. 7. The same spectrum as Fig. 6, but after the separation of the loosely united oxygen from the blood pigment.

Fig. 8. Spectrum of the light of fixed stars and Syra after Secchi. (Secchi's Typus 1.)

Fig. 9. Spectrum of the fixed stars β. Pegasus (Typus 2) after Secchi.

Fig. 10. Spectrum of α Orion slightly magnified after Secchi.

THE physical world is, according to the view of the Natural Philosophers of our age an ocean of unimaginable extent, consisting of a fluid, which is not perceptible to our senses and in which, the so-called celestial bodies move apparently without resistance. This fluid, which is diffused throughout the universe, does not manifest any sensible attraction to our earth, and is also imponderous; but it penetrates the celestial bodies, consequently also the substances of which our earth and our own bodies are composed; indeed it not only fills interstices of the minutest physical particles of each body, but penetrates into the interior of the finest structure of the molecules. It is in continual motion as far as we are able to examine it and although it is invisible and intangible its movements are apparent to our senses in the form of *light* and *heat*.

One of the greatest triumphs of which Natural Science can boast, is, that of having recognised the important laws of motion of that fluid, to which Natural Philosophers have given the name *Ether*; but I cannot speak here of the peculiarities of the motions of *Ether*, but of the *origin* and disappearance of these motions; the appearance and extinction of the oscillatory motions of light and heat and of those only as far as it may be necessary for the examination and explanation of these phenomena; in short, I will describe the most important properties of the oscillatory motions of *Ether.*

Ether, like atmospheric air, can also produce strong or weak, slow or quick vibrations; the more powerful motions are perceptible as intense light, its weaker movements as a slight glimmer, if we compare the light of phosphorus in the dark with the light of the sun, there can be no doubt, that the latter exhibits the more powerful oscillations. Excited at-any given point, the vibrations of light extend in waves, in every direction with the extraordinary rapidity of more than 200,000 Miles in a second, proportionally losing in intensity. It is otherwise with respect to the duration of single vibrations; they remain unchanged however far the undulations of light may extend in the intervals of space. The vibrations of the waves of light, when emitted from the sun, exhibit the same oscillatory-duration, as when they reach our eye.

The proportions of the oscillatory motions of ether have been very fitly compared with those of the atmospheric air of our earth. The sounds of musical instruments, for example, those of an organ, become fainter and fainter the further we are removed from them, but the harmony remains the same, be they near or distant. High tones are the vibrations of the air of shorter duration, the deep tones on the contrary are produced by the increased length of each particular vibration and as our ear distinguishes the velocity of the consecution of the single vibrations of air in the high and low tones, so the finest organ of our senses, and that, which discloses the world to us, viz *the eye*, is able to discern the greater or lesser oscillatory duration of the ethereal waves; we recognise red, yellow, green, blue, violet light and innumerable transitions from one colour to another.

Natural Philosophy does not only teach us, that the duration of the vibrations of violet light is shorter than that of blue, and that the vibrations of blue are of still shorter continuance than those of green; that the oscillatory motions of red light are the slowest, those of yellow quicker and those of green more rapid than those of yellow, and, moreover, that the vibrations of ether, which are slower than those of red light, are only felt by us as warmth and are no longer perceptible to the eye as light, but it has also measured with great exactness, in a variety of ways, the duration of the oscillations of each of those kinds of coloured light.

It is not difficult for a practised ear to detect each particular tone of which a accord is composed, but the eye can only imperfectly discern the colours, which are contained in the rays of light, which meet it; however, we possess simple means by which we are enabled to make this analysis and the eye is rendered capable of beholding the various colours, which are exhibited in a ray of light and which, proceeding from the same source, must, in their variegated confusion remain a mystery to the naked eye. *The object of Spectral Analysis is to resolve light into the different colours of which it is composed.*

The most simple instrument for such an analysis is a triangular Prism of glass, two sides of which must be well cut and polished. If rays of light fall on one of these sides in such a direction, that they pass through the Prism and the other polished side, we perceive, first, that they are refracted and then, that the refraction of the violet light is greater than that of the red light. If the light, which is conducted through a Prism contain a variety of colours, and the vibratory motions of which are therefore of different duration, the component parts of the light as it passes through the Prism are resolved, the coloured lights being still more strongly refracted, the shorter the duration of their oscillatory motions.

The white light, which is emitted to us by the sun and which is also reflected by the moon, as well as the light of burning oil, candles and illuminating gas, contains a mixture of variously coloured lights, of which the yellow always appears the most intense to our eyes. If we analyze such a light through a glass Prism in the manner we have already described, we can perceiye the whole of the colours in succession, in the same order, in which they excite our admiration in a rainbow, the origin of which is no other, than the refraction and reflection of the rays of the sun by innumerable drops of falling rain.

If we examine a flame through a Prism, the before mentioned phenomena of colours are to be seen clearly at the edges only; the middle of the flame is quite white just as it appears to us before the insertion of the Prism; but if we look at a fixed star or any other distant shining spot through the Prism, the colours appear in the centre of the figure separate and distinct. A flame of light presents to the eye a bright surface; every point of this surface casts a variously coloured light towards the Prism and the eye, and in the middle of the spectrum the powerfully refracted colours of the one side of the flame, are covered by the weakly refracted colours of the other side.

To avoid this evil, we cover the flame with an opaque black screen, in which there is a narrow perpendicular slit through which alone the light from a very small part of the flame can penetrate; we then examine the rays, which stream through the aperture, with the Prism, which is also placed in a perpendicular position. This arrangement is however insufficient.

If water flows through a narrow channel into a reservoir, it is not only the water, which spreads itself out on all sides but also the waves, which are produced on its surface as soon as it has left the narrow pass of the channel. It is exactly the same with the undulations of ether; when they have forced their way through the narrow slit, they diffuse themselves on all sides, just as if the source of their excitation lay in the aperture itself. The undulations of light are now collected together and brought into the same direction, by intercepting them by a convex glass lens, which is so placed, that the slit through which the light penetrates stands in its focus. The light proceeding from this lens is then analysed by the prism, and the coloured spectrum obtained thereby, is intercepted by a screen of white paper, or still better, examined through a telescope, which must be placed at a short distance from the Prism in the same direction as the rays of light, which stream forth from it.

The series of coloured compartments or stripes, which we obtain, by the decomposing light of a flame, by means of the above-named apparatus is called the *spectrum*, and the apparatus used for the purpose of separating the light into the coloured component parts of which it consists is a *Spectroscope* or *Spectral Apparatus*.

The views, experiments and methods of examination, which we have already described, have for many years past been generally adopted in Natural Philosophy, and Natural Philosophers have not failed to subject the diverse and various sources of light such as the light of the sun, lamp-light, phosphorescent bodies, as well as the flame of many other processes of combustion to a very minute examination. Already in the year 1802 *Wollaston* observed, that the solar spectrum exhibited some black lines, which he considered to be the boundaries of the different coloured rays of light. In 1814 the renowned optician *Frauenhofer* of *Munich*, first described more minutely the solar spectrum, adding to his description numerous measurements and an excellent sketch of the solar spectrum engraved by himself; he specified the principal dark lines by letters of the Alphabet, an arrangement, which has since that time become generally adopted, and he very ingeniously made use of these lines to measure the strength of the refractive light of the Prisms and thereby laid the real foundation of spectral analysis. The dark lines in the solar spectrum are still called *Frauenhofer's lines*, after their discoverer. The whole of the communication sent by *Frauenhofer* to the Academy in Munich, which is not more than 33 pages in length, and in which he describes this discovery, remains to this day an exceedingly copious source of knowledge particulary as regards spectral phenomena. The later examinations of the light of different sidereal and telluric sources have until now added very little, that is new to former discoveries. The renowned *Sir David Brewster*, whose loss we have recently been called to deplore, extended the nformatio n respecting the Solar Spectrum and particularly taught us to understand the influence of coloured substances on the different coloured parts of the Spectrum. The English Natural Philosopher *Stokes*, and about the same time *Ångström* in *Sweden* attained very important results with respect to the relation of the light absorbed by a body, to the rays of light, which the same body emits in ignition; but all these discoveries, however interesting and important they were to the further development of optics, always remained a department, which was only particularly appreciated by single individuals, and which entirely appertained to Natural Philosophy, and was quite unknown to the greater part of the educated public until in 1859 two Professors in Heidelberg *Kirchhoff* and *Bunsen* attained by joint experiments a clearer comprehension of the circumstances, which prevail, when light is emitted or absorbed by bodies in different temperatures.

These last researches not only excited the greatest interest among Natural Philosophers, who were occupied with similar questions but the great importance of these discoveries was acknowledged far beyond their circle, although it was not possible to comprehend at once their whole bearing and importance. Further investigations have followed those of *Kirchhoff* and *Bunsen*, and their inferences have not only been corroborated by different parties, but many further conclusions have been drawn from them, and there is no doubt, that those works, which have made such a sensation during the two years which have elapsed, since their having been made known, have promoted our knowledge of the physical world more than any other discovery, and very considerably increased the store of means by which we are enabled to become further acquainted with it.

Among a great number of important results arising from these researches are two which may be particularly regarded as the basis of all further investigations in this department; viz. 1) that the light, emitted from the glowing vapour of many substances, particularly from the combination of many light metals, when decomposed in the Spectrum, exhibits light streaks of a certain colour, which are so characteristic of these metals, that we can recognise in them the presence of the smallest traces of these metals in a flame; further 2) that every body absorbs precisely light of those colours, which it emits, when it is in a glowing state. The explanation of *Frauenhofer*'s lines in the solar spectrum, was annexed to this last thesis by means of the supposition, that the atmosphere of the sun contains many of our earthly metals in the form of vapour. The hypothesis, that a body of light eagerly absorbs the same colour, which it emits, when in a state of glowing heat, sounds so paradoxical, that it is necessary to enter into a fuller explanation, but it will be first requisite to make an examination of the relation, which has until now been recognised between the physical and chemical constitutions of bodies on the one side, and the rays of light, which are emitted from those bodies, when in a glowing state on the other.

We will first arrange the light, which streams from the recognised sources of light, by decomposing it by means of the *Spectroscope*, into its various coloured rays.

We have already said, that the Solar Spectrum, as a permanent Spectrum contains each kind of coloured light in the following order; viz. *red*, *orange*, *green*, *blue*, and *violet*; and each of these colours gradually dissolves into that one which follows it, and that innumerable dark lines, strong and fine, intersect this spectrum in every part, but particularly in the green and blue compartments.

Fig. 1 in the frontispiece will give an idea of the arrangement of the principal lines discovered by *Frauenhofer* in the Solar Spectrum; it is true that every pictorial illustration of this spectrum is very imperfect, particularly with respect to the colours and their transitions; the spectacle, which a Solar Spectrum presents to our view, when represented by a good apparatus is so very beautiful, that every painter would immediately renounce the idea of faithfully portraying the delicacy of the tints, and their transitions, and the fine lines and groups therein displayed.

The light of an oil-lamp or a gas-burner produces the same invariable spectrum as that of the sun-light, but the blue and more particularly the violet are very feeble and *Frauenhofer*'s lines are here entirely wanting. We can produce a very strong light if we burn charcoal or a very strong iron wire in oxygen, or a magnesium wire in atmospheric air or oxygen. Phosphorus, sulphur, and zinc, as well as many other metals, when burned in oxygen, produce intense light and particularly vivid are the scintillations of charcoal in a strong galvanic current. All these sources of light furnish continuous Spectra, as also the faint light of the glow-worm, and of phosphorus, in atmospheric air of the usual temperature. It is true, that there are many varieties in the Spectra of the above-named lights, for example, in the blue and violet part of the Spectrum, the light of burning sulphur and particularly of Magnesium is very intense, whereas that of phosphorus in a common temperature and of the glow-worm is very feeble, while in the sulphureous light yellow in almost entirely wanting and that of phosphorus and zinc, exhibits a much greater intensity in the green parts of the Spectrum; but the Spectra of all these kinds of light are continuous and free from black lines, and if light lines and stripes are more or less conspicuous in them, they owe their origin to the presence of a small quantity of other substances, to which phenomena we shall soon turn our attention.

In all these cases light is produced by chemical processes, namely combinations with oxygen; however if we, independently of this process, heat to a red heat various substances, which do not undergo any chemical changes in fire, we shall find on a spectroscopic examination, that platinum, clay, lime, in short, all fire proof solid matter, when gradually heated emits at first a dark red, then a light red, then a yellow, afterwards a green, subsequently a blue, and at last a violet light; while the Spectrum is more and more developed towards the violet side as the temperature increases also the intensity of the colours, which have already appeared, is greatly augmented. The spectrum of glowing solid matter is in every case continuous and contains all the colours of the solar spectrum; the intensity of each single part of the Spectrum increases with the temperature. The qualitative difference in the light of matter heated to red heat and white heat can, as is already known, be recognized with the naked eye, and it is only in some exceptional cases, that certain coloured rays of light are emitted with a peculiar intensity from glowing solid matter, as *Bahr* and *Bunsen* have proved in the case of the two rare substances *Erbic and Didymic oxyds* impregnated with phosphoric acid. These substances heated to strong incandescence emit a light the Spectrum of which is distinguished by some bright stripes of coloured light, corresponding to that, the naked eye also recognizes a specific colouring of the light, which these substances emit, when heated to white heat.

The flame of illuminating gas dœs not clearly prove, that *gases* have the power of emitting light when strongly heated, as the light of all our common flames is generally to be traced to the glowing of separated particles of coal (however great may be the deficiencies in this explanation); whereas, for example, in the flame of one of *Bunsen*'s gas-burners the secretion of solid matter certainly does not exist, and yet this flame gives a feeble, but specific light.

Bunsen's gas-burner has become an indispensable expedient in spectral analysis, we will, therefore examine its flame more minutely. According to the light, we can plainly distinguish in its interior four different divisions. The inmost cone contains that mixture of gas and athmospheric air before it is in a state of combustion, which rises out of the pipe of the burner without any perceptible light. A fine Platinum wire held obliquely through the lower part of the flame, does not glow as far as it extends into the interior of the cone. This dark cone enveloped in a thin, bluish-green, relatively bright shining mantle, in which the chemical combination of oxygen and the ingredients of illuminating gas takes place. This cover is surrounded by a second space, similar to the last, possessing a very feeble power of emitting light, indeed it appears to be entirely without light; no further chemical combination occurs in this space, such an one can first take place again in the extreme edge of the flame, which is distinguished by a feeble blue light and in which the rest of the gas is burned, which had remained still unconsumed in the interior of the greenish cover. We may say, that in the interior of the greenish mantle, the combustion of oxygen takes place in surplus gas; in the blue external edge of the flame, the combustion of carbonic oxyd only, and a small quantity of hydrogen, into surplus oxygen. If the quantity of atmospheric air, which is drawn into the tube of the burner by the gas and the combustion, is not sufficient to transform the carburetted hydrogen to a mixture of carbonic oxyd and hydrogen, carbonic acid and water, white light is to be seen between the external edge and the interior of the green covering, or indeed, as the point of the latter, and a cold china plate inserted in this bright part of the flame will be covered with soot.

If we admit, oxygen with a surplus of inflammable gas, by means of a oxyhydrogen gas-blow-pipe, into a glass tube, which is closed at the lower end and supplied with a small narrow opening at the upper part, the flame of oxygen, which burns in a surplus of gas exhibits the same properties as the green mantle of the flame in *Bunsen*'s gas-burner, while that mixture of gas, which escapes through the upper opening of the glass tube either burns with a feeble blue flame, or if much gas and very little oxygen enter the glass tube, produces also a white light.

That bluish-green light, which proceeds from the space, which surrounds the dark inner cone of the flame of *Bunsen*'s gas-burner, was first analyzed by *Swan* in his Spectrum, and minutely investigated, before the results of *Kirchhoff* and *Bunsen* were published. Fig. 2 in the coloured frontispiece represents the Spectrum of this light. Lines of green, blue, and violet, characteristically grouped, and separated from each other by total darkness, with a faint glimmer of red, and a bright shining yellow line (which however, is caused by the presence of sodium in the flame, which it is scarcely possible to avoid), are exhibited by this extraordinary Spectrum. This Spectrum is always produced during the examination of those flames, which contain hydro-carbons with insufficient or sufficient oxygen, and as every kind of carburetted-hydrogen, when burned, developes this light, whereas a mixture of carbonic oxyd and hydrogen in a state of combustion do not produce it, we may conclude, that this development of light arises from the separation of carbon and hydrogen. Cyanogen-gas gives a splendid red flame, when it is burned in atmospheric air or pure oxygen. When the light of this flame is decomposed in the Spectrum, it exhibits a very complicated combination; numerous bright lines and bands, separated from one another by spaces of total darkness, appear in entirely different parts of the Spectrum and a few of them correspond with the hydrocarbon Spectrum represented in Fig. 2 of the frontispiece. The gas from ammonia-gas, phosphuretted-hydrogen and other gases, when in a state of combustion exhibit also a light with beautiful interrupted stripes, that is, to say stripes of coloured light divided from each other by dark parts, while other gases, for example combinations of sulphur, and carbonic oxyd afford continuous Spectra.

The Spectra of light displayed by evaporating metals such as Potassium, Sodium, Lithium, Cæsium, Rubidium, Calcium, Barium, and Strontium, or their salts, are very simple, beautiful and easily observed. If we bring a grain of common salt or soda or any other combination of Sodium into the flame of *Bunsen*'s gas-burner, by means of a fine Platinum wire, the flame becomes of a pure yellow colour and shines with great intensity; traces of combinations of sodium, which cannot be weighed by the most accurate scales, have the power to impart this colouring to the flame. After a wire of Platinum has been exposed to the air for a short time, it always produces this yellow colour as soon as it is introduced into a flame, if only for a moment. If we detonate in a room a small quantity of a mixture of nitrate of saltpetre and charcoal each flame obtains a yellow colour from the invisible particles of dust, which fly about and contain sodium. The

Spectrum of this yellow flame of sodium is extremely simple; when it is examined with a small spectral apparatus it appears to consist of a yellow line; but when Prisms are used, which greatly disperse the Spectrum, or several Prisms are combined in the spectral apparatus, this line diverges into two others standing close to one another. When the combinations of Lithium are brought into the flame of *Bunsen*'s gas-burner, they exhibit as Spectrum a beautiful red, and a feeble reddish yellow line; combinations of Potassium exhibit a dark red and blue violet line at both ends of a very feeble continuous spectrum in yellow green and blue. The Spectra which gas light affords when combinations of Calcium, Strontium, and Barium, are introduced into it are much more complicated; they also consist of separated bright lines and groups of lines, and, indeed, the combinations of Calcium are distinguished by a red and a green line, combinations of Strontium particularly by a beautiful deep red line, and combinations of Barium by a number of green lines. In the coloured plate at the commencement of this pamphlet Fig. 3 represents the line of the combinations of Sodium, and Fig. 4 the Spectrum of the combinations of Potassium.

Kirchhoff and Bunsen perceived on carefully examining the purified salts of the metals already specified, that the bright spectral lines were produced by every evaporable combination of the same, and that we may infer that wherever those lines appear in the Spectrum of a flame, the vapour of those metals must exist, thereby, presenting Chemistry with an extremely simple and important method of searching for those metals in the most various natural and artificial mixtures and combinations.

The discovery of two metals, which had hitherto escaped the notice of chemists, immediately followed these examinations: viz. *Caesium* and *Rubidium*, of which very slight traces of their combination, are to be found in minerals and mineral waters. The disclosures of *Bunsen* were followed, in the department of spectral analysis, by the discovery of *Thallium*, by *Crookes* and *Lamy*, and of *Indium*, by *Reich* and *Richter*.

Frauenhofer had already observed, that a Spectrum could be obtained by the decomposition of light by electric sparks, which is interrupted by black parts, and differs essentially from the light of the sun. Later, examinations by *Masson*, *Ångström*, *Plücker* and *Kirchhoff* have proved, that the light of electric sparks varies according to the kinds of gas, which the spark traverses and the chemical nature of the points between which it passes. We may presume, that in the extremely high temperature of the electric sparks metals and other substances between which the sparks pass, become volatilized, and the vapour of these bodies ignites just like the gas, which fills the space between the ends of the wire. It is possible to design the characteristic spectrum of the glowing vapour of every metal, by inserting the same in a galvanic current of sufficient power, in such a manner, that the sparks passing between the metallic points can be observed with the Spectroscope.

The flame, which is produced in the fabrication of the so called *Bessemer* metal, by atmospheric air being blown into melted carboniferous iron, contains various coloured rays of light according to the stage in which this metallurgical process takes place. Although the cause of all the light streaks, which are to be seen in the Spectrum of this flame is not known, the spectroscopical examination of the changes of the flame in the course of the process has already proved a very important means of discerning the separate stages of the same.

Many a problem remains unsolved with respect to the explanation of spectral phenomena. The usual acceptation, that the vapour of some bodies can be brought to develope light in a slightly raised temperature, others, when it is greatly increased, does not appear satisfactory. In the flame of *Bunsen*'s gas-burner, Quicksilver, Zinc, Cadmium, Indium, besides several combinations of alkaline metals (Kalium, Sodium &c. &c.) easily evaporate, but neither Quicksilver, Zinc, nor Cadmium develope light, and yet, in a chemical point of view, *Indium*, the vapour of which displays a bright light, stands nearest in relation to Zinc and Camium. The development of light, which so often appears during the transformation of a chemical substance into another, at a lower temperature, the glowing of phosphorus, of the glow-worm and many other phenomena indicate, that at least, other causes besides the temperature are conditional to the development of light.

Let us now turn to the phenomena of absorption of light by different substances, phenomena, which are much more diverse than those of the emission of light, which come under our observation in every day life.

We learn in our childhood, that the rays of the sun, which are thrown back from the surface of water or from a pane of glass are not emitted by those surfaces, but are to be considered as reflected; but still more frequently the phenomenon is presented to our eyes (which is more difficult to understand), of more or less brightly coloured light, which appears to be emitted from a substance, for example, from a dyed stuff, while in the dark every coloured object of this kind proves, that it contains no light within itself. That the colour of substances, the green of plants, the variegated colours of blossoms, entirely proceed from the light of the sun, which shines on these bodies, that a red rose only possesses its red colour as long as red-light falls on it, can only be proved by much deeper examination. Every body with a smooth surface, has the power to reflect the rays of light, which fall upon it like a looking glass, but if the rays of light do not incline towards the flat surface in a very acute angle, a portion of them enter the body and therein, undergo a greater or lesser alteration according to the nature of the substance, and we can say, speaking in a general sense, that the physical arrangement of the particles in a substance, stipulate for the direction of the oscillatory motions of ether (its polarization) and the chemical construction of the molecule of the body for its property of absorption and its *fluorescence.*

Light is transmitted through very many crystals apparently unchanged; for example through rock-crystal, as well as glass, water, and atmospheric air; while, on the contrary, coloured glasses, and solutions of different metallic salts, alter the light, which enters them, and absorb certain kinds of light, while they let other kinds of coloured light pass through them unmolested. The greater part of the so-called opaque substances possess the property of strongly absorbing certain colours in their superficially illuminated layers, and of reflecting other kind of coloured light in every direction.

The colour of a substance in white sun-light, is the remainder of the light which this substance has not absorbed; this is clearly proved in a spectral examination.

When the light of an oil-lamp or that of a ball of lime heated by a hydro-oxygen blow-pipe or still better the burning magnesium wire, is decomposed, we obtain as Spectrum, by means of the Spectroscope, a regular succession of the colours of the rainbow; but if we admit the light through a blue glass into the Prism of the apparatus, either before or after its decomposition, we shall perceive several defects in the Spectrum in certain places, particularly in the yellow; if we, however, transmit the light through a solution of chromate of potash, instead of the blue glass, we shall find the defects particularly in the blue and violet. The blue glass, therefore, powerfully absorbs the yellow, while the reddish-yellow chromate of potash absorbs the blue and violet light.

The variety in the influence of coloured substances on white light is very great, and as little as we are able to recognise from the colour of the light of a flame, what kind of light it contains, as little can we recognize from the colouring, which is shown by a substance in white day-light or lamp-light, which coloured kinds of light it absorbs either weakly or strongly; the decomposition in the Spectroscope of the altered light, which is again emitted from the substance can alone explain this phenomenon.

We have already seen, that the light, which is emitted from a self-luminous body either contains every kind of coloured light or only several and therefore it produces, in the latter case, a curtailed or interrupted spectrum. The phenomena of absorption are completely analogous. Many substances absorb every coloured light and then appear gray or black, as *graphite*, coal &c. &c., others leave a little red and yellow and then look brown like the soil of a field; while others only absorb violet or blue light and then appear yellow; whereas there are other substances, which absorb with great eagerness every sort of coloured light excepts red and yellow, which remain almost unimpaired and have an orange-reddish colour like the bi-chromate of Potash, but a great number of very brilliant pigments, absorb with great predilection particular pieces of the Spectrum, relatively leaving the other parts untouched. Thus if we examine white light after it has passed through a solution of hypermanganate of Potasium we shall find the Spectrum traversed by 5 black stripes in the yellow, green, and blue light, and divided into separate pieces; innumerable black lines and stripes appear in the Spectrum if the white light has passed through the vapour of hyponitric acid before it enters the Spectroscope. The colourless atmospheric air, particularly, when it is very moist, also produces black lines of absorption in the Spectrum of the light of the Sun and stars.

Very beautiful phenomena of absorption are effected by the 2 pigments, which play so important a part in the life of superior animals and plants; viz: chlorophyll or the green matter of the leaves of plants and the red pigment in the blood of human beings, and vertebral animals. The influence of chlorophyll is distinguished by the powerful absorption of a certain part in the dark red field of the Spectrum, as well as the strong absorption of blue and violet; the two last mentioned colours are immediately changed into a red light phenomenon of fluorescence, which we cannot now more closely examine. A weak solution of the red colouring matter of the blood, powerfully extinguishes two parts in the yellow and yellowish green fields, which are not very far distant from one another; so that two strong absorption stripes appear here as soon as we examine sun or lamp-light with the Spectroscope, which has passed through a sufficiently diluted solution or thin layer of this pigment on its way to the apparatus.

The combination of this colouring matter is changed in a most striking manner during the circulation of the blood. During the passage of the blood from the arteries to the veins through the capillary vessels, it loses oxygen, and this chemical change has a very decided influence on the absorption of light. The colouring matter of arterial blood is of a scarlet, that of a venous of a much darker greenish red colour; the latter absorbs less blue light than the colouring matter of arterial blood but a greater quantity of orange-red light. If we by means of reductive substances remove from the colouring matter its loosely chemically combined oxygen, it no longer exhibits in white light two absorption stripes, but a single one, in which the contour is less sharply defined in that part of the Spectrum, where the arterial colouring matter shows a yellowish green light between the two absorption stripes already designated. The slightest chemical alteration in this colouring matter, also totally changes its influence on the light. In the Frontispiece, Fig. 5 delineates the operation of a weak solution of Chlorophyll, represented in the Solar Spectrum; Fig. 6 that of the arterial colouring matter of the blood, and Fig. 7 that of the pigment of the blood freed from oxygen.

In the above description of the phenomena of absorption I have continually referred to a continuous Spectrum, like that, which glowing solid substances, lamp-light or sun-light afford; I will now add a short examination of the phenomena, which light absorbing bodies produce, when the source of light does not emit all the rays of light of the Solar Spectrum, as such cases possess a practical interest. It is well known, that the most brilliant illumination with innumerable oil-lamps, candles, or gas flames, is not able, to replace, in every respect, the light of the sun; because the flame of gas, oil or of a candle contains red, yellow, and green light, but blue appears very faintly, and violet particularly sparingly. It is, at the same time, a known fact, that substances, which have the most beautiful and brilliant violet or blue-violet tint, look by lamp-light dim and faint, and that it is very difficult to distinguish blue from green by the light of a lamp. Every violet, and almost all blue pigments, which are used to dye stuffs, and colour paper &c. &c. absorb, very powerfully the yellow and yellowish-green rays of light, but when these colours are absorbed by those materials, and those coloured sorts of light, which do not affect those stuffs, and are only furnished by the source of light in a very slight degree, then these substances must appear very dark. Among the blue colouring matters, smalt, ultramarine, indigo, and cyanine, show strong absorption stripes in the yellow of the spectrum and by lamp-light appear very dark and greenish, or rather violet, according to their power of absorbing red or green.

If a source of light only produces light of one colour, as for example the glowing vapour of Sodium, every substance, which absorbs this light appears black, and that, which does not absorb it white. A coloured picture, a bouquet of variously coloured flowers, illuminated by one of *Bunsen*'s gas-flames into which a little common salt, is introduced, exhibit only shades, a strip of paper dyed with aniline red and another with cyanine, appear equally in this light to be dyed slate colour, while crystals of bichromate of potassium appear quite white. As the colouring matter of the blood exercises a strong absorptive power over the Sodium light, the red colour in the cheeks appears as a black shadow in the face, and the blood as a black fluid. But, on the contrary if we illumine all these substances with magnesium light the variegated colours of the picture and of the flowers appear, and aniline red and cyanine exhibit the great difference, which exists in their colours, bi-chromate of Potassium becomes orange-red, the cheeks of human beings redden, and blood itself shows its scarlet colouring.

We first considered the dependance of the emission of light upon the chemical nature of the substances, and I endeavoured to explain, that the *absorption* of rays of light is only determined by the chemical condition of the bodies; but the *emission* of light and its *absorption* correspond with one another in the one respect, viz: that their intensity augments as the temperature rises, and that new rays of light appear to come forth with the increase of the temperature, the red glow dissolves into the white, and thus in a higher temperature new rays of light appear te be emitted.

Of course we allude only to those substances, which suffer no chemical alteration from an increase of temperature, therefore, particularly, the so-called anorganic substances. Among these, a great number of oxyds exhibit a dark tint when heated; bioxyd of tin and oxyd of zinc when heated strongly become; yellow yellow protoxyd of lead appears brown and the light red peroxyd of mercury as well as the oxyd of iron are quite black when heated to red heat. All the above named substances resume their light colouring as soon as they become cool. The hyponitrous acid affords a highly interesting example of the increase of the absorption of light, when the temperature is raised. It appears at — 20° in the form of colourless crystals, at 0° as a light yellow fluid and as the temperature increases, it produces an orange-red vapour, which gradually becomes dark brown according to the increasing heat of the temperature, and at last appears quite black and completely opaque. If we bring a glass tube filled with this vapour to the slit in the Spectroscope and then allow a ray of light from the sun or from a lamp to pass through this tube into the apparatus, we shall obtain a Spectrum traversed by innumerable fine and broad lines and stripes, the absorption streaks of which increase continually in number and breadth, in proportion to the increased heat of the vapour in the tube until at last all the light in the vapour is absorbed, and consequently the Spectrum entirely disappears.

Analogous observations as well as theoretical examinations have, for some time, pointed out to us, that the emission of light from a glowing body must necessarity be in a certain proportion to the absorption of light for one and the same substance. The fact has long been known, that substances, which strongly absorb caloric rays emit them again with the same power. Caloric rays, are rays of light in which the oscillatory motions are of long duration, but there are different phenomena, which seem to show another proportion for rays of light in which the duration of the oscillatory motions is shorter, particularly for blue and violet light. Indeed, the rougher and more porous the surface of a glowing substance is, the greater amount of every kind of light is emitted from it, and the radiation of light and heat are proportionate, as well as their absorption; however, on the one side the wonderful phenomena of *Fluorescence* appear to contradict the supposition, that a substance absorbs the same rays of light, which it has the power to emit, and it has been found, that bodies, which possess very different absorptive powers for the single rays of coloured light, at the common temperature, when heated do not show any difference in the rays of light which they emit; a piece of chalk, gray platina, and black coal, when heated emit all the rays of light of the continuous Spectrum in the same manner. The following theorem was adduced by the English Natural Philosopher *Stokes* and afterwards, independently of him, by the Swedish Philosopher *Ångström*, based on different observations; viz: that a substance just emits those rays of light, which it has the power to absorb. *Ångström* based his theory on the principle, which had been expressed by the renowned Mathematician and Natural Philosopher *Euler*, more than a hundred years before, the tenor of which was that every body absorbs light of that oscillation which its own particles exhibit; a principle which compares the origin of the colour of bodies with the nature of the resonance of sounds. *Kirchhoff* came also to the conclusion, by means of theoretical speculations, that a body absorbs those rays of light, which it has the power to emit, and in 1860, he not only succeeded in furnishing the indubitable experimental proof of his theory, with respect to some metals, but also in drawing very important consequences.

Before I describe the elegant experiments by which *Kirchhoff* proved that the light, which is emitted from a body and that, which is absorbed by it are identical, I will first mention some every day experiences indicating this fact. If we heat a piece of iron or clay until it is red hot, it shines, independently of its chemical nature, according to its temperature and surface; after a certain thickness it is quite indifferent as to the quantity of light emitted, what thickness the substance may be. Undoubtedly its interior particles are incandescent and emit light, but the light, which proceeds from every particle is absorbed by that, which surrounds it, and it is proved by facts, that light is only emitted from its surface. In a dark space an object is much better illuminated by the light of 12 candles properly placed, than when 6 are extinguished, but on the contrary, if we illuminate the object with 6 candles placed behind each other, the light cannot be increased by 6 other candles being placed exactly behind those, which are already there, if we avoid collateral light.

Among the experiments, which *Kirchhoff* particularly valued as a proof of the above question, one is very beautiful and striking and easy to be made. *Roscoe* found that a glass tube closed at the top and bottom, containing sodium and hydrogen gas, hung up perpendicularly and heated at the lower end so that the Sodium evaporates, appears in the interior totally black and opaque, when it is placed near a flame, which emits a yellow sodium light. *Kirchhoff* placed such a tube before the Spectroscope and admitted the light of a candle or of an oil-lamp into the spectral apparatus; he then found, that two absorptive stripes, which were near one another were produced in the almost continuous Spectrum, which corresponded with the situation of those brilliant lines, which the vapour of Sodium emits in an ignited state. This very beautiful experiment shows most convincingly, that the vibrations of the light, which is emitted from the glowing vapour of Sodium and that, which it absorbs are identical. All other kinds of light are transmitted undiminished through the vapour of Sodium.

Kirchhoff obtained from the vapour of Potassium and Lithium, the absorption of those rays of light, which the vapour of these metals emitted, while in a state of incandescence. Later *Bunsen* discovered, that solutions, which coutain *Didymic* or *Erbic* oxyds absorb those kinds of coloured light, which these oxyds especially emit, when in a glowing state.

The relation of the absorption of light in bodies, to their power of emission of which we have just spoken is a very important physical fact, but it would be very uninteresting for the uniniated, if *Kirchhoff* had not through this discovery given the first and undoubtedly the correct explanation of *Frauenhofer*'s lines in the Solar Spectrum, and finally added extensive inferences on the physical and chemical constitution of the sun and stars. As I have already mentioned several times the solar spectrum is interrupted by thousands of fine and thick black lines, the broadest of which are indicated in Fig. 1 in the frontispiece. Two opposite causes can produce these lines. Either the sun does not emit those rays of light which, according to the duration of their oscillations answer to the *Frauenhofer* lines, or the Sun emits light of every colour, (as we have seen by solid bodies,) but on the way from its source to our eye, the light has to pass through substances, which absorb the kinds of light, which correspond with *Frauenhofer*'s lines.

We have already mentioned that the atmosphere of our earth is not without influence in this respect, and that some of the spectral lines of the solar light are most decidedly caused by this influence. The lower the Sun stands in the heavens, the darker are these lines, as the way is longer, which the rays of the sun have to pass over before they reach the apparatus and the eye. But that every spectral line is not caused by the atmosphere of the earth is particularly clearly and simply proved by the fact, that many of these lines are entirely wanting in the Spectrum of some of the fixed stars, the light of which must be affected by the atmosphere in the same manner as that of the Sun.

In the middle of the most radiant yellow of the Solar Spectrum, there is a group consisting of two thick dark lines, which are very near to each other and appear as *one* line, when viewed through a prism of weak dispersive power; *Frauenhofer*, who first carefully observed this group designates them both together by the letter D; it had already struck him, that the yellow double line, which he recognized in the spectroscopic examination of different flames so strongly resembled the double line D in the Solar Spectrum, *Kirchhoff* observed, that the double line D of the Solar Spectrum became much sharper and darker, when he examined sun-light after it had been transmitted through the flame of aqueous alcohol, which contained a little common salt, and that, on the contrary, the light double lines of sodium appeared in the place of the dark lines as soon as the light of the sun was excluded from the flame and the apparatus, and the light of the spirit flame was examined alone.

According to all *Kirchhoff's* experiments it is indubitably settled, that the group of Sodium lines takes exactly the same place in the Spectrum as the double line D. The careful comparisons, which have been further made respecting the situation of the dark lines in the Solar Spectrum and the light lines, which is exhibited by the incandescent vapour of metals when they undergo a spectral examination, have proved with the greatest exactness, that iron, magnesium, and other metals exhibit, like sodium, bright lines in that part of the spectrum, where black lines are to be found in the solar spectrum and this important discovery must immediately lead to the acceptation, that the main substance of sun light emits all the colours of the Spectrum and that *Frauenhofer's* lines, as far as they are *not* produced by the atmosphere of the earth, proceed from absorption in the atmosphere of the sun, as that contains the vapours of sodium, iron, magnesium, chromium, nickel &c. &c. and that they absorb light, of the same duration, which they have the power to emit. An explanation has not yet been found for all the lines in the solar spectrum and there are many metals, which do not appear to be contained at all in the atmosphere of the sun or at least in very small quantities.

It is perfectly to be understood, that the light of every planet and its satellites, which have no power to emit light but only emit to us the light of the sun, which is reflected on their surface, must, in a spectroscopic examination perfectly correspond with that of the sun, if no substance be found on their surface, which powerfully operates as an absorbent on certain rays of light. *Frauenhofer* remarked, that the spectrum of Venus entirely corresponds with that of the Sun; and the Moon's spectrum has also till now exhibited an entire conformity with it. *Secchi* found streaks of absorption in the spectrum of *Saturn* and *Jupiter*, which do not appertain to the light of the sun; likewise in the blue field of the spectrum of *Mars*. These absorptions caused by the chemical substance of the surface of these planets, are added in the Spectrum to those of sun-light and the atmosphere of the earth. It is otherwise with the fixed stars.

The light of the most brilliant fixed-star is so faint even when the sky is quite clear and the air still, that the most simple spectral apparatus must be applied to the telescope when they are to be examined in order to avoid every possible loss of light. In spite of the numerous examinations, which have been made, in the last few years, in this interesting department by Father *Secchi* in *Rome*, *Huggins* and other Natural Philosophers and Astronomers, no general rules have been discovered although some important points have been proved. *Secchi* divided the fixed stars into 3 classes according to the spectral appearance of their light in one of which (*Secchi*'s third class) the rays of light and lines of absorption closely correspond with those of sun-light, while both the others differ very widely from them. In the frontispiece the 3 last spectra, Fig. 8. *9.* 10 are taken from the typical sketches of *Secchi.* No fixed star, which has hitherto been examined completely corresponds with the sun in the combination of its light. The *Arcturus* (Bootes) Pollux and Capra as well as many other stars with a yellow light resemble the Sun and exhibit the principal lines of *Frauenhofer.* A second class of stars (according to *Secchi*, the first and most frequent type of very bright stars) to which belong *Sirius* (the spectrum of which is described by *Frauenhofer*) α Lyra, α Aquila, the Pleiades, Hyaden, the Stars of the Great Bear, exhibit in their Spectrum two or three very dark and broad lines, of which the one coincides with the line F of the solar spectrum and both the others lie in the violet; besides innumerable lines in the yellow and green, and finally the third class, *Secchi*'s second type, produces spectra in which the light parts are separated from one another by broad dark stripes and in the light parts of which very peculiar shadings are to be found. To this type we may particularly class α Hercules, β Pegasus and α Orion. *Secchi* was further convinced, that in certain celestial regions and particularly in certain constellations one and the same type of the Spectrum belongs to all or almost all the stars.

The faintly shining nebula and comets were examined by *Huggins* and *Secchi* and they agreed, that their Spectra simply consisted of a few light lines, nay even that one of the comets, which they observed was found to consist only of *one* line. The tail of the Comet exhibited a faint continuous spectrum. *Huggins* obtained two Spectra, one above the other, from a Comet, which was only visible for a short time, and a star, which was covered with a misty veil; of which the one contained bright lines of light the other absorption lines in a continuous Spectrum. *Secchi* has lately analytically examined numerous stars, up to the 8^{th} magnitude, but found no important new Spectra. A new examination of the spectrum of Syrius resulted in the discovery of an elegant line in the red, numerous lines in the green and very sharp double lines in the situation of D in the Solar Spectrum so that *Sirius* must contain sodium in its atmosphere as well as the sun and all the fixed stars.

The examinations of star-light, which have hitherto been made, have been till now neither sufficiently minute nor carried out far enough to render it possible to make an entirely comprehensive comparison between the light of the sun and that of our terrestial bodies. *Secchi* designated his examinations as *preliminary*, but still it is to be perceived from the descriptions we have given, that the various heavenly bodies differ widely from each other in circumstance and condition.

An increased perfection of optical expedients as well as continuous persevering study will bring to that untiring thirst for knowledge which exists in the human mind, new satisfaction in this sublime cosmical department of science and incite to the solution of new questions; but it is not alone in the broad expanse of the heavens, that the motions of ether promise a more profound knowledge of the laws of the world, but also in the study of the motions of the atoms, which represent chemical combinations and decompositions, and in the investigation of the whole physical and chemical formation of the substance of our earth, that may expect to gather light from light.

(331)

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