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THE SPECTROSCOPE IN ASTRONOMY.

BY PROF. W. W. PAYNE, OF CARLETON COLLEGE.

To present this subject most directly and effectively, a stereopticon with suitable projecting apparatus and certain chemicals should be at hand, that the person conducting the exercise might illustrate, at least, the prominent features of this new science, and in this way easily answer general queries concerning its fundamental principles, in a practical and *perhaps* somewhat entertaining way. But, in the absence of these important aids, we are left to depend wholly on the statement of facts and principles, accompanied with a few illustrative drawings, by the aid of which the nature of the spectroscope and its practical use in astronomy may be hastily unfolded on the present occasion.

In 1672 Newton discovered that a ray of sunlight in passing through a prism would be drawn out into an oblong band of rainbow-tinted colors, like the illustration seen from the map before you. (See Johnson's large astronomical charts) A century later Wallaston found that if a ray of light were admitted through a narrow slit instead of a circular aperture and permitted to fall on a prism in a dark room, dark lines could be seen crossing the colored band, showing that dispersed sun-light did not seem to possess continuous refrangibility.

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In 1814, Fraunhofer, a German optician, used a small telescope with which to view this band of colored light, and in it he saw and determined the position of 576 dark lines, which have since been called Fraunhofer lines, in honor of his attempt to map them.

The spectroscope of the present time, has one or two small telescopes with a prism, or a piece of diffraction grating as its main working parts; a very simple contrivance indeed, that differs in no important principle from that used in earlier times, except in employing the grating instead of the prism when the observer so desires; his instrument is then called a diffraction spectroscope. The grating, as it is called, is usually made by ruling a piece of glass or speculum metal by fine equidistant lines, from 2,000 to 20,000 to the inch. The light admitted through a small telescope to the grating is transmitted, if it be glass, and reflected if it be of speculum metal, and then received into another telescope when the dispersion is seen and read by proper scales in the focus of the instrument. If the prism be used, dispersion of the light will be proportionate to the number of prisms employed. Instruments of efficiency will contain from five to eleven prisms in the train with suitable appliances for ready manipulation. The power of the diffraction grating will depend on the fineness and evenness of surface and rulings. Mr. Rutherford, of New York, has succeeded in ruling on silvered glass so perfectly that a dispersive power has been secured equal to that of a train of thirty prisms. Though less brilliant than the prismatic spectrum, the grating gives more accurate results and furnishes the standard in case of dispute.

The principles on which the spectroscope acts are these:

1. An incandescent solid or liquid always shows a perfectly continuous spectrum containing neither dark lines nor bright ones. (See map.)

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2. The spectrum of a glowing gas always consists of narrow bright lines or bands separated by dark spaces.

3. The spectrum is crossed by dark lines.

These three statements are called the laws of spectrum analysis, and are all proved by experiments in the physical laboratory.

It is a curious fact that if a spectrum consist of bright lines only, the *positions* of these lines on the reading-scale becomes the certain characteristic by which the element that causes them is known. It is also a strange fact, if an incandescent solid or liquid is viewed through absorbent vapors, that the dark lines of the third law will be seen, *always* in positions peculiarly their own.

It is then understood, and will be taken for granted, that when the spectroscope is turned on a solid or liquid body heated to incandescence a continuous band of variously colored light is *always* seen, and the *band* is continuous because the substance is liquid or solid in form.

If the substance be purely gaseous, then its spectrum will contain only *bright* lines peculiar to itself, and these always appear because the body under view is gaseous. Liquid bodies scatter the light of the spectrum broad cast and fill the band continuously with colors, but the vaporous or gaseous bodies husband the light and cause it to flow in channels and hence bright lines only appear. The case of mixed spectra is not so simple; and yet this point must be clearly apprehended and will be readily seen in the light of a few statements.

If a substance under the spectroscope be partly liquid and partly gaseous the observer ought to see a continuous band of light emanating from the incandescent fluid, and also bright lines projected from the gas if he could separate them, and it were true, that the presence of one spectrum would in no wise interfere with the other. But this is not true. There is disturbance. All spectroscopists know that if the light of an

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incandescent liquid flows through a gas or vapor raised from the same substances the vapor selects light peculiar to itself and absorbs it—quenches it, or puts it out. But the pure gas shines in the spectroscope in bright narrow lines,—so its power to quench light from liquids or solids is also in narrow lines; the spectrum is then said to be *reversed*, because in the place of bright lines, dark ones are seen, and hence the observer now knows that he is viewing both the liquid and gaseous state of the same substance. This is the third kind of spectrum mentioned before, and is commonly seen in studying the sun and the fixed stars. The cause for the dark lines lies in the important fact, that it is the nature of the gas to absorb just such light, from other sources passing through it, as its own pure spectrum would show. Again, in mixed spectra, if the gas gives out the same amount of light, or more than the burning solid or liquid, the dark lines are not seen, but a continuous spectrum with superposed bright lines. If the bright lines are weak because the gases are relatively cool, the observer will *increase* the dispersive power of the spectroscope and thereby weaken the continuous spectrum without diminishing the brightness of the lines. The principle is the same as that which enables us to look at stars in day light by the aid of the telescope. The telescope lessens the brilliancy of the sky, while a star, being a mere point of light is kept at the same intensity.

Hence, if the light of the sky is diminished and that of the star remains the same, it is evident that the star will appear relatively brighter, and proportionately so, as more or less power is applied. This was the mode of reasoning, and the process carried out by Mr. Lockyer in his notable discovery of the solar prominences upon the sun's limb without the favoring circumstances of a total eclipse. By increasing or diminishing the dispersive power of the spectroscope the continuous, or the bright-line spectrum may be made more or

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less prominent while other spectra will become weak or wholly disappear, at the pleasure of the observer.

Before these principles are applied to explain modern discoveries in Astronomy, we need to notice the wave-lengths of light of different colors; and it is assumed that the propagation of light is understood,—that its waves move in ether, nearly in the same way as sound waves move in the air, and that the color of light depends certainly on its wave-length, and con versely that certain wave-lengths in propagation give well-known colors.

The approximate numerical relation is as follows: There are 35,000 waves of red light in the space of one inch; orange, 42,000; yellow, 44,000; green, 50,000; blue, 56,000; indigo, 58,000; violet, 60,000. The range being from 35,000 to 60,000 in and English inch. Now as the spectroscopist knows the light emitted from the incandescent vapors of metals of the earth, he can easily compare the light of the sun and stars with these known spectra and deduce certain conclusions respecting the elements of these celestial bodies. In this way the following substances have been identified in sunlight by the aid of the spectroscope: Sodium, iron, calcium, magnesium, nickel, barium, sulphur, copper, zinc, cobalt, chromium, titanium, alumium, hydrogen, and, latest of all, oxygen. Since 1872 the spectroscopists of different nations have been discussing Dr. Draper's observations relating to the existence of oxygen in the sun. The complete and scholarly way in which this New York observer has investigated this question has given his opinions weight everywhere.

However, this knotty problem has not yet been fully and certainly solved, although many leading scholars in the science hold that the question has been settled during the last year. Young, of Princeton, says that the coincidences of the bright and dark lines are too numerous and too exact to be accidental, and that the presence of oxygen in the sun must be con-

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sidered as proved. This is a wonderful step in advance in this new science; and yet there are "serious difficulties in the way of accepting the conclusion;" for, as Young suggests, it is not easy to explain why oxygen should be represented by bright instead of dark lines, in the solar spectrum, while these lines are not seen in the spectrum of the chomosphere, which consists of bright lines. Dr. Schuster replies that oxygen under different circumstances presents four different spectra, varying from the faint continuous spectrum to one of few or many bright lines. This seems to suggest the existence of this non-metallic element in allotropic states, and gives a hint to the chemist that further study of oxygen in the laboratory may lead to important discoveries.

In the study of these non-metallic elements the *spectroscopist* is now calling to his aid the marvelous power of celestial photography. He already has hints of the existence of carbon and nitrogen in the sun, but as yet he cannot prove it, although the absence of these two elements has been a continual puzzle to astronomers, because their presence would be most natural to support high incandescence. When the proper conditions of the sensitive plate are known, these and other non-metallic elements will doubtless be seen and their existence proved; for M. Janssen, of France, one of the most noted spectroscopists in the world, has recently succeeded in photographing the minute cloud-like forms that are floating in the sun's atmosphere in groups, and that compose what is known in the books as its granular structure. To obtain these beautiful and marvelously perfect photographs the sensitive plate must not be exposed to the sunlight to exceed 1–500th of a second of time. This incredibly short time must be measured and used, or failure is certain. It is said by those who know that the difference between exposing the plate 1–100th of a second and 1–500th would make all the difference between success and failure. It is believed and hoped that the surprising powers of the sensitive plate may be soon turned to wise uses in the study of present unknown spectra. Before passing from the sun to notice what has been gained by the spectroscope from other celestial bodies, it is needful to explain another phase of this instrument which is by no means of little importance to the astronomer.

Until recently, science had no means of measuring the motion of the celestial bodies except by using the co-ordinates of right ascension and declination as they are called. With accurately divided circles, these co-ordinates will rigorously measure celestial motions, *only* when their direction is obliquely or perpendicularly across the line of sight. If a celestial body be moving *to*, or *from* the observer in a straight line, this means of detecting its motion would plainly avail nothing. However, strange as it may seem, these motions are accurately measured by the spectroscope if the body, in motion, be light-giving or sufficiently illumnated; but this instrument is powerless to ascertain the motion of bodies directly across the line of view. It therefore supplements the telescope by supplying a third and most useful means of determining the motion of celestial bodies. Let me illustrate carefully. I choose the words of Mr. Lockyer. "Imagine yourself in a ship at anchor, and the waves passing you, you can count the number per minute; now let the vessel move in the direction whence the waves came, you will then meet more waves per minute than before, and if the vessel goes the other way, less will pass you, and by counting the increase or decrease in the number passing, you might estimate the rate at which you were moving. Again suppose some moving object causes ripples on smooth water and you count the number per minute reaching you, then, if that object approach you still moving, and so producing waves at the same rate, the number of ripples per minute will increase, and they will be, of course, closer together for as the object is approaching you, every subsequent ripple is started not from the same place as the preceding one, but a little recover to you, and also nearer to the one preceding which it follows more closely. By an increase of the number of ripples, and also by a decrease of distance between them, one can estimate the rate of motion of the object *producing* them, for, the decrease of distance between the ripples is just the distance the object travels in the time occupied between the *production* of the *two waves*, which was ascertained when the object was stationary."

Now let us apply this reasoning to light. The light, we now behold is due to a state of vibration of the particles of an invisible ether, or an extremely rare fluid, pervading all space, and the waves of light although extremely small, move among these particles. Now, we know that it is the length of the waves of light which correspond to their refrangibility or color and therefore anything that increases or diminishes their length alters their place in the spectrum. As the waves of water are altered by the motion of the body producing them, moving *to*, or *from*, the observer, so the waves of light are changed by the motion of the luminous body in the same way, and this change of refrangibility is detected by the spectroscope. By measuring the wave-length of the F–line, as shown in these crayon drawings and determining the amount of change in position, we can determine the velocity at which the light source is approaching or receding from us.

Again, if the spectroscope be turned on a sun-spot the two dark lines of this figure (crayon drawing of the spectroscopic view of a particular sun-spot) become perceptibly wider, as faithfully sketched in the figure. That phenomenon means an increase of the *quantity* or *density* of the incandescent gas or vapor represented by these two lines. Not only, then, do we determine the existence of metallic vapors and measure the velocity with which they move in the line of vision, but we also perceive the varying *densities* of those great clouds of

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vapor that sweep across the field of the instrument. In this drawing the F–line is divided and one portion retains its place nearly, while the other portion is wafted toward the blue end of the spectrum. That means a change of the wave-length of the light, which is from hydrogen gas, and indicates that the motion was towards the observer at the terrible rate of 130 miles per second. In the next figure this same F–line is divided and wafted both ways, showing that these hydrogen clouds are sweeping both towards and away from the observer, at once suggesting to our thought the existence of a tremendous solar cyclone. Now, let us see if we can understand how these velocities are known. By careful measurements the noted Angstrom has shown that the absolute length of the waves of light of hydrogen giving the F–line, is 4,860 ten-millionths of a millimeter (a millimeter is about 0.04 of an inch). The dots on either side of the F–line of the drawing show where the light must fall, if it vary 1, 2, 3 or 4 ten millionths millimeters from the usual length of the waves of this line. If it fall on the fourth point toward the blue the wave-length of the light is reduced one-fourth of 4,860, or one one thousand one hundred and fifteenth of the unit of measure. The velocity of light per second is the unit, which, by very recent calculation, is 186,300 miles per second; such a fractional part of this number is 145 miles. Hence, we say those burning jets of hydrogen shown in the pink pictures before you, that can so distort and break up the F–line are sweeping towards us at the astonishing rate of 145 miles per second. If such a hurricane were playing on the earth's surface, it would spread a track of fire from Minneapolis to Chicago in little more than two seconds of time.

This a specimen of the storms and cyclones seen in the sun almost daily, by the aid of the spectoscope, which, for magnitude and fierceness, we can no more realize than we can comprehend the magnitude of the sun itself.

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The spectroscope has given material aid in the recent study of the planets. It offers a new classification which will enable us to consider them in pairs. Mercury and Venus (as shown in this figure of Johnson's map) are similar, shining by reflected light, and differing little in the atmosphere belonging each. Dr. Vogel, of Berlin, thinks that the light of Venus is reflected from the highest regions of its atmosphere, and its spectra do not show absorption in any considerable degree, as would be naturally expected, for it is known that Venus has a dense atmosphere, though it is not so certain in the case of Mercury.

Mars is grouped with the earth. The spectroscope shows that this planet has an aqueous vapor surrounding it that is denser, or stronger, as some writers term it, than that of the earth. A well-defined bright line is also seen that has no corresponding one in the solar spectrum, and hence a new element not found in the earth.

Jupiter and Saturn are peculiar in that they have no solid crust, but their masses are probably molten matter surrounded by a densely vaporous atmosphere. The evidence of this, that the spectroscope furnishes, is, the absorption bands, as they are called, seen in the case of both planets, which clearly show the presence of vaporous envelopes; but further than this, when the instrument is turned on the rings of Saturn no traces of atmosphere are detected. This is precisely as it should be, if the prevailing theory respecting the constitution of the rings holds, viz: that they are only an orbital ring or stream of meteors moving around the planet in obedience to the law of gravitation. If that be true, it is plain that they could have no atmosphere like our own in any important particular.

In the telescope, Uranus and Neptune are similar, and would be classified easily with Mercury and Venus; but the spectroscope shows a constitution wholly different. The dark

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absorptive bands indicate in these also dense atmospheres and an age, perhaps, much younger in geological development, than the others named. In view of the thick and heavy atmospheres that surround these remote members of the system, it is plain why astronomers have not seen spots on their surfaces by which to determine the time of their rotation.

This paper must not be lengthened to speak particularly of the spectra of new, temporary, or variable stars, which have been a theme of profound interest since 1866, when that star suddenly flashed up in *Corona borealis* and became of the second magnitude in brightness, and in a few days after rapidly sank back to a star of the ninth magnitude. The spectrum of that star showed the bright lines of hydrogen gas and indicated a conflagration of most astonishing proportions. Other illustrations of variable and temporary stars might be named but this one must suffice.

The constellation of *Ursa Major* furnishes an example of star-drift. By referring again to the map before you, it will be seen that the stars of this constellation are divided into three groups indicated by the colors, red blue, and yellow. The red stars are traveling to left, the blue stars are traveling to the right, and the yellow stars are traveling nearly downward relatively. It should be remembered that these colors for the several groups are chosen accordingly, and have no meaning beyond the idea of grouping the stars that are moving in the same direction.

The spectra of comets have been important to astronomy and conclusive in settling some questions. Cometary matter is now known to be self-luminous, though the nature of it is still uncertain. In the spectra of different comets there is a general resemblance to that of olefiant gas. Comet *d* of 1880, known as Hartwig's, showed a spectrum like that of carbon, and also was similar to the spectrum of Encke's comet of 1871.

Again, the spectroscope in connection with the photometer, as used during the last three or four years has enabled the

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astronomer to make great advancement in the study of the fixed stars. Not only is the vexed question of magnitudes now being settled on scientific principles, but the distances and *dimensions* of the stars are being computed by the skill and labor of American astronomers. It seems certain that if our text books keep apace with the easy on-going strides in every department of modern astronomy, there will be need of revision almost annually.

Finally, the spectroscope has shown the nature of sun-spots, as much as we know of them; the nature and extent of those great solar storms that occur daily; many substances in the sun and stars that are either metallic or non-metallic; the motions and varying densities of gases and metallic vapors in the vicinity of sun-spots; something of the photosphere, chromosphere and corona of the sun; new evidence is also given concerning the zodiacal light, comets, meteors, variable stars, fixed stars and nebulæ. Recently this instrument has been exceedingly helpful with others in the discovery of nebulous stars, a particular branch of work almost wholly unimproved. It has also done important work in the study of the planets known even from most ancient times.

In double-star astronomy it has become an auxiliary to the micrometer and photometer in weighing the masses, and in actually determining the diameter of the fixed stars, which is manifestly one of the greatest achievements of instrumental labor in the present decade.

In view of this wonderful unfolding of the beautiful and perfect handiwork of GOD, it is not strange that the devotees of science have recently laid vigorous hold on the spectroscope and applied it with assiduity to many important questions in physical astronomy. Its record though brief in time, has been unparalleled in usefulness.

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