Spectra, by whatever method observed, may be divided into three groups:

1. Continuous spectra: those in which a more or less continuous sheet of color is seen, usually beginning with violet and ending with red. Such spectra are produced by the light which is emitted from solid objects in a highly heated state.

2. Interrupted or bright-line spectra: those in which the colors are seen in the form of narrow lines or bands, separated by proportionately wide, dark spaces. Such spectra are derived from light emitted by gaseous bodies in a highly heated condition.

3. Absorption spectra: those in which a nearly continuous series of colors is present, but interrupted by dark lines or bands. Such spectra are produced by various conditions, principally, however, by the transmission of white light, or light which would give a continuous spectrum, through substances which have the power of absorbing or annihilating special vibrations. In the applications of the spectroscope to medicine and organic chemistry these absorption spectra are the most important.

It is obvious from the above considerations that we have in the spectroscope, whether of the refraction or of the diffraction form, a very valuable means of studying structure. In the first place, we can determine with great exactness the character of the source of light, *i.e.*, whether it is composed of gaseous matter intensely heated or of solid particles. Further, taking a source of known character, we can, by interposing various substances in the path of the light, determine the effect which these substances produce upon the different forms of light vibrations present in the ray, and, as particular effects are often peculiar to particular bodies, we have here a means of identification. Thirdly, using a source of heat practically non-luminous, such as the flame of the Bunsen burner, we can detect different substances by the color which they impart to this flame, and when several such substances are present the eye alone is unable to separate and distinguish the colors, but by the spectroscope each tint is distinctly indicated.

As stated above, it is the absorption spectra that are most important in reference to the medical applications of the spectroscope. Except in the comparatively rare cases of the study of the character of light emitted by luminous organic bodies, living or dead, and in the detection of certain metals present in minute amount in the tissues and secretions, *e.g*, lithium, the direct study of normal spectra is not much resorted to in biological work.

The arrangement of the spectroscope for observation of absorption spectra is simple. An oil or gas flame is adjusted so as to throw a beam of light through the slit of the instrument, by which a continuous spectrum not broken at any point by dark lines is obtained. Sunlight does not answer so well for the purpose, because, owing to certain interfering conditions occurring at the surface of the sun, and also during the passage of the sunlight through our atmosphere, there are numerous absorption bands (Fraunhofer's lines) always present in its spectrum.

The material to be examined is placed in a cell with flat sides in the path of the light before it enters the slit. It is scarcely necessary to observe that to secure a satisfactory result the body must be sufficiently transparent to permit some light to pass through, otherwise no comparison as to the effect on different parts of the spectrum can be made. Such a condition is easily obtained by using solutions of the substance in the usual colorless solvents—water, alcohol, ether, glycerol, etc., and diluting until a satisfactory result is obtained. The character of the absorption spectra sometimes differs, according to the solvent used and the presence of free acid or alkali. Working spectroscopes are generally arranged so that two spectra can be compared, one being a standard obtained under known conditions, the other being that of the body to be tested.

To understand the functions of the spectroscope it is necessary to bear in mind that the colors seen are practically images of the slit through which the light passes, and that when the ray contains all the colors—that is, every vibration from violet to red—the prism, in setting out the vibrations according to dispersive power, gives, of course, a continuous series of images, that is to say, a continuous spectrum. When, however, in the ray of light that enters the slit any vibrations are missing, as in sunlight, or when by some interposed condition certain colors are struck out of the ray, the images which would otherwise be formed by those rays are missing, and hence the spectrum appears interrupted. When the interposed substance strikes out many rays, *e.g.*, deep-colored glasses, the great bulk of the spectrum is missing. The red glasses, for instance, used in photographic dark rooms strike out almost all rays but the red. The spectroscope as ordinarily constructed is, unfortunately, subject to serious defects, which can be avoided only by instruments of very expensive form. It has been found that all the forms of glass possess marked absorption powers for certain rays of light. If, instead of employing glass lenses and prisms, we use those made of quartz, and employ as a source of light the electric arc, or burning magnesium wire, a spectrum is obtained which is very much extended at the violet end. This portion of the spectrum exists to a greater or less extent in white light from any source, but is absorbed to such an extent by glass that it is not seen in the ordinary spectroscope. There are also color waves beyond the red, which are only demonstrable by special apparatus. In the usual applications of the spectroscope we cannot, therefore, utilize the so-called ultra-red and ultra-violet rays.

A very important advance has been made recently in practical spectroscopy in the application of photography. A sensitive plate is capable of responding to and recording conditions which the eye is unable to recognize, and we have, therefore, not only a method of extending our knowledge of spectra, but we may obtain permanent records of absolute accuracy, and independent of any general or special defects in vision. The photographic plate is especially capable of receiving impressions from the violet and ultra-violet portions of the spectrum, which are especially those which the eye appreciates with the greatest difficulty, while the yellow and red rays are practically inactive.

Many substances are known which have the power to retard the rate of vibration of light rays, so that they change the color of the light falling on them. Now the ultra-violet rays, which are inappreciable to the human eye, are caused by extremely rapid vibrations; any substance which will reduce this rate will bring the rays within the range of vision. This property is known as fluorescence. It does not come within the scope of this article to more than refer to it, but it may be mentioned that one of the best methods for the preparation of photographic plates is to incorporate into the sensitive material some fluorescent body by which the rays of light are modified and effects produced with colors that would otherwise be inactive.

The only way of acquiring familiarity with spectroscopic appearances is by actual use of the instrument. No drawing, colored or otherwise, can convey perfectly the appearances. Nevertheless, a method of indicating the character and position of the lines is useful, and several plans have been adopted. The use of colored plates is, of course, the most vivid, but too costly for most purposes. The usual methods are either by recording the position of any line, or the centre of a band, by its position on an arbitrary and fixed scale, or by angular position. A form of spectroscope made by Browning, of London, has this latter arrangement. The view telescope moves in a graduated arc, and cross-lines in the field enable it to be brought to exact position with any line. By such method or by the scale the lines may be mapped in their relative positions as seen in that particular instrument.

Another method is to indicate the positions of lines by their calculated wave lengths; that is, the length of one complete movement constituting the ray which produces a line at the given point. Such a method has the

advantage of being an absolute indication, and not dependent on any particular instrument. Wave lengths are determined by mathematical calculation by means of the phenomena observed in diffraction, and the calculation may be easily applied to ordinary cases by plotting off on a chart certain lines of which the wave lengths are known, and interpolating those of which it is desired to determine the wave length. These lengths are very minute, and are usually expressed in millionths of a millimetre.

Description of Special Spectra.—*Bright-line Spectra.*—Each of the known elements gives a special and distinct spectrum when heated sufficiently to become a luminous gas. It has been pointed out at the beginning of the article that solid substances give continuous spectra, and hence there is no appreciable difference between the spectroscopic appearances of the different elements as long as they remain solid bodies. When the temperature rises sufficiently to convert them into gases, and render them at the same time luminous, the characteristic bright-line spectra are obtained. This temperature can be attained with most elements only by the use of the electric spark. A few bodies, among which are potassium, sodium, lithium, barium, calcium, strontium, and boron compounds, yield, at the temperature of the non-luminous gas flame—Bunsen-burner flame—a limited number of rays which are early observed by the spectroscope as bright lines. Sodium imparts to flame a deep yellow color which consists of two tints, and is seen in the spectroscope as a narrow double line. Potassium gives red and violet lines. By increasing the temperature some of these spectra are modified. When the electric spark is employed the spectra obtained are usually more complex, the bright lines being numerous. The detection of the different elements by this means is not so widely applicable as might at first be supposed, for the method is extremely delicate, and it is difficult to distinguish between the minute traces which often have no significance and the presence of an appreciable amount. Nevertheless, the method has been of great usefulness in special cases in showing the occurrence of some elements in unexpected relations, and the wide distribution of others in minute quantities. Several elements, occurring in such minute quantities that ordinary chemical analysis would have failed to indicate them, have been discovered by the spectroscope.

There are a few substances which give a limited bright-line spectrum before reaching the temperature at which they became gaseous.

Absorption Spectra.—These are of several kinds. The absorption may affect a considerable part of one or both ends of the spectrum, by which a whole block of color may be cut out, or it may take place in broad bands or in fine lines. The spectrum of the sun and of many of the fixed stars is an example of the latter class. The lines of absorption are numerous, but they are narrow and represent but a small portion of the entire field, which appears to the unassisted eye to be a uniform sheet of color. Band absorption—that is, the cutting out of a considerable number of rays at some point on an otherwise continuous spectrum—is brought about very easily by means of many organic bodies.

Extended absorption, by which a considerable portion of the spectrum is absorbed, is seen in many substances possessing deep color, and the absorption may include all but a single color. Various colored glasses may be used. To test the effect of a graduated increase of color wedge-shaped glasses may be employed. Hollow wedge-shaped cells are often used for the examination of colored liquids.

The method of observing absorption spectra has been given above. It has been also already pointed out that no description, nor even drawing, can give an adequate idea of the actual appearances of spectra, but for the purpose of completing the article and indicating some of the practical applications of the methods a few absorption spectra will be described.

Line-absorption Spectra.—Some of the rarer elements possess the peculiar property, when in solution, of absorbing special rays of light. Among the best known of these are the metals formerly included under the term didymium. It consists of two elements, forming compounds that have distinct colors, but, even when so far diluted as to make the tint not perceptible, they give absorption bands. The vapors of bromine and of nitrogen dioxide, NO_2, which to the eye have much the same color, give each a peculiar series of numerous fine absorption lines in the central part of the spectrum. The absorption lines that normally occur in the spectra of the sun and stars are an important clue to the chemical composition and physical condition of those bodies, but a consideration of this topic does not belong here.

Band Absorption.—One of the most familiar and striking instances of this form of absorption is seen in *chlorophyl*, which is the general term under which the green coloring matter of plants is designated. A solution of this substance is easily obtained by macerating leaves with ether or alcohol. The filtered liquid being diluted so as to be fairly transparent, has a beautiful green color by transmitted light, and when viewed through the spectroscope transmits all the colors except a band in the extreme red, at which point there appears a well-marked broad dark band. The position of this band is highly characteristic of this substance, and can be detected by careful observation, even when the solution is too dilute to exhibit the color to the eye. In this way the adulteration of animal oils by vegetable oils—for instance, of lard oil by cotton-seed oil—may often be detected, for cotton-seed oil exhibits the absorption band of chlorophyl derived from the vegetable tissue.

Valuable use is made of absorption spectra in detecting the nature of various natural and artificial coloring matters. Fuchsin, for instance, not infrequently employed as an artificial coloring matter in wine, gives a broad but not very sharply marked band about the junction of the green and yellow of the spectrum.

It is, however, with reference to the absorption bands produced by the fluids of the animal body that the clinical applications of the spectroscope are seen. The most important of these are the appearances seen in blood under various conditions. These appearances are due to the hæmoglobin. As ordinarily seen by examining blood much diluted with water, the spectrum is that of oxidized hæmoglobin, *oxyhæmoglobin*. The dilution must be sufficient to allow considerable light to pass, and a modification of the absorption spectrum is obtained by continually adding water until no absorption at all occurs. The same effect may be produced by examining the solution through a wedge-shaped cell, gradually diminishing the thickness of the solution through which the light passes. The effects are briefly as follows: In rather strong solution, all the light is cut off except a portion of the orange and red; when the solution is diluted somewhat, green rays are transmitted, and the dark interval between these and the orange constitutes a broad absorption band; still further dilution produces a yellowish-green mass of light dividing the dark space into two nearly equal portions, developing, therefore, two well-marked absorption bands. On still further diluting, the absorption becomes reduced to a single band in the yellow. When to a solution of blood of sufficient density to give the two bands we add some reducing agent, *i.e.*, some body having an affinity for oxygen, the hæmoglobin is *reduced*, and a new spectrum is obtained. For this reduction ammonium sulphide is preferred. The spectrum of reduced hæmoglobin is a single band, broader than, and not exactly coincident with, either of the bands obtained from oxyhæmoglobin, the darkest portion corresponding to the mass of light dividing the two bands in that spectrum. The chemical condition of the blood in the vessels may in this way be tested. Another important result is in determining the effect of various gases and chemical substances in blood, either by direct action or by poisoning animals and quickly subjecting the blood to examination. If we examine blood charged with nitrous oxide (N_2O), we find the spectrum of re-

duced hæmoglobin, but agitating the blood with air will reproduce the oxyhæmoglobin. When, however, carbon monoxide (CO), carbonic oxide, is introduced into blood, we get a new condition which gives a spectrum resembling, but not identical with, that of oxyhæmoglobin, there being two bands, but their position being slightly nearer the violet.

Furthermore, we cannot so easily restore the original condition by agitating the blood with air, nor will the ordinary reducing agents produce the spectrum of reduced hæmoglobin. Carbon monoxide is known to be one of the most active of the gaseous narcotic poisons, and the above observations show, in part at least, the peculiar action it has on the essential breathing constituent of the blood. The carbon-monoxide-hæmoglobin spectrum is seen in the blood of persons poisoned by water-gas or fumes of burning charcoal, and an examination of the blood by the spectroscope in cases of this character may be an important medico-legal point. Another important modification of the hæmoglobin is produced by the action of sulphides, especially by hydrogen sulphide (H_2S), sulphureted hydrogen. This gas is often present in sewer air, cesspool exhalations, and in other foul places, but not invariably, nor in so great quantity as is generally supposed. When its action upon blood is examined we find a spectrum which presents the broad single absorption band of reduced hæmoglobin (see above), but in addition a band in the red just at the junction with the orange. This band does not disappear on shaking the blood with air, although the two bands of oxyhæmoglobin appear. The body produced by the action of hydrogen sulphide on blood, and to which the properties above described are due, has been called *sulphæmoglobin*. It has been noticed that this substance cannot be formed by the action of hydrogen sulphide on reduced hæmoglobin, which is the form that exists in the veins; hence hydrogen sulphide may be introduced into the venous circulation without marked effect, but taken into the arterial system it is very dangerous. The difference between inhalations of this gas, by which it would get directly into arterialized blood, and its introduction into the system through the veins, has been shown strikingly in a method formerly in vogue of treating phthisis by injections of hydrogen sulphide and carbon dioxide. In this case the gas is taken up by the veins of the portal system and excreted before it comes in contact with the arterial blood.

If a solution of blood be exposed to the air for some time it undergoes various changes, accompanied by an alteration in the absorption spectrum. This alteration can be brought about by the action of weak acids, and also of potassium permanganate, on blood. A substance called *methæmoglobin* is formed. Its absorption bands are three, nearly coincident with those seen when sulphæmoglobin is shaken with air, but one band is more completely within the limits of the red. Methæmoglobin is believed to be a highly oxidized hæmoglobin, but its constitution is in some doubt.

Many other changes in the absorption spectra of blood are known, but while the investigation of them has much to do with physiological chemistry, the matter is too technical for discussion here. It is obvious, from what has been said, that very important medico-legal, toxicological, and even clinical questions can be determined by means of the spectroscopic appearances. The different effects produced on blood by different poisonous gases and vapors, the general symptomatology of which may be the same, offer a means of determining even post mortem the character of the gas.

Clinically, the spectroscopic appearances may be utilized for examining the fluids of the body either in their normal or in their abnormal condition. The spectrum of bile, for instance, may be utilized for the detection of it in the urine, for when the color reaction is too faint to be perceived by the unassisted eye, the spectroscope will show it. Normal urine contains a coloring matter believed to be derived from a constituent of bile, which gives a broad absorption band on the green. In certain febrile affections another band appears, also in the green, toward the border of the yellow. Blood in urine may also be detected by the spectroscopic tests. If it be in solution in the urine, the absorption spectrum is seen without difficulty. If the blood be present in the form of methæmoglobin, as is sometimes the case, it will give the three bands peculiar to that body, but it is necessary to distinguish these bands from those produced by a decomposition product of hæmoglobin known as *acid hæmatin*. This distinction can be made by the use of ammonium sulphide, when, if methæmoglobin is present, the band of reduced hæmoglobin, as described above, will appear. If the blood is in the insoluble form no absorption bands may be shown. In this case the blood is filtered and the filter paper treated with alcohol and ammonia, and then with ammonium sulphide; bands then appear which are due to *reduced hæmatin* formed by decomposition.

In the accompanying map (Fig. 4340) are shown some of the important absorption spectra as seen in a refraction

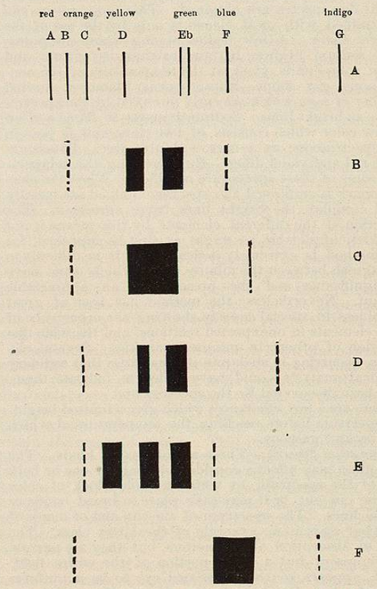

Fig. 4340.—A. Principal lines of solar spectrum as seen in a refraction spectroscope. B. Absorption bands of oxyhæmoglobin. C. Bands of reduced hæmoglobin. D. Bands of carbon monoxide hæmoglobin. E. Bands of methæmoglobin. F. Spectrum of normal urine.

spectroscope of moderate power. Over the plate has been placed indications of the limits of the various colors, but these must be regarded as a mere approximation, as it is not possible to determine precisely at what point one color ceases and another begins. The dotted lines at each end of the plates represent the limits of the visible spectrum in each case, and it will be noticed that there is considerable extinction of color, especially toward the violet end. *A* represents the spectrum of sunlight, with some of the principal absorption bands, and the letters which distinguish them. All these bands, as has been remarked above, are absent in the light of ordinary flames and electric lights. The observation of absorption spectra being made with artificial light does not therefore show any such bands. *B* shows the absorption bands of oxyhæmoglobin. The visible spectrum, it will be seen, extends only from green to a short distance on the red. *C* shows the spectrum of reduced hæmoglobin. The limits of the visible spectrum are extended slightly toward the violet. *D* is the spectrum of carbon monoxide hæmoglobin, that is, of blood impregnated with carbon monoxide. *E* is the spectrum of methæmoglobin. *F* is the spectrum seen commonly in normal urine. The broad band is at about the junction of the blue and green and is somewhat faint.

Limited practical clinical application is made of these spectroscopic appearances. The instruments required are expensive and involve delicate adjustment, and hence they are unsuited to the general uses of the practitioner. A combination of spectroscope and polariscope has been constructed for use in rapid approximate estimation of sugar in urine. The use of the spectroscope in the detection of various natural and artificial colors, and in the recognition of blood stains, belongs to special treatises.

Henry Leffmann.

SPEECH. See *Larynx, Physiology of the.*

SPERMACETI.—(*Cetaceum*, U. S. P., B. P.; Ger., *Blanc de Balsine ou Cetine;* Cod. Med., *Sperma-Ceti*). A solid paraffin-like substance obtained from cavities in the head of the sperm-whale, *Physeter macrocephalus* L. (order *Cetacea*). This whale is the largest living animal, gregarious in its habits and found in the oceans of both hemispheres, from the extreme north to the tropics. It is hunted for its oil, which is one of the most valuable of its class.

Crude spermaceti is a semisolid, yellow substance as it is scooped out from its reservoirs, but becomes hard and brittle upon exposure to cold; for purification, it is then pressed in bags, when the oil squeezes through, and the solid *cetaceum* is left behind. This can be further purified by melting in water, skimming, and recrystallization. Purified spermaceti is a pearly white, glistening, crystalline, translucent, odorless, and tasteless solid, insoluble in water; soluble in ether, chloroform, and boiling alcohol. Melting point 111° to 112° F. It is mostly composed of *palmitic* acid combined with *cetyl* (instead of glycerin); there are also small quantities of compounds of *stearic*, *myristic*, and *lauric acids*. It is fairly permanent in the atmosphere, in this respect excelling most fats.

Use.—Spermaceti has no active medicinal qualities. It is sometimes used in sore throats, etc., where its value is mostly as a protective. Its principal employment in medicine is as an ingredient of cerates and ointments, to which it gives consistence, blandness, and permanence.

There is an official cerate (*Ceratum Cetacei*) consisting of 35 parts of white wax, 10 of spermaceti, and 55 of olive oil, made by melting together the two former, adding the oil, previously heated, and stirring constantly until cold. Spermaceti is also an important constituent of ointment of rose water or cold cream (*Unguentum Aquæ Rosæ*, U. S. P.).

W. P. Bolles.

SPERMATORRHŒA. See *Sexual Organs, Male, Diseases of.*

SPERMATOZOA.—(Greek, σπέρμα, seed, and ζῶον, an animal.) A *spermatozoon* is a free, usually motile cell that is capable of uniting with an ovum to form the germ of a multicellular organism. The penetration of the ovum by the spermatozoon and the union of the nuclei of the two cells constitute the chief processes in the act of fertilization, which is the essential feature in sexual reproduction; and the ability to produce spermatozoa or their equivalent is the essential distinction of organisms of the male sex (see *Sex*). The spermatozoon is distinguished from the ovum by being vastly smaller and generally by being capable of locomotion (see *Ovum*).

Historical.—Spermatozoa were observed for the first time by Ludwig Ham, a pupil of Leeuwenhoeck, who in turn communicated the discovery to the Royal Society of London in a letter dated November, 1677. The discovery of these minute living bodies in the semen of man and a number of animals aroused great interest, especially as Malpighi a few years before (1672) had published the results of his observations on the embryology of the chick, and had concluded, in contradiction to Harvey, that the embryo is preformed in the egg. Now the question arose as to whether the moving elements of the semen might be germs which enter the eggs and develop into embryos. Leeuwenhoeck took the affirmative position and had many followers, but a greater number of the preformationists took the opposite view and held those bodies to be merely internal parasites. The name "spermatozoa" was given to them by von Baer with this idea in mind. The position of the "ovists" was strengthened by Bonnet's discovery of parthenogenesis, published in 1762 (the experiments were begun in 1740), which showed that in some cases an embryo can be formed without a male parent.

The first successful step toward a real knowledge of spermatozoa by means of experiments in artificial fertilization of ova of animals was made by Jacobi, and communicated to the Berlin Academy by Gleditsch in 1764. Jacobi placed the ripe spawn of salmon and trout in water and added seminal fluid squeezed from a male. After five weeks the eggs showed signs of life. It was apparently not these experiments, however, but some unsuccessful attempts made by Malpighi much earlier that led to the truly remarkable series of experiments by Spallanzani (1786). He wisely chose the amphibia for his material. First, he showed that eggs taken from the oviduct could be caused to develop by the addition of sperm taken from the seminal vesicles, while similar eggs not so treated failed to develop.

Second, he disproved the idea current at that time that the fertilizing element was an *aura seminalis*, a seminal vapor. This was done by causing frog's eggs to adhere to a watch glass, which was then inverted over another containing some of the sperm, and both were put in a warm place. The eggs became wet by the condensation of the vapor that was distilled from the sperm, but no fertilization took place. After some of the material in the lower watch glass had been added to the eggs, however, they speedily developed.

Third, by filtering the sperm he showed that the *liquor seminalis* has no fertilizing effect, but that the residue washed from the filter paper has undiminished power. Spallanzani was prevented from reaching correct conclusions as to the nature of the spermatozoa, however, because he accepted Bonnet and Haller's theory of the preformation of the germ in the female, the truth of which he thought he had demonstrated in the amphibia. Spallanzani produced artificial fertilization also in the eggs of silk moths and in a dog.

The next important contribution to the history of the spermatozoa is furnished by the brilliant observations and experiments of Prévost and Dumas (1824). They studied the anatomy and secretions of the reproductive organs of vertebrates of all classes above the fishes, and found that spermatozoa are produced in the testes only, and that these are the only organs essential to the fertility of the male; that spermatozoa exist in all fertile males and are absent from immature and senile individuals and from infertile hybrids; and that each species has its own peculiar form of spermatozoon. Having thus shown the close relation between the spermatozoon and its host and the correlation between the presence of spermatozoa and fertility of the male, these authors proceeded to repeat Spallanzani's experiments upon frog's eggs. They made improvements upon his methods, making the experiments more exact, and they demonstrated further that the spermatozoa are capable of penetrating the jelly surrounding the eggs. Spallanzani's results in regard to the aura seminalis and the liquor seminalis were confirmed and the important conclusion added that the spermatozoa are the essential fertilizing elements.

After all this it seems very strange to find the spermatozoa included in Owen's article on "Entozoa" in