A Qualitative Determination of the Reflection Coefficients of Some Metals in the Schumann Region*

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THE great majority of the investigations of the optical properties of metals have stopped short at λ 1850. This wave-length constitutes a natural boundary in the spectrum, as the absorption of air makes necessary, for work with light of shorter wave-length, the use of a vacuum spectroscopy and Schumann plates with accompanying complications. If we proceed farther into the region of extremely short wave-lengths, we soon reach a point (λ 1250) beyond which light is transmitted by no solid substance, so far as is known. We are therefore soon forced to use in any optical system, not refracting, but reflecting members exclusively. It is then evident that a knowledge of the reflection coefficients of various substances is necessary, before apparatus is designed for work in the region of extremely short wave-lengths.

The work which has been done upon the reflection coefficients of metals for light of wave-lengths lying between, say, λ 2800 and λ 1850 may be briefly reviewed. Schumann,¹ in collaboration with L. Mach, published an account of an investigation he made on alloys in different proportions of aluminium and magnesium. The work is entirely qualitative and extends as far as λ 1850. Two alloys, No. IV (Al 1.25, Mg 1) and No. V (Al 27, Mg 24.3), reflected the ultra-violet better than anything else he tried. Hagen and Rubens² have done a great deal of work upon metallic reflection, but they did not include the region shorter than λ 2500. They studied eleven metals and with one exception found that they were characterized by low reflection coefficients (less than 50 per cent) for λ 2500. At this point they found magnalium to have a reflection coefficient of approximately 67 per cent. Glatzel³ measured the reflecting power of silver, steel, nickel, and copper as compared with Brandes-Schünemann alloy. He does not state explicitly the shortest wave-length with which he worked but it seems probable that it was about λ 2380. Beyond λ 2500 none of the metals tried was superior to the alloy. Nutting⁴ investigated the reflection coefficients of ten metals by a photographic method and gives graphs showing variation of reflection coefficient for the region extending from λ 4000 to λ 1850. At λ 1850 he ascribes to aluminium and brass a reflection coefficient of 65 per cent. The other metals fall below this, with 35 per cent for speculum metal. At approximately λ 2200 the absorption of the gelatine of the photographic plate begins to play an important rôle, and it seems improbable that quantitative results of much accuracy can be obtained beyond this point without the use of Schumann plates.

In all of the work described above the reflection coefficient has been determined by the "direct" method. There is a second method, the "indirect," in which the reflection coefficient is derived from a measurement of the constants of the elliptical polarization produced when a beam of plane-polarized light is reflected from the substance in question. A very convenient method of doing this has been devised by Voigt⁵ and applied by Minor⁶ Meier,⁷ Frédericksz,⁸ Erochin,⁹ and Foersterling and Frédericksz.¹⁰ These five papers provide data obtained by the same method for some twenty different metals extending in some few cases as far as λ 2260 and in nearly all cases to λ 2573. In general, the reflection coefficient for the shortest wave-length measured lies between 20 and 40 per cent. The following values are perhaps worthy of mention: silver, λ 2263, 18.4 per cent; platinum, λ 2573, 37.1 per cent; mercury, λ 2570, 57.9 per cent; Wood's metal (composition not given), λ 2573, 52.7 per cent; chromium, λ 2570, 69.8 per cent; and tin, λ 2570, 71.4 per cent.

The most recent and by far the most extensive work upon the reflection coefficients of metals which extends to λ 1850 has been carried on by Hulburt.¹¹ He used the direct method and measured the intensity of light by means of a photo-electric cell. Twenty-eight metallic mirrors were tried, namely, aluminium, antimony, bismuth, cadmium, carbon, carborundum, chromium, cobalt, copper, gold, lead, magnalium, magnesium, molybdenum, nickel, palladium, platinum, selenium, silicon, silver, speculum metal, steel, stellite, tantalum, tellurium, tin, tungsten and zinc. For each of the metals tried there

is published a graph showing reflection coefficient as a function of wave-length between λ 1850 and λ 3800. With one exception, carborundum, the trend of the curve as we pass to the region of shorter wave-length is downward. In the case of carborundum the reflection coefficient is 15 per cent at λ 3800 and rises to 20 per cent at λ 1850. Furthermore, with one exception, silicon 60 per cent, the reflection coefficient is 30 per cent or less at λ 1850. Magnalium, for which, in view of the work of Schumann and Mach, and of Hagen and Rubens, referred to above, we should expect a large reflection coefficient, reflects less than 10 per cent of the light at λ 1850.

There are no data dealing with the optical properties of metals for wave-lengths less than λ 1850. Lyman¹² has recently extended the spectrum to λ 600, and it herefore seems desirable to continue the investigation of reflection coefficients into the region beyond λ 1850. The minimum wave-length dealt with in this paper is λ 1030, at which point we come to a second natural boundary in the spectrum. By the use of extremely pure hydrogen and an oscillatory discharge, the spectrum may be extended to λ 900, and the extension to λ 600 was achieved by substituting an atmosphere of helium for hydrogen in the spectroscopy.

Since the difficulties of measurement of energy in the Schumann region have proved prohibitive up to the present time, and since the nature of the Schumann plate renders the results of photographic photometry of very questionable value, it has not seemed advisable, in the present work, to attempt to obtain quantitative determinations of the reflection coefficients of various metals such as is desirable for the testing of theoretical treatments of the optical properties of substances. The purpose has therefore been restricted to the investigation, in a qualitative manner, of the reflection coefficients of several metals in order to determine what ones are best suited for use in the construction of apparatus for work in the region of extremely short wave-lengths.

As speculum metal has in the past been used for the construction of gratings for the resolution of Schumann light, it was adopted arbitrarily as the standard reflect-

ing metal with which the other metals were compared. We obtain then, not the reflection coefficient directly, but determine at once what metals are superior to speculum metal for the making of gratings and other optical parts.

A bit of speculum metal and the metal to be tested were so mounted that their polished faces were adjacent and in the same plane. They were then placed in such a position that the light from the quartz discharge tube was reflected (angle of incidence approximately 45°) through the slit and upon the grating. One half of the slit was illuminated by light reflected from speculum metal, the other by light reflected from the metal to be tested. For light of the wave-length to be studied, the astigmatism of the grating in the first order spectrum is so slight that we obtain simultaneously two spectra side by side, the relative strengths of which enable us to determine by inspection which is the better reflector. The method is illustrated in detail in Fig. 1, which is a horizontal section taken through the vacuum spectroscopy and discharge tube. *L* is the discharge tube which serves as source of light, *M* is the composite mirror, and *G* is the grating. The spectrum is received on the photographic plate *P*. The grating used has a radius of curvature of 102 cm, and is ruled with approximately 6000 lines to the centimeter. The ruled portion is 2.8×5.3 cm. By photographing the two spectra at the same time we eliminate any effect due to variation of intensity of the source. There remains an outstanding error due to possible unsymmetrical placing of the source in such a manner that the two mirrors are unequally illuminated. This may be largely eliminated by interchanging the two mirrors and taking a second exposure. This method, while simple, is sufficiently accurate for the purpose of the work. For if the reflecting powers of two metals are so nearly identical that the eye detects no differences in the two images on the Schumann plate, obviously one metal is, so far as the reflection coefficient is concerned, as suitable for use in the construction of apparatus as the other.

The vacuum grating spectroscopy used was patterned

very closely in its essentials after the one used by Lyman.¹³ It differed in that it used a much larger plate (2.5×8.5 cm) which in turn made necessary the very large hole for the removal of the plateholder. This hole was closed by a conical plug 9.6 cm in diameter. The reflection of the light by the mirror necessitates the placing of the discharge tube on the side of the spectroscopy instead of on the end plate. A novel feature, perhaps worthy of mention, is the mounting of a miniature incandescent lamp on an arm so that it may be swung down immediately in front of the center of the grating. If the mirrors are in correct adjustment the light from this lamp passes through the slit of the spectroscopy, is reflected by the mirrors down the capillary of the discharge tube, and the image of the slit may be seen by looking through a telescope pointed along the axis of the capillary. It would have been extremely difficult to test the adjustment of the mirrors without some such arrangement.

The quartz discharge tube which served as source of light was of the external capillary type. It is shown in section at *L*, Fig. 1. The electrodes were of aluminium and the internal diameter of the capillary was about 0.6 cm. There is no window at the inner end separating the interior of the discharge tube from the interior of the spectroscopy. The spectroscopy is commonly filled with hydrogen at a pressure of approximately 1.8 mm and the spectrum obtained is that of hydrogen. The spectrum usually extends from λ 1640 to λ 1030 and is filled with lines very close together.

The directions for making plates given by Schumann¹⁴ were followed quite closely. A device for dropping the plateholder controlled by a magnet on the outside and similar to that used by Lyman¹⁵ was provided so that four exposures might be taken on one plate without opening the spectroscopy. The lengths of the four exposures were usually 30, 60, 120 and 240 seconds.

The methods has been applied to nine substances, namely, silicon, gold, stellite, platinum, copper, nickel, aluminium, silver and steel. The majority of the metals were selected because the ease of working and permanence of surface seem to make them adaptable for the construction of mirrors, if they should prove to be good reflectors. Silicon was chosen as a direct result of the work of Hulburt, who attributed to it a reflection coefficient of 60 per cent at λ 1850. The aluminium was very difficult to polish. I was led to test it by the fact that Nutting (*loc. cit.*) gives it a reflection coefficient of 65 per cent at λ 1850. Following will be found a complete account of the preparation of the mirrors and the results obtained with them.

The speculum metal mirrors used in this work were sawed from a broken grating and polished by Alvan Clark & Sons, Corporation. They were repolished from time to time as conditions demanded.

Silicon.—The specimen of silicon was obtained from the Carborundum Works at Niagara Falls and was sawed into slabs and polished by means of rouge on a beeswax lap at the laboratory. Silicon polishes easily and the surface is permanent and does not tarnish. Silicon is much the best reflector of all the substances that I have tried. Throughout the entire range (λ 1640— λ 1030) it is a better reflector than speculum metal, although the difference is less marked for wave-lengths shorter than λ 1300. Between λ 1600 and λ 1300 I estimate that the reflection coefficient of silicon is twice as large as that of speculum metal. This estimate is only approximate and indicates that, to the eye the spectrum reflected from silicon with a two-minute exposure is fully as strong as that reflected from speculum metal with a four-minute exposure.

Gold.—The gold mirror was prepared by deposition from a cathode. Gold spatters very rapidly, and from six to ten minutes are sufficient to produce an opaque film. The spectra reflected from gold and from the speculum metal are very nearly identical in strength. Between λ 1300 and λ 1030 gold is perhaps slightly superior, but the difference is not sufficiently marked to encourage the use of gold for mirrors.

Stellite.—The stellite mirrors were cut from a block of stellite obtained from the Stellite Works, Kokomo, Ind. It is an alloy, chiefly of chromium and cobalt. The exact composition is a commercial secret. The mirrors were polished by means of diamantine on a beeswax lap. Hulburt found stellite superior to speculum metal between λ 2000 and λ 3000. His diagram indicates that its reflecting power falls off as we approach λ 1850. The spectra reflected from the speculum metal and stellite are identical in strength. In the Schumann region there is no advantage in substituting stellite for speculum metal.

Platinum.—The platinum mirrors were deposited on glass from a cathode. About thirty minutes were required to deposit an opaque film. Between λ 1600 and

¹³The Spectroscopy of the Extreme Ultra-Violet, Longmans, Green & Co., 1914, p. 34.

¹⁴Annalen der Physik, 5, 349, 1901.

¹⁵Op. cit., p. 35.

*The Astrophysical Journal, Vol. XLV, No. 1.

¹Sitzungsberichte der K. Akad. der Wiss. in Wien, 108, 11a, 154, 1899.

²Zeitschrift für Instrumentenkunde, 22, 42, 1902.

³Physikalische Zeitschrift, 2, 176, 1900.

⁴Physical Review, 13, 193, 1901.

⁵Physikalische Zeitschrift, 2, 303, 1901.

⁶Annalen der Physik, 10, 581, 1903.

⁷Ibid., 31, 1017, 1910.

⁸Ibid., 34, 780, 1911.

⁹Ibid., 39, 213, 1912.

¹⁰Ibid., 43, 1227, 1914.

¹¹Astrophysical Journal, 42, 205, 1915.

¹²Ibid., 43, 89, 1916.

λ 1300 platinum is not superior to speculum metal, in fact one or two of my negatives indicate that it is slightly inferior. But beyond λ 1300 the spectrum reflected from the platinum is distinctly the stronger. It would be very interesting to investigate the reflecting power of platinum throughout the region discovered by Lyman (λ 1250– λ 600). As noted above, silicon is a much better reflector than speculum metal in the portion of the spectrum with which this article deals, but, as compared with speculum metal, its reflecting power is growing less as we pass to the shorter wavelengths, whereas in the case of platinum the reflecting power is increasing.

Copper.—Copper spattered readily on glass from a cathode. The mirrors tested were quite opaque. The copper mirrors which I made were markedly inferior to those of speculum metal through the entire region. Hulburt finds that at λ 1850 the copper was slightly better as a reflector than the best speculum metal mirror which he tested.

Nickel.—About three hours were required to produce a brilliant opaque film on glass by cathode deposition. Between λ 1600 and λ 1300 the reflection from nickel and from speculum metal is the same. Beyond λ 1300 the nickel is very slightly superior to the speculum metal.

Aluminium.—Two pieces of aluminium cut from commercial sheet stock were polished by Alvan Clark & Sons Corporation. It was very difficult to polish, but a surface was finally obtained which was quite good. Aluminium reflects very poorly in the Schumann region. Only a few of the stronger groups of lines show in the four-minute exposure.

Silver.—The silver mirror was cut from a coin and polished. Speculum metal is much superior to silver over the whole range upon the plate. At the end of longer wave-length the speculum metal reflects twice as well as does the silver.

Steel.—The steel mirror was hardened and polished by Alvan Clark & Sons Corporation. Steel reflects markedly better than speculum metal from γ 1600 to approximately λ 1300. At λ 1200 the speculum metal reflects slightly better than the steel.

Conclusion.—The reflecting power of nine metals, silicon, stellite, copper, nickel, gold, platinum, aluminium, silver and steel, has been investigated in the portion of the spectrum lying between λ 1600 and λ 1030. The purpose has not been to determine the reflection coefficients on an absolute scale, but rather to determine directly what metals are superior to speculum metal for the construction of reflecting surfaces to be used for light in this region. The results indicate that:

1. Silicon is much the best reflector of all the metals tried, and over a portion of the region it reflects the light approximately twice as well as speculum metal.

2. The reflecting power of platinum as compared with that of speculum metal is increasing as we pass to shorter wave-lengths. It may possess advantages over other metals for work beyond λ 1030.

3. Stellite, copper, nickel, gold and steel show only minor variations of reflection when compared with speculum metal.

4. Silver and aluminium are very much poorer than speculum metal, with silver ranking above aluminium.

Peat as Locomotive Fuel

REPORTS from Sweden appear to be very favorable as regards the use of peat as a fuel for use upon locomotives, the peat being dried and powdered, and employed in the latter state, which is affirmed to be the best for firing locomotive furnaces. The government railroad administration appointed a commission within a recent date in order to make a thorough examination of powdered peat as a fuel, and after a series of tests upon the preparation and combustion of this substance, the commission reported in its favor, stating that the results were conclusive. The report established the fact that powdered peat can be utilized as a good source of fuel and concluded that it should be employed on a large scale. Accordingly the Swedish government is taking measures to erect a plant of considerable size near the peat fields of Lake Vetter for the purpose of making peat dust. As to the use of this fuel on locomotives, it is stated that all the locomotives on the 60-mile Falköping-Nassjö railroad line are now running on peat fuel with great success. The official tests showed that peat fuel as regards calorific power (by weight) is about two-thirds the value for coal. The results which are already obtained are claimed to justify the erection of large plants to utilize this national resource. In order to keep this production clear of all complicated questions regarding competition from coal, the government decided to have the new plants operated by the state, at least for the present, and is now engaged upon the plans for utilizing several large peat beds. For instance the Hästhagen fields would afford some 20,000 tons of powdered peat per annum, this to be used for the railroads, and on this basis the beds would last 20 years.

A Kinetic Hypothesis to Explain the Function of Electrons in the Chemical Combination of Atoms*

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BEGINNING with Davy¹ and Berzelius, during the first part of the nineteenth century, chemists generally accepted the theory that chemical combination is due to electrical forces, but when Dumas discovered the chloroacetic acids in which chlorine atoms, supposedly negative, replace positive hydrogen atoms it was believed that the theory had been shown to be false and it was practically abandoned. Following this, for fifty years or more, a theory of valence which took no account of electrical forces was developed and while occasional reference was made to positive and negative atoms and groups, no definite meaning in an electrical sense was attached to these expressions. Helmholtz in his Faraday lecture in 1881² drew the attention of chemists once more to the very close connection between chemical forces and electrical phenomena and spoke for the first time of "atoms of electricity." He also pointed out that the "sulfur of sulfuric acid must be charged with positive equivalents of electricity." In 1887 Arrhenius proposed his theory of electrolytic dissociation and with the help of Ostwald and van't Hoff the belief in a separation of molecules into electrically charged parts in solutions was rapidly accepted. J. J. Thomson³ gave precision to the atomic character of electricity in 1897 when he demonstrated the material character of cathode rays and the very minute mass of the corpuscles carrying negative charges. Van't Hoff⁴ seems to have suggested for the first time that electrically charged atoms may play a part in reactions not usually considered as ionic. The same idea was proposed by the author⁵ and by Steiglitz,⁶ a little later. J. J. Thomson⁷ seems to have been the first to suggest that two atoms may be held together by the electrical forces resulting from the transfer of an electron from one to the other. He assumed a shell of electrically positive matter within which there was a

static arrangement of electrons. Abegg⁸ in an entirely independent paper published the same year, discussed the relation between electrons and ionization and the connection with older theories of Helmholtz and others. He also raises, I think for the first time, the question of polar and non-polar valences but seems to have decided that the former are more probable.⁹ Rutherford¹⁰ has advanced strong reasons for considering that atoms contain a positive nucleus around which electrons are rotating and this hypotheses has been further developed by Bohr,¹¹ Nicholson,¹² Moseley¹³ and others.

Physicists in general have directed their attention to rotating or rapidly moving electrons and to the relation between these and spectral lines, the disintegration of atoms and other phenomena involving individual atoms. Chemists, on the other hand, following the suggestion of J. J. Thomson, have considered chiefly the rôle which the valence electrons probably play in the combination of atoms. Sir William Ramsay¹⁴ in his address on "The Electron as an Element" considered that the electron takes a position between the two atoms which are held in combination. In a very recent paper, probably the

last which he wrote,¹⁵ he elaborates this thought further and describes models to illustrate the magnetic attractions which would result from electrons rotating in contiguous parts of two molecules. The magneton theory of the structure of the atom has also been developed elaborately by Parson.¹⁶ It cannot account for ionization where, if we accept the electron theory at all, electrons must be transferred completely from the positive atom or group to the negative. Falk and Nelson,¹⁷ Fry,¹⁸ L. W. Jones,¹⁹ Stieglitz²⁰ Bray and Branch,²¹ G. N. Lewis,²² and others have discussed the phenomena connected with the transfer of valence electrons from one atom to another but, with the exception of the magneton theories referred to above, no one, so far as I can discover, has suggested a possible connection between the motion of the valence electrons and chemical combination between atoms.

In the hypotheses here proposed the following assumptions, now more or less current among physicists and chemists, are made:

1. The atoms are of a complex structure made up of positive nuclei and electrons, of which the latter, at least, are in very rapid motion. If we assume that the electrons are 1/1800 the mass of hydrogen atoms and that they obey the same laws of motion as other atoms, their average velocity would be about sixty times the velocity of molecules of hydrogen (H_2). I will not attempt to discuss here the question whether the law of equipartition of energy actually holds for electrons.

2. That the electrons are of two kinds in their relation to the structure of the atom. Some of them are so involved in their orbits or motions among the positive nuclei that they can never escape from the atom. Others, called valence electrons, may be transferred to other atoms.

Let us suppose that two atoms, which have an affinity for each other are brought close together. A valence electron which is rotating around a positive nucleus in the first atom may find a positive nucleus in the second atom sufficiently close so that it will include the latter in its orbit and it may then continue to describe an orbit about the positive nuclei of the two atoms. During that portion of the orbit within the second atom that atom would become, on the whole, negative while the first atom would be positive. During the other part of the orbit each atom would be electrically neutral, and the atoms might fall apart. When we remember, however, the tremendous velocity of the electrons and the relatively sluggish motions of the atoms it seems evident that the motion of an electron in such an orbit might hold two atoms together. In ionization the electron would, of course, revolve about the nucleus of the negative atom leaving the other atom positive. It seems impossible to explain ionization otherwise than on the supposition of the complete transfer of the electron. This complete transfer in ionization is one of the strongest arguments against the magneton theory as the only explanation of chemical combination.

An interesting feature of the hypothesis proposed is that it may be used to account for that localization of the affinities in particular parts of atoms which is indicated by many of the properties of organic compounds. Thus if we suppose that there are four (or eight) positive nuclei in a carbon atom around which valence electrons may rotate, an atom of hydrogen may be held to the neighborhood of one of these nuclei as indicated in the figure.

I wish to acknowledge my indebtedness to Julius Stieglitz, R. D. Carmichael, J. B. Shaw, Jacob Kunz, A. P. Carman, A. A. Noyes and R. C. Tolman, who have read the first draft of this paper and of whom several have made helpful suggestions.

Photographic Color Prints on Silk

THE Manufacture Nationale des Gobelins has recently adopted the process of Messrs. Vallette and Férét for photographic color printing, the process being applied to articles de luxe that cannot well be printed by machine. Three successive impressions are made, in blue, yellow and red. The precision which is required in the superposition of the three impressions is secured by means of a special frame on which the article is stretched with the aid of metallic eyelets. The sensitizers used are alkaline phenols and diazo sulphites, and the colors are developed by exposure to the electric light.—*Engineering*.

¹⁵Ramsay, Sir W., *London, Proc. R. Soc.*, (A), 92, 1916, (451).

¹⁶Parson, A magneton theory of the structure of the atom. *Washington, Smithsonian Inst., Misc. Collect.*, 65, 1915, No. 11.

¹⁷Falk and Nelson, *New York, Sch. Mines Q.*, Columbia Univ., 30, 1909, (179), *J. Amer. Soc., Easton, Pa.*, 32, 1910, (1637).

¹⁸Fry, *J. Amer. Chem. Soc., Easton, Pa.*, 34, 1912, (1268), *Zs. physik. Chem.*, Leipzig, 76, 1911, (385, 398, 591).

¹⁹Jones, L. W., *J. Amer. Chem. Soc., Easton, Pa.*, 36, 1914, (1268).

²⁰Stieglitz, *Ibid.*, 36, 1914, (272); 38, 1916, (2046).

²¹Bray and Branch, *Ibid.*, 35, 1915, 1913, (1440).

²²Lewis, G. N., *Ibid.*, 35, 1915, (1448).

*A paper presented before the National Academy of Sciences, and republished from the *Proceedings*.

¹Davy, *London, Phil. Trans. R. Soc.*, 1807, p. 1.

²Helmholtz, *London, J. Chem. Soc.*, 24, 1881, (291).

³Thomson, J. J., *Phil. Mag., London*, (Ser. 5), 44, 1897, (291).

⁴Van't Hoff, *Ibid.*, 23, 1901, (797).

⁵Noyes, W. A., *J. Amer. Chem. Soc., Easton, Pa.*, 23, 1901, (463).

⁶Stieglitz, *Ibid.*, 23, 1901, (797).

⁷Thomson, J. J., *Phil. Mag., London*, (Ser. 6), 7, 1904, (237).

⁸Abegg, *Zs. Anorg. Chem., Hamburg*, 39, 1904, (330).

⁹*Loc. cit.*, Note 8, p. 347.

¹⁰Rutherford, E., *Phil. Mag., London*, (Ser. 6), 21, 1911, (669).

¹¹Bohr, N., *Ibid.*, 26, 1913, (1,476,857). On p. 862 Bohr discusses the hypothesis that atoms may be held in combination by electrons rotating about the line joining the positive nuclei of two atoms. This is similar to Ramsay's view mentioned below.

¹²Nicholson, *Phil. Mag., London*, (Ser. 6), 27, 1914, (54).

¹³Moseley, *Ibid.*, 26, 1913, (1024).

¹⁴Ramsay, Sir W., *London, J. Chem. Soc.*, 93, 1908, (775).