RP39

REFLECTING POWER OF BERYLLIUM, CHROMIUM, AND SEVERAL OTHER METALS

By W. W. Coblentz and R. Stair

ABSTRACT

In this paper data are presented on the ultra-violet reflecting power of various metals—beryllium, chromium, cobalt, nickel, silver, speculum, stellite, and stainless steel. For chromium and beryllium the observations extend into the infra-red.

The observations show that contrary to the general experience with other metals, beryllium has a high reflectivity at 250 mμ in the ultra-violet, followed by an appreciably lower reflectivity with a minimum at about 400 mμ in the visible spectrum.

Chromium has a higher reflectivity than nickel in the ultra-violet and is, therefore, the more efficient as a reflector of ultra-violet radiation.

The reflectivity of chromium is conspicuous for its relatively high maximum (70 per cent) at 425 mμ followed by a wide flat minimum which extends from about 600 mμ in the orange to wave lengths beyond 2,000 mμ in the infra-red.

CONTENTS

	Page
I. Introduction	343
II. Apparatus and procedure	344
III. Reflecting power data	348
1. Nickel	348
2. Silver	349
3. Stellite	350
4. Stainless steel	350
5. Speculum	350
6. Cobalt	351
7. Beryllium	351
8. Chromium	352
IV. Corrosion by ultra-violet radiation	354

I. INTRODUCTION

In a previous paper[1] it was shown that a common property of all metals thus far investigated is a low reflecting power in the ultra-violet and in the visible spectrum, followed by a rapid rise in reflecting power, with high values beyond 2,000 mμ, in the infra-red. Subsequent investigations obtained on other material confirm these early deductions. The significance of this phenomenon does not seem to be understood. It is therefore relevant to call attention to the deep minima of reflection previously observed at about 1,000 mμ in zinc, and at about 400 and 700 mμ in beryllium and chromium, respectively, reported upon in the present paper.

---

[1] Coblentz, B. S. Bull. No. 152, 7, p. 197; 1910.

In recent years it has been found possible to electroplate unusually fine surfaces of chromium upon other metals. The data obtained in the present paper were obtained in connection with the question of the reflecting power in the visible spectrum of chromium as compared with nickel, for use as a plating for headlight mirrors. In addition to obtaining data to answer this utilitarian question, we have extended our observations into the ultra-violet and the near infra-red, thus completing the investigation as nearly as can be done at the present time.

In view of the fact that surfaces of substances, especially metals, are subject to corrosion, and that ultra-violet light accelerates the disintegration of metal surfaces,[2] it is to be emphasized that these data are applicable only to freshly polished surfaces.

While there is no metal surface that can be used indefinitely as a standard of reflection without frequent repolishing, in the present paper it is shown that chromium is highly resistant to corrosion and has a high reflecting power which extends far into the ultra-violet. Chromium should, therefore, prove useful for mirrors and diffraction gratings having a high reflectivity, especially in the ultra-violet.

II. APPARATUS AND PROCEDURE

The measurements recorded in this paper were made spectroradiometrically. The radiometer used consisted of a portable vacuum thermopile,[3] and an ironclad galvanometer [4] of improved design (assembled in 1923) which can be operated in a vacuum, although it was not used in this manner in the present investigation. For measurements in the ultra-violet a shutter of red glass was used to eliminate the effect of stray radiation, as described in previous papers.

The measurements in the infra-red were made with a completely inclosed spectrometer,[5] which was provided with mirrors 50 cm in focal length and 10 cm in diameter and a large quartz prism which gave a large dispersion but permitted making observations only to 4,000 mμ.

The measurements in the ultra-violet were made with a quartz spectropyrheliometer [6] having plano-convex lenses 6 cm in diameter, and 18 cm focal length, which was adapted to the present investigation. For this purpose the focus (also the width) of the entrance slit was kept constant and, as shown at *V. T.* in Figure 1, the exit slit (the thermopile slit, 0.8 mm wide) was focused upon the different spectral lines. This was facilitated by covering the thermopile slit

---

[2] Coblentz and Hughes, Science, **60**, p. 64; B. S. Sci. Paper No. 493, **19**, p. 577; 1924.

[3] Coblentz, B. S. Sci. Papers No. 413, **17**, p. 187; 1921.

[4] Coblentz, B. S. Sci. Papers No. 282, **13**, p. 423; 1916.

[5] Illustrated in B. S. Bull. No. 204, **10**, p. 1; 1913.

[6] Coblentz and Kahler, B. S. Sci. Papers No. 378, **16**, p. 233; 1920.

with a fluorescent screen (white paper saturated with anthracene) which rendered the ultra-violet lines visible to the eye.[7]

The reflecting power in the infra-red was determined by comparing the intensity of the radiation reflected from the unknown sample with that reflected from a metal of known reflecting power.[8] In a previous paper a direct measurement in absolute value was obtained by substituting for the mirror of known reflecting power the hypotenuse face of a right-angle prism,[9] and measuring the intensity of the radiation totally reflected from the glass or quartz prism as indicated at *R. P.* in Figure 1.

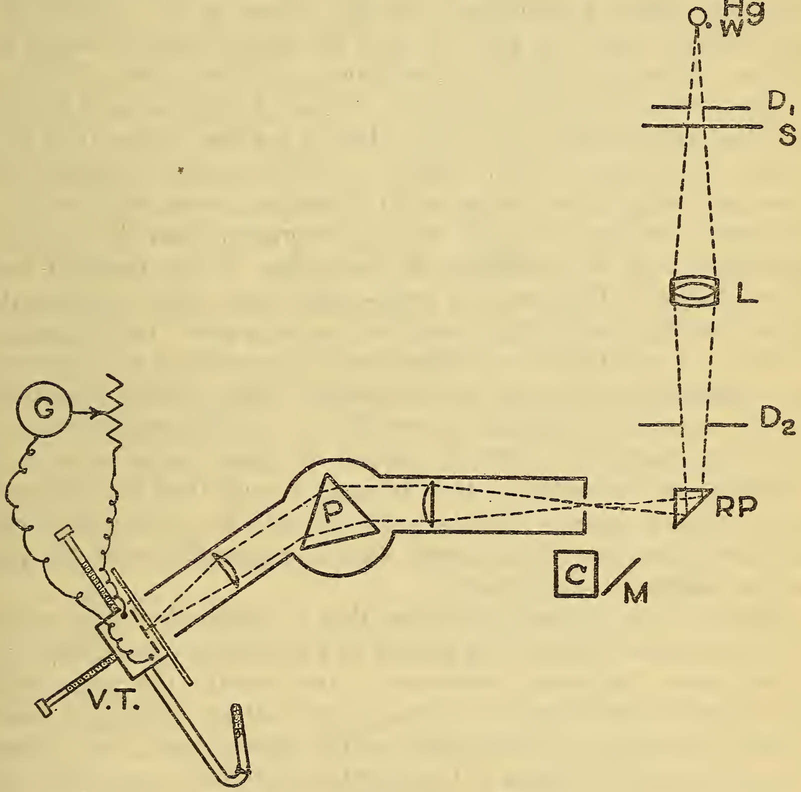

FIG. 1.—*Arrangement of apparatus*

The reflecting power in the ultra-violet was determined directly in absolute value by comparing the intensity of the radiation reflected from the mirror with the intensity of the radiation totally reflected from the right-angle prism of quartz as indicated in Figure 1.

In order to compensate for the lengthening of the optical path introduced by the right-angle prism a plane-parallel piece of the same

---

[7] Coblentz, J. Opt. Soc. Am., 7, p. 451; 1923.

[8] Coblentz, B. S. Bull. No. 152, 7, p. 197; 1911.

[9] Coblentz and Emerson, B. S. Bull. No. 308, 14, p. 307; 1917.

material (having the same effective thickness as the right-angle prism; *C* in fig. 1) was placed in the path of the rays after reflection from the mirror under investigation. By proceeding in this manner no corrections are necessary for losses by reflection from the faces of the right-angle prism.

We have used the right-angle prism with and without the compensating block in the optical path with the mirror and have found our results in good agreement (within 1 per cent) after making corrections for losses by reflection when the compensating block was not used.

The use of the right-angle prism has the apparent disadvantage that the angle of incidence upon the mirror is 45°, whereas it is usually the custom to give the data for approximately normal incidence. However, from the calculations and observations of Wilsey [10] it appears that the reflecting power of a metal, for a beam of radiation incident at an angle of 0°, is only about 1 per cent higher than for an angle of incidence of 45°. Hence, as will be noticed presently (see data on nickel), the variation in reflecting power with angles of incidence less than 45° is of far less importance than the manner of preparation or the condition of the surface of the material under investigation. The use of a right-angle prism, with compensating block, which is a novelty introduced in the present investigation, is therefore a satisfactory simplification of the problem of determining the reflectivity of metals in the spectral region where transparent prism material is available, especially in the ultra-violet where the reflecting power of metals is subject to great variation with the condition of the surface. It is relevant to add that the right-angle prism (size of faces 3 by 3 cm) was cut with the optic axis perpendicular to the base of the prism; that is, perpendicular to the plane of the illustration in Figure 1.

It is to be understood, of course, that in this method it is assumed that the quartz block which is used as a compensator and the quartz prism have the same transparency and exactly the same polish. In a previous investigation [11] it was found that the cylinder of quartz, which was used as a compensator in the present work, was perfectly transparent in the region of the spectrum in which we are interested.

Owing to the large angle of incidence of the radiation upon the mirror, which increases the polarization, and owing to the further polarization of the rays in passing through the spectroradiometer, the question arises as to the effect this would have upon the reflectivity measurements.

We have, therefore, measured the intensity of the emission line at 365 mμ after reflection at an angle of 45° from a large chromium-plated mirror (*S*, described on a subsequent page) when placed at

---

[10] Wilsey, Phys. Rev., **8**, p. 396; 1916. Chant, Astrophys. J., **21**, p. 211; 1905, observed practically no variation in the reflecting power of silver for angles of incidence less than 50°.

[11] Coblentz, B. S. Bull. No. 237, **11**, p. 471; 1913.

the exit slit (*V. T.* in fig. 1) so as to reflect the radiation (1) in a horizontal direction and (2) in a vertical direction.

The results obtained show that, to less than 1 part in 200, there was no difference in the intensity of the radiation after reflection in these two positions of the mirror. It is, therefore, assumed that, within the limits of experimental errors, the effects of polarization need not be considered in these measurements.

A slight difference in polish may easily introduce an error of 1 or 2 per cent. This, however, would be a constant error that would not affect the intercomparison of the reflecting power of all the metals, in which problem we are especially interested.

The source of radiation was a 110-volt Cooper-Hewitt vertical "Uviarc" mercury arc lamp. An achromatic quartz-fluorite lens (*L* in fig. 1) 3.5 cm in diameter and 25 cm focal length was used for projecting the radiation from the lamp upon the mirror and from thence upon the entrance slit of the spectrometer. The image of the column of incandescent mercury vapor was about 6 mm wide, which was ten times the width of the spectrometer slit. Hence, there was no difficulty in obtaining an image of uniform intensity over a sufficient width, so that a slight lateral displacement of the image upon the entrance slit of the spectrometer did not produce errors in the measurements. This was tested by actual displacement of the image of the lamp upon the spectrometer slit.

To facilitate adjusting the mirror in the same plane as the hypotenuse face of the right-angle prism a fine wire (*W* in fig. 1) was attached close to the quartz mercury arc, and an image of this wire was projected upon a fine line on a piece of white paper placed at the side of the entrance slit. By tilting the mirror horizontally and vertically the image of certain marks on the wire, reflected alternately from the mirror and the prism, could be projected exactly upon the same spot on the paper. In this manner, exactly the same part of the column of incandescent mercury vapor was projected upon the entrance slit of the spectrometer.

The method of observation consisted in setting the thermopile upon a certain wave length and noting three to five galvanometer deflections produced by radiation reflected (1) from the prism, then (2) from the mirror, after which the measurements on (1) and (2) were repeated. At the completion of the series of measurements throughout the spectrum, further observations at 254 mμ and 265 mμ were made and always found in agreement with the original measurements, showing that the disintegrating effect of ultra-violet light was negligible in the course of the measurements.

Unless otherwise stated, all the surfaces were highly polished and accurately flat to within less than a wave length of light.[12]

---

[12] Acknowledgment is due E. F. Webb and L. T. Wood for their patience and skill in preparing these mirrors.

III. REFLECTING POWER DATA

Under the present caption are given the spectral reflecting power data, in absolute value, of various metals, including several previously examined.

1. NICKEL

Previous determinations of the reflecting power of nickel were made on mirrors which were electroplated on steel, then polished.[13]

The present measurements were made upon electroplated nickel, also upon pure nickel that had been fused and solidified in a vacuum.[14] The latter appeared to consist of three large crystals. The electroplated samples were deposited upon plates of hardened, highly polished steel. The samples reported upon in this paper were as follows:

I. A highly polished surface of nickel electroplated upon a steel plate 23 by 37 mm in area;

II. A highly polished cross section of a solid rod of pure nickel, 20 mm in diameter, which had been fused and solidified in a vacuum, and

III. A cross section sawed from a rolled rod of refined nickel, 32 mm in diameter.[15] The polish on this sample was not so good as on the other two samples.

The data on the ultra-violet reflecting power of nickel are illustrated in Figure 2. From this illustration it may be noticed that the spectral reflection of the electroplated surface (○○○) is decidedly different from that of the electrolytic material that has been fused and solidified in a vacuum (...). This is substantiated by the measurements of Hagen and Rubens [16] and by Hulburt,[17] whose observations are depicted in Figure 2.

The surface of the rolled rod (⁄⁄⁄) had a slightly hazy appearance which explains the lower reflecting power. As shown in the upper part of Figure 2, when this sample was examined eight years ago (the surface being highly polished and free from fine granulations) the reflecting power at 550 mμ was 63.5 per cent, which is in agreement with other measurements. Evidently in the recent repolishing of this mirror the fine grinding was not sufficiently prolonged, which left depressions of microscopic size that caused considerable scattering of the light. It is to be emphasized that the inclusion of the data on this sample is to show the presence of the minimum reflection at about 300 mμ in the massive material, which minimum is practically obliterated by the much lower reflecting power at 250 mμ in the electro-

---

[13] Hagen and Rubens, Ann. der Phys., **1**, p. 352; 1900; **8**, p. 1, 1902; **11**, p. 873; 1903.

[14] Kindly supplied by L. Jordan, of the metallurgy division.

[15] Kindly supplied by Dr. P. D. Merica, the International Nickel Co., Bayonne, N. J.

[16] Hagen and Rubens, Ann. der Phys., **1**, p. 352; 1900.

[17] Hulburt, Astrophys. J., **42**, p. 205; 1915.

plated material. The cause of the relatively much lower reflectivity of the electroplated material at 250 mμ is not known to us.

The curve for the vacuum-fused sample (fig. 2) is the average of five sets of values obtained with different ajdustments of the mirror, including one set of observations which were obtained after further rubbing and polishing of the surface on chamois skin moistened with alcohol, which, however, had no effect upon the minimum at 300 mμ.

Such depressions at 250 to 300 mμ were observed in a previous investigation of metals and sulphides of metals.[18]

It is relevant to add that the lower reflecting power of the electroplated material (I) in the visible spectrum is inherent in the sample, and is not owing to the polish such as occurred with the rolled sample (III). This was evident by observing the sky and leaves of trees reflected from these two mirrors. Nevertheless, at 350 mμ in the ultra-violet the electroplated sample has the higher reflecting power.

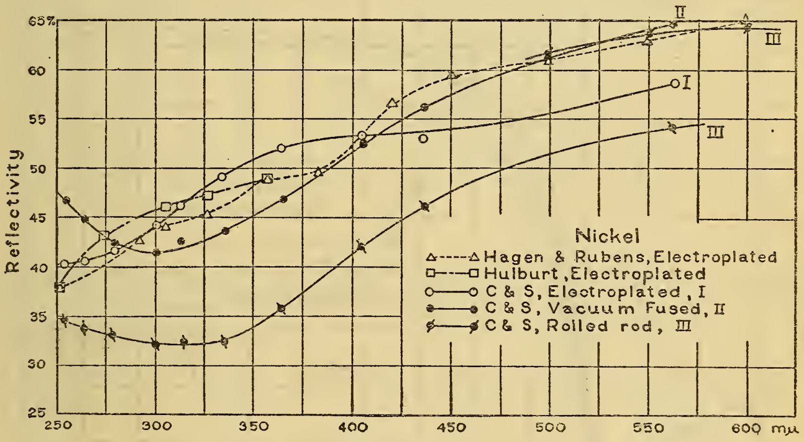

FIG. 2

2. SILVER

The ultra-violet measurements were made upon a freshly silvered surface, chemically deposited upon glass. These data (see fig. 3) are in good agreement with previous measurements. The reflecting power of this sample in the blue and the violet is several per cent higher than previously observed. As mentioned under the preceding caption, this might be owing to a slight difference in the polish of the right-angle prism and the compensating block, which would accentuate the errors in the present instance, although it is not apparent on substances that reflect only 40 to 50 per cent.

---

[18] Coblentz and Hughes, B. S. Sci. Papers No. 493, **19**, p. 577; 1924.

3. STELLITE

The absolute measurements (in the visible spectrum) are in good agreement with previous data which were obtained by comparison with silver.[19] The value of $R=66.5$ per cent (67 per cent for normal incidence) at 550 mμ, is slightly lower than previously observed ($R=68.3$ per cent) which was obtained on the assumption that the reflecting power of the comparison surface of silver was 91.5 per cent. In the meantime the stellite mirror has had considerable use.

This sample of stellite (an alloy of Co, Cr, and Mo) has a minimum at 265 mμ (see fig. 4) while Hulburt (loc. cit.) observed a minimum at 240 mμ on a different sample of this material.

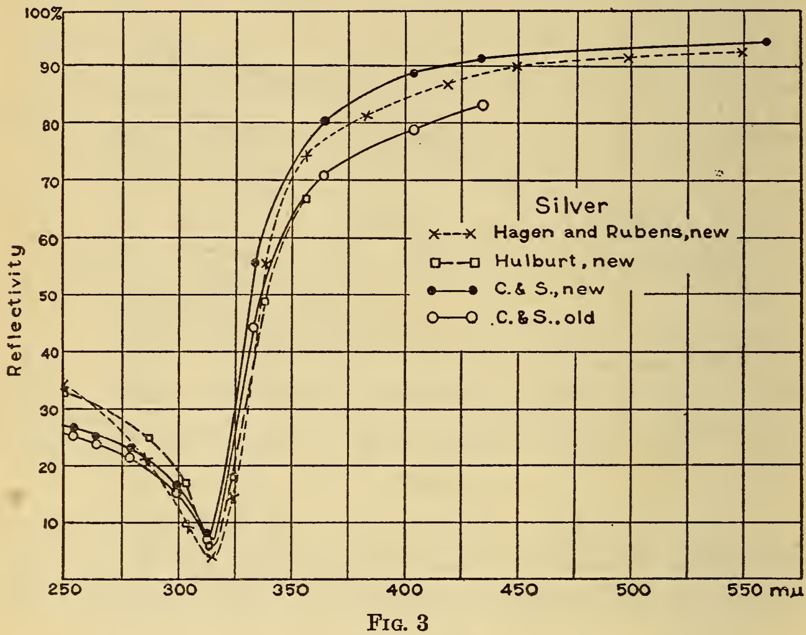

FIG. 3

4. STAINLESS STEEL

The sample examined was reported to contain 13 per cent of chromium but no nickel. The spectral reflecting power in the ultra-violet (fig. 4) is similar to and about 20 per cent higher than that observed by Hagen and Rubens (loc. cit.) on soft steel.

5. SPECULUM

The sample examined was freshly polished to remove the tarnish. The spectral reflecting power (fig. 5) is in fair agreement with the observations of Hulburt (loc. cit.), who gives data showing the rapid decrease in reflectivity with increase in tarnish of this alloy.

---

[19] Coblentz, B. S. Sci. Papers No. 379, 16, p. 249; 1920.

6. COBALT

The sample examined was in the form of a sheet, about 0.6 mm thick, soldered upon a thick plate of brass. Although it was repolished since the previous measurements [20] were made, it was found impossible to remove the hazy appearance caused by microscopic pores which scatter the light and decrease the absolute values in the short wave lengths.

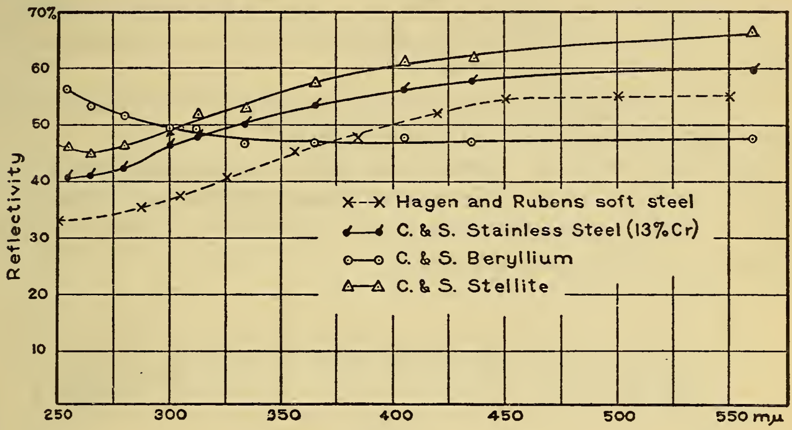

FIG. 4

As shown in Figure 5, the spectral reflecting power is similar to that of nickel.

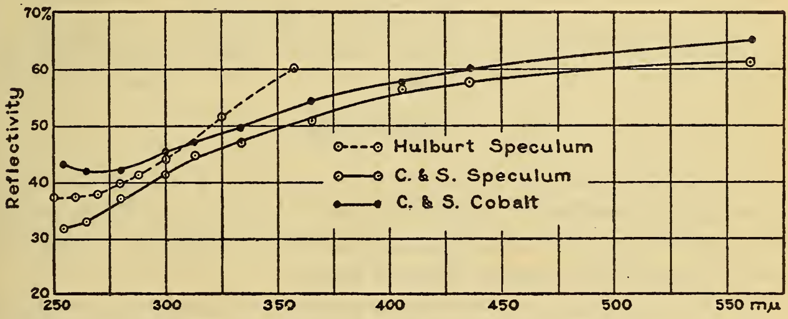

FIG. 5

7. BERYLLIUM

The material examined was obtained from The Beryllium Corporation of America. Chemical analysis indicated the presence of about 1 per cent of Fe, 0.2 per cent of Ba, a trace of Si, and 98.7 per cent of Be.

---

[20] Coblentz, B. S. Bull. No. 45, 2, p. 457; 1907.

The surface examined was ground and polished upon the flat side of an ellipsoidal mass of this material which was about 4 cm in its greatest diameter. The polished surface, which was about 25 mm in diameter, contained a few scratches and cracks.

The ultra-violet reflecting power of beryllium (fig. 4) is unusual in being considerably higher at 250 mμ than in the longer ultra-violet wave lengths, which is just the opposite of the usual experience with metals.

The reflecting power from the extreme ultra-violet to about 3,000 mμ in the infra-red is illustrated in Figure 7.

From this curve it appears that the low reflecting power in the visible spectrum of beryllium is not caused by imperfections in the surface, but is a property of this metal, which has a minimum reflectivity at about 400 mμ in the violet.

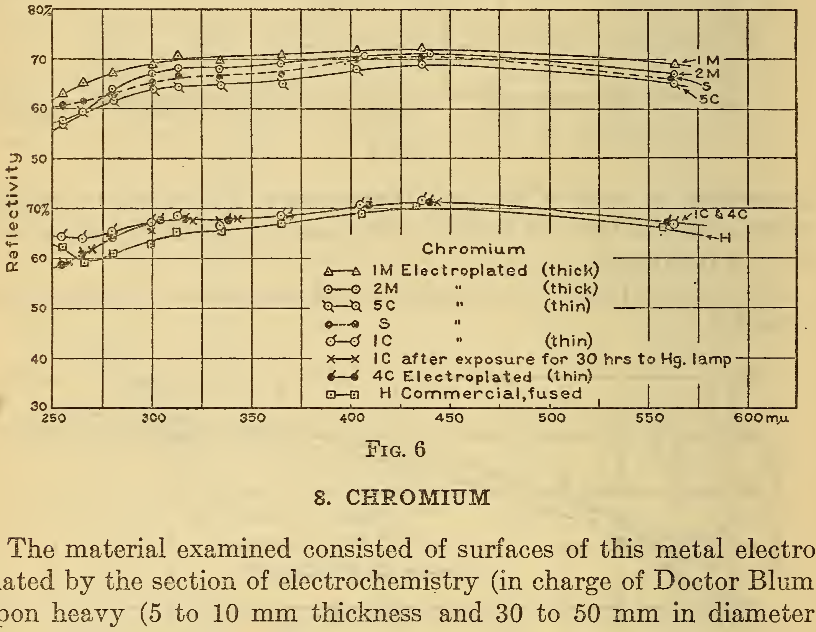

FIG. 6

8. CHROMIUM

The material examined consisted of surfaces of this metal electroplated by the section of electrochemistry (in charge of Doctor Blum) upon heavy (5 to 10 mm thickness and 30 to 50 mm in diameter) blocks of hardened, highly polished steel.

The examination included also a sample of commercial crystalline material (*H*, fig. 6) upon which the infra-red reflecting power was previously determined.[21] For the recent examination the surface was highly polished and quite free from the imperfections reported in the previous paper, which diffused the incident radiation and lowered the specular reflecting power.

The "thin" coatings of the electroplated material were about 0.005 mm in thickness. The "thick" coatings were perhaps 0.1 mm

---

[21] Coblentz, B. S. Bull. No. 152, **7**, p. 214; 1911.

in thickness. All the samples were optically flat, highly polished, and free from scratches.

There seems to be no direct dependence of the spectral ultra-violet reflecting power upon thickness of the coating, within the above limits. This is illustrated in Figure 6, which gives two groups of reflecting power curves.

The depression in the reflectivity curve at 265 mμ is sometimes observed in other metals. In the region of the spectrum of wave lengths less than 300 mμ the reflecting power seems to vary from sample to sample. For ultra-violet wave lengths longer than 300 mμ the reflecting power seems to be fairly constant for different samples, which is encouraging. All of the samples of chromium examined have a much higher reflecting power than nickel.

In Figure 7 is depicted the composite spectral reflection curve of the sample *S* of chromium, electroplated upon a block of steel 1 by 4 by 5 cm, as observed by means of the ultra-violet quartz lens spectroradiometer (. . .) and the infra-red (○○○) mirror spectroradiometer. At 4,000 mμ the cross (xx) shows the observations[21] previously made upon the commercial sample of solid chromium H which, because of the poor quality of the surface used at that time, gave low values in the short wave lengths. However, from the data obtained in the present investigation it appears that the low reflectivity previously observed at 500 to 2,000 mμ is not owing entirely to scattering of the light by the poorly polished surface, but is a property of the material.

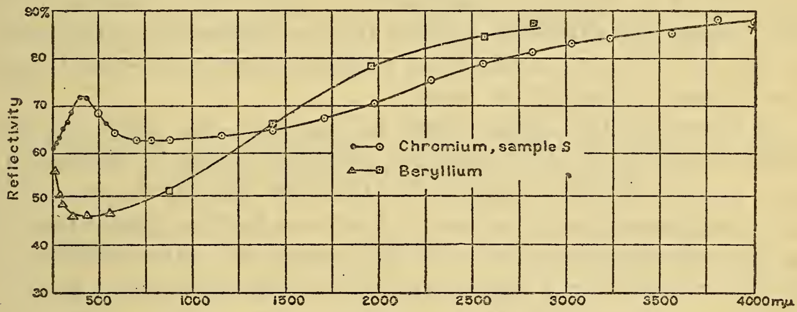

FIG. 7

The present investigation shows that a characteristic of chromium is a relatively high reflectivity at about 425 mμ followed by a wide minimum of reflection which extends from about 600 mμ in the orange to wave lengths beyond 2,000 mμ in the infra-red. In this respect chromium appears to be unique. Other metals—for example, silver, gold, and zinc[22]—which have deep minima of reflection (zinc

---

[21] Coblentz, B. S. Bull. No. 152, 7, p. 214; 1911.

[22] Coblentz, B. S. Sci. Papers No. 379, 16, 249; 1920.

at 1,000 mμ) attain a high reflectivity (90 per cent) at 1,500 mμ or even at shorter wave lengths.

From these observations it appears that chromium is more useful than nickel for reflection work in the ultra-violet, but the reverse is true in the spectral region from 600 to 4,000 mμ. However, when one considers the fact that nickel tarnishes readily while a chromium surface is not easily affected, there is probably no great advantage in using nickel as a reflector.

IV. CORROSION BY ULTRA-VIOLET RADIATION

In the introductory part of this paper attention was called to the fact that the ultra-violet reflecting power of metals and sulphides of metals decreases as the result of corrosion or disintegration of the surface by the action of ultra-violet radiation.

It was, therefore, of interest to determine the effect of prolonged exposure of a surface of chromium to ultra-violet radiation. For this purpose the chromium mirror, 1C, was exposed, at a distance of 15 cm, for 30 hours to the total radiation from a 110-volt Cooper-Hewitt quartz mercury arc lamp.

As shown by the crosses (xxx) in Figure 6, the effect of ultra-violet radiation in decreasing the reflecting power of chromium is most marked for wave lengths less than 300 mμ, the decrease at 254 mμ being from 64 to 59 per cent. For wave lengths greater than 300 mμ the reflecting power curve of this sample, 1C, after exposure was about 1 per cent lower than that of the unexposed sample, and practically coincident with the reflectivity curve of the (unexposed) sample 4C.

From this it appears that ultra-violet radiation has but little effect upon the disintegration and consequent lowering of the ultra-violet reflecting power of chromium.

WASHINGTON, October 1, 1928.

⁂