slow neutron scattering cross section is strongly affected by the interaction of ^3S with ^3D as has been pointed out by Schwinger. For a given range the data determine the proton-proton interaction probably to within better than 0.3 percent.

We would like to acknowledge our indebtedness to the two groups of experimenters for their whole hearted cooperation and to Messrs. Share, Hoisington and Kittel for occasional help. We are especially indebted to Professor Herb and Dr. Tuve for many discussions which have helped to clarify the interpretation. Grateful acknowledgment is made also of the financial assistance received from the Wisconsin Alumni Research Foundation, the Carnegie Institution of Washington and the WPA project in natural sciences at the University of Wisconsin.

Note in proof.—According to Lennart Simons [Phys. Rev. **55**, 792 (1939)] $\sigma_{\pi\nu}=14.8\times10^{-24}$ cm² so that $\sigma_{th}=59\times10^{-24}$ cm² and $D_{\pi\nu}=11.5(2)$ Mev. This differs by only 1.5 percent from $D_{\pi\pi}{}^c=11.35$ Mev. Potentials such as the meson potential which are more concentrated at small r may reduce this difference to zero.

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Reflectivities of Evaporated Metal Films in the Near and Far Ultraviolet

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The reflectivities of evaporated metal films from the visible to 450A have been determined for the following metals: Aluminum, antimony, beryllium, bismuth, cadmium, chromium, copper, gold, iron, lead, magnesium, manganese, molybdenum, nickel, palladium, platinum, silver, tellurium, titanium, zinc and zirconium. Photographic methods were used. From the visible to 2400A, a quartz mercury arc with calibrated wire screens and a quartz prism spectrograph were employed. From 2400A to 450A it was necessary to use a vacuum spectrograph with grating, a discharge tube, and oiled photographic film. The accuracy of the work in the near ultraviolet is of the order of three percent and in the far ultraviolet not better than five percent. Curves of reflectivity against wave-length for these metals are included.

1. INTRODUCTION

THE purpose of this paper is to extend the available information on the reflectivities of evaporated metal films. Most previous work has been confined to the determination of the reflectivities of metals in bulk or of sputtered and electrolytically deposited films. The reflectivities reported here are those which would normally be expected under ordinary laboratory conditions where the mirrors are exposed to air. They do not necessarily give the true reflectivity of the metallic surfaces before contamination by vapors and gases.

2. APPARATUS AND PROCEDURE

The method of evaporation and the equipment used are similar to that described by Williams and Sabine.[1] The metal to be evaporated was placed in a conical helix of fifteen-mil tungsten wire which could be heated by an electric current. In some cases, it was found to be advantageous to wrap two or three inches of the metal to be evaporated, if it were obtainable in wire form, around a short length of twenty-five-mil tungsten wire. This proved to be particularly useful in the case of metals which attack tungsten when molten or which evaporate only at very high temperatures.

The films were deposited on special scratch-free plate glass which had been washed with a strong solution of potassium hydroxide, then with hydrochloric acid, and finally dried in front of a fan with ethyl alcohol. Rubber gloves were worn on the hands and the glass was held

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* Now at the Kodak Research Laboratories.

[1] R. C. Williams and G. B. Sabine, Astrophys. J. **77**, 316 (1933).

by a vacuum suction cup attached to a short length of brass rod. This avoided the possibility of getting grease from the fingers on the glass and made the handling of powerful reagents simpler. The cleaning of the glass is very important; it is useless even to attempt to coat a glass surface which water will not wet.

Pumping was continued for at least an hour and a half before evaporation in order to make certain that traces of water vapor and other volatile substances were removed so far as possible. The vacuum obtained was about 10^{-5} mm of mercury as read by a McLeod gauge. Filament currents of from fifteen to twenty-five amperes were used.

In the case of the mirrors prepared for this work, the thickness of the coating was regulated by continuing evaporation until the lighted filament was just visible through the film. Evaporated films will not reflect appreciably more light when made so thick as to be opaque; in fact, it is noticeable in some instances that the surface tends to crackle if the film is very thick. Except in the instances noted below, the mirrors reported on in this paper transmitted less than one percent of visible light as measured with a Weston Photronic cell.

The reflectivities were measured with different apparatus according to the region of the spectrum in which the measurement was to be made. For the region 2400–5000A the radiation from a quartz mercury arc was focused by a quartz-fluorite achromat upon the slit of a Hilger E3 quartz spectrograph and neutral screens (wire screens) of known transmission mounted near the lens were used to calibrate the photographic plate. The precautions pointed out by Harrison[2] in his discussion of near ultraviolet photometry were observed.

The arc was mounted on an arm which could be swung about a pivot to give any angle of incidence. (Approximately 18° was used.) The actual source was a small piece of plane quartz ground to a good diffusing surface on both sides and illuminated by the body of the arc. The enlarged image of this bit of quartz was focused on the slit of the spectrograph. The mirror holder ran in brass ways and was mounted at the hinge around which the arm holding the source rotated. Thus, the length of the light path from source to slit was the same for both the reflected and direct beams. The calibrated filters were inserted in the direct beam as close to the lens focusing light on the slit as possible. Eastman Commercial plates developed in D61a were used.

The plates were reduced in the standard manner on a Moll microphotometer. Characteristic curves were plotted for each wave-length at which the reflectivity was measured and each plate had its own calibration exposures. The accuracy of this work is difficult to estimate because some of the determinations necessarily had to be made on the underexposed heel of the characteristic curve. The error is considered to be of the order of three percent of the indicated reflectivity.

For measurements in the far ultraviolet, quite different apparatus was necessary. A vacuum grating spectrograph accommodating a 150-cm glass grating with 15,000 lines to the inch was used. The relative positions of plate holder and slit were the same as those described by O'Bryan.[3] The slit, the grating rulings, and the spectrum lines were horizontal and the dispersion of the grating was vertical so that the spectra were formed in narrow vertical strips. The film holder, which was semi-cylindrical in shape, could be moved independently of the mirror holder, thus providing for a large number of exposures. Both film and mirror holders could be moved from the outside by means of greased joints and their positions determined by means of pointers and scales.

The calibration exposures were made by swinging the mirror to such a position that its face lay along a plane perpendicularly bisecting the grating, thus permitting the beam from the grating to miss the mirror and be incident on the film. The reflected exposures were made by moving the mirror to the desired angle of incidence (about 18°) and moving the film into such a position that the reflected beam was incident upon it.

The source consisted of a semi-capillary water-jacketed end-on discharge tube. The electrodes

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[2] G. R. Harrison, J. Opt. Soc. Am. **18**, 492 (1929).

[3] H. M. O'Bryan, Phys. Rev. **38**, 32 (1931).

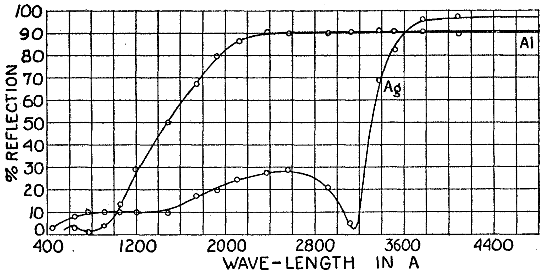

FIG. 1. Reflectivities of silver and aluminum.

were made of brass and were hollow so that they could be internally water cooled; each one was separately cooled with its own water circulating system. The central portion of the discharge tube, consisting of two concentric Pyrex glass tubes between which water was circulated for cooling, was waxed to the electrodes by means of ground joints. The gas used in the source was ordinary air admitted at reduced pressure through a controllable leak. This was found to furnish a satisfactory number of lines at all wave-lengths and to be steady in operation. The excitation was provided by a high potential transformer (about 35,000 volts) with a condenser of 0.005 microfarad capacity across the line and a commercial quenched spark gap in series with the tube.

The method of Harrison and Leighton[4] was followed in the calibration of the film. The constancy of slope of the H and D curves was found to extend to lower wave-lengths than those which they used. Eastman Superspeed film oiled with Cenco pump oil gave satisfactory photometric results. The film was mounted between glass plates and reduced by means of a Moll microphotometer. H and D curves were plotted for each wave-length at which reflectivities were measured and two calibration exposures were made for each exposure time. Two reflected exposures of different times were also made on each film.

The errors in this work may be considerable. The principal ones arise from irregularities of emulsion response because of variations in oil thickness and from fluctuations of intensity in the source. Since reflectivities determined from two different times of exposure differing by a factor of five were in good agreement, it is presumed that reciprocity law failure was not important. In general, it is expected that reflectivities in the wave-length region 2400A to 450A are not accurate to better than five percent of the indicated reflectivity and for reflectivities less than ten percent the error doubtless goes up very rapidly and may approach fifty percent.

The following metals were evaporated and their reflectivities measured in the near and far ultraviolet.

Aluminum

(Figure 1) This metal is easily evaporated and forms very brilliant films which are a gray-blue by transmitted light. The surfaces are rather soft but can be hardened by rubbing gently with absorbent cotton moistened with water. If deposited over chromium and hardened they are extremely resistant to scratching and can be cleaned if care is taken not to rub grit into the film. They do not suffer seriously by aging; indeed, mirrors remeasured after five months were found to retain their reflectivity substantially unimpaired.

The small hump shown in the reflectivity curve of aluminum near 650A is also reported in some unpublished work of H. M. O'Bryan. For wave-lengths shorter than 1200A, aluminum is exceeded as a reflector by several metals.

Silver

(Figure 1) The reflectivity curve shown here for silver is substantially the same in the near ultraviolet as that for chemically deposited films or for the metal in bulk. Silver is easy to evapo-

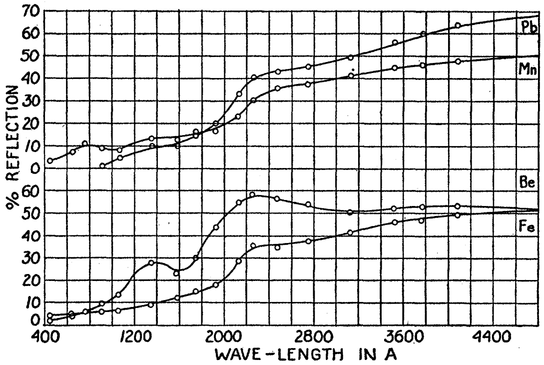

FIG. 2. Reflectivities of lead, manganese, beryllium and iron.

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[4] G. R. Harrison and P. A. Leighton, J. Opt. Soc. Am. **20**, 313 (1930).

rate and forms very brilliant films which are blue-gray by transmitted light and quite soft. The far ultraviolet reflectivity is definitely better than that for most metals. Unfortunately, it tends to tarnish rather badly.

Lead

(Figure 2) Very low filament temperatures are sufficient to evaporate lead. The deposit is extremely soft, and when first made is very bright. In the course of a week lead mirrors are completely destroyed by the formation of the oxide. When fresh they are brownish by transmitted light.

Manganese

(Figure 2) This metal forms hard bright films which are brownish by transmitted light and resemble chromium. It evaporates without serious difficulty.

Beryllium

(Figure 2) Next to aluminum, beryllium is perhaps the most satisfactory evaporated film. It does not evaporate readily, but with a little care, very good films can be prepared. The sharp minimum in reflectivity near 1600A corresponds roughly to a very deep minimum reported by Gleason[5] although his sputtered mirror was evidently much inferior to the evaporated film. Beryllium films do not tarnish noticeably with age.

Iron

(Figure 2) Iron was evaporated by wrapping a short length of wire around 25-mil tungsten wire. The films are surprisingly brilliant and quite hard. They resist tarnish and even when months old do not show signs of ordinary oxidation.

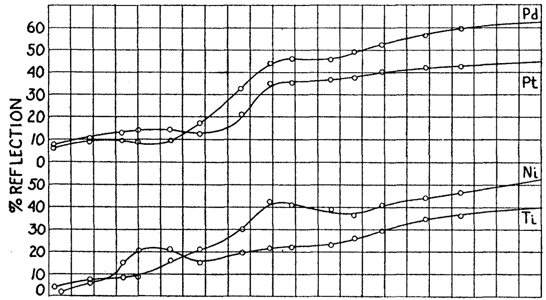

FIG. 3. Reflectivities of palladium, platinum, nickel and titanium.

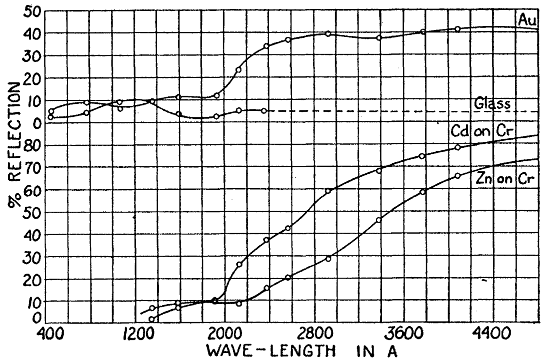

FIG. 4. Reflectivities of gold, glass, cadmium and zinc.

Palladium

(Figure 3) With the exception of platinum, palladium is the best far ultraviolet reflector so far investigated. It is evaporated in the same manner as iron and with this treatment forms very handsome durable films which are moderately hard.

Platinum

(Figure 3) For all work involving reflections at wave-lengths less than 1200A, platinum is the best mirror surface known. The extremely high melting point, however, makes it difficult to evaporate and materially increases the danger of contamination from the tungsten filament. The films are moderately hard, very resistant to tarnish, and quite bright. This film transmitted three percent of incident visible radiation. The reflectivity in the vacuum region is a little lower than that given in some unpublished work of H. M. O'Bryan. Gleason[5] reports a reflectivity at 600A for a sputtered platinum film nearly twice as great as that given here.

Nickel

(Figure 3) As in the case of iron, it is necessary to wrap nickel wire around a 25-mil tungsten filament because it dissolves tungsten very readily. The films are gray by transmitted light and very hard.

Titanium

(Figure 3) Evaporation of titanium is so difficult that it again is a metal for which the

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[5] P. R. Gleason, Proc. Nat. Acad. Sci. **15**, 551 (1929.)

data here given are not completely satisfactory. It forms hard films which are gray-brown by transmitted light and are not very bright.

Gold

(Figure 4) Gold evaporates easily though rather slowly. The films are bright yellow by reflected light and a brilliant green in transmission. The deposit is very soft, but does not tarnish even after standing for long periods of time. Its reflectivity is only fair in the near ultraviolet, but is well above average in the far ultraviolet. Qualitatively, this checks the results of Gleason's[5] work.

Glass

(Figure 4) The sample of glass whose reflectivity curve is shown in the far ultraviolet is ordinary plate glass of index of refraction 1.52. The dashed portion of the curve was taken from Nutting.[6]

Cadmium

(Figure 4) It was found necessary to evaporate cadmium over a previously evaporated film of chromium because it deposits in blotches on a glass surface. It is extremely soft and the mirrors appear brilliant, but have a bad tendency to form a bluish haze over the surface which is particularly noticeable by the light of a mercury arc. It is suspected that the very poor ultraviolet reflectivity of cadmium in the vacuum region is connected with the presence of this haze; zinc, which exhibits the same phenomenon, also has a very poor far ultraviolet reflectivity.

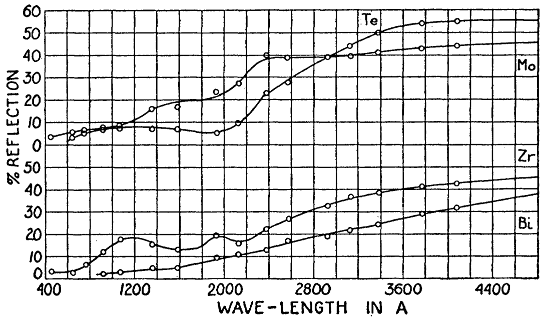

FIG. 5. Reflectivities of tellurium, molybdenum, zirconium and bismuth.

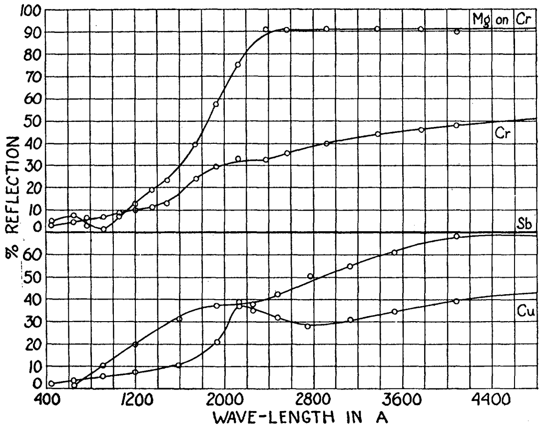

FIG. 6. Reflectivities of magnesium, chromium, antimony and copper.

Zinc

(Figure 4) Many of the remarks made about cadmium are equally true of zinc. It too must be evaporated over a film of chromium, and, as already mentioned, it gives trouble by the formation of a bluish haze sooner or later after it has been removed from the vacuum. Zinc is very soft and lasts well except for the formation of the haze.

Tellurium

(Figure 5) This metal evaporates with great ease. It forms soft bright films which are a brilliant red in transmission.

Molybdenum

(Figure 5) The data for molybdenum are not completely satisfactory because of the great difficulty in evaporating a sufficiently thick layer of the metal. The films are brownish by transmitted light, fairly hard, and not subject to tarnish.

Zirconium

(Figure 5) This metal evaporated with great difficulty and the mirrors so far produced have been too thin. The films are soft and went to pieces after a few days. The far ultraviolet reflectivity of zirconium is surprisingly good, but not better than that of other metals which are more permanent and easier to evaporate.

Bismuth

(Figure 5) Films of bismuth are readily produced, but have a very low reflectivity. The

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[6] P. G. Nutting, Phys. Rev. 16, 129 (1903).

deposit is pale yellow by reflected light and gray by transmitted light. It is exceedingly soft and loses in reflectivity rapidly when exposed to air.

Magnesium

(Figure 6) Like cadmium and zinc, magnesium must be deposited over a film of chromium. Fresh magnesium surfaces are extremely brilliant and have a very high reflectivity in the near ultraviolet. They tend to tarnish, however, and in the course of a month show definite signs of aging.

Chromium

(Figure 6) This metal forms extremely hard tenacious films which are brown by transmitted light. Its reflectivity is fairly high throughout the near and far ultraviolet. Although it has a tendency when molten to dissolve tungsten, it is not unduly difficult to evaporate.

Antimony

(Figure 6) Films of antimony are very easy to produce, but are exceedingly soft. It is grayish blue by transmitted light and is quite lasting. The reflectivity down to 1200A is fairly good.

Copper

(Figure 6) The evaporation of copper is very easy. It forms bright reddish films which are green by transmitted light. They are soft and tarnish after a week or so in air.

A number of other metals have been attempted unsuccessfully. In general, the difficulty has been either that the film was destroyed rapidly by standing in air, or that it was impossible to evaporate it with the apparatus here described. In the first class fall the alkali metals, calcium, gallium, indium, thallium, and tin, in addition to zinc and cadmium which have been discussed above. The other group consists of cobalt, columbium, iridium, rhodium, silicon, tantalum, uranium, and vanadium.

In conclusion, the author wishes to express his indebtedness to Professor R. C. Gibbs whose constant encouragement and friendly advice have made it possible to bring the work to a conclusion. He is also heavily indebted to Drs. J. E. Ruedy and R. C. Williams for advice in carrying out the evaporation work, and to Dr. H. M. O'Bryan for his generous aid in connection with designing the vacuum spectrograph for determining reflectivities in the far ultraviolet.

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The Magnetoresistance of Nickel in Large Fields

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The magnetoresistance of a nickel foil has been measured in fields up to 24,000 gauss. A drop of the curves in large fields is found, in disagreement with Alocco's results on similar material, but in agreement with Gerlach's theory that a resistance decrease is produced proportional to the square of the increase of spontaneous magnetization. The constant of proportionality is shown to be dependent on the temperature. It is concluded that spontaneous magnetization may be increased by a magnetic field without saturation appearing, even up to fields of 200,000 gauss as produced by Kapitza.

A FERROMAGNETIC material, unmagnetized in the technical sense, is supposed to consist of randomly oriented domains all magnetized spontaneously to saturation. An external field changes the orientations of these domains and thereby alters the electrical resistance of the material. Furthermore, it appears to be a well established fact that if the spontaneous magnetization of the domains is increased the resistance is decreased. Two obvious ways of changing the spontaneous magnetization consist in (1) varying the temperature of the material,