THE OPTICAL PROPERTIES OF RUBIDIUM.

By J. B. Nathanson.

SOME time ago there appeared in the Astrophysical Journal,[1] an account of an investigation, I made, on the reflecting powers of sodium, potassium and rubidium. A direct method was used, employing a photo-electric cell as a photometer.

Up to the present, the polarimetric method of investigating the optical properties of the alkali metals, has been applied only to sodium by Paul Drude,[2] and to sodium and potassium by R. W. and R. C. Duncan.[3] It therefore seemed desirable to apply the polarimetric method to the determination of the optical properties of rubidium, at the same time affording a comparison between the values of the reflecting powers of rubidium as obtained by the former direct method, and the present polarimetric method.

The Mirror.

The rubidium mirror used in this investigation was the same as that used in the former one, the mirror still being in very good condition. A description of the method of preparation of the mirror was given in The Astrophysical Journal, but for the sake of clearness it will be briefly repeated. The mirror was prepared in a vacuum by the distillation of the rubidium upon a piece of plane parallel glass P (Fig. 1), 2.5 cm. square, and 1.74 mm. thick. This glass plate formed part of a glass cell C. A mixture of rubidium chloride and calcium was placed in the hard glass tube D. Upon heating to a high temperature, the rubidium vapor passed to A, where it was condensed. The metal was purified by being redistilled from A to B. A small globule of the molten metal was then transferred to F, from where on further heating the metal was vaporized and condensed upon the glass plate P, the outside of which was kept ice cold. After the formation of the mirror, the cell was sealed off at E. Of several mirrors made, the best one was used in this investigation.

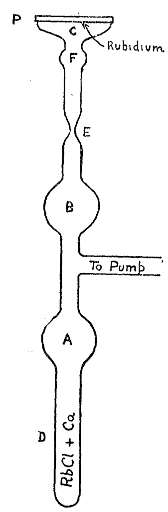

Fig. 1.

[1] Astrophysical Journal, 44, 137, 1916.
[2] Annalen der Physik, 64, 159, 1898.
[3] Phys. Rev., 36, 294, 1913.

The Experimental Method.

The optical constants were evaluated from observed values of the phase difference and azimuth of the reflected elliptically polarized light. These were determined by means of a simple Babinet compensator and two nicols mounted on a large spectrometer of the Societe Genevoise.

A 250-watt nitrogen-filled tungsten lamp was used as a source of light. One filament of this lamp was focused on the slit of a Hilger spectrometer H, Fig. 2. The eyepiece was removed, allowing a very narrow beam of monochromatic light to fall upon the slit of the collimator C. The beam of parallel rays then passed through the nicol N_1, whose plane of polarization was at an angle of 45° with the plane of incidence.

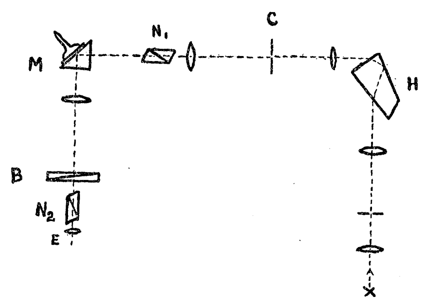

Fig. 2.

In order to avoid the disturbing reflection from the glass surface of the mirror M, the latter was pressed against the hypotenuse side of a right angle prism, cedar oil being placed between the prism and mirror. Light incident on one leg of the right angle prism was reflected from the mirror at an angle of 45°, passing out normally through the other leg of the prism. Thus the only changes in azimuth and in phase difference were those due to reflection at the metal glass boundary.

After reflection from the mirror, the elliptically polarized light was rendered plane polarized by the Babinet compensator B, and extinguished by the analyzing nicol N_2 which was viewed by the eyepiece E.

Method of Observation.

The constant of the Babinet compensator was determined several times for each wave-length used. Settings were made on the band of zero phase difference, and then on the bands of -2π and $+2\pi$, there being ten readings taken for each position. The mean value of the constant for any wave-length was calculated from as many as 180 individual settings. Having obtained the position of the dark band representing zero phase difference, the telescope carrying the compensator and analyzing nicol was rotated through 90°, the mirror put in place, and the new position of the band noted. The amount of displacement of the dark band represents the phase difference Δ produced on reflection at the rubidium surface.

In order to obtain the azimuth ψ, the polarizing nicol was set with its plane of polarization making successively angles of 45°, 135°, 225°, and 315° with the plane of incidence. For each position of the polarizer, the two positions of the analyzing nicol were determined by setting for maximum blackness of the bands. Ten readings were taken for each position, or a total of 80 settings for the determination of ψ. The mean of all the readings of the analyzer for two positions of the polarizer 180° apart was subtracted from the corresponding mean of all the readings for the other two positions of the polarizer. This difference is equal to 2ψ.

The following example will illustrate briefly the method of calculating 2ψ and Δ.

Table I.

$\lambda = 454.6\ \mu\mu$.

Position of Polarizer	0° 18′.	180° 18′.	90° 18′.	270° 18′.
Position of analyzer	237° 42′ 54° 36′	237° 42′ 54° 54′	141° 48′ 323° 54′	141° 54′ 323° 30′
Mean	146° 9′	146° 18′	232° 51′	232° 42′
Mean of means	146° 14′		232° 47′	
Difference = 2ψ	86° 33′			

For Babinet Constant.

	-2π.	0.	$+2\pi$.
Position of compensator	20.270	27.581	34.839
Differences	7.311		7.258
Mean	7.285		

Position of compensator upon reflection from rubidium = 29.613

$$\Delta = \frac{29.613 - 27.581}{7.285} \times 360 = 100° 25'.$$

Attention must be called to the use of the right angle prism in eliminating disturbing reflections from the front of the mirror. Considerable trouble in the determination of Δ was experienced with the first prism used. It was found when studying the reflection from the prism itself, that the value of Δ obtained for internal reflection was about 30 per cent. less than the theoretical value of Δ as given by Drude's equation,

$$\tan\frac{\Delta}{2} = \frac{1}{n}\sqrt{n^2 - 2}, \tag{1}$$

where the angle of incidence is 45°, and n is the index of refraction of the glass prism. No amount of cleaning of the prism altered the value of Δ. It was accordingly assumed that this deficit in Δ was due to internal strains, and so another prism was finally obtained which upon close examination yielded values of Δ agreeing to within one per cent. of the theoretical value.

FORMULÆ.

Drude's equations in the rigorous form were used. The approximative equations as used for ordinary metals cannot be employed in this case due to the low value of the index of refraction, *i. e.*, the square of the sine of the angle of incidence cannot be neglected in comparison with the complex dielectric constant.

Let

$$\tan Q = \sin \Delta \tan 2\psi,$$

$$\cos 2P = \cos \Delta \sin 2\psi,$$

$$S = \sin \phi \tan \phi \tan P,$$

where ϕ is the angle of incidence $= 45°$ throughout this investigation. The coefficient of absorption k is given by

$$k = \tan \frac{X}{2}, \tag{2}$$

where

$$X = \frac{S^2 \sin 2Q}{S^2 \cos 2Q + \sin^2 \phi}.$$

The index of refraction n is given by

$$n^2 = \frac{S^2 \cos 2Q + \sin^2 \phi}{1 - k^2}. \tag{3}$$

The principal angles of incidence and of azimuth are evaluated by means of the following equations:

$$\sin^4 \bar{\phi} \tan^4 \bar{\phi} = n^4(1 + k^2)^2 - 2n^2(1 - k^2) \sin^2 \bar{\phi} + \sin^4 \bar{\phi}, \tag{4}$$

$$k = \tan 2\bar{\psi}. \tag{5}$$

The reflecting power R of the metal for normal incidence is given by

$$R = \frac{n^2(1 + k^2) - 2n + 1}{n^2(1 + k^2) + 2n + 1}. \tag{6}$$

RESULTS.

The values of Δ and 2ψ and of the calculated optical constants are given in Table II. The values of Δ and 2ψ are the results of an extended series of observations. The constants refer to the metal in contact with glass. The values of the reflecting powers as obtained directly by the use of the photo-electric cell are listed in the last column to afford comparison with those obtained by calculation from Drude's formulæ.

TABLE II.

Metal—Glass Boundary.

λ in $\mu\mu$.	Δ.	2ψ.	n.	k.	R (Calc.).	R (Direct.)
640.9	119° 30′	86° 52′	0.093	10.51	0.827	0.840
589.3	113 23	86 46	0.087	9.28	0.810	0.808
539.6	110 41	86 29	0.093	7.97	0.787	0.817
488.8	104 34	86 33	0.089	6.49	0.766	0.816
454.6	100 36	86 38	0.091	5.28	0.745	0.789

In general the reflecting powers as obtained directly by use of the photo-electric cell are somewhat lower than those obtained by the polarimetric method. It is possible that this may have been due to a slight deterioration of the mirror surface. It is also interesting to note that with the polarimetric method, the reflecting powers decrease more rapidly for the smaller wave-lengths than is the case with the photo-electric cell method. A comparison of the curves for the reflecting power is shown in Fig. 3.

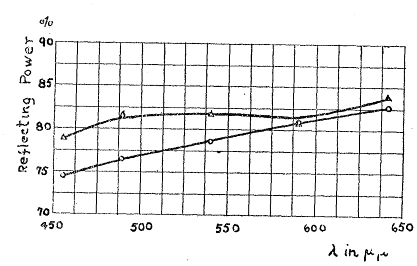

Fig. 3.

The principal angles of azimuth $\bar{\psi}$ and of incidence $\bar{\phi}$ can be calculated from the values of k and n. In this case the values of n in Table II. must be multiplied by the refractive index 1.51 of the glass plate of the mirror, in order to obtain the values of n referring to the metal in contact with the air. It is assumed that k remains the same. The results of the calculations are given in Table III., together with the reflecting powers for the metal-air boundary. There is very little variation in n.

TABLE III.

Metal—Air Boundary.

λ in $\mu\mu$.	n.	$\bar{\psi}$.	$\bar{\phi}$.	R (calc.).
640.9	0.140	42° 17′	62° 42′	0.840
589.3	0.131	41 56	60 1	0.811
539.6	0.140	41 26	58 44	0.780
488.8	0.134	40 37	55 29	0.739
454.6	0.137	39 39	53 22	0.700

From Tables II. and III. it appears that for the larger wave-lengths the reflecting powers for the air-metal boundary are greater than the reflecting powers for the metal-glass boundary, as we should expect. Oddly enough this is however reversed for the smaller wave-lengths.

Examination of R. W. and R. C. Duncan's[1] results for potassium, reveals a parallel case. For $\lambda = 665.0\ \mu\mu$ and $589.3\ \mu\mu$, the reflecting powers of potassium for the glass-metal boundary are less than for the air-metal boundary, while for $\lambda = 472.0\ \mu\mu$, the case is just reversed, *i. e.*, R (air-K) = 86.9 per cent. while R (glass-K) = 87.8 per cent. It follows that for some value of the wave-length, the reflecting power of the metal must be the same irrespective of whether there is air or glass as the medium in contact with the metal. If this is the case, then

$$\frac{n^2(1 + k^2) - 2n + 1}{n^2(1 + k^2) + 2n + 1} = \frac{n^2(1 + k^2)1.51^2 - 2n\cdot 1.51 + 1}{n^2(1 + k^2)1.51^2 + 2n\cdot 1.51 + 1},$$

where 1.51 is the index of refraction of the glass, and n refers to the glass-metal boundary. Solving this equation for k,

$$k = \frac{1}{n}\sqrt{0.66 - n^2}. \tag{7}$$

For large values of k and small values of n, *i. e.*, $n < 0.81$, the right-hand side of the equation is real, and the equality is possible.

The calculations for the reflecting powers have been made on the assumption that k of the metal is not affected by the character of the medium in contact with that metal. Various investigations on this point do not seem to be in harmony. Ingersoll[2] showed experimentally that the reflecting power of a metal in contact with air can be obtained from the values of n and k for the metal in contact with a transparent medium, by multiplying n by the refractive index of that medium, and assuming k unchanged. On the other hand Tate's[3] results for silver in contact with air and with glass, show that k as well as n is affected by the medium in contact with the metal, k being about half as large for the silver-glass boundary as for the silver-air boundary. In fact Tate's values for the reflecting powers of silver in contact with air cannot be obtained from the values of n and k for the silver-glass boundary, by merely multiplying n by 1.51 and keeping k constant.

From all the aforesaid, it therefore appears unreliable to calculate the reflecting power of an air-metal boundary from the values of n and k

[1] PHYS. REV., 36, 294, 1913.

[2] PHYS. REV., 29, 392, 1909.

[3] PHYS. REV., 34, 327, 1912.

obtained from the metal-glass boundary, by merely correcting for *n*. It is not safe to assume that *k* remains the same. Further investigation of this question is desirable.

Summary.

The optical constants of rubidium were obtained for wave lengths ranging from 454.6 $\mu\mu$ to 640.9 $\mu\mu$. A simple Babinet compensator and two nicols were employed to measure the phase difference and azimuth. The constants were calculated by means of Drude's formulæ.

The rubidium mirror was formed by distillation of the metal in vacua, with subsequent condensation upon a piece of plane parallel glass. A right angle prism served to eliminate troublesome reflections from the glass front of the mirror.

The reflecting powers of the metal in contact with glass were, with the exception of that for $\lambda = 589.3\ \mu\mu$, somewhat lower than those obtained directly by means of a photo-electric cell in a previous investigation.

The results do not warrant the assumption that the coefficient of absorption of rubidium remains constant irrespective of the medium in contact with the metal.

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