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PRODUCT MANUAL

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PRODUCT MANUAL FOR

BABINET COMPENSATOR



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Address: No. 610, 5th main, 8th cross Tatanagar, Bangalore - 560 092, INDIA
Website: www.kamaljeeth.net, Email: labexperiments@kamaljeeth.net

CALIBRATION OF A BABINET COMPENSATOR AND PHASE SHIFT VARIATION BETWEEN THE ORDINARY RAY AND THE EXTRAORDINARY RAY

Jeethendra Kumar P K

KamalJeeth Instrumentation and Service Unit, Tata nagar, Bangalore-560 092, INDIA

Email: labexperiments@rediffmail.com

Abstract

Using a quartz based Babinet compensator, the nature of the light emerging from a Babinet compensator is determined. By varying the prism thickness, the phase variation between the ordinary- and the extraordinary- ray is established and thickness of the mica sheet required for making quarter wave plate and half wave plate is determined and compared with the corresponding standard values.

Introduction

The Babinet compensator is an improved version of a Quarter wave plate and is used to produce and analyze elliptically polarized light. A quarter wave plate or a half wave plate produces only a fixed phase difference (or path difference) between the ordinary and the extraordinary rays and can be used only with light of a particular wavelength. For different wavelengths, different quarter wave plates are to be used. To avoid this difficulty, Jacques Babinet (1794-1872) designed a compensator in 1867 by means of which the desired path difference can be introduced between the ordinary and extraordinary rays and is named after him as Babinet compensator.

Babinet compensator (BC)

Babinet compensator consists of two wedge-shaped prisms A and B of quartz or any other birefringent material [1], as shown in Figure-1. The optical axis lies lengthwise (longitudinal) in A and breadth wise (transverse) in case of B. The outer faces of the compensator are parallel to the optic axis. Therefore, the ordinary and the extraordinary rays travel along the same direction but with different velocities inside the compensator. Moreover, the extraordinary ray inside the quartz prism A behaves as the ordinary ray in B and vice versa [2]. A parallel plane beam of polarized light, incident at the point of incidence C splits into extraordinary and ordinary rays, as shown in Figure-1. The optical path for the ordinary ray is $CD_1 = t_1 \mu_o$ and for extraordinary ray $CD_2 = t_2 \mu_e$, where t_1 and t_2 are the respective thickness of the two prisms.

Path difference between two rays inside the crystal = $CD_1 - CD_2$

$$\Delta = (t_1 - t_2) (\mu_o - \mu_e)$$

...1

Hence the phase difference

$$\delta = \frac{2\pi}{\lambda} (t_1 - t_2) (\mu_O - \mu_E)$$

...2

where δ is the phase difference;
 μ_E is the refractive index corresponding to the extraordinary ray;
 μ_O is refractive index corresponding to the ordinary ray;
 t_1 and t_2 are the thickness of the wedge A and wedge B respectively; and
 Δ is the path difference between the ordinary and the extraordinary ray.

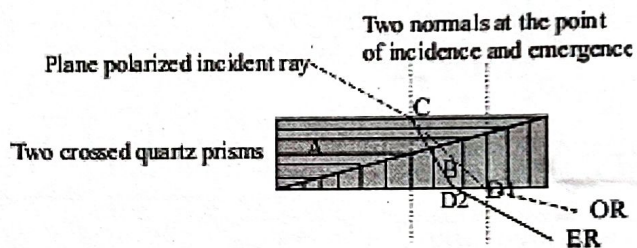


Figure-1: Two wedge shaped quartz prisms and splitting of the incident ray into ordinary and extraordinary rays

Producing variable path difference between the ordinary and the extraordinary rays

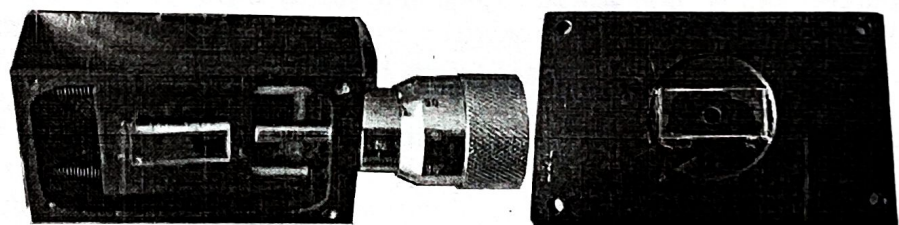


Figure-2: The two prisms of the Babinet compensator; the prism on the left, A, is fitted on to a micrometer screw which slides over the fixed prism B fitted on the back cover (right)

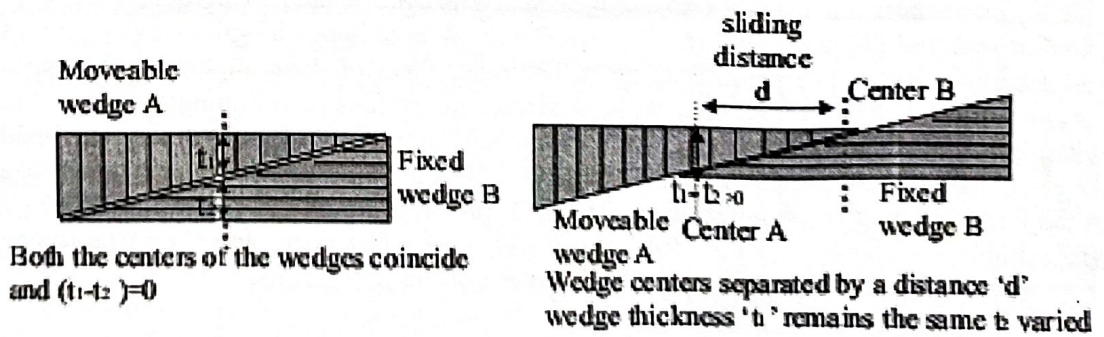


Figure-3: Wedge thickness t_1 is fixed whereas the thickness of t_2 varies as the prism A slides over the prism B by the distance 'd'

One of the quartz wedges A is mounted on a precision micrometer attachment inside the closed cell (Figure-2). The prism B is fitted on the back cover of the compensator enclosure, as shown in Figure-2. Hence the prism A slides along the surface of B with the help of a rack and pinion arrangement. The horizontal movement from left to right and right to left by the rack and pinion moves the moveable prism away from the centre of the fixed prism, hence (t_1-t_2) vary or the phase difference can be varied continuously. Figure-3 shows how the thickness varies, by sliding the moveable prism. From Equation-1, it is seen that the phase difference is proportional to the difference in the thickness of the two prisms.

When both the prism centres coincide, $t_1=t_2$ which gives $t_1-t_2=0$, or the resultant path difference is zero. In this case light emerges from the compensator as a single ray and there is a change in its polarization state. Similarly plane polarized light emerges from the compensator. At this position the micrometer shows 0.00mm reading. The micrometer is marked with the centre as zero, so that the prism B is free to slide on either side to get positive and negative phase shift. The movable prism slides over the fixed prism on either side by 10mm, as shown in Figure-3. For all the values of $(t_1-t_2) > 0$ and $(t_1-t_2) < 0$, the light emerging from the Babinet compensator is elliptically polarized. Hence Babinet compensator produces elliptically polarized light.

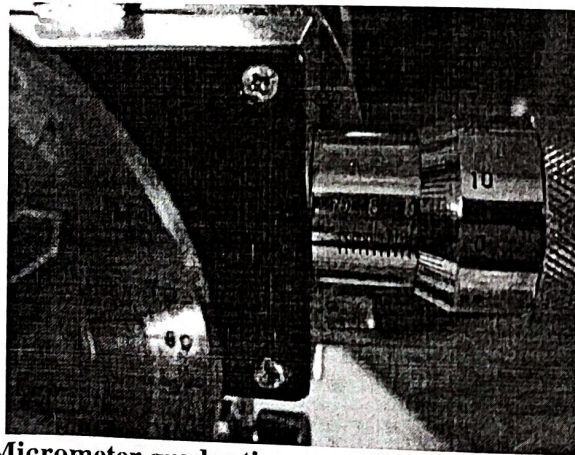


Figure-4: Micrometer graduations; reading corresponding to 1mm

Relation between the micrometer reading (d) and difference in the prism thickness (t_1-t_2)

From Figure-3 it is clear that micrometer reading and the actual prism thickness are different. The difference in thickness between the two prisms (t_1-t_2) and the micrometer readings needs to be correlated before further measurements. This can be done by taking thickness difference between the two prisms and the corresponding micrometer reading. If 'd' is the difference in the micrometer reading, then one can write

$$d = K (t_1-t_2)$$

...3

Where 'K' is a constant of conversion which can be evaluated by determining the fringe width experimentally. Equation (3) connects the phase difference with the prism thickness. From this

relation the micrometer movement required to produce quarter, half, full wave phase difference can be calculated. The procedure for connecting the micrometer reading with the prism thickness is known as the calibration of the Babinet compensator.

Nature of output light of the Babinet compensator

The polarizer of the Babinet compensator converts the un-polarized incident light on it to output polarized light with an angle θ with the optical axis of the Babinet compensator. Light passes through the two prisms of the Babinet compensator and comes out from it. When the phase shift is zero in the wedges of the prism, the light coming out from the Babinet compensator is linearly polarized. For all other values of the phase shift the light emerging from it is elliptically polarized. Let us now consider how to distinguish between the linearly polarized and the elliptically polarized light.

To the naked eye linearly polarized, elliptically polarized or circularly polarized light appear the same, like ordinary light. Hence naked eye cannot distinguish polarized light. However, by recording the light intensity one may be able to easily identify the nature of polarization state. For this purpose, one may also use an analyzer in combination with a quarter wave plate [3].

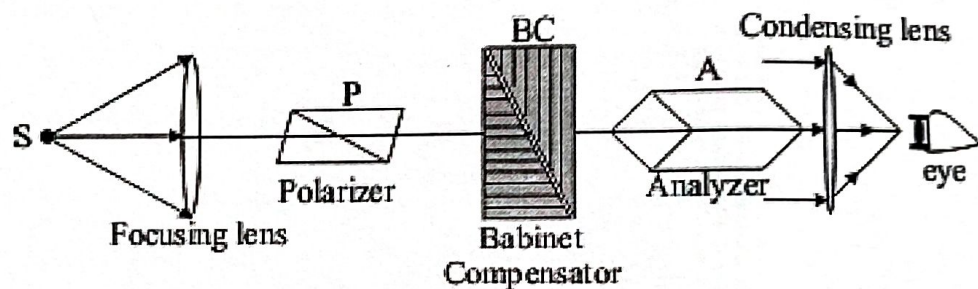


Figure-5: Babinet compensator placed between the polarizer and the analyzer

The polarizer is oriented such that the plane polarized light emerging from it and falling normally on the compensator makes an angle ' θ ' with the optic axis of the compensator. The light emerging from the compensator is also plane polarized at those points of the compensator for which the path difference is $0, \lambda, \dots, n\lambda$ and the vibrations are in the same plane as that transmitted by the polarizer P. When the analyzer A is in a crossed position these vibrations are stopped and we get a set of dark bands in the field of view. For the intermediate positions with the values of the path difference $\lambda/2, 3\lambda/2, 5\lambda/2$, etc., the light emerging from the compensator is plane polarized with vibrations inclined at an angle of 2θ with the plane of the incident vibration. The analyzer A does not get rid this light. When analyzer makes an angle $\theta = 45^\circ$, the light will be completely transmitted giving rise to the regions of maximum brightness without appearance of any dark fringe. At these positions the fringes vanish and bright light emerges from the Babinet compensator. Between two dark fringes, the light is elliptically polarized as shown in Figure-6, hence the light coming out of the Babinet compensator is elliptically polarized. If white light is used instead of the yellow sodium light, the central band will be dark while other bands will be coloured, as shown in Figure-8. The dark band is well defined with narrow width whereas the bright band is quite wide.

To identify the nature of the light emerging from the Babinet compensator the tests, as indicated in Table-1, are conducted [3]. The light emerging from the Babinet compensator is studied first with the analyzer on board. If there is no change in the intensity of light emerging from the Babinet compensator, Table-1 is used and further tests are conducted. If intensity variation with the analyzer is observed then Table-2 is used and further tests are conducted to determine the nature of the emerging light from the Babinet compensator.

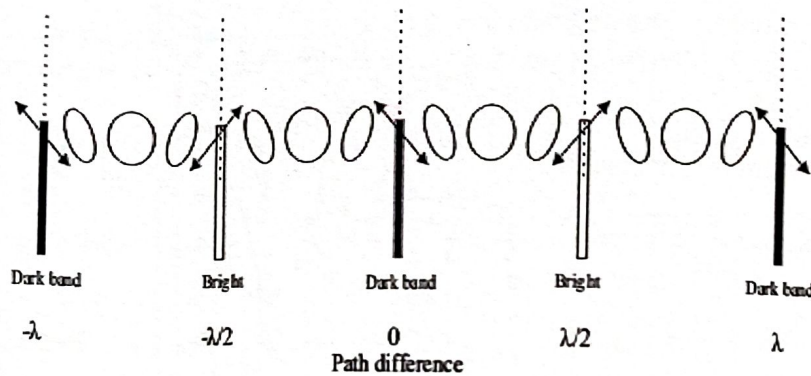


Figure-6: Elliptically polarized light between the bright and dark bands

Table-1: Absence of intensity variation with analyzer, test and nature of light

Absence of intensity variation with analyzer alone		
If with $\lambda/4$ plate in front of the analyzer	If with $\lambda/4$ plate in front of the analyzer one finds a maximum, then	
One has no intensity variation, <i>Then the light is un-polarized light</i>	If one position of the analyzer gives zero intensity, <i>Then the light is circularly polarized light</i>	If no position of the analyzer gives zero intensity, <i>Then the light is mixture of circular polarized and un-polarized</i>

Table-2: Intensity variation with analyzer, test and nature of light

If one position of analyzer gives	If no position of analyzer gives zero intensity		
Zero intensity, <i>Then the light is plane-polarized</i>	Insert a $\lambda/4$ plate in front of the analyzer with optical axis parallel to position of maximum intensity		
	If get no zero intensity		
	If zero intensity with analyzer, then the light is elliptically polarized	<table border="1"> <tr> <td>But the same analyzer setting as before gives the maximum intensity, <i>Then the light is a mixture of plane polarized light and</i></td> <td>But some other analyzer setting than before gives a maximum intensity, <i>Then the light is a mixture of elliptically polarized and plane</i></td> </tr> </table>	But the same analyzer setting as before gives the maximum intensity, <i>Then the light is a mixture of plane polarized light and</i>
But the same analyzer setting as before gives the maximum intensity, <i>Then the light is a mixture of plane polarized light and</i>	But some other analyzer setting than before gives a maximum intensity, <i>Then the light is a mixture of elliptically polarized and plane</i>		



Apparatus used

The experimental set-up consists of a Babinet compensator, Sodium vapour lamp set and thin mica sheet. The complete experimental set-up is shown in Figure-7.



Figure-7: Babinet compensator experimental set-up using white light

Experimental procedure

The experiment consists of three parts, namely

Part-A: Determination of the polarization state of light emerging from the Babinet compensator

Part-B: Variation of the path difference between the ordinary ray (OR) and the extra ordinary ray (ER)

Part-C: Determination of the thickness of the quarter wave plate and the half wave plate

Part-A: Determination of the polarization state of light emerging from the Babinet compensator

For identifying the nature of the light, viz. Its polarization state, emerging from the Babinet compensator, following steps is performed, as listed in Table-1 and Table-2.

1. The micrometer reading is set to 1mm. This indicates that there is some phase difference between ordinary and extra-ordinary rays.
2. Observing through the analyzer, it is slowly rotated to find the variation in the intensity of light.

Observed light intensity variation, through analyzer rotation; the fringes disappear; bright light like moon appears in the field of view for certain positions of the analyzer and any further angular variation in the same direction makes the fringes reappear. There are two maxima and two minima for 360° rotation of the analyzer.

Hence Table-2 is followed and further tests are conducted

Once again the analyzer is rotated to find any zero intensity position, however, as no zero intensity is noted, therefore the light is *not plane polarized*.

3. The thin mica sheet is now held by hand between the analyzer and the Babinet compensator and the analyzer is rotated slowly to look for any zero intensity position.
4. Minimum (but not exactly zero) intensity position is observed for a certain position of the analyzer.

From Table-2 it is noted that the light is *elliptically polarized*.

Part-B: Variation of the path difference between the ordinary ray (OR) and the extra ordinary ray(ER)

5. The Babinet compensator is set in front of the sodium light and viewing through the analyzer eye piece bright and dark fringes are observed, as shown in Figure-8. By rotating the micrometer screw, S, the first dark fringe on the left is coincided with vertical cross wire and the corresponding micrometer reading is noted.

Micrometer reading corresponding to first dark band = 0.00mm

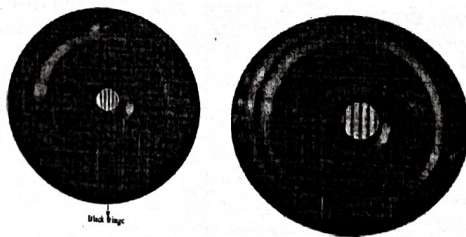


Figure-8: Six dark and yellow bands observed for the sodium light and coloured fringes observed with white light (Colour picture on the cover page of this LE issue)

6. The vertical cross wire is now coincided with second dark band and the corresponding micrometer reading is noted

Position of the second dark band = 1.41mm

7. Similarly the micrometer readings corresponding to 3rd, 4th, 5...9th (till the last dark band) are noted by coinciding the dark band with the vertical cross wire and the micrometer reading are recorded in Table-3.

Table-3: Micrometer readings corresponding to the dark bands

Band	d(mm)	Band	d(mm)
0	0.00	5	7.25
1	1.41	6	8.71
2	2.81	7	10.01
3	4.38	8	11.64
4	5.84	9	12.95

8. A graph is drawn with band number on X-axis and micrometer reading on Y-axis and the slope of the straight line obtained is determined which gives the average separation between two consecutive dark bands.

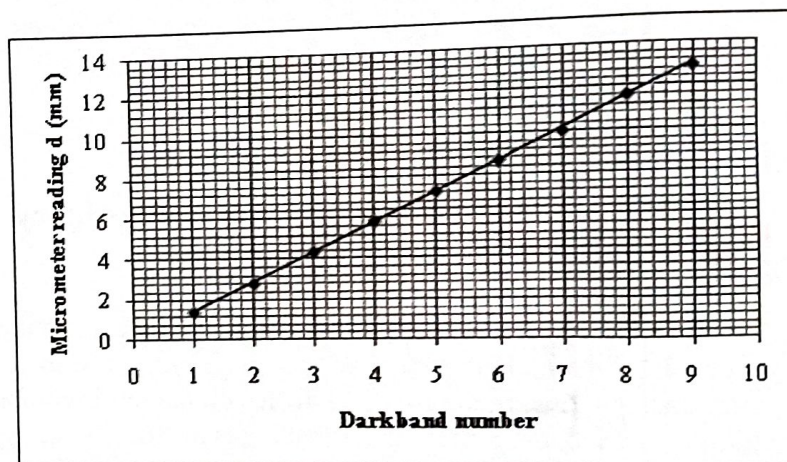


Figure-9: Variation of micrometer reading with band number

Separation between two consecutive dark bands = 1.371mm

The phase difference between two consecutive dark bands is 2π . Hence micrometer reading 1.371mm corresponds to 2π phase difference between OR and ER. Using Equation-3, one can determine the prism thickness corresponding to the path difference of 2π .

$$d = K(t_1 - t_2) = 1.371\text{mm} \quad \text{From Equation-2 we have} \quad \dots 4$$

$$\delta = \frac{2\pi}{\lambda} (t_1 - t_2) (\mu_0 - \mu_E) = 2\pi$$

Simplifying one obtains

$$(t_1 - t_2) = \frac{\lambda}{(\mu_0 - \mu_E)} = \frac{590 \times 10^{-9}}{9.1 \times 10^{-3}} = 64.83 \mu\text{m}$$

Substituting this value of $(t_1 - t_2)$ in Equatiouon-4, we get

$$K = \frac{1.371 \times 10^{-3}}{64.83 \times 10^{-6}} = 21.147$$

Hence we have connected the micrometer reading, d , with the prism thickness difference and we can write

$$(t_1 - t_2) = \frac{d}{K} = \frac{d}{21.147} \quad \dots 5$$

In this manner the Babinet compensator is calibrated for further measurements and one can, calculate the path difference or the phase difference for a given micrometer movement. Table-4 shows the micrometer movement (d) and the corresponding theoretical value of the path difference.

9. A graph is drawn with the path difference along X-axis and micrometer reading on Y-axis, as shown in Figure-10. From the graph, micrometer reading corresponding $\lambda/4$ and $\lambda/2$ path difference is noted as

For the quarter wave path difference, the micrometer has to be moved by the distance " d " = 0.348mm.

For the half wave path difference, the micrometer has to be moved by the distance " d " = 0.696mm.

For one full wave, the path difference, the micrometer has to be moved by the distance " d " = 1.392mm.

Table-4: Micrometer reading and path difference between the Ordinary Ray and the Extraordinary Ray

Micrometer movement d (mm)	$(t_1 - t_2)$ μm	Path difference Δ (μm)	Path difference fraction of λ
0.5	23.28	0.212	0.359 λ
1	46.57	0.423	0.718 λ
2	93.15	0.847	1.430 λ
3	139.73	1.271	2.15 λ
4	186.30	1.695	2.87 λ
5	232.88	2.118	3.59 λ
6	279.46	2.543	4.31 λ
7	326.04	2.966	5.02 λ
8	372.61	3.390	5.75 λ
9	419.19	3.814	6.46 λ
10	465.76	4.238	7.18 λ

Part-C: Determination of the thickness of the quarter wave and half wave plate

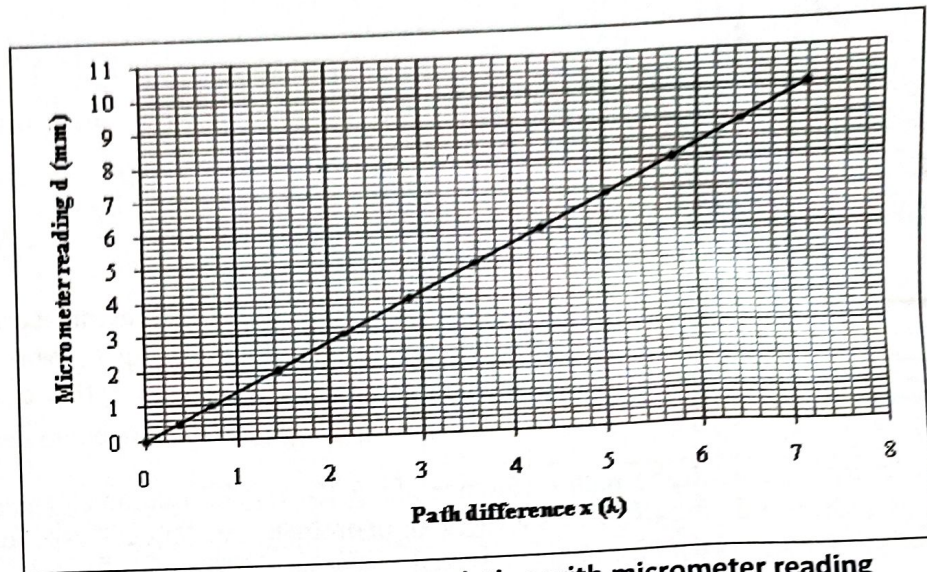


Figure-10: Path difference variation with micrometer reading

The thickness of the mica sheet for making a quarter wave plate

$$t_1 - t_2 = t = \frac{\Delta}{9.1 \times 10^{-3}} = \frac{0.25\lambda}{9.1 \times 10^{-3}} = 0.0162 \text{ mm}$$

The thickness of the mica sheet for making a half wave plate can be calculated as

$$t_1 - t_2 = t = \frac{\Delta}{9.1 \times 10^{-3}} = \frac{0.5\lambda}{9.1 \times 10^{-3}} = 0.0324 \text{ mm}$$

Hence one may take a mica sheet of appropriate thickness for making quarter wave and half wave plates.

Results

The values of thickness of the mica sheet for making quarter- and half wave- plates are listed in Table-5 for sodium light.

Parameters	Expt.	Std.
Thickness of mica sheet for quarter wave plate	0.0162mm	0.0175mm
Thickness of mica sheet for half wave plate	0.032mm	0.035mm

Discussion

The light emerging from a Babinet compensator is elliptically polarized, as may be seen from Table-2, Part-A. A relation between micrometer reading and prism thickness is established based on the theoretical considerations. The thickness of the mica sheet required to make a quarter wave plate and a half plate is calculated for sodium light and compared with the standard value.

Reference

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