Advanced Higher Physics: Assignment Support

Astronomy & Physics Education Group

School of Physics & Astronomy

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Measurement of refractive index of glass by prism spectrometer

Introduction – A prism spectrometer

A prism spectrometer is an instrument for observing spectra and measuring angles of deviation of light by a prism. Figure 1 details the key components: collimator, prism table, telescope..

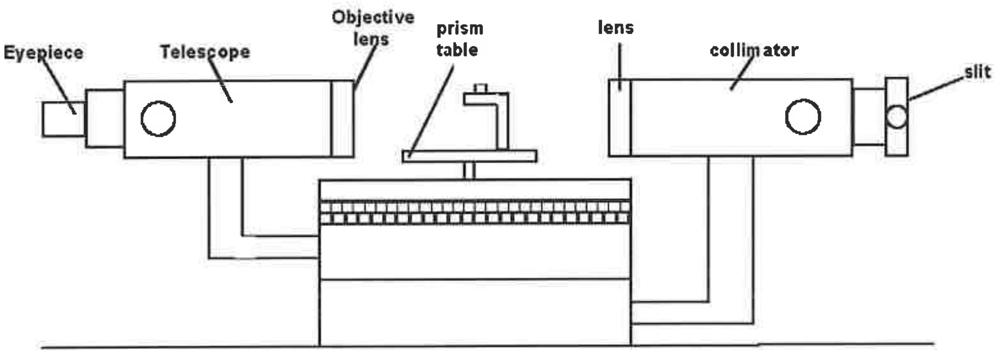

Figure 1: A prism spectrometer

Collimator: This is a tube with an adjustable slit at one end and an achromatic converging lens system at the other. The slit should be vertical, and it is usually placed at the focus of the lens so that, when it is illuminated, a beam of parallel light emerges from the collimator. The collimator is fixed to the base of the instrument.

Prism table: This should be horizontal and can be rotated about a vertical axis. A Vernier scale allows the rotation to be measured with respect to the collimator.

Telescope: This is mounted so that it is free to rotate about the same axis as the prism table. It may be focussed to receive parallel light from the collimator. The rotation of the telescope can be measured by another Vernier scale. These are cross-wires in the eyepiece of the telescope, and these should be vertical and horizontal.

The positions of the arms of the spectrometer are measured using angular Vernier scales. A Vernier scale is used when we need to make a measurement of a distance or angle to a greater accuracy than that obtainable though direct visual reading of a liner scale. In this experiment, the Vernier scales mounted on the spectrometer looking something like Figure 2.

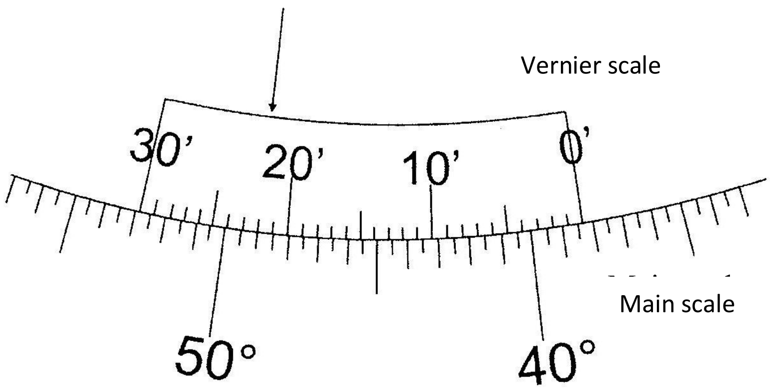

Figure 2: A Vernier scale

The position as read from this example is $38^{\circ}\ 22'$. This means "38 degrees 22 arcminutes". (There are 60 arcminutes in a degree.). How do we get this result?

- The first thing to look for is the position of the ZERO on the Vernier scale. In Figure 3, this is after 38°, but before 39°.

- To determine position further, look for a point of alignment between the two scales – i.e. a point where the tick marks from both scales light up. In this case, the position is marked by the arrow – at $22'$ on the Vernier scale.

- The final position is then the addition of these two numbers - $38^{\circ}\ 22'$.

Measuring n via refraction through a prism

Figure 3 shows one possible arrangement of the prism spectrometer, with light entering the collimator and then being viewed through the telescope. Here the prism has three faces: AB, BC and CA. BC – positioned against the support bracket on the prism table – is ground. Light is refracted at AC and AB. The angle between the incident and emergent direction of the light through the prism is called the angle of deviation, δ. If the prism table is rotated clockwise and anti-clockwise the observed spectrum will also move. There will come a point, though, where as the prism table is turned the observed spectrum will stop and then move in the opposite direction. The point where this happens is the angle of minimum deviation. When this occurs the rays passing through the prism are parallel to BC.

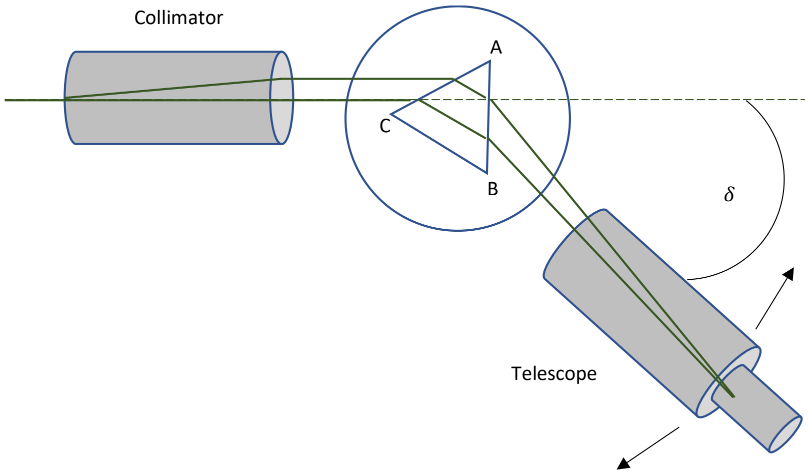

Figure 3: Light refracting through a prism

Once the value of δ has been determined, it is possible to calculate the refractive index of the prism material provided the size of the apex angle, A, is known. For the prism used here – an equilateral triangle – it should be 60° but this should be confirmed.

Consider Figure 4, which shows the passage of a monochromatic ray through the prism at minimum deviation. Since the external angle of a triangle equals the sum of the interior opposite angles it follows that

$$\delta = (\theta_a - \theta_g) + (\theta_a - \theta_g) = 2(\theta_a - \theta_g)$$

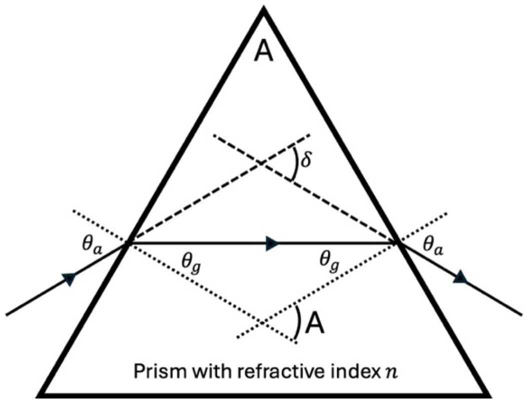

Figure 4: Light passing through prism

and

$$\mathrm{A} = \theta_g + \theta_g = 2\theta_g \Rightarrow \theta_g = \frac{\mathrm{A}}{2}$$

$$\Rightarrow \theta_a = \frac{\delta}{2} + \theta_g = \frac{\delta}{2} + \frac{\mathrm{A}}{2} = \frac{\delta + \mathrm{A}}{2}$$

Applying Snell's law at the first boundary, and remembering that $n_a = 1$ we see ...

$$n_g = \frac{n_a \sin(\theta_a)}{\sin(\theta_g)} = \frac{\sin(\theta_a)}{\sin(\theta_g)}$$

$$\boxed{\Rightarrow n_g = \frac{\sin\left(\frac{\delta + \mathrm{A}}{2}\right)}{\sin\left(\frac{\mathrm{A}}{2}\right)}}$$

[1]

Measuring n through reflection off a prism

An electromagnetic wave is comprised of an electric field component and a magnetic field component, each at 90° to each other. Most light sources are unpolarised – this means that the electric and magnetic field vectors are emitted in random planes. Unpolarised light can become polarised by passing it through a polariser. This is a filter that has lots of very thin, closely packed, parallel lines on it that only allows light through in one plane. The outgoing light is now referred to as being plane polarised. Unpolarised light can also be plane polarised by *reflection* from any flat transparent electrical insulator, such as glass, water or Perspex. The degree of polarisation depends on the incident angle, θ_i, and the refractive index of the material, n.

θ_i is known as the Brewster Angle, θ_p, when the reflected light is 100 % plane polarised. This occurs when the angle between the reflected ray and the refracted ray is 90°. Figure 1 which shows the arrangement when $\theta_i = \theta_p$.

Assuming that the incident light is initially in air, where $n = 1$ and that the grey box represents a glass block with refractive index n, then applying Snell's law at the boundary tells us

$$n = \frac{\sin(\theta_i)}{\sin(\theta_r)}$$

When $\theta_i = \theta_p$, and recalling that the angle of reflection equals the angle of incidence, then we can see that

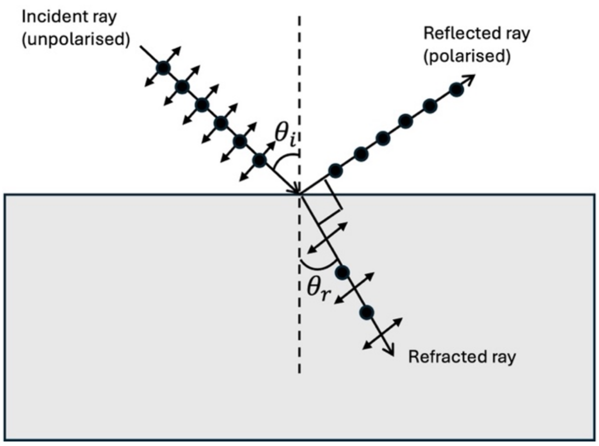

Figure 5: Brewster angle situation

$$\theta_r = 90 - \theta_p$$

$$\Rightarrow n = \frac{\sin(\theta_p)}{\sin(\theta_r)} = \frac{\sin(\theta_p)}{\sin(90 - \theta_p)} = \frac{\sin(\theta_p)}{\cos(\theta_p)}$$

$$\boxed{\Rightarrow n = \tan(\theta_p)}$$

[2]

To determine the refractive index this way with a prism spectrometer, the apparatus is set up as shown in Figure 6: light reflects off one face of the prism and into the telescope. In front of the telescope has been placed a analyser – a filter that can be rotated. When the analyser is rotated, the brightness of the reflected image will vary – this shows that it has been partially polarised. As the angle of incidence is varied, there will come a point at which when the analyser is rotated the reflected image vanished entirely – when this occurs the angle of incidence equals the Brewster angle. To determine what this angle is, the position of the telescope is noted on one of the pair of Vernier scales. Then the prism should be removed and the telescope rotated round until it is directly aligned with the collimator. The new position should then be recorded. The difference between these two readings $= 180° - 2\theta_p$ since at the Brewster angle the angle of incidence and the angle of reflection to the prism face are both equal to θ_p, thus making the angle between collimate and telescope equal to $2\theta_p$.

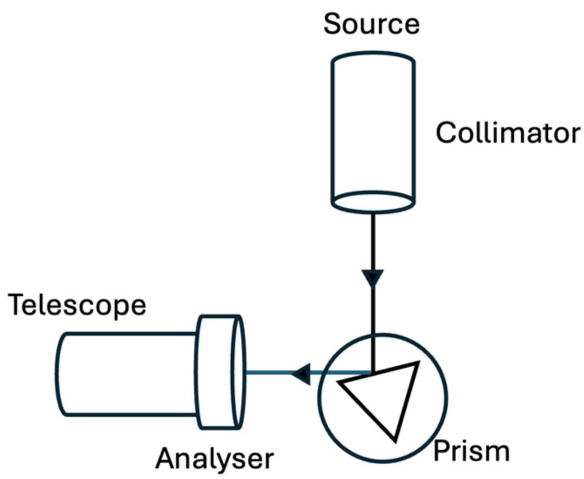

Figure 6: Reflection off a prism

Notes on equipment

Equipment list

- Spectrometer
- Glass prism
- Sodium source

Equipment guidance

Confirming the apex angle, A

- Turn the prism so that angle A is pointing along the axis of the collimator as shown in Figure 7; make sure that the light is reflected from each of the two faces adjacent to A. (Check it can be seen in the telescope on both sides.) Once happy, fix the prism table in place.
- Note the vernier reading of the telescope on either side of the prism; the difference in these two values will equal 2A.

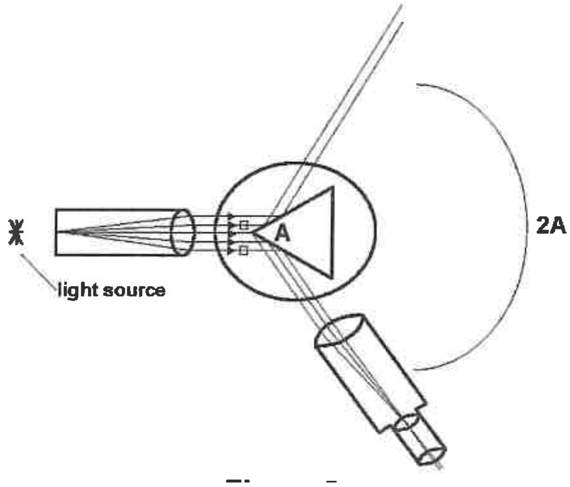

Figure 7: Confirming A

Adjusting the position of the prism

- The prism can be rotated by physically turning the prism table by hand – there is also a fine control for making smaller adjustments. Best practice is to use the table to get the prism to roughly where it should be, then switch to the fine control.

Finding the spectrum

- It can take some time to find the emission spectrum using a prism spectrometer – patience is key. If you are struggling, it is best to aim for an angle of incidence of around 50° for the refraction experiment and around 45° for the reflection experiment. These don't need to be measured precisely – just gauged by eye to help get started.

Focussing the Collimator and Telescope

I. Focussing the telescope and cross-wires

- Rotate the telescope to view a point in the lab as far as way as you can.
- Focus the telescope until you get as sharp an image as possible.
- To focus the cross-wires adjust the eyepiece of the telescope until the cross-wires appear sharp. Make sure that the cross-wires are horizontal and vertical. ONCE YOU ARE SURE YOU HAVE THESE FOCUSSED, DO NOT TOUCH THE EYEPIECE AGAIN!

II. Focussing the collimator and telescope using Schuster's method

- Set the equipment so that you can see the line spectrum from the sodium lamp, with the prism turned to the angle of minimum deviation.
- Turn the prism table away by around 5° from the minimum angle so that the ground face of the prism is closer to parallel to the axis of the collimator. In Figure 3, this would mean turning anticlockwise. Now, focus the collimator – adjust the knob on the side of the collimator until the image is a sharp as possible.
- Now turn the prism back through the minimum angle until you are about 5° round on the other side. (Now going clockwise in Figure 3.) Focus the telescope – adjust the knob on the side of the telescope until the image is a sharp as possible.
- Repeat this procedure until no further improvement in the sharpness can be seen.
- The telescope and collimator are now focussed for parallel light.

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