APPENDIX-A: THE SPECTROMETER

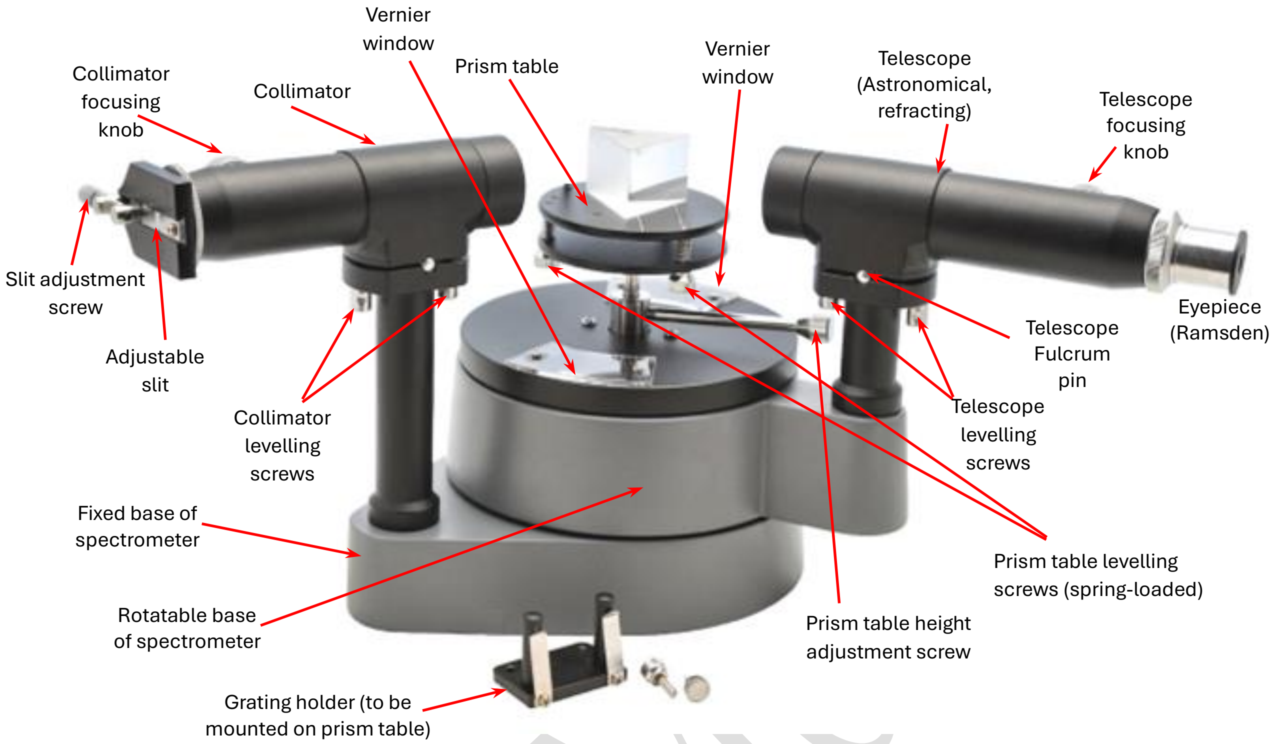

Fig-1A: Picture showing a student grade laboratory spectrometer, its components, adjustment knobs and screws.

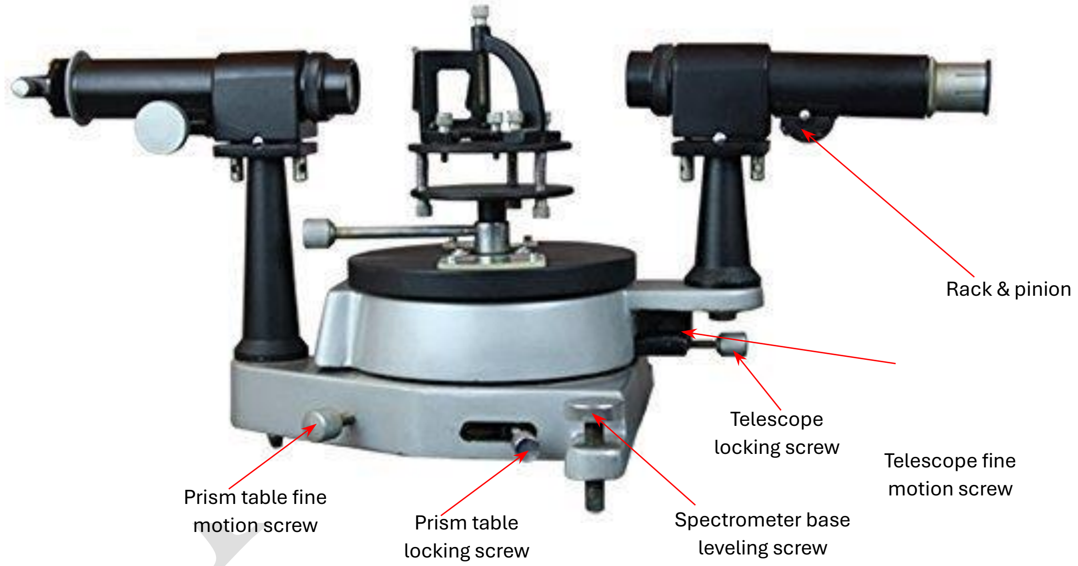

Fig-1B: Picture showing a student grade laboratory spectrometer, its components, adjustment knobs and screws.

Fig-2: Picture showing rack and pinion for converting the rotary motion of the focusing knobs to translatory motion of the inner tube of the telescope or the collimator.

1. Description of the Spectrometer

A general-purpose college lab spectrometer is a complex instrument and has several adjustment screws and knobs attached to it. A precise adjustment is necessary to achieve the required accuracy and precision in the measurement of wavelengths or other quantities of interest. Fig-1A and fig-1B, show a labelled image of the type of spectrometer one usually gets to see in a college laboratory. There are several parts and allied adjustments that are discussed hereunder.

The images above show a heavy base on which three primary components are mounted, the telescope, the collimator, and the prism table.

The axis around which the prism table is free to rotate coincides with the axis about which the telescope revolves. This axis is the center of the spectrometer as well. The collimator and the telescope always face this axis. The collimator is mounted on an upright attached to the fixed part of the base, ready to throw light through the central axis of the spectrometer, whereas the telescope is mounted on an upright attached to the movable part of the base.

a. The function of a **collimator** is to render an incoming divergent beam of light, parallel. This is achieved with the help of a fine slit at one end of a length adjustable tube and an achromatic combination of convergent lenses at the other. When the slit lies at the focus of the convergent lens system, the light is rendered parallel. The collimator has a set of screws attached to it, one for adjusting its level and the other for fixing the adjustment.
    i. Adjustable **entrance slit** is available at the back end of the collimator whose width, height and tilt can be adjusted by the experimenter according to the requirement.
    ii. **Focusing knob** with rack and pinion arrangement is provided to alter the effective tube length and thereby making adjustments for rendering the emergent beam of light parallel, as if coming from an infinitely placed source.
    iii. If the entrance slit is made to lie exactly at the focus of the achromatic combination of **collimating lens**, the emergent beam of light is rendered parallel.

b. As the collimator throws light parallel onto any optical element placed on the prism table, an **astronomical telescope** is provided on the rotating part of the spectrometer base such that it is always ready to receive light through the center of the spectrometer. The telescope also has a set of screws attached to it, one for adjusting its level and the other for fixing it. The telescope objective too is an achromatic combination of lenses, and a Ramsden eyepiece is provided for reasons explained later in the text. **Focusing knob** with rack and pinion arrangement is provided for focusing the telescope of a large range of distances.

c. A height adjustable, rotatable **prism table** is mounted centrally to the spectrometer vertical axis. It comes with three spring loaded levelling screws.

d. In case, one is using a prism, it must be placed such that the refracting edge of the prism lies close to the centre of the prism table. However, in case of a diffraction grating, it must be placed centrally on the prism table.

e. Light source to be studied is placed close to the entrance slit of the collimator such that enough light enters the slit and the source is exactly in line with the collimator.

    Some of the components are not elaborated here as their labels are self-explanatory and to avoid making the text too lengthy and unwieldy. *Do consult the laboratory instructors in case of a requirement.*

2. Preliminary adjustments

a. Focusing: To begin with, it's essential to focus the telescope onto an object positioned at an infinite distance from it, and to adjust the collimator for rendering an incoming divergent beam of light parallel. To achieve this, move the spectrometer from the darkroom to a location near a window and point the telescope towards a very distant tree (the farthest you are able to see). Ensure nothing comes in between the objective of the telescope and the object being viewed. Bring its leaves and twigs to sharp focus by adjusting the focusing knob. Once done do not disturb this setting through the experiment. Henceforth, any requirement of focusing must be carried out using the collimator focusing knob. The eyepiece in itself too is a double tube arrangement that can be taken out a little. By doing this we may bring its crosshair to sharp focus. This adjustment needs great care! Once the crosshair is in sharp focus, check for parallax by moving your eye slightly left and right. If the crosshair and the image of distant object move in the same direction you can safely assume that there is little or no parallax. However, if they move in opposite directions then the eyepiece needs further adjustment.

b. **Levelling:** A rough levelling of the spectrometer and its components is done with the aid of level adjustment screws provided and using a spirit level. After placing the spectrometer at an appropriate location in a proper orientation, close to the light source of interest. Initially, the base of the spectrometer is levelled. Then the collimator and the telescope are levelled and finally the prism table. A spirit level is used to carry out the levelling of all the aforementioned components.

c. **Optical alignment:** For a rough alignment, illuminate the entrance slit of the collimator using a light source of your interest, like sodium or mercury vapor lamp. Ensure that the collimator is exactly in line with the source. Look through the lens and adjust the spectrometer base to receive maximum light, through the center of the collimator objective. Make the slit as fine as possible. Bring the telescope in line with the collimator and focus the image of the slit using both the focus knobs. Bring the image to the center of the field of view by using the telescope fine motion screw. This is an ad hoc alignment that will be refined further.

3. Placement of light dispersing element: Once all the above outlined adjustments have been made the grating is to be placed centrally and vertically on the prism table so that it receives light from the collimator normally onto its surface.

4. Reading the Vernier scale of a spectrometer: The main scale mark just before the zero mark of the Vernier is the main scale reading (MSR) in degrees. Usually, the smallest division on the main scale is 0.5 degree, so the reading will necessarily be an integral multiple of half a degree. Seldom, one would find main scale markings of 1 degree.

   To read the Vernier, just look for the Vernier coincidence. It is that Vernier mark on the Vernier scale that most closely matches any one of the lines on the main scale. This is just a number either between 0 and 30 or 0 and 60 depending upon the design of the spectrometer scale. This number multiplied by the least count of the instrument is in degrees and can be added to the main scale reading to get the total reading.

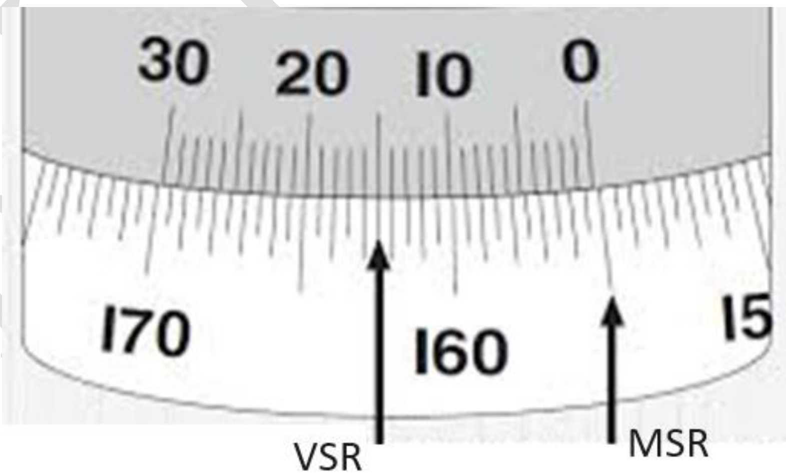

Fig-3: Diagram showing how to read main scale (MS) and Vernier scale (VS) of a spectrometer.

IMPORTANT PRECAUTIONS

Never mix the readings of window-1 with those of window-2, they are to be processed separately.

It is to be noted that often one might end up getting obtuse results while measuring acute angles using a spectrometer. The idea can be exemplified using the following example. Suppose the angle to be measured between two positions of the telescope is as shown in the fig-4. Now, this angle is evidently less than 180 deg. However, directly subtracting the positional values 290 and 18 leads to 272 deg, which is in no way correct, as it is evident from the diagram as well. Therefore, whenever the telescope crosses the 0 deg mark, a correct way to calculate the angle is, (360 - 290) + 18 = 70 + 18 = 88

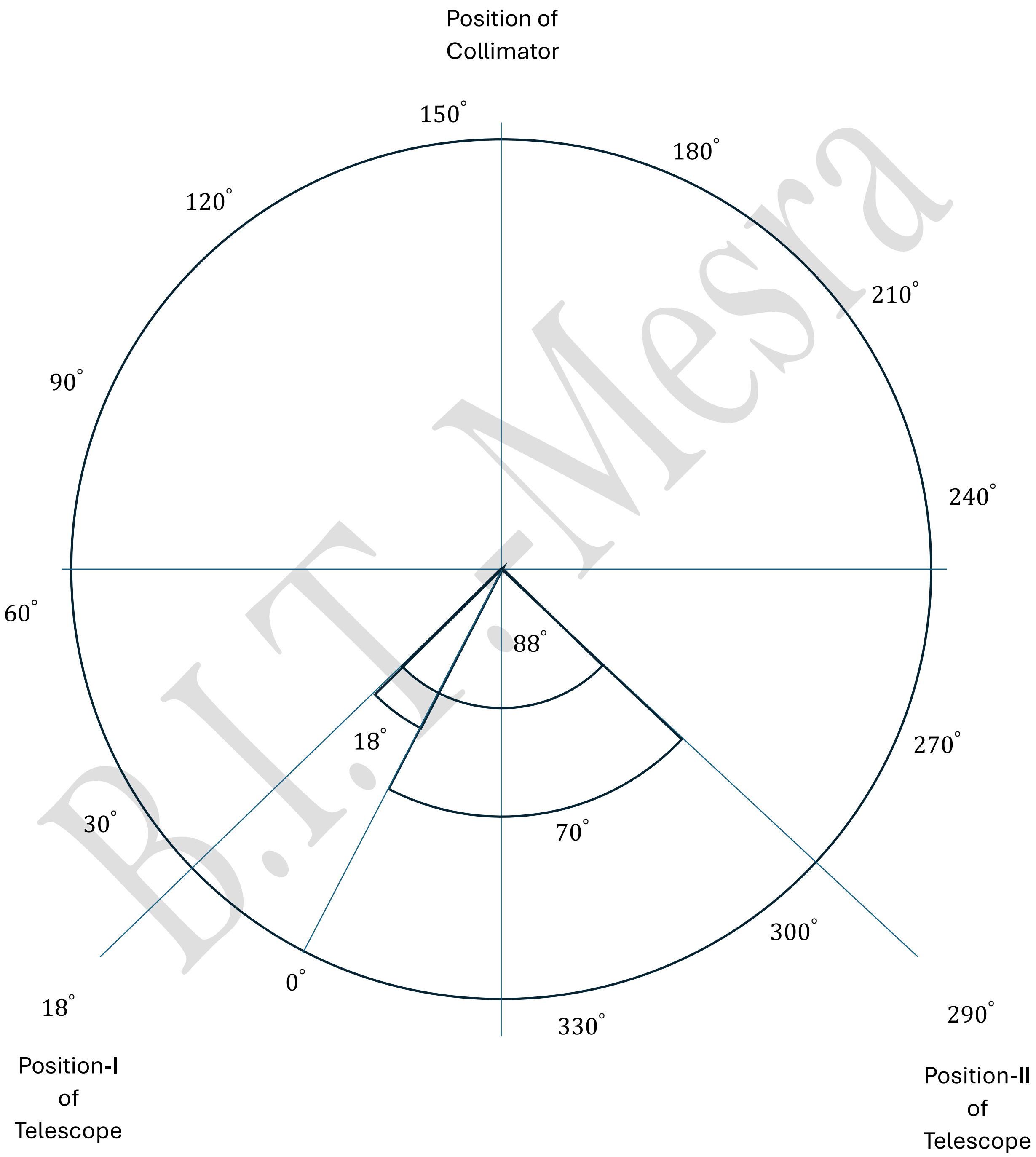

Fig-4: Diagram showing telescope positions on a spectrometer for measurement of angles, for explaining and exemplifying the precaution to be observed.

Rough levelling: The spectrometer stands on three sturdy legs out of which on is fixed to the body and the other two are thick screws that can be rotated to move them up or down thus making it possible to adjust the leg size. Level the base of the spectrometer using a spirit level and the two adjustable levelling screws provided for the purpose. Repeat the same for the collimator and the telescope in almost the same way. Once levelled the axis of the spectrometer is a vertical and the telescope moves in a horizontal plane.

Optical levelling: Under the illuminated condition of the entrance slit of the collimator we place a grating (or a plane glass plate) centrally on the prism table with the help of a grating holder. Make sure that the grating is perpendicular to the prism table and the collimator. View the direct ray through the telescope and note its position with the help of a Vernier scale. See if it is centrally located in the field of view. If not adjust the telescope and the collimator levelling screws to bring it to the centre. Then move the telescope through 90° (approx.) to one side. Then rotate the prism table such that the reflected image of the entrance slit is visible through the telescope. Once again check whether the image is almost at the center of the field of view. If not check for the same, by rotating the telescope through 180° to the other side. Now, if the image either appears to be sinking to the bottom or hanging from the top, in the field of view on both the sides then adjust the telescope and collimator levelling. However, if the image changes its position from sinking on one side to hanging on the other then adjust the three levelling screws of the prism table. Repeating the process a couple of times would make the spectrometer optically levelled.

Schuster's focusing: Illuminate the slit of the collimator using a sodium vapor discharge lamp and position the telescope in front of the collimator. You should be able to see the image of illuminated slit through the telescope. Focus the telescope for utmost clarity. Place a prism on the prism table such that its refracting edge coincides with the central vertical axis of the prism table and its base is parallel to the telescope-collimator line. Push the telescope 2 to 3 mm towards the refracting edge and rotate the prism table so that the base of the prism makes an angle of 20 deg to the collimator and the refracting edge is towards the telescope. Rotate the telescope towards the base of the prism to view the refracted image of the slit. Further, rotate the prism table as well as the telescope, so that the angle of deviation is at its minimum. Focus the telescope once again in case of any blurring.

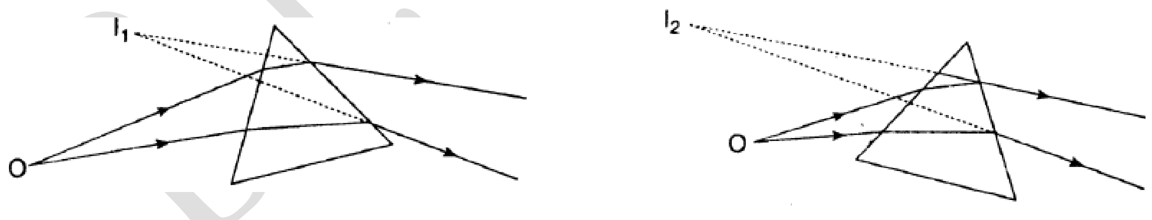

Fig-5: Ray diagram showing for explaining the reason behind Schuster's focusing method.

Now, rotate the prism table so that the refracting edge of the prism moves towards the collimator. Do this while viewing the image of the slit through the telescope, so that the image is pushed to one side in the field of view. In case of any blurring or defocusing, focus the image using the collimator focusing knob.

Rotate prism table to bring the refracting edge of the prism towards the telescope this time, again while viewing the image of slit through the telescope, so that the image comes to the center and then again goes to one side in the field of view. In case of any blurring or defocusing, this time focus the image using the telescope focusing knob.

Repeating the process around four to six times would adjust the collimator and the telescope for parallel rays.

Alternatively, you may take the spectrometer close to a window and point the telescope (not through a collimator) onto a distant object or a tree and focus it for a sharp image. Then, illuminate the slit of the collimator using a sodium vapor discharge lamp and position the telescope in front of the collimator. View the image of the illuminated slit through the telescope and focus it for utmost clarity.

The common perception prevalent among the students is that the telescope on the spectrometer is a terrestrial telescope. On the contrary it is an **astronomical telescope** because, the spectra that is produced by a prism or a grating spectrometer is usually not of very high intensity. Hence, it is a good idea to avoid the use of an additional image inverting lens, in between the objective and the eyepiece and loose light further, owing to the inevitable reflections from the surface of the lens. This image inverting lens is a part of **terrestrial telescopes**. In case of spectral lines produced by a spectrometer, it really doesn’t matter whether the lines are straight and erect or inverted. Hence, structurally the spectrometer telescope is astronomical although with much less magnification and aperture.

Focusing the **crosshairs**: Rotate the telescope towards any illuminated background. On looking through the eyepiece, you will probably find a blur image of the crosshairs. Move the eyepiece inwards or outwards until the crosswires appear distinct. Once this has been done, the focal plane of the eyepiece lies in the plane of the crosshairs.

RAMSDEN EYEPIECE

Fig-6. Schematic diagram of Ramsden eyepiece consisting of two lenses at a small separation with its focal plane and ray diagram.

The Pros

It is simple, small, and cheap. Gets rid of an aberration known as coma and reduces spherical aberration and distortion. It has a very small chromatic aberration. Reduces **chromatic aberration** more than some other eyepieces. The focal plane of Ramsden eyepiece lies outside the lens system, just in front of the field lens, making it a lot easier to place a **crosshair** or a **measurement scale**, that would aid measurements. It is possible to widen the field of view using this eyepiece, also the magnification can be increased considerably. All these make it a good choice for spectrometers where viewing light color distinctions is important.

The Cons:

Narrow field of view (typically 35 degrees only)

Short eye relief (although it is good for glasses wearers and shooters) *Eye relief is the maximum distance between eye and eyepiece at the point where you can see the maximum field of view.*

Aberrations:

Doesn’t mitigate lateral achromatism. Some other aberrations are only minimized, not eliminated.

GRATING

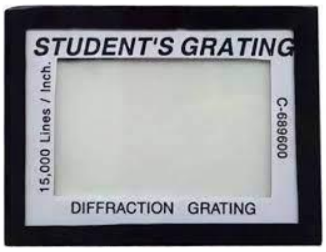

Fig-7. Actual image of a plane transmission grating (students' grade, replica grating)

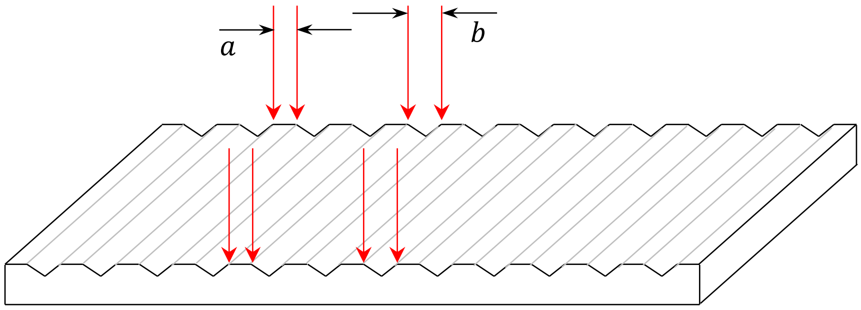

Fig-8. Schematic diagram of a master grating showing transparent windows (a) separated by opaque grooves (b), where, $(a+b)$ is the grating element.

PLANE TRANSMISSION DIFFRACTION GRATING

Diffraction grating is an optical element capable of dispersing light of different wavelengths due to diffraction of light through a large multitude of closely spaced ultra-fine slits. Gratings find their utility in spectrometers using which spectra of light sources can be produced.

A line spectrum of a composite light is produced if the light source utilizes electrical discharge through a material in its vapor phase. To performing measurements on any spectrum we employ an optical instrument known as spectrometer.

So, it must be amply borne in mind that diffraction grating or the spectrometer alone are of no use. To make a spectrometer functional, it must be paired with a light-dispersing element. The most common dispersing elements used are prisms and diffraction gratings. When a spectrometer uses a prism as its primary dispersing element, it is referred to as a prism-spectrometer. Similarly, if it uses a diffraction grating, it is called a grating-spectrometer.

Gratings come in a variety of types, each with its own set of advantages, disadvantages and applications. The name *plane transmission diffraction grating* might appear intriguing to you. So, it is always good to know the reason behind it. The term *plane*, because there are *curved gratings* as well, that not only disperse light, they focus it as well. Some gratings allow the light to pass through them hence the term transmission. It is worth mentioning that there are reflection type grating too.

Master grating is manufactured by a very sophisticated and precision machining process wherein, very closely spaced fine grooves are made using a diamond-tipped stylus on a high-quality glass plate. The scratched grooves scatter the light in a completely random fashion and act as non-transmitting or opaque portions whereas the plane glass plate portions in between two scratch marks transmits the light, acting as fine windows. The light that emerges out of these fine windows, undergo diffraction.

The cost of a master grating is prohibitively high. Hence, mostly a replica grating is used in the labs. A replica grating is made by pouring a thin layer of a polymer material and spreading uniformly over the master grating surface, so that it acquires the surface profile of the master grating is replicated on the thin polymer layer. Then it is allowed to dry up and harden, after which it is carefully removed and sandwiched between two thin glass plates to form one composite unit known as the replica grating. Its cost is relatively much lower, that might land somewhere on a ballpark value of INR 1500 to 6000, depending upon the quality. So, handle with care!