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Letter

Direct-vision spectroscope using water-prism

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Abstract : A liquid prism containing water as the medium is both theoretically and experimentally investigated. It is confirmed that the dispersion power of the prism with an apex angle of 95^o is about 5 times higher compared to that of the prism with 60^o apex. Using the 95^o prism, a simple direct-vision spectroscope was constructed having a fairly high spectrum resolution. This model offers an extremely low price spectroscope of high quality suitable for physics education especially in less privileged countries.

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1 INTRODUCTION

The availability of a simple, compact and inexpensive direct-vision spectroscope is highly desirable for bringing physics, in particularly the applications of optics and spectroscopy more readily and closer to the students in the classrooms and laboratories. As a result, such instruments have undergone continuous improvement toward better portability and easier assembling from parts available on the shelf at science supply shops. Nowadays, prism based compact direct-vision spectroscopes with high resolution are already available at the science supply shops. More recently, the use of replica grating instead of prism in the spectroscope has become very popular for a self-made unit as it offers advantages in terms of price and simplicity, although the principle of wavelength dispersion is simpler to describe with a prism than a grating.

In this paper, an even much cheaper and easily constructed spectroscope is proposed using a water prism made of a properly shaped acrylic or glass vessel filled with water. In addition to the attractive high quality rainbow colors spectrum produced by this simple instrument, the use of water prism also helps to dispel the commonly held misperception about the requirement of 60^o apex angle for the best performance of color dispersion. It is shown in this work that the apex angle of 60^o is in fact far from the best choice for the spectroscopic performance and the condition of optimal choice is derived and the result is demonstrated. The flexibility provided by using different liquids in the prism will further enrich the educational aspect of the related experiment. It will therefore serve to introduce the wavelength dispersion concept on a firmer and more comprehensive basis without compromising the quality of its observed spectra.

2 RESULTS AND DISCUSSION

To proceed with explanation of the working concept, let us consider the water prism in Fig. 1 which shows a ray transversing the prism under the condition of minimum deviation. As in the case of a glass prism at the condition of minimum deviation, the refracted ray inside the prism makes equal angles with the two prism faces. This can be easily understood by considering the reversibility of an optical ray; namely, if this proposition were not true, we would be led, upon reversing the ray, to the conclusion of having two angles of minimum deviation.

In the case of water prism, almost the same relations can be obtained as in the case of a glass prism.1-2 Thus, denoting respectively ?, I r and ? respectively as the apex angle of the prism, the incident angle,

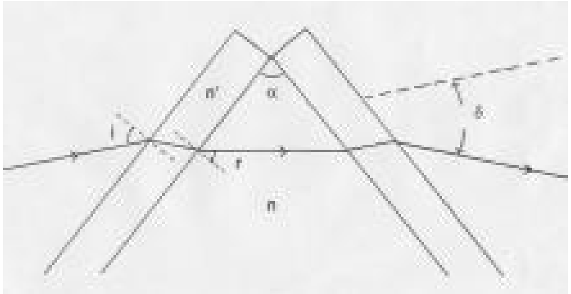

FIGURE 1: A diagram for the ray transverses in the water prism.

refracted angle in the water and the deflected angle of the ray as indicated in Fig. 1, we may derive the following relationship:

$$r = \frac{\alpha}{2} , \quad (1)$$

$$\delta = 2i - \alpha , \quad (2)$$

$$\frac{n}{(n')^2} = \frac{\sin\left[\frac{1}{2}(\alpha+\delta)\right]}{\sin(\alpha/2)} . \quad (3)$$

If the prism is made entirely of glass with a refractive index of n, then $n' = 1$ in Eq. (3). From Eq. (3), the deviation of the deflection angle due to variation in refractive index of the water can be derived to yield the following expression,

$$\frac{\mathrm{d}\delta}{\mathrm{d}n} = \frac{2\sin(\alpha/2)}{(n')^2\cos\left[\frac{1}{2}(\alpha+\delta)\right]} . \quad (4)$$

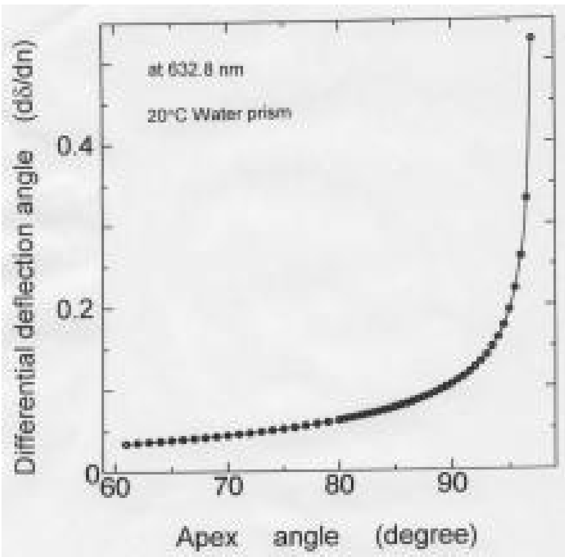

FIGURE 2: Deflection angle variation due to the change of 1×10^{-3} in the refractive index of the water as a function of the apex angle of the water prism.

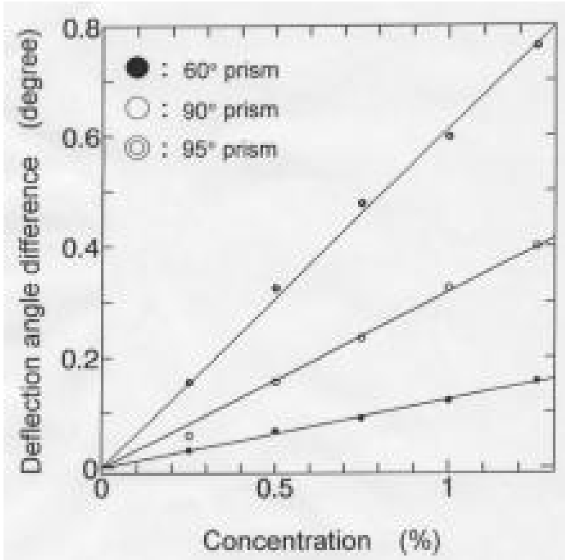

FIGURE 3: Deflection angle difference as a function of the content of sugar in water for three water prisms with different apex angle.

Fig. 2 shows the calculated value of $\mathrm{d}\delta/\mathrm{d}n$, the variation in the deflection angle δ due to a change of 1×10^{-3} in the refractive index of the water, as a function of α. The calculation was made for light with a wavelength of 632.8 nm. The refractive indices of the glass plate and the water at that wavelength are 1.5146 and 1.3317 respectively. The variation of α was terminated just before the total reflection occurs in the prism. From this result, it is seen that the dispersion for the 60o water prism is rather low compared to that of the 90^o water prism. Furthermore, it should be noted that the dispersion ability increases rapidly above 900.

The actual beam deflection was measured using a He-Ne laser using aqueous solution of sugar in the prism. Fig. 3 shows the deflection of laser beam by a

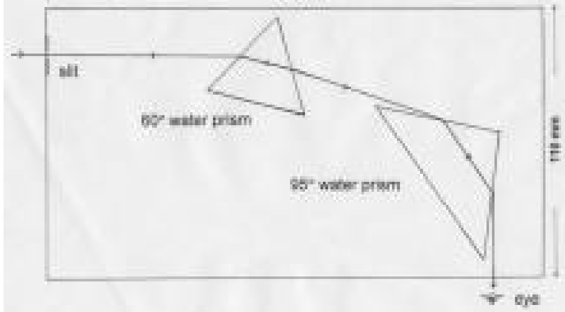

FIGURE 4: Arrangement for a simple direct-vision spectroscope.

600, 90^o and 95^o prism of sugar solution. The ratios of the dispersion power in the three cases is 1 : 2.7 : 5.2. This result is in good agreement with the theoretical result shown in Fig. 2. We are thus led to conclude that a 95^o water prism provides 5 times the dispersive power obtainable from a 60^o water prism.

Fig. 4 shows the simple configuration of the direct-vision spectroscope designed in our laboratory. The spectroscope consists of only three components, a slit, the 60^o water prism and 95^o water prism. These are fixed on the wooden plate painted with black ink, and the base plate was enclosed in a small paper box of which the inside was also painted with black paint. The cell for the water prism was made of a glass plate and acrylic plate attached together by means of adhesive.. Pure water was injected into the cell through a small hole on the upper plate of the prism. The slit was made of a black plastic sheet with a neatly cut edge. The slit width was fixed at 0.3 mm. The 60^o prism was mainly used for adjusting the configuration of the 95^o prism; it has relatively insignificant effect on the dispersion power of the system. This system configuration allows the spectrum to be observed from the direction perpendicular to that of the axis of the incident light directed to the slit. Without using 60^o water prism, the angle between the incident light and the viewing optical axis will be around 105^o, which is rather inconvenient for the spectral observation. During the assembling process, an adjustment should be made to insure that each prism is properly positioned and configured to produce a minimum deviation. This was done by searching for the clearest slit image with the naked eye while rotating the prism.

Fig. 5 displays the spectrum of the light source produced by the spectroscope and recorded using a reflective type camera (Asahi Pentax) and ASA 40^o color film. The light source is the discharge tube of He-Ne laser. It is clearly seen that the spectrum exhibits high brightness with high resolution.

It must be emphasized that the total cost for making this spectroscope is less than 5 dollars, including the material cost and even the workshop fee for cutting the glass plates, but excluding the light source. Students in junior high school can construct the spectroscope within about 3 hours if suitable guidance is given and the necessary components are at their disposal.

The quality of this spectroscope is excellent. The resolution attained in the spectrum is about half that of a commercial prism-direct-vision spectroscope. It should be emphasized that even the Fraunhofer lines in sunlight can be clearly seen using this self-made spectroscope. The student can enjoy observing the beautiful spectra from many different kinds of light source. We believe that this self-made equipment will help to stimulate the student's interest in making further acquaintance with the spectroscopic phenomena and the associated underlying physical principles. It will thereby contribute to physics education, especially in developing countries where the cost of the more conventional instrument is a severe constraint.

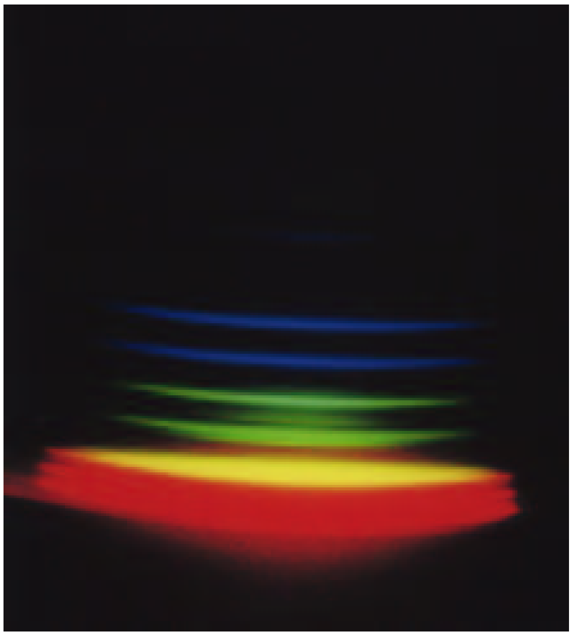

FIGURE 5: Spectrograph of side light emitting from *He-Ne* laser tube taken using the direct-vision spectroscope. A reflective camera was set in place of eye observation. Exposure time is 5 s. ASA 400 color film was used.

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