9.6 Colour and Wavelength

INVESTIGATION 9.6.1

Wavelengths of Visible Light (p. 485)
What are the wavelengths of the colours in visible light?

Table 1 The Visible Spectrum

Colour	Wavelength (nm)
violet	400–450
blue	450–500
green	500–570
yellow	570–590
orange	590–610
red	610–750

We know from the dispersion of white light in a prism that white light is made up of all of the colours in the visible spectrum. From our work in Section 9.5, we also know that helium–neon laser light has a wavelength of 630 nm. But what are some of the other wavelengths found in visible light? Investigation 9.6.1 in the Lab Activities section at the end of this chapter will give you the opportunity to use a white light source with filters to measure the wavelengths of red and green light.

Figure 1 shows three interference patterns: one for white, one for red, and one for blue light. You can see that the separation of the nodal lines is greater for red light than it is for blue. This is to be expected, since red light has a longer wavelength than blue. The relationship $\lambda = \frac{d\Delta x}{L}$ shows that the wavelength for red light is approximately 6.5×10^{-7} m and the wavelength for blue light is approximately 4.5×10^{-7} m. Similar determinations produce values for all the colours in the visible spectrum. Some of these are given in **Table 1**.

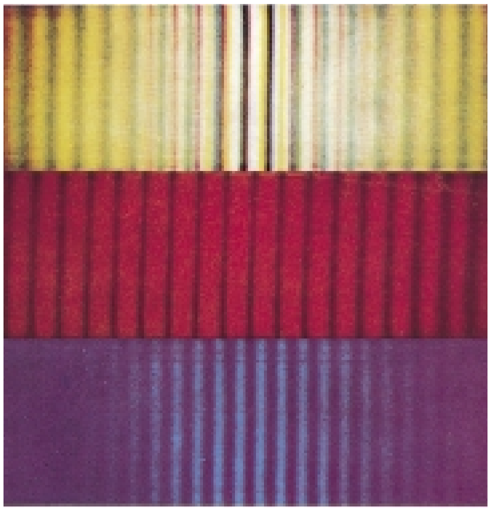

Figure 1
Interference of white, red, and blue light produced separately, using the same apparatus in all three cases

When white light passes through two narrow slits, the central bright areas in the interference patterns are white, whereas the spectral colours appear at the edges (**Figure 1**). If each spectral colour has its own band of wavelengths, each will interfere constructively at specific locations in the interference pattern. Thus, the colours of the spectrum are observed in the interference pattern because each band of wavelengths is associated with its own colour.

On passing through a prism, white light is dispersed, broken up into its components to form the spectrum. Each of the colours bends by a different amount and emerges from the prism at its own distinctive angle (**Figure 2**).

To explain dispersion, the wave theory must show that different frequencies (wavelengths) are bent by different amounts when they are refracted. Careful measurements in a ripple tank demonstrate this. Thus, if the frequency of a wave varies, the amount of refraction varies slightly as well, thereby explaining dispersion.

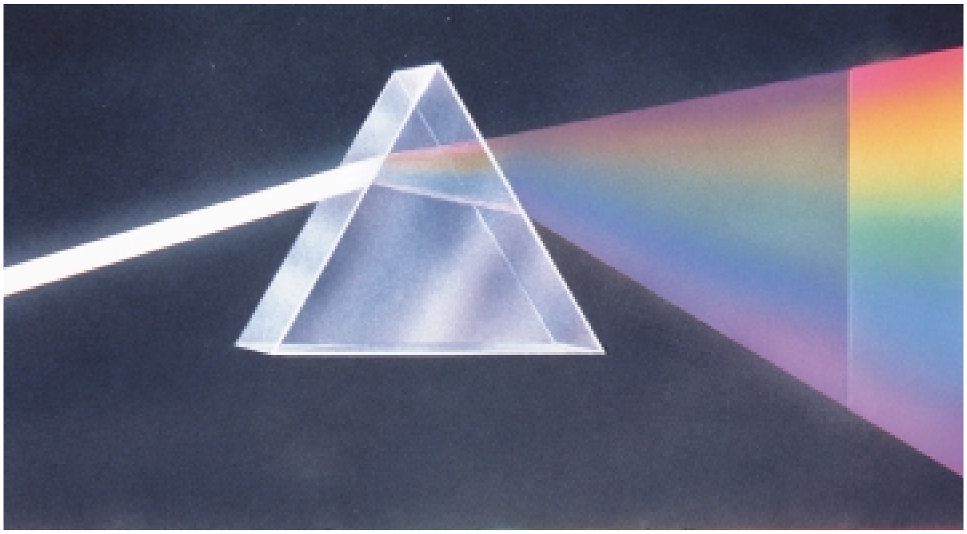

Figure 2
Dispersion of white light in a prism

Although the wavelength of the light does affect the amount of refraction, the behaviour is the reverse of what we encounter with water waves in a ripple tank. Shorter wavelengths, such as those at the violet end of the spectrum, are refracted more than the longer wavelengths in the red region of the spectrum. Each spectral colour, having a wavelength different from the others, is refracted a different amount. This explains the prism's separation of white light into the spectrum.

Since each of the wavelengths of visible light undergoes a slightly different amount of refraction by the prism, the glass must have a slightly different index of refraction for each colour. For example, the index of refraction of crown glass is 1.53 for violet light and 1.51 for red light. The speed of violet light in glass is slightly less than that for red.

The mathematical relationships governing waves in such media as ropes and water can be applied to optics:

$$v = f\lambda$$

$$\frac{\sin \theta_1}{\sin \theta_2} = n$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\frac{n_2}{n_1} = \frac{v_1}{v_2}$$

$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

For example, we find from the equation $v = f\lambda$ that the frequency of red light, with a wavelength of 6.5×10^{-7} m, is

$$f = \frac{v}{\lambda}$$

$$= \frac{c}{\lambda}$$

$$= \frac{3.00 \times 10^8 \text{ m/s}}{6.5 \times 10^{-7} \text{ m}}$$

$$f = 4.6 \times 10^{14} \text{ Hz}$$

LEARNING TIP

The Speed of Light
The speed of light c equals 3.00×10^8 m/s.

SAMPLE problem

Red light with a wavelength of 6.50×10^2 nm travels from air into crown glass ($n_2 = 1.52$).

(a) What is its speed in the glass?

(b) What is its wavelength in the glass?

Solution

(a) $\lambda = 6.50 \times 10^2$ nm

$n_2 = 1.52$ $\quad$ $n_1 = 1.00$

$v_2 = ?$ $\quad$ $v_1 = 3.00 \times 10^8$ m/s

$$\frac{n_2}{n_1} = \frac{v_1}{v_2}$$

$$v_2 = \frac{n_1}{n_2}v_1$$

$$= \frac{1.00}{1.52}(3.00 \times 10^8 \text{ m/s})$$

$$v_2 = 1.97 \times 10^8 \text{ m/s}$$

The velocity of red light in the glass is 1.97×10^8 m/s.

(b) $\lambda = ?$

$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

$$\lambda_2 = \left(\frac{v_2}{v_1}\right)\lambda_1$$

$$= \left(\frac{1.97 \times 10^8 \text{ m/s}}{3.00 \times 10^8 \text{ m/s}}\right) 6.50 \times 10^2 \text{ nm}$$

$$\lambda_2 = 4.28 \times 10^2 \text{ nm}$$

The wavelength of red light in the crown glass is 4.28×10^2 nm.

Practice

Understanding Concepts

1. The wavelength of orange light is 6.0×10^{-7} m in air. Calculate its frequency.
2. Light from a certain source has a frequency of 3.80×10^{14} Hz. Calculate its wavelength in air, in nanometres.
3. A certain shade of violet light has a wavelength in air of 4.4×10^{-7} m. If the index of refraction of alcohol relative to air for violet light is 1.40, what is the wavelength of the violet light in alcohol?
4. The index of refraction of turpentine relative to air for red light is 1.47. A ray of red light ($\lambda_r = 6.5 \times 10^{-7}$ m) passes from air into turpentine with an angle of incidence of 40.0°.
   (a) Calculate the wavelength of the red light in the turpentine.
   (b) Calculate the angle of refraction.
5. A certain Young's apparatus has slits 0.12 mm apart. The screen is at a distance of 0.80 m. The third bright line to one side of the centre in the resulting interference pattern is displaced 9.0 mm from the central line. Calculate the wavelength of the light used. What colour was it?
6. Sunlight incident on a screen containing two narrow slits 0.20 mm apart casts a pattern on a white sheet of paper 2.0 m beyond. Find the distance separating the violet ($\lambda = 4.0 \times 10^2$ nm) in the first-order band from the red ($\lambda = 6.0 \times 10^2$ nm) in the second-order band.

Answers

1. 5.0×10^{14} Hz
2. 789 nm
3. 3.1×10^{-7} m
4. (a) 4.4×10^{-7} m
   (b) 26°
5. 4.5×10^{-7} m
6. 2.0×10^{-3} m

Young's Experiment Today

It may be obvious to us now, but it was not obvious to the experimenters in the eighteenth and nineteenth centuries, that to produce an interference pattern, it is necessary to have two point sources of light in phase. Although the frequency of light sources is very high, what makes interference impossible is the way light is emitted from an incandescent source. The light from each source comes from a large number of individual atoms. Atoms send out light in time intervals of about 10^{-9} s. The probability that the atoms or groups of atoms in each source would emit their light waves in phase is nearly zero. Therefore, the interference pattern produced by two point sources changes in an irregular fashion every 10^{-9} s or so and is impossible for an observer to see. In recent years it has been possible to produce interference with two lasers. Laser light is monochromatic; in the case of helium–neon laser light, the wavelength is at the red end of the spectrum, 6.3×10^{-7} m. When two lasers have been made to operate in phase (they are then said to be "phase locked"), the interference fringes are seen. Since phase-locking is not perfect, some drifting of the pattern occurs. Even today, the easiest way to show the interference of light is to use Young's technique of putting a single emitter behind two apertures.

SUMMARY *Colour and Wavelength*

- White light is made of all of the colours found in the visible spectrum, each with its own range of wavelengths.
- Dispersion occurs because the refractive index of light is slightly dependent on the frequency of the light.

Section 9.6 Questions

Understanding Concepts

1. For both converging and diverging lenses, explain how the focal length for red light differs from that for violet light.
2. When white light passes through a flat piece of window glass, it is not broken down into colours as it is by a prism. Explain why.
3. A certain shade of red light has a wavelength in air of 7.50×10^{-7} m. If the index of refraction of alcohol is 1.40, calculate the wavelength of this red light in alcohol.
4. The wavelengths of the visible spectrum range from 4.00×10^2 nm to 7.50×10^2 nm. Calculate the range of the frequencies of visible light.
5. Calculate the angle for the third-order maximum of 5.8×10^2 nm wavelength yellow light falling on double slits separated by 0.10 mm.
6. Determine the separation between two slits for which 6.10×10^2 nm orange light has its first maximum at an angle of 3.0°.
7. Using your calculations in questions 5 and 6, explain why it is difficult to observe and analyze the interference pattern produced by a double slit.

Making Connections

8. Explain why a rainbow is impossible just after sunrise and just before sunset.