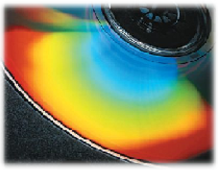
SPH4U
UNIVERSITY PHYSICS

THE WAVE NATURE OF LIGHT

☞ Diffraction Gratings
(P.520-525)

Wave Nature of Light

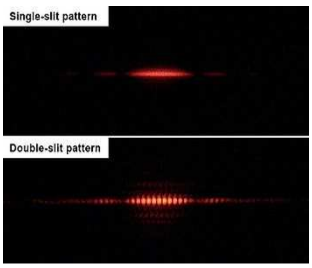
Not only did Young's double-slit experiment demonstrate the wave nature of light, it also paved the way for applications of interference and explained many phenomena that had been observed but not understood. For example, the rainbow of colours that appear in a CD or the spectrum of colours that shimmer across the scales of an Indigo snake. In fact, Newton himself had observed some effects of interference of light, but he did not know that interference caused these effects.



Diffraction Gratings

NOTE!

*It is difficult to measure the wavelength of light accurately using the interference pattern from either a double slit or a single slit – the interference pattern may be dull or fuzzy. Thus, most researchers use a **diffraction grating** to help eliminate these problems.*

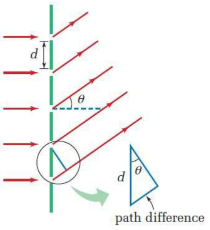


Diffraction Gratings

The principle on which a diffraction grating is based is the same as that of a double slit (recall Young's double-slit experiment). The diffraction grating simply has thousands of pairs of double slits that all work together to create very fine, bright fringes that are separated by large dark fringes. For example, a grating with 2000 lines/cm would have a slit spacing of:

$$d = \frac{1}{2000}\text{ cm}$$

or $d = 5 \times 10^{-4}$ cm

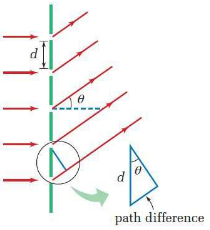


Diffraction Gratings

So when m = 0 and the path lengths of all of the rays are the same, the rays go directly through the grating, creating a central bright fringe. The next bright fringe above or below the central fringe is called the "first-order fringe." The naming continues with second-order, third-order, and so on.

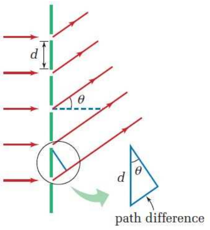
NOTE!

The formulas for a diffraction grating are the same as those for a double-slit.



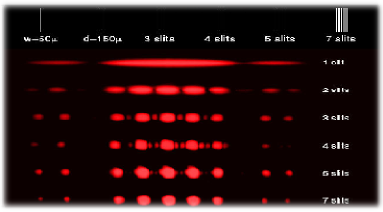
Diffraction Gratings

*There are two types of diffraction gratings: **transmission gratings**, in which light passes through the slits, and **reflection gratings**, in which light is reflected by smooth lines separated by non-reflective surfaces. CDs and DVDs are common examples of a reflection grating. Transmission gratings are typically used in spectroscopy.*



Diffraction Gratings

*The advantage of a diffraction grating over a double slit is the amount of destructive interference between the peaks of constructive interference. As the number of slits increases, the maxima become narrower and more sharply peaked. The resulting pattern of bright and dark lines are called **diffraction fringes**.*



Diffraction Gratings

DIFFRACTION GRATING

- device with a large number of closely spaced parallel slits
- produce interference patterns similar to those from a double slit except the maxima are narrower and more intense
- as the number of slits increases, the maxima become narrower and more sharply peaked
- uses the same formulas as double-slit interference
  - d = 1/N where N is the # lines/cm

Diffraction Gratings

PRACTICE

1. Light with a wavelength of 540 nm is incident on a diffraction grating that has 8500 lines/cm.
   (a) What is the spacing of the slits?

   (a) $d = 1.2 \times 10^{-6}$ m

Diffraction Gratings

PRACTICE

1. Light with a wavelength of 540 nm is incident on a diffraction grating that has 8500 lines/cm.
   (b) Calculate the angles of the first two maxima.

   (b) m = 1 ... $\theta_1 = 27°$
   m = 2 ... $\theta_2 = 67°$

Diffraction Gratings

PRACTICE

2. Light emitted by a particular source is incident on a diffraction grating with 9000 lines/cm and produces a first-order maximum at 32.0°. Determine the wavelength of the light.

   $\lambda = 5.89 \times 10^{-7}$ m

Diffraction Gratings

PRACTICE

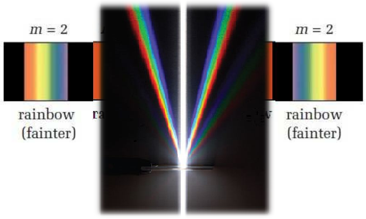
3. Consider two diffraction gratings, one with 8500 lines/cm and one with 10,000 lines/cm. Compare the separations between adjacent maxima for these two gratings. Recall $\Delta x = \lambda L/d$.

   since d = 1/N and $\Delta x \propto 1/d$ then $\Delta x \propto N$
   so as the # of lines/cm (N) increases so too does the spacing between adjacent maxima

Diffraction Gratings

NOTE!

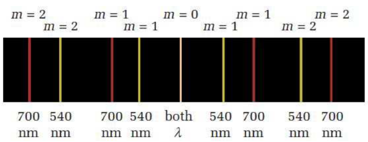
For a given diffraction grating with constant slit separation, the angle that results in constructive interference depends on the wavelength of the light (i.e. $m\lambda = d\sin\theta$). Since different colours have different wavelengths, colours are separated when light passes through a grating.



Diffraction Gratings

PRACTICE

1. What would you see if only the colours red and yellow passed through a diffraction grating together?



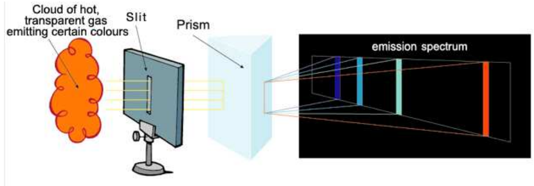
It is this property of diffraction gratings that makes them very useful!

Applications of … – Spectroscope

A ***spectroscope*** *uses a diffraction grating to separate light into very narrow bands of specific colours (wavelengths) that can then be analyzed.*

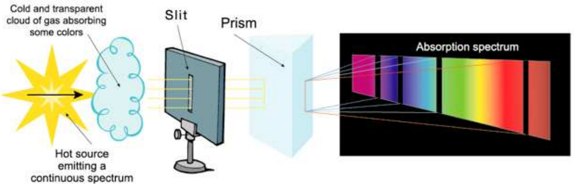
Applications of … – Spectroscope

*For example, when a gas is heated or has an electric discharge through it, it will emit light at very specific wavelengths. The set of wavelengths emitted by a pure substance is called the substance's **line spectrum** or **emission spectrum**.*



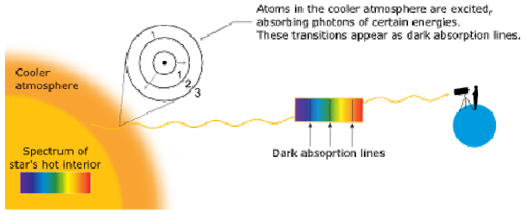
Applications of … – Spectroscope

Since atoms and molecules also absorb light at the same wavelengths at which they emit it, spectroscopes can also analyze absorption spectra.



Applications of … – Spectroscope

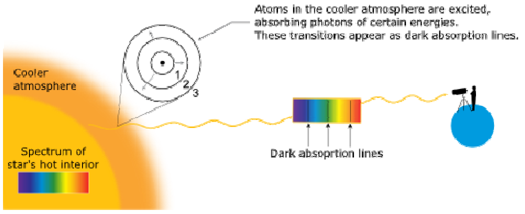
For example, the Sun's core emits a continuous spectrum but atoms and molecules in the sun's outer atmosphere absorb specific wavelengths, causing the Sun's spectrum to have several narrow black lines. Therefore, by identifying the wavelengths of light that have been absorbed by the Sun's outer atmosphere, physicists are able to identify the atoms that are present there.



Applications of … – Spectroscope

NOTE!

Careful analysis of the Sun's absorption spectrum reveals that at least two thirds of all elements present on Earth are present in the Sun. In fact, this technique is used to identify the composition of stars throughout our galaxy.



December 9, 2012 4U4 - Diffraction Gratings 18

Applications of … – Spectroscope

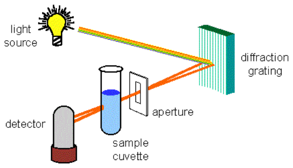
SPECTROSCOPE

- uses a diffraction grating to separate light into fine bands of colour
- since each element has a specific emission spectrum, the resulting spectrum is used to identify the atomic composition of the light source
- astronomers use absorption line spectra to determine the composition of stars

December 9, 2012 4U4 - Diffraction Gratings 19

Applications of … – Spectrometer

A ***spectrometer*** *is a device used in chemistry and biochemistry laboratories to identify and measure compounds in solutions. A spectrometer has a diffraction grating that separates white light into all wavelengths. You can select a specific wavelength and send it through a sample of a solution. The spectrometer then measures the amount of light of the wavelength that is absorbed by the sample and you can then calculate the concentration of the compound in the solution.*

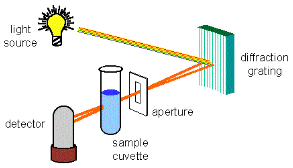


December 9, 2012 4U4 - Diffraction Gratings 20

Applications of … – Spectrometer

SPECTROMETER

- has a diffraction grating that separates light into all wavelengths
- used in chemistry and biochemistry to identify and measure compounds in solutions



✔ Check Your Learning

TEXTBOOK

P.525 Q.1-7