

**Problem 1.**

We would like to take an absorption spectrum of a sample that we believe has its absorption maximum at 200 nm. Which of the following materials should our cuvette be made of: borosilicate glass, polystyrene, or quartz? Explain why your choice is the best option.

**Solution**

In order to measure the absorption in our sample, we need to ensure that our cuvette does not absorb our signal. Borosilicate has a very low transmission fraction below 300 nm or so, so it is a poor choice. Similarly, polystyrene has a strong, broad absorption peak at 250 nm, making it unsuitable for this cuvette.

**Problem 2.**

Why are mirrors preferred over lenses for imaging in many spectroscopic instruments that must cover multiple wavelengths?

**Solution**

Lenses may absorb wavelengths of interest, depending on their materials. Mirrors cover a broad wavelength range, e.g. 250 nm to 20  $\mu\text{m}$  in the case of Aluminum-backed mirrors.

**Problem 3.**

What performance characteristics of a monochromator are affected when only the grating groove density is changed?

**Solution**

This affects the resolution of the monochromator. More groove density means that the spacing between the grooves is smaller. This means that the resolution,  $R = \frac{\lambda}{\Delta\lambda} = nN$ , increases.

**Problem 4.**

A ray in air ( $n=1.33$ ) is incident on a block of sapphire ( $n=1.77$ ) at a  $40^\circ$  angle from the normal to the glass surface. At what angle relative to the normal will the ray be transmitted through the glass?

**Solution**

$$\begin{aligned}n_1 \sin \theta_1 &= n_2 \sin \theta_2 \\ \theta_2 &= \arcsin \frac{n_1 \sin \theta_1}{n_2} \\ &= \arcsin \frac{1.33 \times \sin 40^\circ}{1.77} \\ \theta_2 &= 28.9^\circ\end{aligned}$$

**Problem 5.**

What is a birefringent crystal? How does a birefringent crystal work if you send light through it? What is an example of a birefringent crystal?

**Solution**

A birefringent crystal is a crystal made of a material whose index of refraction depends on the polarization of the incident light. When light is sent through the crystal, it splits into two different beam paths and **double refracts**. An observer on the other side will see two images, offset by a fixed amount. An example of a birefringent crystal is calcite.

**Problem 6.**

List the four types of lenses and identify them as either converging (C) or diverging (D).

**Solution**

There are six types of lenses:

- Biconvex: converging
- Plano-convex: converging
- Positive meniscus: converging
- Negative meniscus: diverging
- Plano-concave: diverging
- Biconcave: diverging

**Problem 7.**

A thin biconvex lens of refractive index 1.47 and diameter of 50.8 mm has radii of curvature of  $R_1 = 1$  cm and  $R_2 = 0.5$  cm.

- (a) Find the focal point of the lens
- (b) If the object is placed 2 cm from the lens, where is the image?
- (c) What is the  $f/\#$  of the lens?
- (d) Calculate the NA of the lens

**Solution****Part (a)**

$$\begin{aligned}\frac{1}{f} &= (n - 1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \\ &= (1.47 - 1) \left( \frac{1}{1 \text{ cm}} - \frac{-1}{0.5 \text{ cm}} \right) \\ \frac{1}{f} &= 1.41 \text{ cm}^{-1} \\ f &= 7.09 \text{ mm}\end{aligned}$$

**Part (b)**

$$\begin{aligned}\frac{1}{f} &= \frac{1}{s_1} + \frac{1}{s_2} \\ \frac{1}{s_2} &= \frac{1}{f} - \frac{1}{s_1} \\ s_2 &= \left( \frac{1}{7.09 \text{ mm}} - \frac{1}{20 \text{ mm}} \right)^{-1} \\ s_2 &= 1.10 \text{ cm}\end{aligned}$$

The image will be 1.10 cm behind the lens.

**Part (c)**

$$\begin{aligned}f/\# &= \frac{f}{D} \\ &= 7.09 \text{ mm} / 50.8 \text{ mm} \\ &= 0.140\end{aligned}$$

**Part (d)**

$$\begin{aligned}f/\# &\approx \frac{1}{2N.A.} \\N.A. &\approx \frac{1}{2f/\#} \\&\approx (2 * 0.140) \\&\approx 3.58\end{aligned}$$



**Problem 8.**

What is the definition of an optical aberration? Also name the two types of optical aberrations.

**Solution**

An optical aberration is a deviation in the behavior of optical elements from the ideal. Two types are:

- chromatic: when broadband light is passed through an optical component, the different wavelengths follow different paths. This results in a spreading of the colors
- monochromatic: aberration in the lens that affects monochromatic light. These result from non-ideally shaped lenses and include coma and astigmatism

**Problem 9.**

A grating has a groove density of 3600 grooves per mm. If the incident beam strikes the grating at an angle of  $30^\circ$ ,

- (a) What diffraction angle will the first order of 240 nm appear?
- (b) What diffraction angle will the first order of 350 nm appear?
- (c) What can we conclude about the relationship between diffraction angle and incident wavelength from the answers you calculated in a and b?
- (d) What wavelength in the 2<sup>nd</sup> order overlaps with the 350 nm 1<sup>st</sup> order beam?
- (e) What is the free spectral range for the 1<sup>st</sup> order at 600 nm?

**Solution****Part (a)**

$$\begin{aligned} m\lambda &= d(\sin\theta + \sin\phi) \\ \phi &= \arcsin\left(\frac{m\lambda}{d} - \sin\theta\right) \\ &= \arcsin\left(\frac{240\text{ nm}}{3600\text{ grooves/mm}^{-1}} - \sin 30^\circ\right) \\ &= \arcsin 0.364 \\ &= 21.3^\circ \end{aligned}$$

**Part (b)**

$$\begin{aligned} \phi &= \arcsin\left(\frac{350\text{ nm}}{3600\text{ grooves/mm}^{-1}} - \sin 30^\circ\right) \\ &= 49.5^\circ \end{aligned}$$

**Part (c)**

To a point, longer wavelengths will be diffracted to larger angles in the first mode.

**Part (d)**

$$\begin{aligned}\phi_2 &= \phi_1 \\ \arcsin\left(\frac{m_2\lambda_2}{d} - \sin\theta\right) &= \arcsin\left(\frac{m_1\lambda_1}{d} - \sin\theta\right) \\ 2 \times \lambda_2 &= 1 \times \lambda_1 \\ \lambda_2 &= \frac{1}{2}350 \text{ nm} \\ &= 175 \text{ nm}\end{aligned}$$

**Part (e)**

$$\begin{aligned}\Delta\lambda &= \frac{\lambda}{m} \\ \lambda + \Delta\lambda &= 600 \text{ nm} \\ \lambda &= \frac{1}{2}600 \text{ nm} = 300 \text{ nm} \\ \Delta\lambda &= 300 \text{ nm}\end{aligned}$$

**Problem 10.**

For a fiber optic probe with core and cladding refractive indices of 1.50 and 1.48, respectively, and  $\theta_i = 28^\circ$ , calculate:

(a)  $\theta_r$

(b) NA

**Solution****Part (a)**

$$\begin{aligned}\sin \theta_r &= \frac{n_1}{n_2} \sin \theta_i \\ \theta_r &= \arcsin \left( \frac{n_1}{n_2} \sin \theta_i \right) \\ &= \arcsin \left( \frac{1.50}{1.48} \sin 28^\circ \right) \\ \theta_r &= 28.4^\circ\end{aligned}$$

**Part (b)**

$$\begin{aligned}\text{N.A.} &= \sqrt{n_1^2 - n_2^2} \\ &= \sqrt{1.50^2 - 1.48^2} \\ \text{N.A.} &= 0.244\end{aligned}$$

**Problem 11.**

A monochromator has the following specifications:

- reciprocal linear dispersion =  $1.5 \text{ nm mm}^{-1}$
- focal length = 320 mm
- $f/\# = 4.6$
- grating size:  $68 \times 68 \text{ mm}$
- groove density = 1800 grooves/mm

Calculate the following at 633 nm assuming the 1<sup>st</sup> order is used:

- (a) Angular dispersion
- (b) Linear dispersion
- (c) Slit width to obtain a 5 nm geometric spectral bandpass

**Solution**