Determining the Refractive Index ($\eta$) of Various Materials Using Scanning Infrared Spectrophotometry

**Introduction:**

The electromagnetic spectrum has many different types of light other than just the visible light we see everyday. These types of light vary in wavelength (the distance from crest to crest in a wave). The wavelength of light affects the energy that each photon (individual packet of light) has. The shorter the wavelength, the greater the energy a photon of light has.

Spectroscopy is the study of the interaction of light with molecules or atoms. The specific interaction that a molecule has with light depends on the types of bonds in the molecule and the energy of the light. Shorter wavelengths of light in the ultraviolet and visible regions (~200-800nm) can cause bonding electrons to change orbitals when the light is absorbed; much longer wavelengths in the microwave region (~100,000-1,000,000nm) can cause bonds to rotate when the light is absorbed. The wavelengths of light between the visible region and microwaves are known as infrared (IR) (~1000-10,000nm) and can cause bonds to vibrate and/or rotate when the light is absorbed.

All of the interaction IR light has with molecules are based on very specific “selection rules.” The selection rules allow for identification of molecules based on the absorbance pattern of the wavelengths of light in the IR region. Also, the absorbance of IR light follows Beer’s law (at low enough concentrations), which means the concentration of molecules can be determined from the absorbance if a calibration curve is prepared.

**Purpose:**

The refractive index of a material is a measure of the speed of light as it is traveling through the material. Light traveling through air has a velocity very close to the maximum speed light can travel (the maximum occurs in a vacuum such as in outer space.) The refractive index of vacuum/air is given a value of 1.0 and other materials have larger values of refractive indices.

When light travels from a material of one refractive index to a material with a different refractive index, not only does the velocity of the light change, but the angle at which it is traveling changes as well. This is the explanation for the phenomenon that occurs when you place a straw in a glass of water and it appears to bend as soon as it enters the water. Furthermore, different wavelengths of light will change angles to different degrees. The wavelength dependence of refraction is the reason the sky looks blue during the day and reddish/orange at sunrise and sunset.

The refractive index can be measured in several ways. A simple IR experiment can provide an excellent means to determine the refractive index of a thin film (2mm to 0.002 mm) if the exact thickness of the film is known. The experiment is based on the specific interactions of individual wavelengths of infrared light with the sample. The interaction of the IR light with the film results in something called “fringing,” and the number of fringes along with the film thickness can be used to calculate the refractive index of the material.
**Safety:**
No hazardous materials should be used in this experiment, but good laboratory practices should still be observed at all times.

**Instrumentation:**
- Model M500 Infrared Spectrophotometer
- Magnetic Film Holder
- Grams/AI Software
- Calipers (to measure thickness of samples)

**Samples:**
- Samples of transparent/translucent material up to 2 mm thick.
  (plastic bags, glass slides, lamination, cellophane, overheads, etc.)

**Procedure:**

**Instrument Setup:**
- Follow the specific instrument procedures in the manual for initial instrument setup
- Make sure the instrument warms up for at least an hour before beginning scans.

**Data Collection:**
NOTE: All scans can be performed on the 3 minute scan cycle. Longer cycles will not improve results a noticeable amount and will only increase analysis time.
- Run background scan from 4000 to 600 cm⁻¹.
- Save the background scan and set it as the background scan. Make sure the instrument is set up to ratio future scans against the background scan.
- Insert sample into film holder and scan.
- Calculate the refractive index of the sample using the equation in the following section

**Calculations:**
The following equation is derived from the fringing phenomenon and Snell’s law.

- Pick two “fringing peaks” at least 5 peaks apart from one another (these will be small peaks that looks similar to the example given below and the greater the distance the two picked peaks are from one another, the more accurate your results will be)

\[
\frac{(n - 1)}{2*(\nu_1 - \nu_2)} = T_f \times \left(\frac{\eta_1}{\eta_2}\right)
\]

n = total number of peaks including first and last peak
\(\nu_1\) = the wavenumber of the first picked peak
\(\nu_2\) = the wavenumber of the last picked peak
\(T_f\) = the thickness of the sample
\(\eta_1\) = the refractive index of air \(\sim 1.0\)
\(\eta_2\) = the refractive index of the unknown
Questions:
- After the refractive index has been calculated, repeat the experiment with a different thickness of the same material (2 or 3 layers overlapping). Using the refractive index, determine the thickness of the new sample. Does this correspond to the measured thickness? Are there any complications to the experiment that could be introduced by using multiple layers of a material?
- Do some research on Snell’s law. Why does Snell’s law have to be used when deriving the equation in the calculations section.
- What are some other possible applications for this experiment?