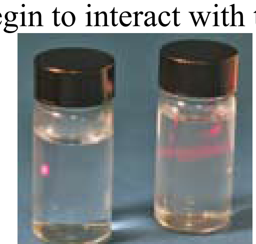
Scatter, Turbidity and Nephelometry

"Why is the sky blue?" This question comes up often and can be quite simple to understand if your students can picture how light scatters. Light scattering occurs when electromagnetic radiation collides with molecules and is deflected in another direction. Because light travels as a wave, the shorter the wavelength, the more likely the light is to scatter. Meaning that as the path light has to travels becomes longer, you observe less short wavelength light, explaining why the sun's reflected light makes our skies blue and the transmitted light of our sunsets so beautifully red.

There are a variety of light scattering theories to relate scatter as a function of the size and shape of the particles, the medium that surrounds them and the wavelength of the incident radiation. A few of these that involve visible light are Raleigh, Mie and Tyndall scattering. We will briefly define each of these and then concentrate on Mie and Tyndal scattering. All of these depend on scattering centers, which are an optical inhomogeneity within an otherwise homogeneous medium.

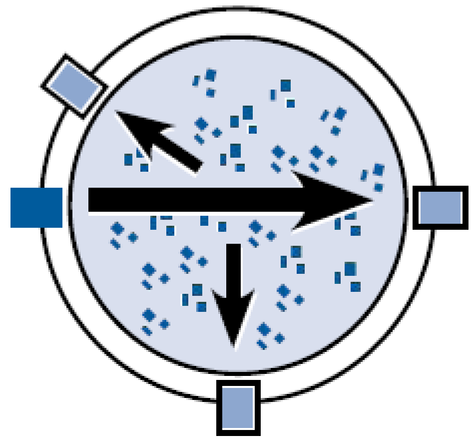
In a true solution, the particle sizes are orders of magnitude smaller than the wavelengths of visible light, 400 to 700 nm, and thus there is no interaction between the solution particles and light unless the solution particles are colored, such as the CrO_4^{2+} ion, which then absorb some of the wavelengths of visible light. As particles get larger, approaching a few orders of the wavelengths of light, the shorter wavelengths of visible light begin to interact with the particles to produce **scattering**.



Rayleigh scattering is highly proportional to 6^{th} power of the particle size and shape, and inversely proportional to 4^{th} power of the wavelength of light. This occurs with particles much smaller than the wavelengths of light. Thus, shorter wavelengths are scattered much stronger than longer wavelengths. This scattering is what produces the blue color of the sky as well as the blue of the ocean.

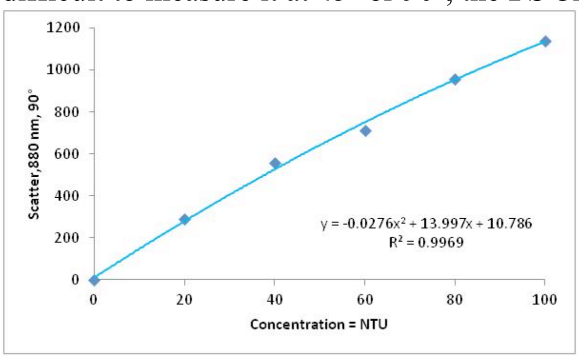
Mie scattering primarily involves spherical scattering centers ranging from 1/10th smaller to 100 times larger than the incident wavelength of light. The directional intensity of the scattered light is a complicated function but with a large portion of the light being scattered in the forward direction. Interestingly, for particles ranging from 1/10 to 10 times the wavelength of light, the larger the particle, the greater the portion of light scattered in the forward direction. (3)

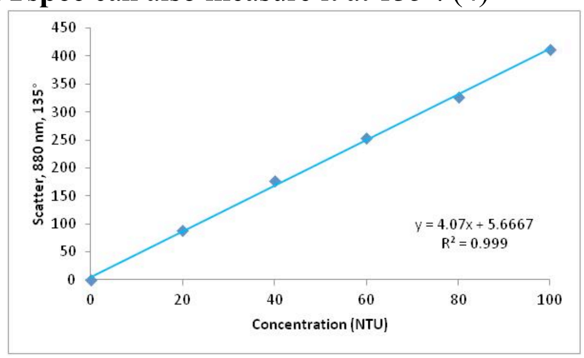
Tyndall scattering generally involves still yet larger scattering centers with no requirement for sphericity of the centers. It is particularly applicable to colloidal suspensions. There obviously is a cross-over point between each of these types of scattering. (1, 2)



Scatter, typically measured in the forward direction, is generally termed **Turbidity**, but in the **FS-522 FASTspec instrument**, it can also be measured at angles of 45°, 90° or 135° to the incident beam. When the scattering centers become so dense in the medium that very little light is sensed in the forward direction, you can increase your sensitivity by increasing the angle of measurement.

Nephelometry generally measures the amount of light scattered at 45° or 90° to the incident beam and uses 800 or 880 nm wavelength light. Most particles do not absorb light of this wavelength and thus any changes in either transmitted or scattered light should be primarily due to one or another of the types of scattering phenomena. Nephelometry is measured in units of Nephelometric Turbidity Units (NTUs). The graph below shows FASTspec scattering measurements for NIST-traceable turbidity standards. Again, if the scattering is so strong that it is difficult to measure it at 45° or 90°, the **FS-522 FASTspec** can also measure it at 135°. (4)





Nephelometry Standards: A similar search for 'nephelometry calibration standards' will produce additional sources. **Nephelometry Standard - Formazin**: while arguably not the most ideal standard, has become widely accepted and is a standard used in EPA and many other methods. It has the advantage that it can be prepared 'in house' with +- 1% accuracy if extreme care is observed. When using this standard, the measurements are given in '**Formazin Turbidity Units (FTUs)**. Instructions for making it can be found at **http://en.wikipedia.org/wiki/Formazine** (5)

Particular advantages of the FS-522 FASTSpec instrument:

Selecting the most sensitive wavelength: The patented, unique design of the **FS-522 FASTSpec instrument** allows the user to select any of the discrete wavelengths of the instrument between 260 and 880 nm for analysis. This allows selecting the most sensitive wavelength for the particular sample analysis.

Approximate particle sizing: Scattering is a function of size and wavelength, particularly in Mie and Tyndall scattering, which is the most typical applications in common usage. Using a set of commercial standards allows obtaining an approximate range of particle sizes in the dispersing medium. This is accomplished using standards of 1/100, 1/10, 1, 10, and 100 times the visible wavelength range. Each of these standards can then be scanned at all 16 wavelengths of the **FS-522**

FASTspec, essentially simultaneously. The scatter pattern can then be observed for each of the discrete wavelengths for each standard and used as a calibration for unknown particles. This need only be done once and the patterns saved for future reference.

As the size of the standard particles increase, a different scatter pattern will be observed for each of the discrete wavelengths. The scatter pattern for the sample is then compared to these scatter patterns for each of the discrete wavelengths to obtain a range of and the average size of the particles in the sample.

Sources:

1. Instrumental Methods of Analysis, 7th Ed., Willard, H. H., Merritt, L. L. Jr., Dean, J. A. and Settle, F. A Jr., Wadsworth Publishing Co. Belmont, CA, 1988, pp 186-187
2. http://en.wikipedia.org/wiki/Light_scattering
3. http://www.amcoclear.com/articles/turbidity.perspective.php Fig. on forward scattering
4. http://en.wikipedia.org/wiki/Nephelometer
5. http://en.wikipedia.org/wiki/Formazine