Optical Scattering

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Scattering in terms of light, refers to the absorption and re-emission of light as it goes through a medium. The basic mechanism relies on the fact that, as a consequence of Maxwell=s equations, light is seen at the radiation produced by an electron bound to a central nucleus. Free electrons will also Ascatter@ in that they will re-emit radiation, but optical scattering is primarily due to bound electrons. So, the electron is bound to the central nucleus. An electromagnetic wave comes along and causes it to oscillate, since it=s a Aspring@ system with the restoring force being due t the attraction of the central nucleus. This oscillating electron is now a source of new electromagnetic waves and the incoming electromagnetic wave has produced an outgoing electromagnetic wave - ie, it=s been scattered. Note that unless the frequency of the wave is a resonant frequency of the atomic system, the incoming electromagnetic wave continues on and may itself react with the scattered wave. This is the cause of the apparent slowdown of light through media, or the refractive index. When the atom re-radiates the incoming light, it does so in all directions, ie spherically. The atom can be considered a point source of a spherically diverging wave. Since there are many, many atoms in a material, usually all of these atoms are all radiating and mostly they will all interfere destructively *except in the forward direction*. This is why light appears to travel in a straight line, the laterally scattered waves all disappear due to destructive interference. However, in some cases, this lateral light is clearly visible and is usually called *scattered light*

The actual scattering of the wave, ie the generation of the new wave due to the electron, can occur in several ways. One possible way is for a delay to occur between the incoming wave and the scattered wave. If this delay is long (minutes, hours, even days) the scattering is known as *phosphorescence* and the material is known as *phosphorescent*. If the delay is extremely short (10^(-7))seconds, the scattering is known as *fluorescence* and the material is known as *fluorescent*. A Aspecial case@ of phosphorescence or fluorescence with quasi-coherent sources is also known as *The Raman Effect*. If there is no delay in the re-emission of the scattered wave, then for a single atom or molecule the scattering is known as *Rayleigh scattering*.

In Rayleigh scattering, the atoms are considered to be far apart, several wavelengths at least. In this case, there is no phase relationship between waves scattered from individual atoms and so the lateral scattering is very strong. It was proved, by (who else !) Lord Rayleigh in 1871 that these waves are dependant on the 4^{th} power of the frequency. Thus a small increase in frequency, by a factor of 2, say, resultts in a 2^4, or 16-fold, increase in scattered light. Since blue is the highest frequency of light, blue light is far more scattered than any other component. Rayleigh scattered light is also polarised. You can see this with a polariser looking up at the sky. The blue of the sky is due to Rayleigh scattering. If you turn so that you looking at the sky at right angles to the sun (have the sun on your left or right). Look at the sky through a polaroid and rotate it, the sky will go darker and lighter.In a liquid, where the atoms are thousands of times closer together than in gas, some of the laterally scattered light gets through. So even though the atoms are thousands of times denser, the actual scattered light from a liquid is very low because most of it has interfered destructively, but not all. Thus even clear liquids look murky in strong enough light.

If the atoms are not far apart, ie the structure of the material is such that the molecular system consists of clumping together of individual molecules (such as water molecules in a cloud), then the components of the clumped molecules will oscillate in response to other molecules in a clump. Thus the Afirst@ molecule is driven into oscillation, which drives it=s immediate neighbour into oscillation which in turn...etc. Clearly as the size of the clump increases the wavelength of the scattered wave also increases. So that, the scattered radiation has a large number of wavelength components and is seen as more whitish. If the molecular clump gets larger than about 700nm, then destructive interference occurs between the front and back of the clump and the scattered radiation decreases.   Thus as the system size increases the scattering looks greyish. This effect was studied by John Tyndall in 1869 and put into a theoretical basis by Gustav Mie in 1908. Hence the *A*whitening of the scattered radiation from large clumps of molecules from, say, colloidal suspensions, is known as the Tyndall effect and the the non wavelength-dependancy of scatter from large atomic/molecular systems is known as Mie scattering.