Diffusion, reflection, refraction and diffraction of light

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For quantities such as the mass of a contaminant, heat or the amount of movement, the existence of a stirring material at microscopic scales is necessary for their diffusion. On the contrary, **light** can propagate in **a vacuum**. It is then not subject to **any distribution**. On the other hand, in a transparent medium, such as air or ice, whose **composition** is **not uniform**, **diffusion may occur**. In English, the distinction between this phenomenon and molecular diffusion is clear since this phenomenon is called *scattering*. The diffusion of light depends on the size of the diffusing objects, read The colours of the sky.

Figure 1. Bluish colours in an ice cave due to Rayleigh scattering. [Source: pixabay]

At the scales of air molecules, or water molecules constituting ice, objects much smaller (nanometers) than the wavelengths of light (between 0.4 and 0.8 µm), scattering is predominant for short wavelengths, thus selecting the color blue. It's **Rayleigh's broadcast**.

Water droplets suspended in clouds and fogs can reach 100 microns, much larger than the wavelength of light. Diffusion is then reduced to **multiple reflections on the droplet surface.** It is **therefore no longer selective**, which explains the white colour of the clouds, with shades of grey depending on the amount of sunlight absorbed.

On the other hand, at intermediate scales, close to the wavelengths of light, such as pollens, aerosols and fumes, **Mie scattering** imposes a slightly bluish greyish grey colour. Thus, this colour is typical of the **blue line of the Vosges** above coniferous forests emitting pollen and isoprene microbeads (originally a compound of natural rubber).

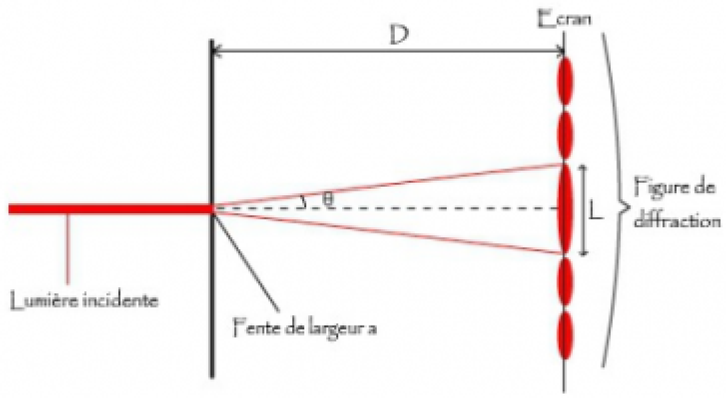

Figure 2. The diffraction of a red light through a thin slit leads to a pattern of red spots separated by dark areas. The central spot has the largest width L= 2Dθ, where the small angle θ is λ/a. [Source: Superprof, Article "All about diffraction", available on : "https://www.superprof.fr/ressources/physique-chimie/terminale-s/optique/diffraction.html]

These three types of diffusion correspond to different modes of interaction of light with the diffusing object. For objects that are **large in relation to wavelength**, it is possible to reason in terms of **light rays**, which corresponds to geometric optics. At the interface between two media, part of the light is reflected, and the other part passes through the interface with a modified propagation direction: this is called **refraction.** This process is observed in a **prism** like the one in the vignette of the focus Deviation of light by a prism (link). The different wavelengths of white light have different refractive angles, which leads to colour separation. Water drops or ice crystals can act as prisms, which leads to rainbows (Spectacular Rainbows) or other atmospheric halos phenomena (Atmospheric Halos). In clouds, reflections and refractions are multiple, which blurs the separation of colors, and restores the white color of sunlight.

Figure 3. Diffraction of polychromatic light through a circular orifice. The central spot is white due to the superposition of all wavelengths. Peripheral spots represent the entire spectrum of visible colours, with the shift in various wavelengths increasing as we move away from the centre. [Source: Superprof, Article "All about diffraction", available on : "https://www.superprof.fr/ressources/physique-chimie/terminale-s/optique/diffraction.html]]

For objects with dimensions close to the wavelength, the wave nature of light intervenes, which leads to the phenomenon of **diffraction**. Diffraction patterns are typically studied behind an orifice cut in a screen. The effect is similar to diffraction by a small object, but it is then easier to observe, thanks to the absorption of non-diffracted light. Figure 2 thus represents the diffraction pattern of monochromatic light of wavelength λ passing through a slit of width a. The diffracted light constitutes a main beam opening at an angle λ/a, surrounded by smaller side lobes. Thus within the limit of a wide slit (λ/a small), the beam remains parallel, in accordance with the geometric optics, while for $\lambda \sim a$, the diffracted beam opens very wide.

For white light, the different components diffract at different angles, leading to the coloured patterns shown in Figure 3 (obtained in the case of a circular orifice). As the short wavelengths are more widely diffracted, it is conceivable that Mie's diffusion is dominated by the blue color, in a way that depends on the size of the particles.

Cover image. Blue sky due to Rayleigh's diffusion with a white cloud that shows a non-selective diffusion by the droplets it contains. [Source: Pixabay, royalty-free]

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