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Determining the Refractive Indices of Aerosol Droplets

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1. Introduction

Droplets of a solution in an aerosol can achieve much higher concentrations of solute than are possible in a bulk solution. This can lead to some interesting properties, amongst which is the **refractive index**, m. Although all materials have a refractive index, the large range of possible concentrations in aerosols make it a particularly interesting property here. The refractive index is a measure of how well light passes through a material, and is comprised of two parts: the first so-called "real" part is a measure of how much light is slowed by the material, by comparison to a vacuum; the second "imaginary" part is a measure of how much light is absorbed into the material.

When light is shone onto a cloud of aerosol - such as the sun shining on the top of a cloud - not all the incident light emerges on the other side. The **extinction efficiency** Q_{ext} is a measure of how efficiently an aerosol allows light to pass through.

This project attempted to find the refractive index of aerosol droplets less than 1μm wide (about one hundredth the width of a human hair). To do this, a relationship bewteen Q_{ext} and m was needed, which would be found from simulations with known m. Then, this relationship could be tested by attempting to recreate the original m from the result of the simulation.

2. Plotting Q_{ext}

To explore the extinction efficiency as a potential tool to determine the refractive index, it is necessary to be able to calculate it. For an aerosol droplet, the extinction efficiency depends on the refractive index of the droplet, and the **size parameter** α, which is a ratio between the diameter of the droplet and the wavelength of light being used.

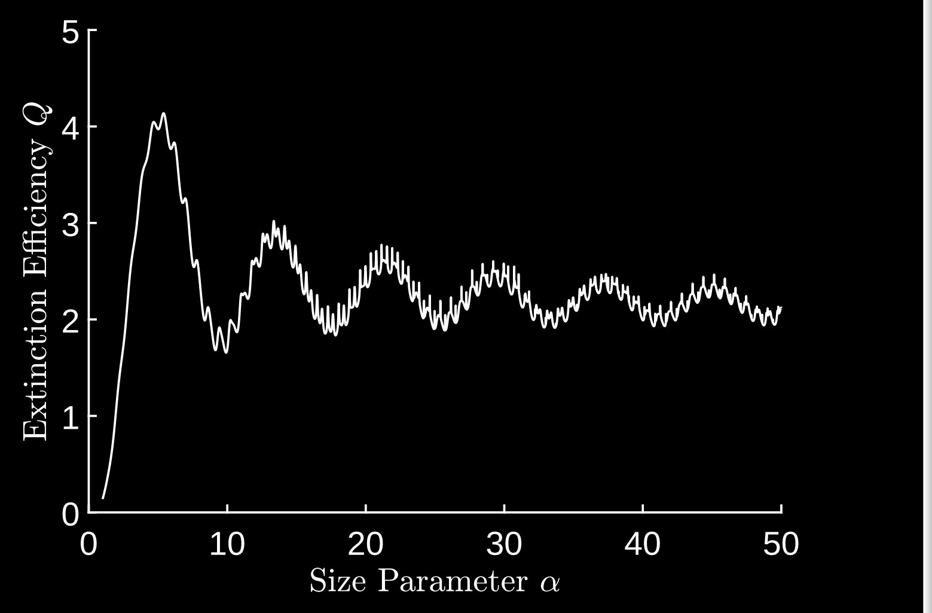

Figure 1: A graph of extinction efficiency over a range of diameters (size parameter) for refractive index $m = 1.3$.

To do this, a programme was written in the MATLAB programming language, and figure 1 is the output of this, over a range of size parameters. As shown in the figure, the extinction efficiency has two main features: the small and the large oscillations. Although both linked to the refractive index and size of the droplet, the larger structure is more useful, specifically the separation of the peaks.

3. Using Q_{ext}

To produce figure 2, the extinction efficiency was calcuated over a range of size parameters (as in figure 1), for many different values of refractive index. Figure 2 is the result of plotting the average peak separation against the refractive index, and it is clear that there is a strong relationship between the two.

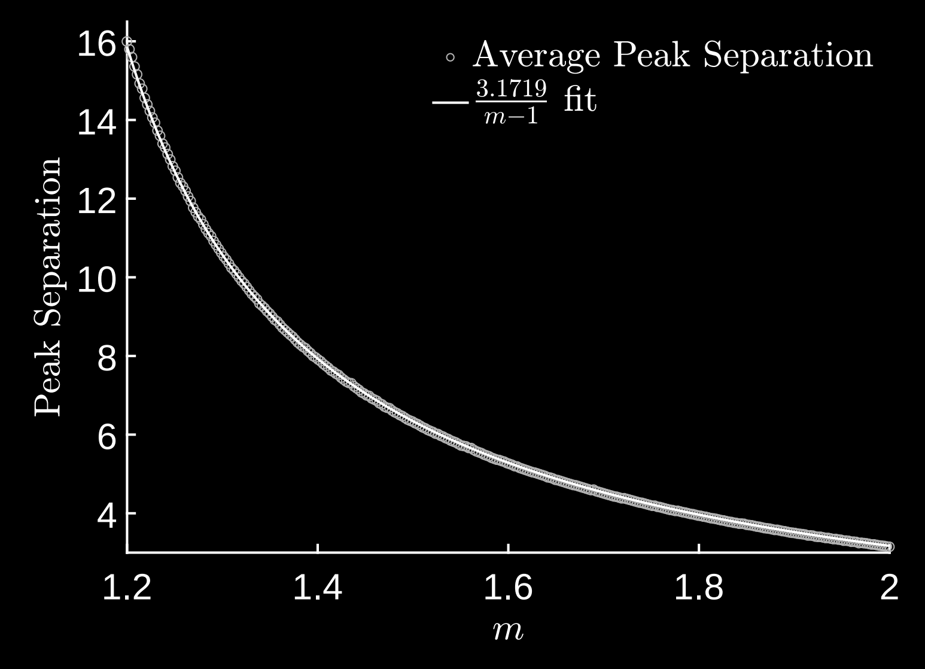

Figure 2: A graph of average peak separation against refractive index m.

This relationship is given approximately by $P = \frac{3.1719}{m-1}$, where P is peak separation, and m is the refractive index. For this, it was assumed that the imaginary part of the refractive index (corresponding to absorption of light) would always be zero - or so close that it could be safely ignored.

4. Finding m

The relationship shown above could be used to find the refractive index from the peak separation in a graph such as figure 1. To test this, random values of m were used to generate graphs like figure 1. Then, the peak separation in these graphs was used to calculate a guess for the refractive index, m_{guess}. This was to see what the error (the difference between m_{guess} and the original m) would be from this method.

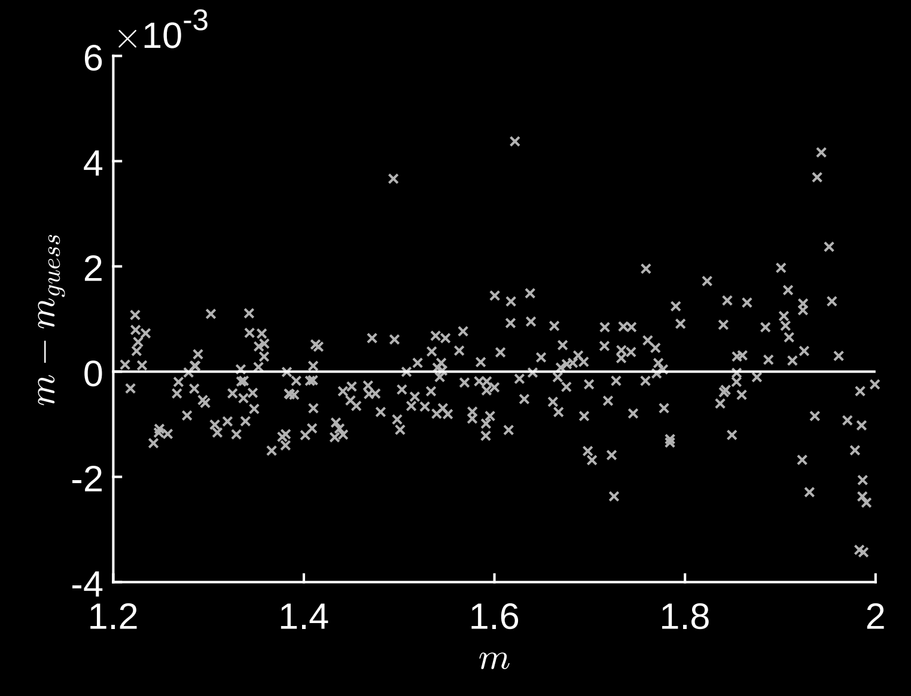

Figure 3: A scatter plot of the error in refractive index guess against actual refractive index.

It was found that the relationship above would not give the correct value of m. For smaller values of m, the guess would be too low, and for larger values, the guess would be too high (with a small accurate region around $m \approx 1.33$). To compensate, an extra linear term was added. Figure 3 is the result of plotting the difference between m and m_{guess} against m. As is clear from figure 3, most guesses for the refractive index are within 0.002 of the actual value.

5. Optical Trapping

Optical trapping involves using light to "trap" a droplet (or other particle) in one place. Optical levitation (the specific variety of trapping used here) uses a vertical laser beam focused to a point, where the droplet is held. If the droplet drifts from this focal point, the more intense light in the centre of the beam excerts a force on the droplet towards the beam's centre, pulling it back. This keeps the droplet trapped in place.

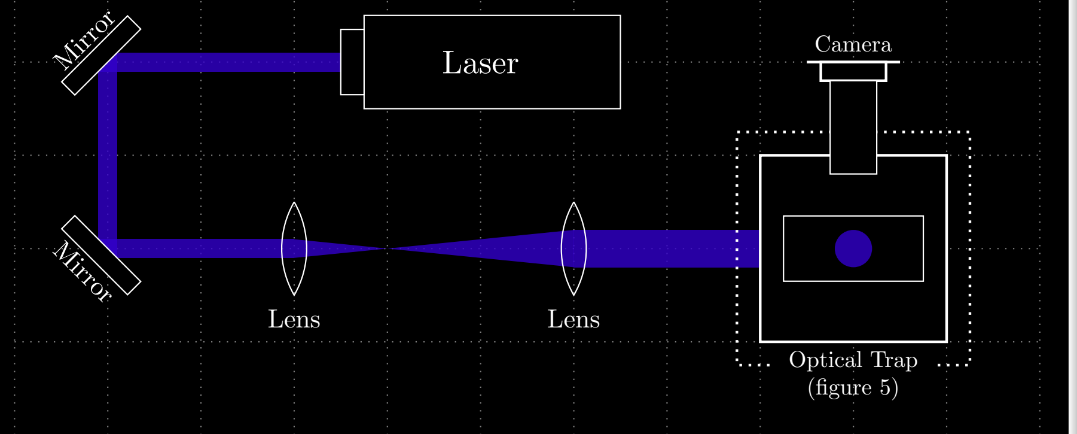

Figure 4: A diagram of the optical set-up used to direct the laser to the optical trap.

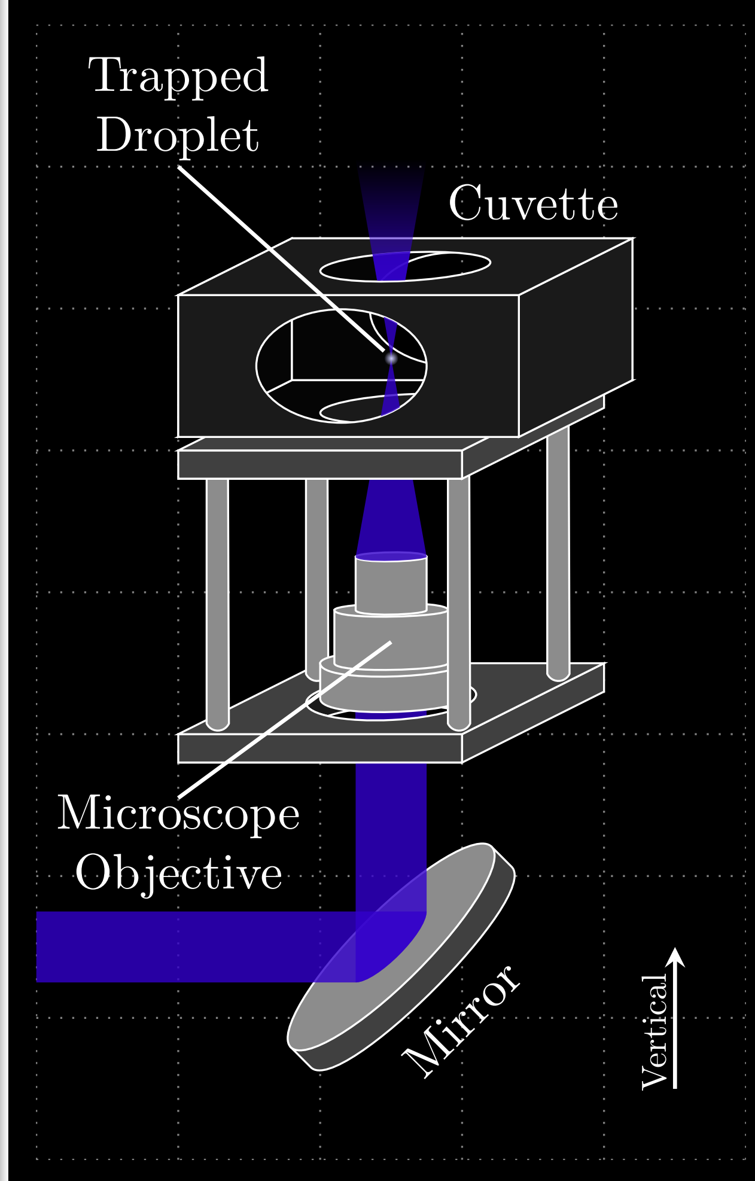

Figure 5: A diagram of the optical levitation set-up.

Figures 4 and 5 show the optical set-up used to trap a droplet. In figure 4, the double mirror arrangement is used to give complete control over the laser's alignment, while the two lenses are used to give the beam the right width, whilst keeping the beam collumnated (neither diverging nor converging). To be most effective, the beam must be the same width as the first lens of the microscope objective in the trap.

In figure 5, the mirror is adjustable in 3 axes, to allow for allignment. It is used to redirect the horizontal beam vertically into the microscope objective above it. The objective itself consists of a series of lenses used to focus the beam to a point, whilst giving it a particular shape needed for successful trapping. The cuvette (a small cuboidal box, with glass windows on some sides) sits above the objective, and is filled with aerosol. The glass window on the base allows the laser to enter without being distorted, and trap a droplet. Windows on the sides allow the droplet to be observed with a camera.

Once trapped, the droplet's position will change as it slowly evaporates. This possition could be recorded, and the extinction efficiency found from this, producing a graph similar to the theoretical graph in figure 1. From here, the refractive index could be found, as outlined above. Unfortunately, although droplets were successfully trapped (as shown in figure 6), no measurements of Q_{ext} were successfully taken.

Figure 6: A photograph of a successfully trapped droplet.