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Schlieren Optics: Unveiling the Invisible

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Abstract: The purpose of this project was to create a well-functioning Schlieren Imaging system using basic everyday objects. It allowed the variations in air pressure and density to be visualised, as a direct consequence of the differences in refractive index between the media, the light has travelled through. Multiple tests were performed confirming predictions about air flow around many daily life items.

Keywords: Schlieren optics, Schlieren Imaging, air currents, refractive index, homemade experiment

1. INTRODUCTION

1.1. Necessary Equipment

To conduct the experiment a spherical concave mirror was used. In this case it was the D160F1300 mirror, which can be commonly found in astronomical telescopes. To capture the desired effect camera Canon EOS 800D with 75-300 lens on a tripod was sufficient. A point light source was also needed. Here it was obtained by covering a 10000 lumen bike lamp with a sheet of aluminium foil having a hole about 1 mm in diameter. Important element of the system was a colour filter allowing to differentiate light rays [3, 11]. It was produced by taping together two thin coloured transparent foils taken from red-blue 3D glasses. It is possible to achieve a similar effect with help of a sharp razor blade [2], but here better results were obtained without it. Moreover, a stable table was required and a place with possibly low surrounding vibrations.

1.2. How the system works

The reason Schlieren setup works is the phenomenon of light refraction [1-6, 8-12]. A light ray travelling through different media changes its path depending on whether it passes through more or less dense surroundings. This effect is a consequence of various optical media having distinct refractive indices. Moreover, these little differences in light paths are sufficient to be detected using a homemade system.

In the homogeneous medium when a beam of light is emitted from a point-like source it spreads hitting the whole surface of the mirror, reflects back and focuses in one point (with a size about the same as a hole in an aluminium foil). However, if the medium is inhomogeneous the area of focus is still close to point-like but is fractionally larger. It is caused by different refractive indices of the media the light has travelled through and the fact that not necessarily whole light, which came to the same precise point, derived from the same part of a point-like light source. Meaning that it is possible to visualise these differences by either blocking a portion of the light using a razor blade (fig. 1), then dimmer and lighter spots appear (fig. 2b) or by marking one half of the light with one colour and the other half with another colour, then the light passing through the more dense medium will appear mostly in the first colour and the less dense in the second (fig. 2c).

Additionally, to amplify the results during setting up the system (aligning the elements) or during the demonstration of this phenomenon, it is advised to compare objects having large differences in density or temperature. Nevertheless, on a well prepared and adjusted set-up it is possible to visualise even slight variations as it will be demonstrated below.

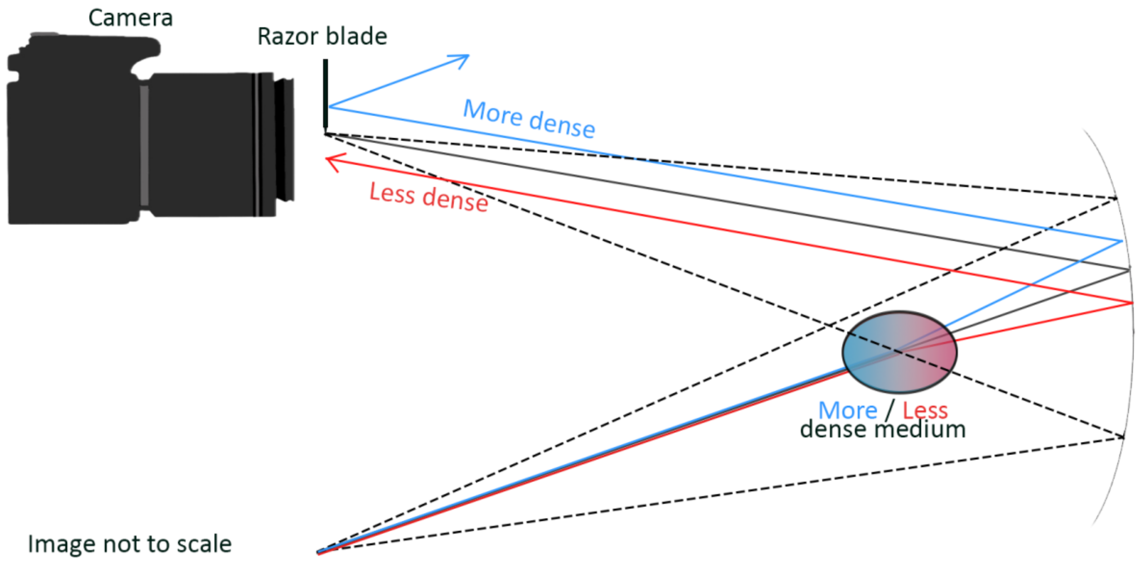

Figure 1. Refraction of a beam of light passing through more or less dense medium

2. SETTING UP THE SYSTEM

2.1. Mirror, light source and camera placement

The whole system should be aligned in one plane [2, 3, 11, 12], it is recommended to choose the horizontal plane for easier adjustments, but vertical or diagonal planes are also possible. Mirror should be placed on a stable surface pointing to the open space. Correct placement of the light source depends on the used mirror, because it should be located in front of the reflective surface with a distance about double the focal length of the mirror, so that the light beam after bouncing off the mirror focuses with a close proximity to the light source [1-3]. It is important to reduce astigmatism of the system and to position the light source in a way that an angle between the light source and the focus point of the light is minimal [1]. Larger angles will result with the reflected image and the one seen by a camera not overlapping perfectly, creating an illusion of seeing objects doubled. In some cases correcting it by moving a light source might be complicated, that is why, sometimes rotating a mirror for a fraction of an angle might be an easier solution.

To check if the light source is set properly it is sufficient to darken the room and move a sheet of paper along the path of reflected light until the lightened area is the smallest - it will be the focus point [1].

To capture the correct image a camera on a tripod should be placed a little further away from the mirror than the focus point. Moreover, it should be positioned in a way that on a camera display the whole surface of the mirror is illuminating (fig. 2a). This effect will appear even if the point-like light source is relatively small. However, if on the camera display only the crescent of the mirror is illuminating, it is advised to change the angle between the camera lens and the plane in which everything should be aligned.

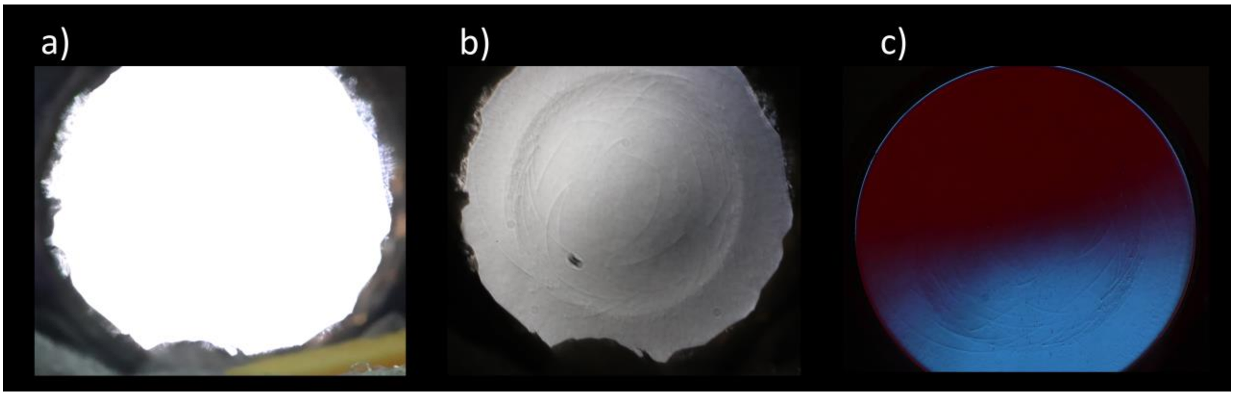

Figure 2. Photos of a) illuminating mirror, b) mirror with proper alignment of a razor blade, c) mirror with proper alignment of a colour filter

2.2. Aligning the razor blade or colour filter

Important aspect of the whole system is a proper alignment of an object responsible for blocking or marking the part of the passing light. No matter which technique is used, the edge of a razor blade or the connection line of the colour filter should be precisely located in a focus point and accurately divide the point-like area into two halves [1-3]. Due to the necessity of exact positioning, it is recommended to use a stable laboratory stand or other rigid object. Here, the filter was attached to a metal stand with a neodymium magnet, which made the alignment easier.

During the adjustment, it is recommended to constantly control the camera display and to continue adjusting until the imperfections of the mirror are visible on the camera screen - in a case of using a razor blade (fig. 2b) or both halves of image have different colours - in the case of using a filter (fig. 2c).

2.3. Placing items in front of the mirror

Generally, items should be placed as close to the surface of a mirror as possible and it should be considered while designing a mirror case or a mirror holder. Here the 4-piece casing (fig. 3a) was designed in 3D using the Inventor Pro software and then 3D printed from PLA on a Prusa printer.

Worth pondering is also the fact what objects or phenomena are going to be observed using the particular set-up and whether it requires extra space in front of a mirror. Here during the demonstration of the Coandă effect the mirror had to be located on the edge to fully achieve the desired effect (fig. 3b).

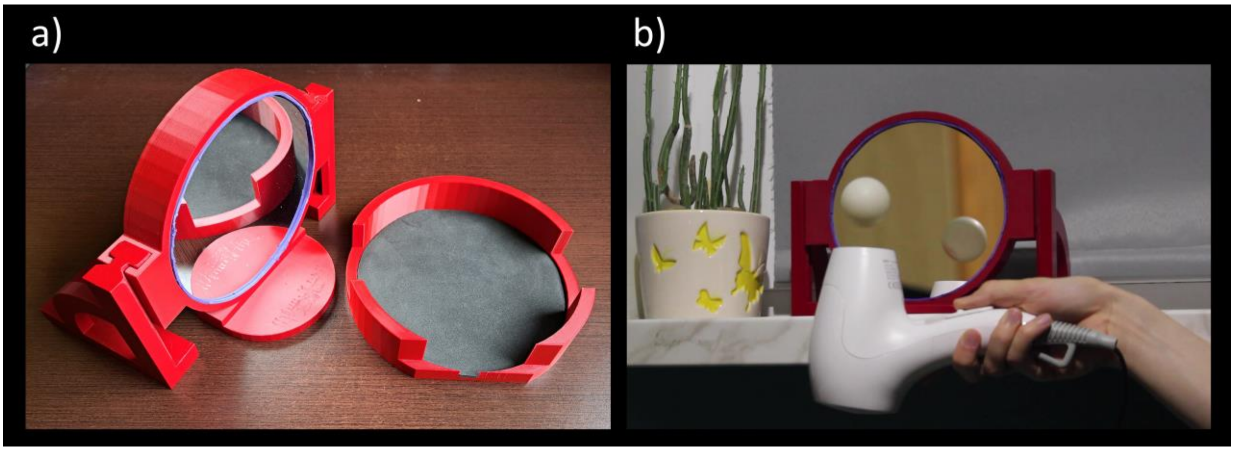

Figure 3. a) Photo of a D160F1300 concave mirror in a 3D printed case next to the protective cover, b) Photo taken during the demonstration of the Coandă effect

2.4. Reducing disturbing factors

Due to the high sensibility of the whole system a lot of factors might disturb the experiments. The most common one (for setups not placed on vibration damping tables) are vibrations caused by walking next to the camera tripod or other components of the system. It is recommended to stand back from a set-up after placing the examined object in front of the mirror and control the camera from a distance if possible. However, while demonstrating an effect requiring presence of a person close to the mirror it is advised to sit still next to it and reduce all unnecessary vibrations.

Another common disturbing factor might be a heat-releasing object located in the space between the camera and the mirror or in close proximity to the system. Especially trammelling are hot air streams produced by cooling fans removing heat from the equipment. Additionally, the presence of a person close to the system also affects the experiment, because the human body temperature is higher than the average room temperature (fig. 4).

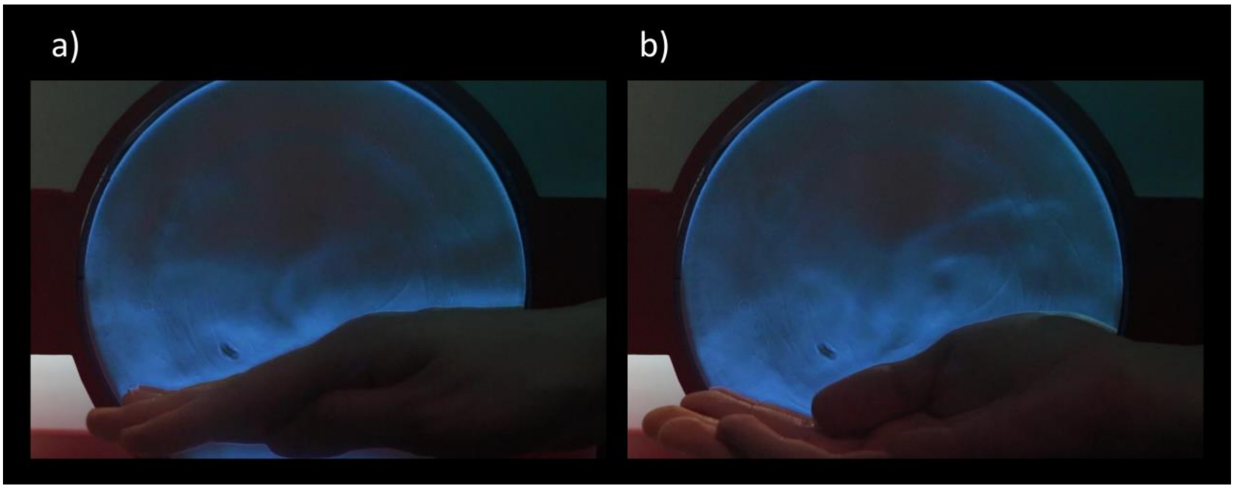

Figure 4. Heat rising from a human hand captured using Schlieren set-up

3. EXPERIMENTS WITH TEMPERATURE AND DENSITY

The properly aligned system allows to visualise the difference in temperature, due to the fact that hot air is less dense than the cold one. The desired effect can be achieved with the help of a lighted candle (fig. 5a). To enrich the demonstration and get the effect shown in a *Figure 5b* a vacuum cleaner might be used to bend the stream of rising hot air and gases (fig. 5c). It is also possible to see the heat generated during striking a match (fig. 6a) and heat rising from a hot soldering iron (fig. 6b), warmed up frying pan (fig. 7a) or a stream of hot air (fig. 7b) produced by a hot air welder (fig. 7c). However, not only warm, rising up, air can be visualised. By placing cooler than surrounding objects it is also feasible to demonstrate the subsiding cold air (fig. 8).

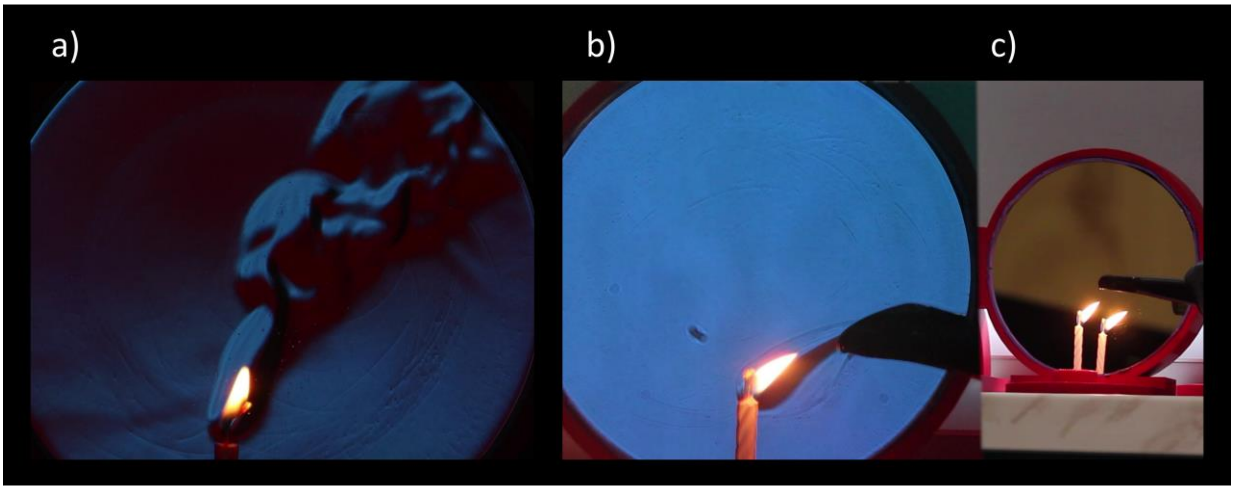

Figure 5. Schlieren image of a) a lighted candle and the mixture of hot air and gases rising from it, b) the rising stream of gases from candle bended with a vacuum cleaner, c) Photo taken during conducting this experiment from a different angle.

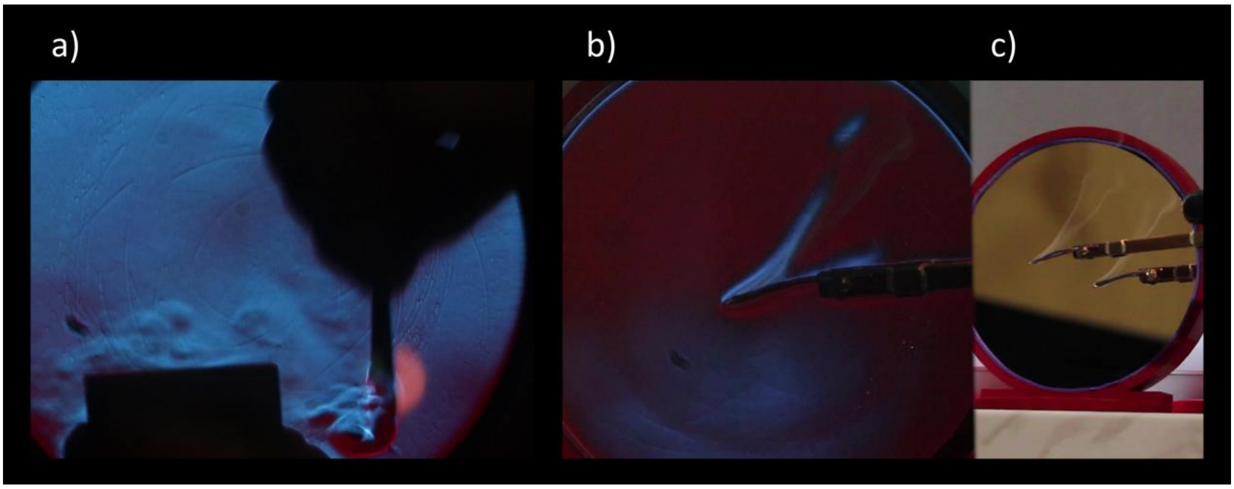

Figure 6. a) Schlieren image of a) a match that is being struck, b) a hot soldering iron, c) Photo of the soldering iron taken from a different angle (visible smoke is caused by heated tin remnants)

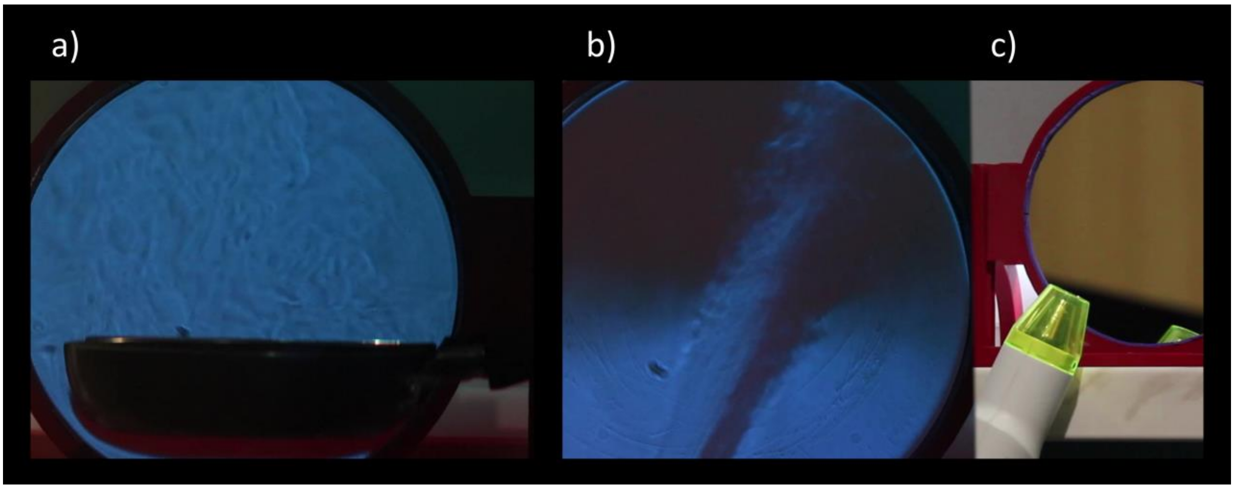

Figure 7. Schlieren image of a) a warmed up frying pan, b) a stream of hot air produced by a hot air welder, c) Photo of the hot air welder

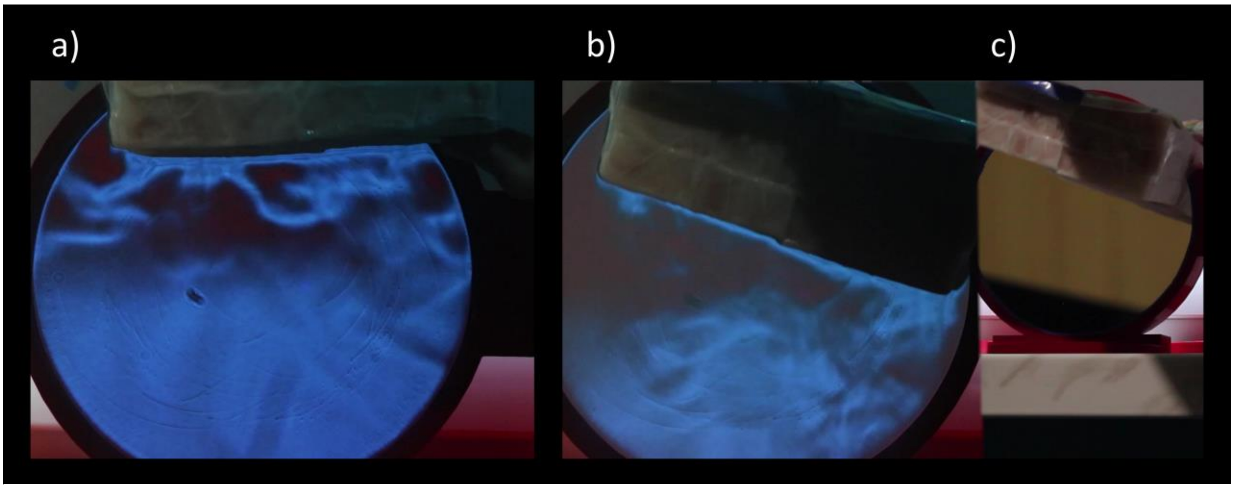

Figure 8. a-b) Schlieren images of an object having temperature close to -10℃, c) Photo taken from a different angle of the object shown in b)

Moreover, the density difference might not only be caused by the variation in temperature. It is equally achievable to visualise gas leakage or a carbon dioxide flow. In *Figure 9b-c)* a gas from a lighter was used, whereas *Figure 9a* presents a cloud of CO_2 caused by squishing the bottle of sparkling water. The carbon dioxide used here primarily originated from a decomposition of a carbonic acid added to sparkling water after shaking the bottle, but it could be replaced by any other transparent fumes having different than surrounding density.

4. EXPERIMENTS WITH PRESSURE

4.1. The Coandă effect

The Coandă effect is a phenomenon playing an important role in aviation, especially in the process of designing rotors and wings. Nevertheless, it is also responsible for a ping pong ball not escaping the air stream produced by a hair dryer (fig. 3b). Effect this can be easily explained using the Schlieren setup [14].

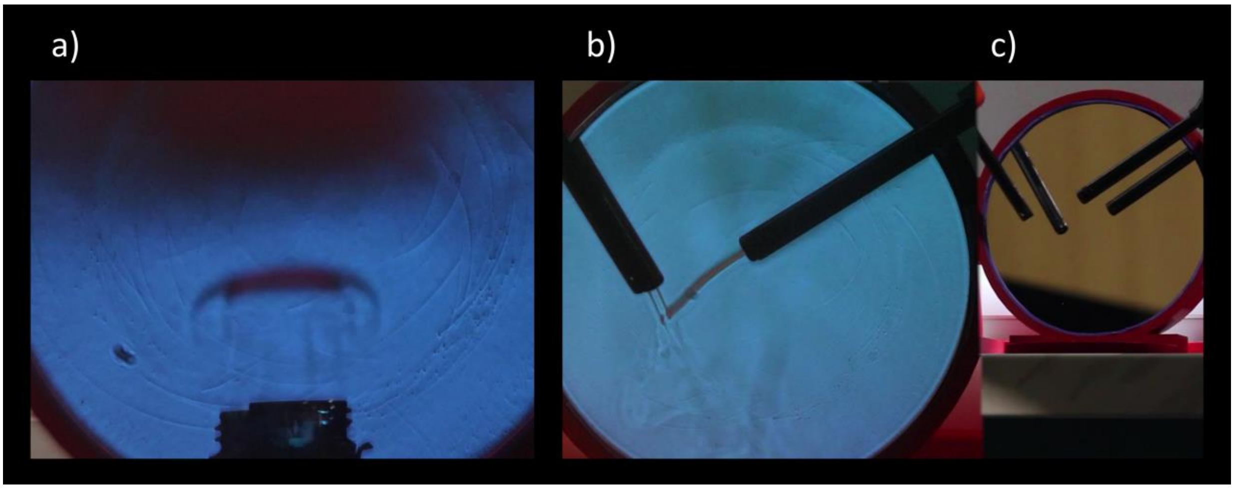

Figure 9. Schlieren image of a) a cloud of carbon dioxide escaping the sparkling water bottle after squishing it, b) a stream of gas coming from a lighter, c) Photo of the situation shown in b) from a different angle

Accelerated air, upon encountering a ping pong ball in its path, flows around it, compressing on the windward side and creating higher pressure regions there (fig. 10a), which result in a creation of a force allowing the ball to float and overcome the gravity. However, air after flowing around the ball, drags the molecules located on the leeward side, creating there a region of lower pressure (fig. 10a). Due to the fact that surrounding air has higher pressure than a leeward side a net force appears acting on a moving air stream, bending it towards the region behind the ball and stabilising the ball in place [14].

Here, during the visualisation, hot air was used to amplify the effect. In *Figure 10a* presented is the ball floating on a horizontal air stream, whereas *Figure 10b* portrays how the pressure regions shift after tilting the air stream by an angle of about 30 degrees.

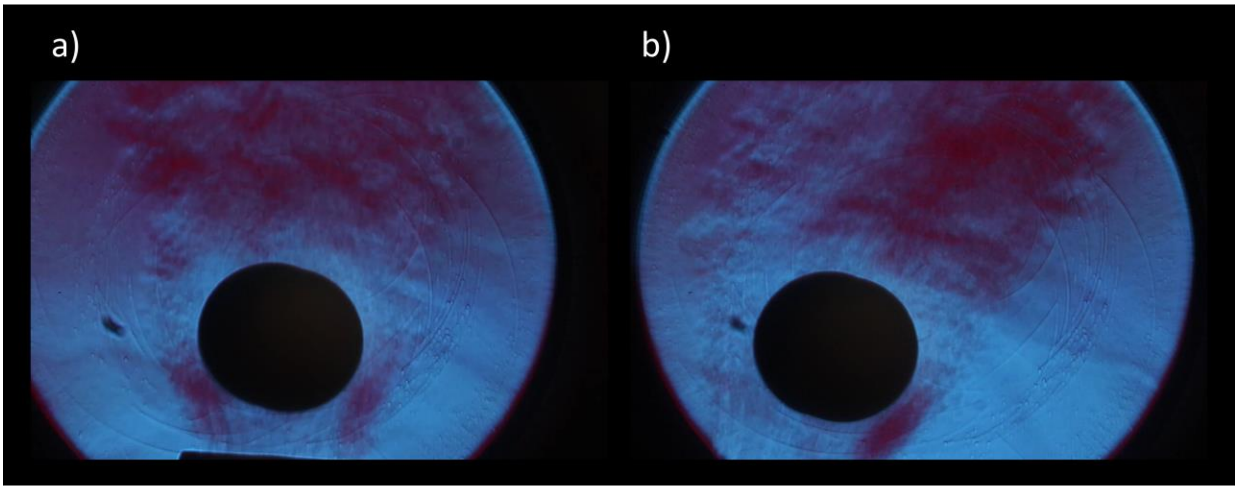

Figure 10. Schlieren image of a ping pong ball floating on a a) horizontal, b) diagonal stream of air

5. CONCLUSIONS

As demonstrated it is feasible to create a working Schlieren Imaging system even in home conditions. However, results are mostly limited by the quality of the camera lens, parameters of the concave mirror and the stability of the whole system.

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