Report on Problem 14: Circle of Light (GYPT 2015)

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1 Introduction

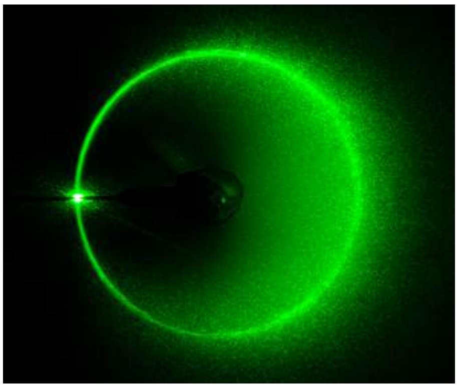
In this report I will take a look at the following problem:

*When a **laser beam** is aimed at a **wire, a circle of light** can be observed on a screen **perpendicular** to the wire. **Explain** this phenomenon and investigate how it depends on the **relevant parameters**.*

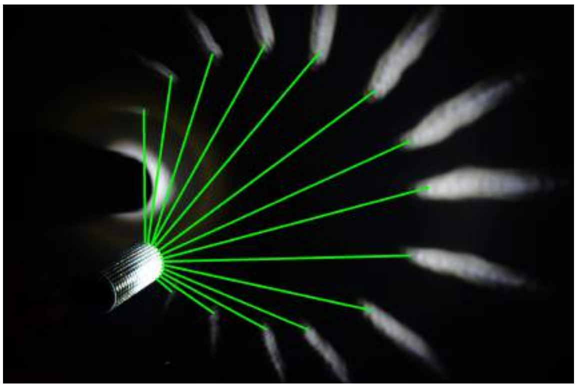
One has to give a basic explanation why we can observe a circle of light, also a comprehensive research is required to determine how the outcome of the phenomenon changes depending on the exprimental setup, followed by a theoretical description.

1.1 Basic explanation

The wire works as a cylindrical reflector. It is illuminated by the laser beam and reflects the light. Due to the cylindrical form of the wire the light is reflected on a circle if the screen is perpendicular to the wire. This pheomenon is demonstrated in figure 1a. To verify that the circle is caused only by reflection on cylinder the experiment was scaled up (see figure 1b). The fact that this phenomenon obviously also works with non monochromatic light (as in figure 1b) proofs that we don't need a laser to produce such a circle.



(a) The phenomenon. Here the wire is mounted direclty on the screen with plasticine.



(b) A pipe with small mirrors mounted on it illuminated by a flashlight to demonstrate how a cylindrical reflector works. The drawn green lines illustrate the path the light is going by reflection. (Picture by Simon Blumreisinger)

1.2 Background research

The task includes monochromatic light and a thin object (the wire) which leads to the suggestion that diffraction might play a role for the phenomenon. Basic knowledge in this field can be found on common websites for students, like "Leifi Physik"[1]. According to the well known Babinett's Principle[**babinet**] one should observe diffraction pattern at thin objects if the light used consists of coherent monochromatic waves. Where these predicted diffraction pattern are visible in the presented phenomenon will also be investigated later in this report. Considering the phenomenon itself it might be interesting how the intensity of the light ring is distributed depending on the experiment parameters. For similar experiments there is already existing literature, for example the work of Sanches-Brea[2]. Before going on in this research all the theoretical assumptions which are made to provide a comprehensive theoretical description of the light ring have to be well studied. To summarize my work considering physical basics and specific theory for this phenomenon in literature I believe that the main part of this investigation can be done by applying basic geometry and optics knowledge taught in school. For the more complex parts of the light ring, like the intensity distribution recent scientific work has to be taken into account.

2 Own research

Here I will present my research process so far. I have designed a suitable experimental setup and developed a theory for the circle radius. I decided to focus on the geometrical parts of the phenomenon because they are easy to measure and seem to fully characterize this optical phenomenon.

2.1 Theoretical model

My first step in this investigation was the prediction of the light ring size in dependency of the laser position and incidence angle of the beam. In figure 2 you can see a schematic sketch of the experimental setup to easily determine how these physical values depend on each other. Looking at the schematic

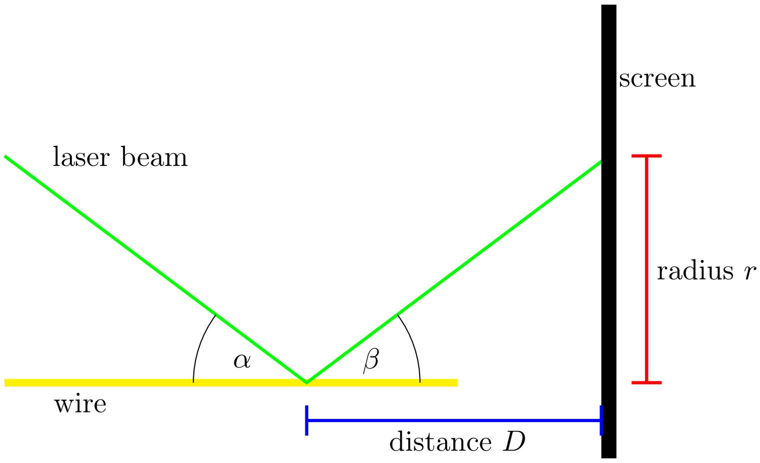


Figure 2: If the wire is mounted as it is required in the task (perpendicular to a screen) the radius r of the light ring can be calculated by applying simple geometry.

drawing gives this basic geometrical relation for the calculation of the light ring radius due to fact that the incidence angle equals the angle of excidence ($\alpha = \beta$):

$$r = D \cdot \tan \alpha \tag{1}$$

2.2 Experimental setup and data analysis

The experimental setup was realised as it is shown in figure 3 The radius r as well as D were obtained by using a tapeline or a ruler. The angle of incidence α can be controlled by a rotary socket and a adjusting plate as a setup base to keep the wire perpendicular to the screen.

2.3 Comparison of Experiment and Theory

Because this setup can be controlled such easily the measurement error for the circle radius was really low, in fact the error of the radius measurements was between 1 and 4 centimenters. Expecially at large scales it was difficult to tell where the circle ended end where diffuse reflection started. The same measurement of the radius will be taken in dependency of α. These first results show that it is possible to predict the ring size if the basic setup parameters are known. It is also to determine α by simply fitting a linear regression curve through the data points in figure 4 which gives a value of $\alpha = 25° \pm 0.5°$

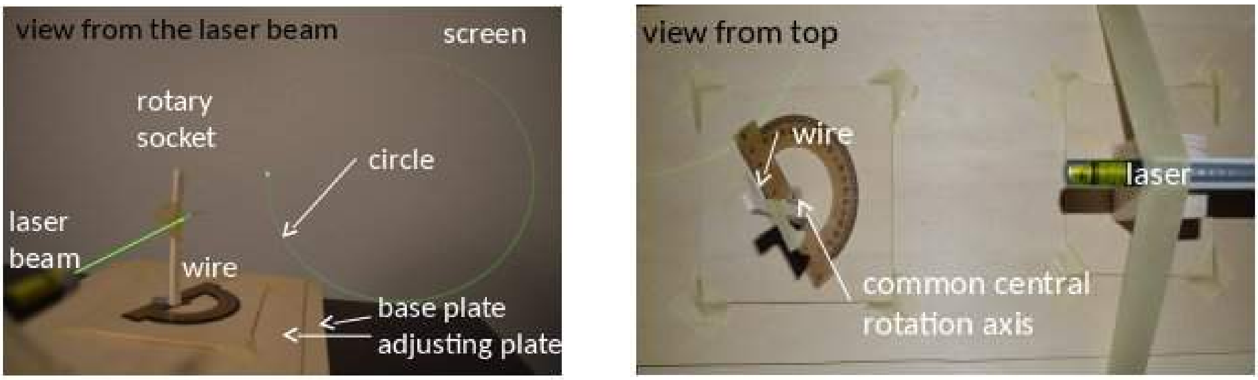


Figure 3: This is how the setup looks like. The incidence angle of the laser beam as well as the distance from the incidence point on the wire and the screen can be easily adjusted. (Setup and picture by Simon Blumreisinger)

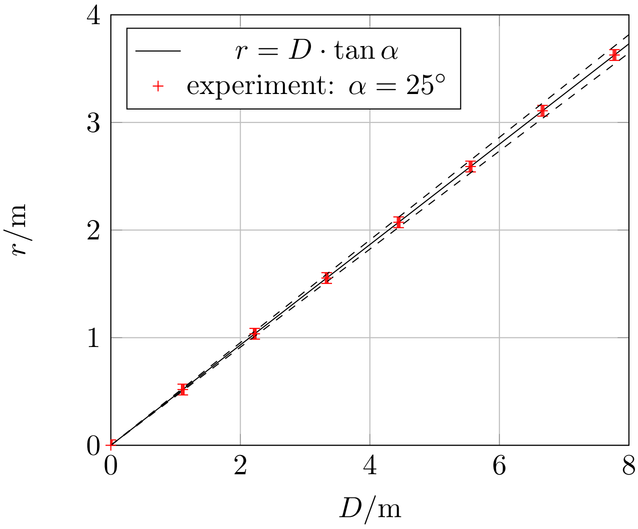


Figure 4: The circle radius is dependend on the distance from the beam incidence point to the screen. This linear dependency regarding equation 1 fits the experimental data nearly perfectly.

3 Discussion and outlook

The experiment showed that we can easily predict the basic geometry of such a circle of light. My hypothesis that we can apply the theory of cylindrical reflector seems to be correct based on the shown basic experiment in section 1. The most important error source is the correct alignment and control of the single setup parts. For the basic geometry like the radius this does not influence the general outcome, but for all other investigations a more precise construction is needed. To demonstrate this, I made preliminary experiments on all the important phenomena I have found. In the following I will mention a few observed phenomena and their possible cause, as well as suitable investigation methods.

3.1 Interference observations

As already told in the literature section interference and diffraction should play a role. It was possible for me to observe such an interference pattern in the ring, right at the point where the laser beam hits the screen directly (figure 5). This interference pattern can also be calculated. The average distance from the 0. maximum to the mth one $y_{m,avg}$ and the wire thickness d is resulting from my setup:

$$y_{m,avg} = \lambda \cdot m \cdot \frac{D}{d} \cdot \tan\alpha \quad (2)$$

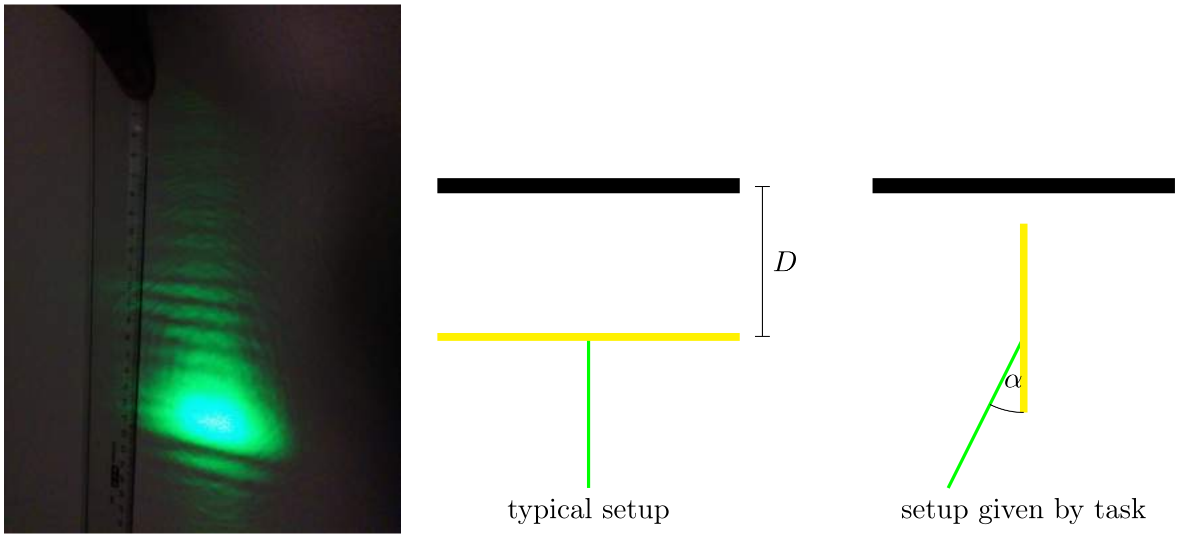


Figure 5: Interference pattern clearly visible when eigher very thin wires or large Ds are used. The close up image on the brightest illumination point shows also that the laser and the wire are not correctly aligned.

3.2 Further geometrical description of the Circle

A rather interesting observation is that the complete ring is only visible if the the laser beam diameter is bigger than the wire diameter as it is illustrated in figure 6. To calculate the exact visible part of the

Figure 6: Incomplete circles dependig on the ratio between beam and wire diameter and laser offset (incorrect alignement in figere 5).

circle again basic geometry can be used. But for experimental comparison I have to find a better way to control the alignement of the laser with the wire, an idea would be a professional adjusting table from an optics lab.

Another geometrical size is the circle circumference thickness which clearly varies as it can be seen in figure 1a and 6. This can be also done by applying simple geometry, but again the experimental verification is a huge problem because measuring the exact circumference thickness without a computerprogramm will result in huge measurement errors. And of course the experiment parameters have to be controlled way better. An intensity profile over the circumference should give at least improved results for determining values out from pictures, but nevertheless professional lab equipment will be needed.

3.3 Intensity Investigation

For the intensity distribution over the circle many factors have to be taken into account beside the geometrical ones. We reflectivity of the wire, the material of the screen (as I take the data for the distribution from a photo), the laser properties such as wavelength and power. In figure 7 such an example distribution is shown. The peak at $\theta = 0$ is obvious because at this point the density of the reflected light is the highest.

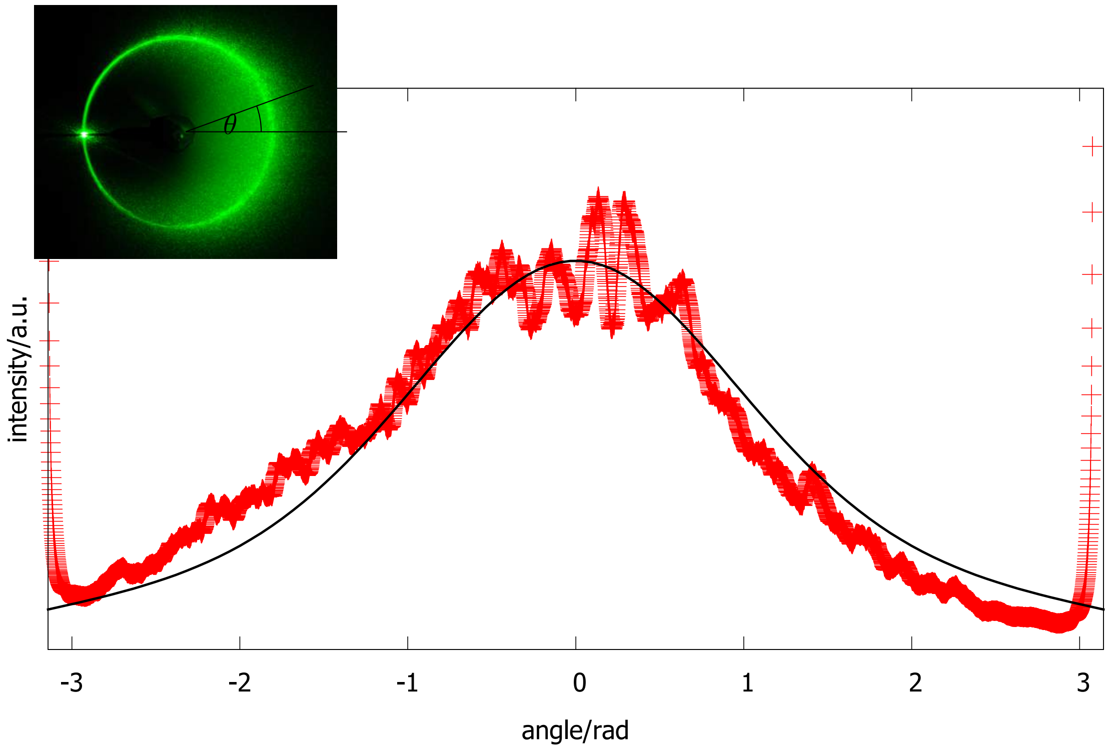


Figure 7: The intensity over the circle given in arbitrary units as the exact material properties of both, wire and screen are not known yet.

4 Planned work until GYPT

1. Determine all geometrical values from the experimental setup
   → contact my school or institution for providing me with some more professional lab equipment

2. Study literature considering intensity distribution over the whole circle
   → find proportionalities or even exact predictions for the intensity

3. More elaborated measurements and variying of all mentioned parameters:
   angle of beam incidence on wire, different lasers, different wires

References

[1] *Leifi Physik*. URL: http://www.leifiphysik.de (visited on 12/06/2016).

[2] Luis Miguel Sanchez-Brea and Eusebio Bernabeu. "Diffraction by cylinders illuminated in oblique, off-axis incidence". In: *Optik-International Journal for Light and Electron Optics* 112.4 (2001), 169–174.