4 Coloured Line

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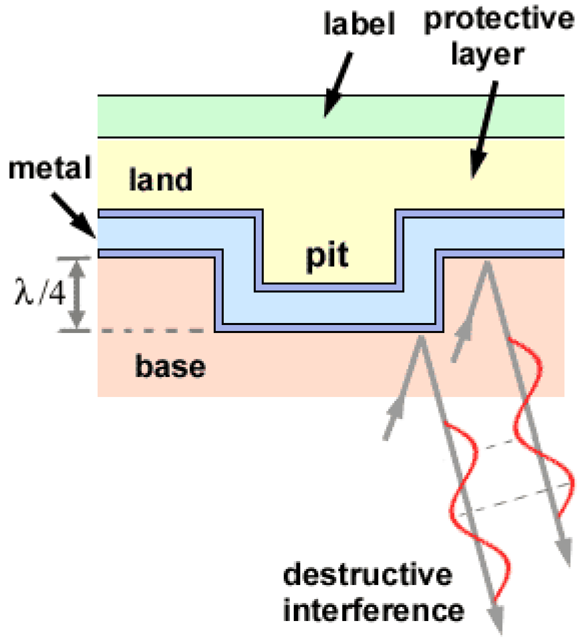
Problem definition

- **EN:** When a compact disc or DVD is illuminated with light coming from a filament lamp in such a way that only rays with large angles of incidence are selected, a clear green line can be observed. The colour varies upon slightly changing the angle of the disc. Explain and investigate this phenomenon.
- **CZ:** Když osvítíme kompaktní disk nebo DVD světlem z žárovky s wolframovým vláknem tak, že jsou vybrány pouze paprsky s velkým úhlem dopadu, můžeme pozorovat jasnou zelenou čáru. Její barva se mění s nepatrnými změnami úhlu náklonu disku. Vysvětlete a prozkoumejte tento jev.

- Frequently used terminology:
  - Pitch (p) – distance between two data lines
  - Pit/Land – lowered/heightened areas of the data line
  - PC layer – transparent polycarbonate layer

- Assumptions
  - In microscopic situations we assume the quasiparallelity of light rays coming out of the light source
  - In macroscopic situations we ignore the thickness of the disc itself and we approximate the light source as a point light shining radially

Fig. 1: Construction of CDs [1]



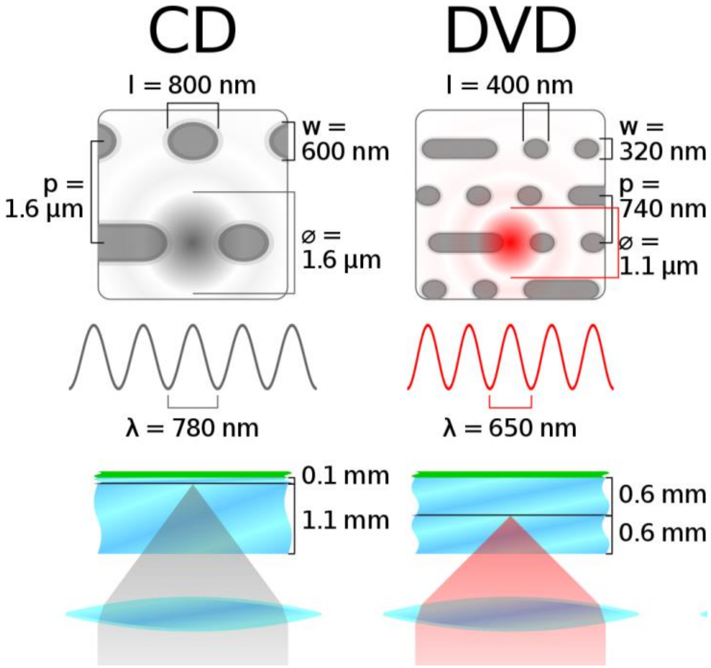
[1] Chris Mueller, 26.6.2015, wOhON.gif, viewed 20.12.2022, https://engineering.stackexchange.com/questions/3324/why-is-it-more-reliable-to-use-the-land-pit-transition-in-a-cd-rom

Observations

- Many optical phenomena, mainly colorful lines and curves can be seen on DVDs or CDs
- Our goal is to explain some of these optical phenomena

Fig. 2: Examples of optical phenomena [2]

Fig. 3: Comparison of construction of CDs and DVDs [3]

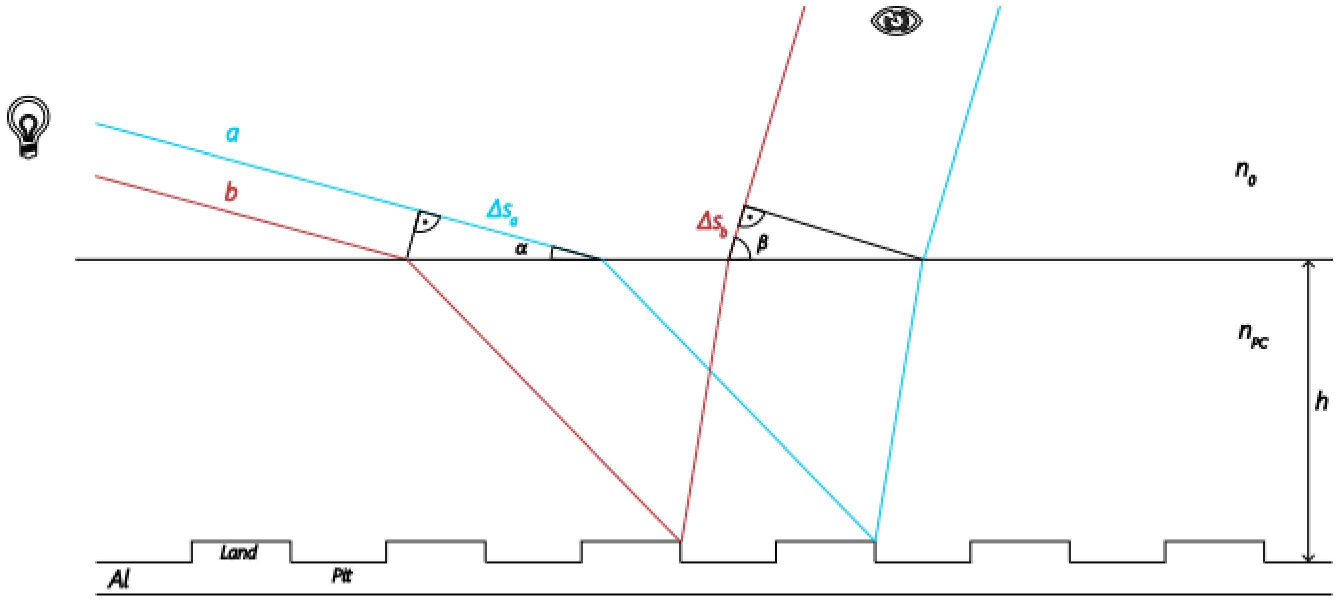


[2] Jon Abe, 10.9.2014, photo1.png, viewed 20.12.2022, https://joabe808.wordpress.com/2014/09/10/optics-cd-rainbow-reflection/
[3] Cmglee, 6.6.2021, File:Comparison_CD_DVD_HDDVD_BD.svg, viewed 20.12.2022, https://en.wikipedia.org/wiki/Comparison_of_high-definition_optical_disc_formats

Hyp. 1 – Refraction and difraction

In the scenario, where we assume two quasiparallel rays of light entering the PC layer via the top, phase shift of the difracted beams occurs. If this phase shift is a $k-$multiple of the wavelength λ, the light undergoes constructive interference and persists. If it is a $\left(k+\frac{1}{2}\right)-$multiple, the light undergoes destructive interference and perishes.

Fig. 4: Diagram of two quasiparallel rays of light



Hyp. 1 – Refraction and difraction

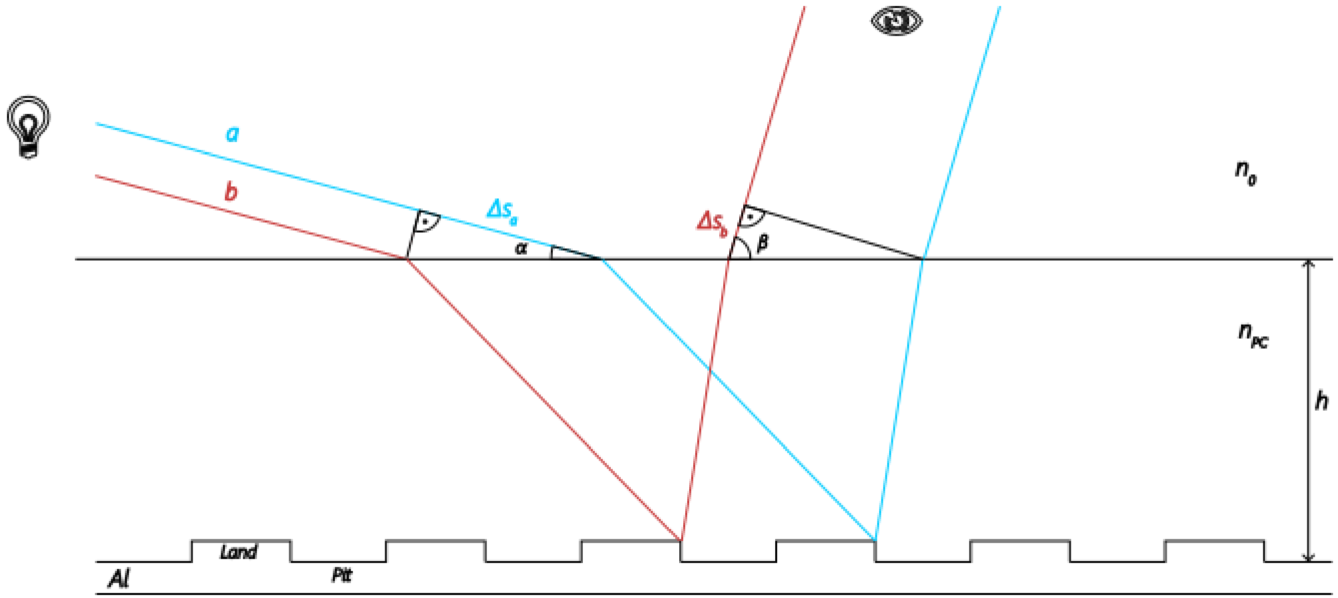
- The phase shift at the refraction points depend on the entrance/viewing angle (α and β respectively)
- The total phase shift is then:

$$\Delta s = \Delta s_a - \Delta s_b = p \cdot (\cos\alpha - \cos\beta)$$

- The rest of the formulation for constructive interference:

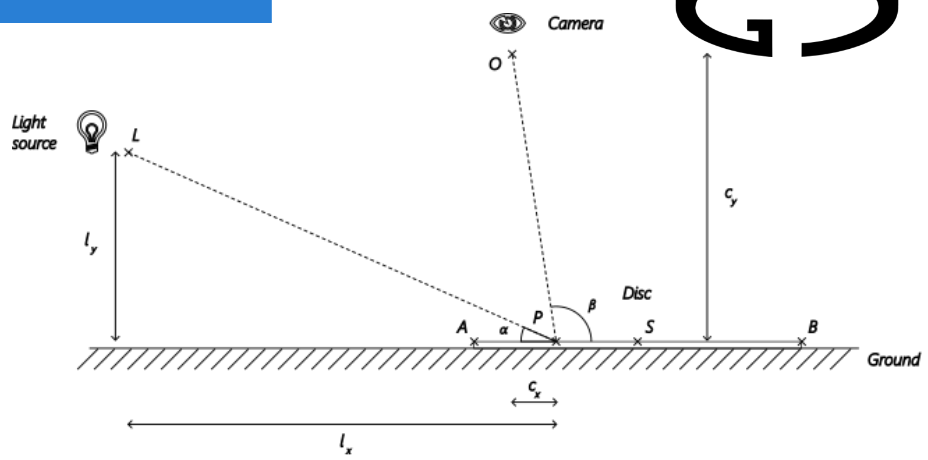
$$\boxed{k\lambda = p \cdot (\cos\alpha - \cos\beta) \qquad k \in \mathbb{N}}$$

Fig. 4: Diagram of two quasiparallel rays of light



Measurements for hypothesis 1

- The angles α and β have been calculated from the relative positions of the light source, viewed disc and camera
- Measured for a total of 6 points
- Mostly a qualitative measurement



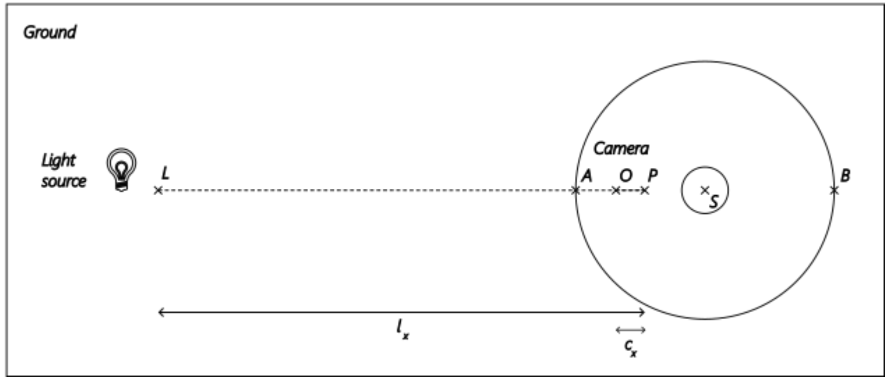


Fig. 5: Diagram of the experiment

Measurements for hypothesis 1

Fig. 6: Photos of the measured points

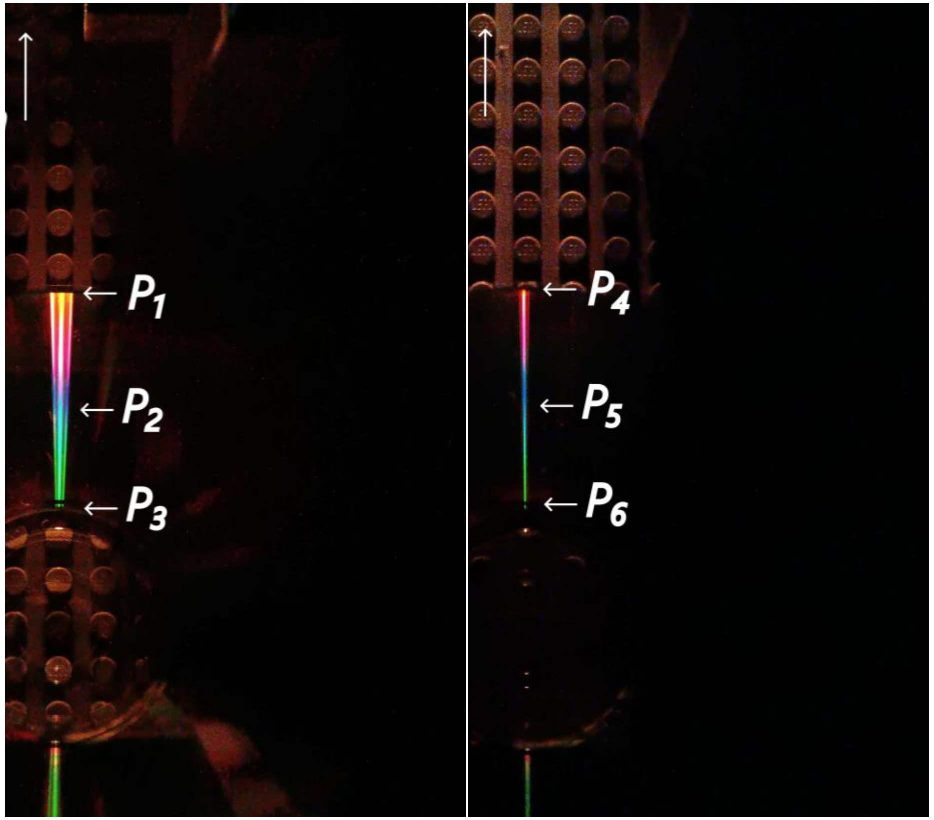
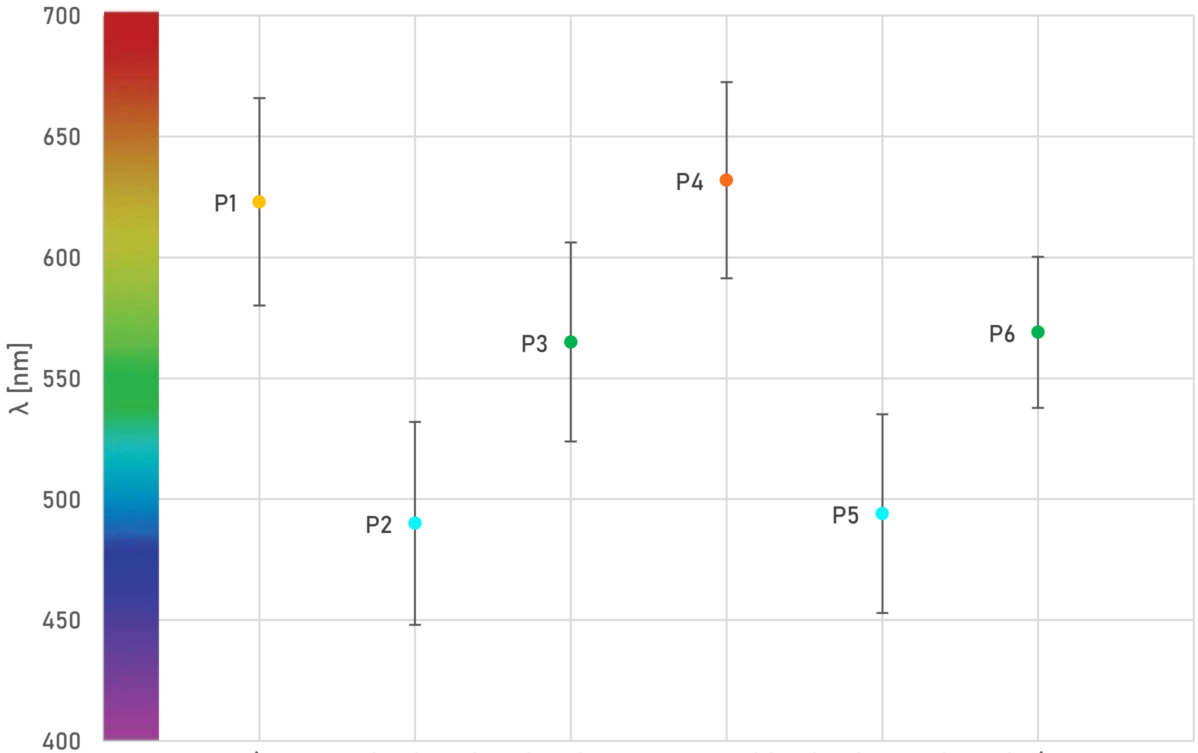


Fig. 7: Measurement results

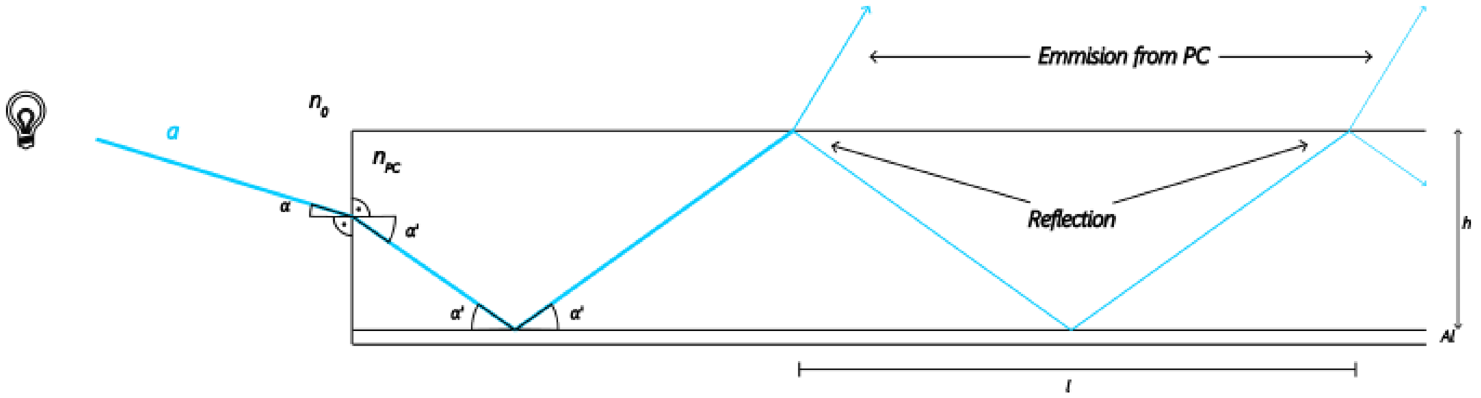


(measured color of each point represented by the data-point color)

Hyp. 2 – Repeated reflection

In the scenario, where a ray enters the PC layer of the disc via the side, the ray can experience multiple reflections within that layer. During each reflection some part of it's energy may be emmited. These reflections will be spaced evenly.

Fig. 8: Diagram of a ray being repeatedly reflected within the PC layer



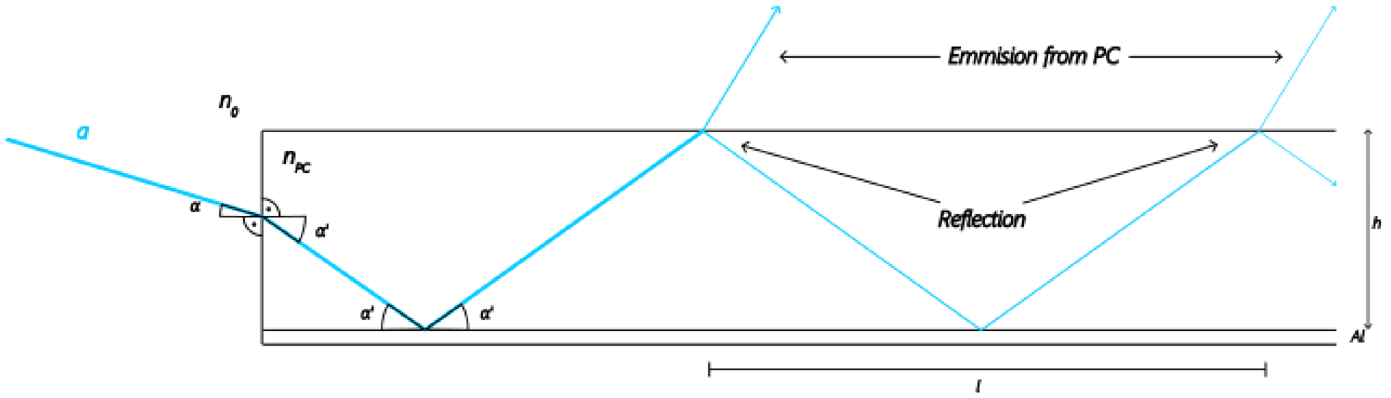
Hyp. 2 – Repeated reflection

- To calculate the distance of two neighboring emmission points (or bands) denoted l, we firstly calculate the angle of travel of the ray using Snell‘s law. The rest is done using simple trigonometry:

$$\alpha' = \arcsin\left(\sin(\alpha)\cdot\frac{n_0}{n_{PC}}\right) \qquad \tan(\alpha') = \frac{2h}{l}$$

$$\boxed{l = \frac{2h}{\tan\left(\arcsin\left(\sin(\alpha)\cdot\frac{n_0}{n_{PC}}\right)\right)}}$$

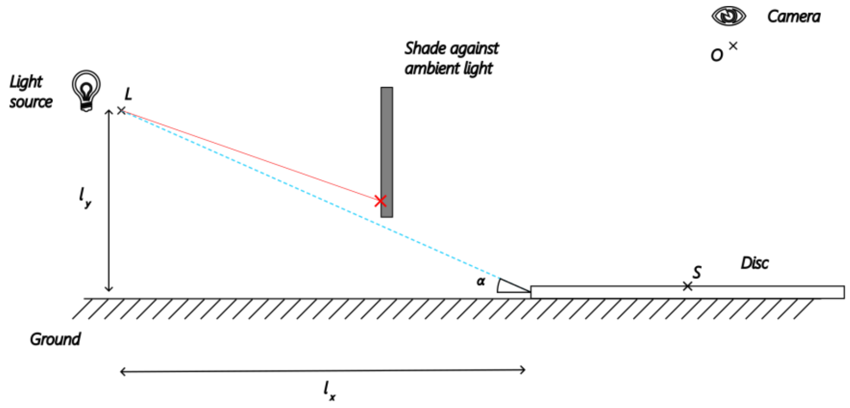
Fig. 8: Diagram of a ray being repeatedly reflected within the PC layer



Measurements for hypothesis 2

- The measurement was simple done by shining a light at the side of the CD from a know position
- From that the angle was calculated
- Ambient light was blocked using a shade, that greatly reduced the amount of light hitting the disc from the top
- Refractive index of the PC layer used [4]:

$$n_{PC} \approx 1.585$$



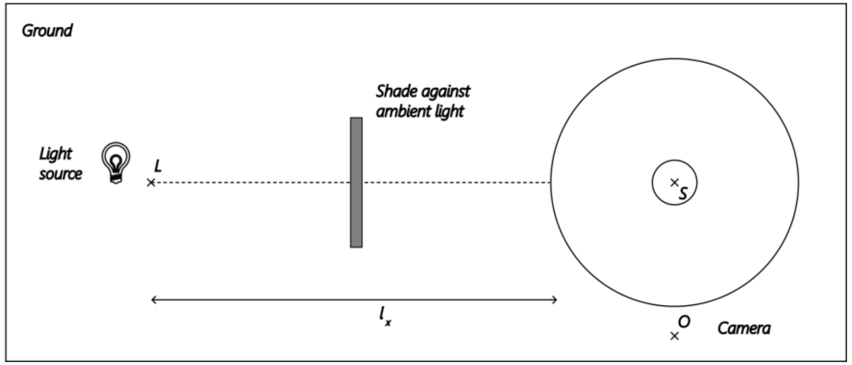


Fig. 9: Diagram of the experiment

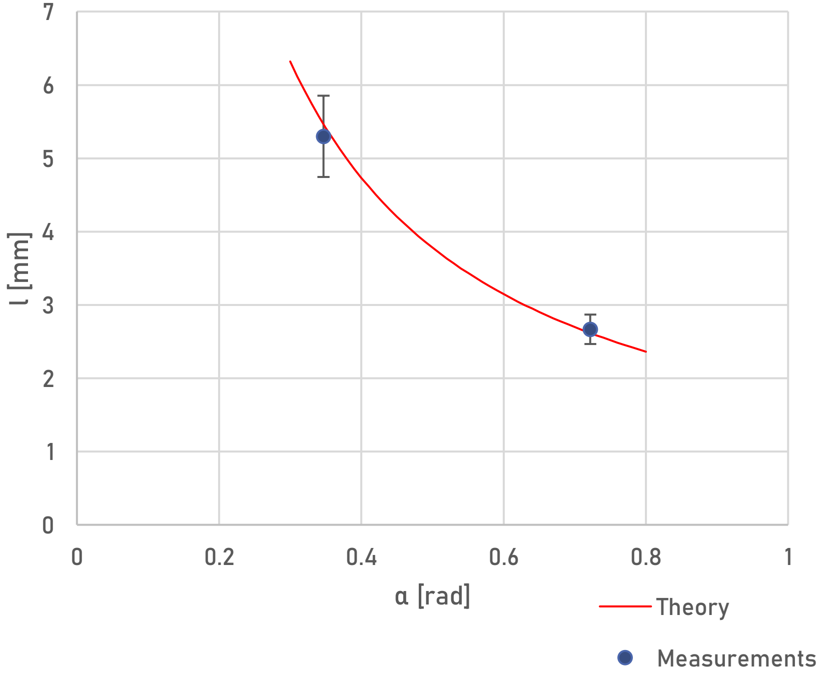
[4] Trisha, 25.4.2012, DVD-Rainbow.jpg, zobrazeno 20.12.2022, https://inspirationlaboratories.com/how-to-make-a-rainbow/dvd-rainbow/

Measurements for hypothesis 2

- Measurements done for two different configurations
- Both result fit the theory very well

Fig. 10,11: Photos of the measured phenomena

Fig. 12: Measurements versus theory for hyp. 2



Future improvements

- Quantitative measurements for hypothesis 1
- More measurements for hypothesis 1

Summary

- We were able to create a hypothesis for the behaviour of the lines. We came up with a formula for the color of such line at any given point and confirmed it qualitatively.

$$\boxed{k\lambda = p \cdot (\cos\alpha - \cos\beta) \qquad k \in \mathbb{N}}$$

- We have created a hypothesis for the banding artefacts. We came up with a formula for the distance of these bands and confirmed it quantitatively.

$$\boxed{l = \frac{2h}{\tan\left(\arcsin\left(\sin(\alpha)\cdot\frac{n_0}{n_{PC}}\right)\right)}}$$

Additional sources

- [1] Chris Mueller, 26.6.2015, wOhON.gif, viewed 20.12.2022,
- https://engineering.stackexchange.com/questions/3324/why-is-it-more-reliable-to-use-the-land-pit-transition-in-a-cd-rom
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- [3] Cmglee, 6.6.2021, File:Comparison_CD_DVD_HDDVD_BD.svg, viewed 20.12.2022, https://en.wikipedia.org/wiki/Comparison_of_high-definition_optical_disc_formats
- [4] Trisha, 25.4.2012, DVD-Rainbow.jpg, zobrazeno 20.12.2022, https://inspirationlaboratories.com/how-to-make-a-rainbow/dvd-rainbow/

Other observed phenomena

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$$\gamma = \frac{1}{2}\theta \cdot \cos\phi$$