TPC 4 - Freaky Chocolate

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It's the most wonderful time... of the year!

It's Christmas time - family gathered around the fireplace, festive movies playing on the TV, chocolates on the table and the cozy holiday spirit filling the air. But wait, the professor has assigned us a project on nanotechnology! As Bear Grylls would say, "Improvise, adapt, overcome". With a Christmas DVD from the TV and the chocolates on the table, we found a way to create an experiment to reveal a nanoscale effect.

The inspiration for this experiment came from a high school project where one of us initially explored DVDs as cheap diffraction gratings for mimicking the nanoscale technology "gecko hands". At the time, it was learnt that DVDs were a bad choice because they feature bumps instead of true grids... but! their periodic structure still provides excellent diffraction properties. Let's understand why and how can we see it with this "weird-shiny-it-doesn't-look-good-to-eat" chocolate that can bait everyone on the table to a huge rant on wave physics that will definitely pleasure every member of the family!

DVD's

Digital video discs (or DVDs) store information using a sequence of microscopic pits and lands, which are burned into a reflective layer. These pits form a periodic structure which, in this experiment, will acts as a diffraction grating (see Figure 1). A standard DVDs grating period is approximately 740 nm [1]. When light interacts with these grooves, diffraction occurs (740 nm $\approx \lambda_{light}$), splitting light into its constituent wavelengths and producing a rainbow-like effect.

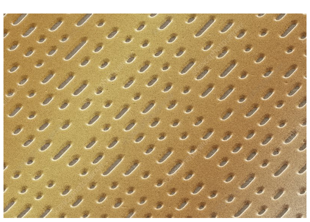

Figure 1: Microscopic surface of a DVD.

The Fun

Materials

- A standard DVD;
- Ethanol;
- A lighter;
- A knife;
- Chocolate;
- A water bath for melting chocolate;
- Laser pointer ($\lambda = 650 \pm 10$ nm);
- Ruler

Steps

1. Separate the DVD layers: heat the outer edge of the DVD with a lighter to soften the adhesive. Then use a knife to carefully separate the DVD into two layers.

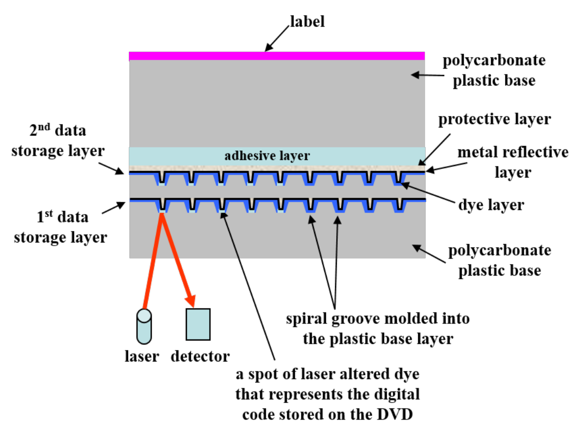

Figure 2: Diagram shows a DVD cross-section. The division is done in the adhsive layer with the metal reflective layer being peeled off as well

2. Prepare the transparent layer: wash the purple reflective coating off the transparent half of the DVD using ethanol to expose the grating structure.

3. Melt the chocolate: place the chocolate in a water bath and heat it until fully melted.

4. Mold the chocolate: pour the melted chocolate onto the exposed grating side of the DVD. Allow it to cool and harden.

5. Observe the diffraction: once the chocolate hardened, rainbow colors appeared when light interacted with its surface, confirming the successful transfer of the DVDs grating.

Figure 3: Chocolate with the DVD's grating.

6. Laser diffraction experiment: shine a laser pointer onto the chocolate surface and measure the diffraction distances on a screen. Record the angles and distances.

Figure 4: Measurement of the distance between the 0 and 1 diffraction order points (left) and the experience's setup (right).

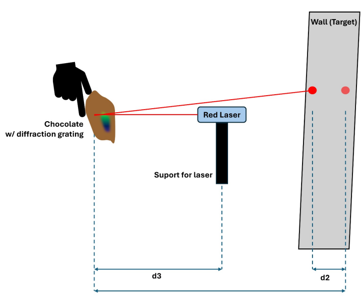

Figure 5: Experience's scheme.

Results

Using the laser diffraction setup, we measured the diffraction distances and calculated the grating spacing using the diffraction equation:

$$\sin\theta_m = m\frac{\lambda}{d}$$

where λ is the laser wavelength, m is the diffraction order, θ_m is the angle of the m-th order maximum, and d is the grating spacing. In this experiment, the only order that was managed to be observed was the 1st order of diffraction (m=1).

Firstly, in order to obtain θ_m, we need the distance between the beams at order m (d_2) and the distance between the chocolate and the laser point inciding on the wall (d_1). We repeate the measures 3 times.

Values	Trial 1	Trial 2	Trial 3	Average
d_1 (cm)	37 ± 1	35 ± 1	37 ± 1	36 ± 1
d_2 (cm)	40 ± 1	42 ± 1	44 ± 1	42 ± 2
d_3 (cm)	6 ± 1	5 ± 1	5 ± 1	5 ± 1

Table 1: Measured distances for three trials with an uncertainty of 1 cm per measurement.

Since $\tan\theta_m = \frac{d_2}{d_1}$, we can obtain the value of θ_m. Using the average distances, we get that $\theta_m = 49$ degrees. Since we know that the laser's wavelength is 650 $\pm$ 10 nm, we can calculate the grating spacing. Replacing these values in the equation, we obtain the value of **856 nm** as the grating spacing, very close to the theoretical value (740 nm, error of 15 %).

Discussion and Conclusion

The experiment was conducted in a very rudimentary manner, which introduced some limitations to the accuracy of the results. For instance, the chocolate had to be held in the experimenter's hand during measurements, requiring it to be rotated manually to find the optimal diffraction point. Furthermore, the laser could not remain completely horizontal because the chocolate, during the molding process, developed a slight curvature.

Measurements were taken using a measuring tape and were reliant on the experimenter's visual acuity to determine the diffraction points. Uncertainties were propagated with an assumed uncertainty of ± 1 cm for the measurements.

$$\left| -\frac{m\lambda\cos(\theta)}{d_1\sin^2(\theta)\left(\frac{d_2^2}{d_1^2}+1\right)} \right| \delta d_2 + \left| \frac{m\lambda d_2\cos(\theta)}{d_1^2\sin^2(\theta)} \right| \delta d_1 + \left| \frac{m}{\sin(\theta)} \right| \delta\lambda \tag{1}$$

These factors, combined with the simplicity of the setup, contributed to a slight deviation in the calculated grating spacing compared to known values.

Despite these challenges, the experiment successfully demonstrated the desired nanoscale effect. The observed diffraction pattern and the calculated grating spacing fell within the same order of magnitude as the expected values for DVD grooves.

And with that, we can confidently say: mission accomplished! Merry Christmas!

References

[1] Yuan Sun et al. "Refractive index sensing using the metal layer in DVD-R discs". In: *RSC Advances* 8.48 (2018), 27423–27428. DOI: `https://doi.org/10.1039/c8ra03191f`. URL: `https://www.researchgate.net/publication/326739410_Refractive_index_sensing_using_the_metal_layer_in_DVD-R_discs`.