CD, DVD, and Blu-Ray Disc Diffraction with a Laser Ray Box

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A compact disc (CD) can be used as a diffraction grating, even though its track consists of a series of pits, not a continuous groove. Previous authors described how to measure the track spacing on a CD using an incident laser beam normal to the surface[1] or one at an oblique angle.[2] In both cases, the diffraction pattern was projected on a screen and distance measurements allowed the track spacing to be calculated. I propose an alternative method using a laser ray box, which is also applied to a DVD and a Blu-ray disc.

Figure 1 shows the simple layout for the experiment. The CD is taped to the edge of a table so that slightly more than half of it sticks up over the edge, which means that the track is approximately vertical near the surface of the table. Half of a sheet of polar graph paper is placed flush with the CD to measure the angles of rays. The origin should be near the outer edge where the curvature of the track is smaller. The laser ray box[3] produces light with a wavelength of 635 nm. Four of the rays are blocked and the remaining ray is aimed at the point where the origin of the polar graph paper meets the CD. The paths of the incoming, reflected, and diffracted rays are visible, especially with the room lights slightly dimmed, so it is very easy to measure their directions. Note that the diffracted light on the paper will curve slightly as it gets further from the CD because it comes from higher up where the track becomes less vertical. Using the outer part of the CD where the track is less curved reduces this effect. The upper portion of the CD could also be masked off to eliminate the problem.

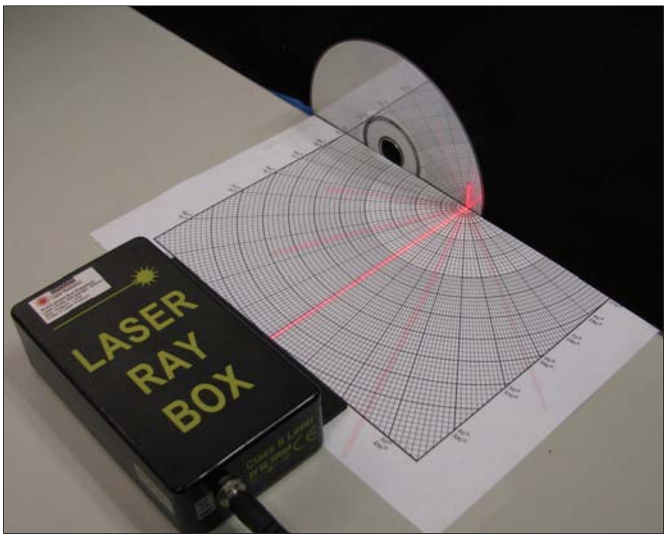

Fig. 1. Experimental setup with the incoming ray normal to the surface of the CD. (The diffracted rays have been enhanced in this image. However, both the rays and the graph paper are visible to the unaided eye with the room lights slightly dimmed.)

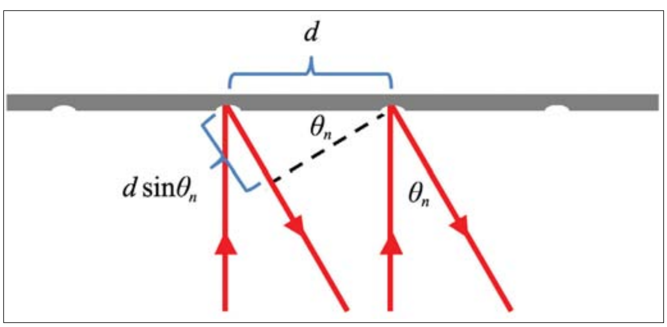

Fig. 2. Geometry for finding the condition for constructive interference with normal incidence.

In the simplest case, the incident ray is normal to the surface of the CD, so the incident and reflected rays overlap. Figure 2 shows the geometry for finding the condition for constructive interference for normal incidence, where d is the track spacing (or pitch) and θ_n is the angle between normal and the nth order constructive interference. The path difference of $d \sin \theta_n$ is highlighted in the diagram. Constructive interference occurs when the path difference is equal to an integer number of wavelengths, which yields

$$n\lambda = d \sin \theta_n . \qquad (1)$$

Table I shows the results for a CD and a DVD with normal incidence. There are first-order and second-order diffracted rays for the CD, but only first-order rays for the DVD because it has smaller track spacing. The measured values of the track spacings compare well with the reported values of 1.6 μm for a CD and 0.74 μm for a DVD.[4] In this configuration, there is no diffracted ray for a Blu-ray disc. Equation (1) implies that the track spacing is less than the wavelength of the light used, so $d < 0.635$ μm.

Light at an oblique incidence, as shown in Fig. 3, can also be used to measure the track spacing. In this case, there are path differences for both incoming and diffracted rays, so the general condition for constructive interference is

$$n\lambda = d|\sin \theta_0 - \sin \theta_n|, \qquad (2)$$

where the angles are measured relative to normal.[2] If the incident angle θ_0 is taken to be positive, the diffraction angle θ_n is positive (negative) when it is on the opposite (same) side of the normal. Alternatively, in terms of the complementary

Table I. Results for the CD and the DVD with normal incidence. The track spacings were found using Eq. (1).

	n	θ_n	d (μm)
CD	1	24°	1.6
	2	55°	1.6
DVD	1	60°	0.73

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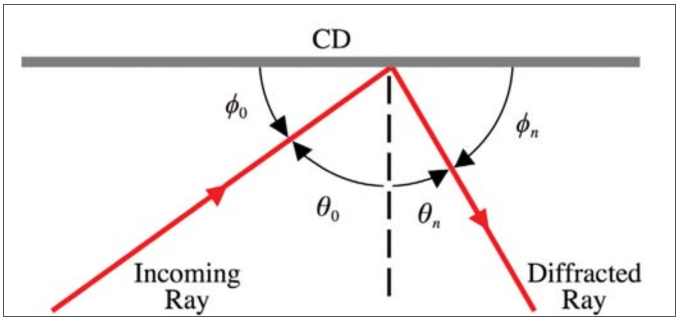

Fig. 3. Definition of angles for oblique incidence. The angle θ_n is negative if the diffracted ray is on the opposite side of the normal (dashed line) from what is shown. The reflected ray is omitted.

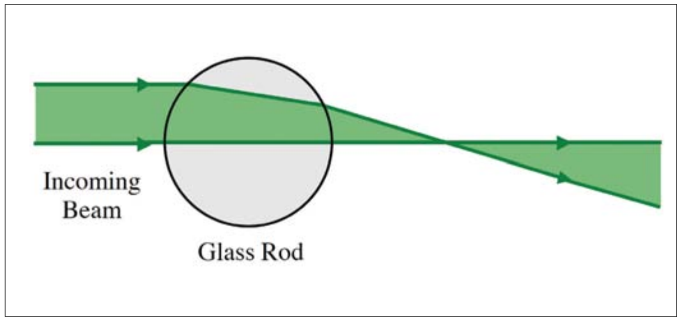

Fig. 4. How a cylindrical rod produces rays that are fanned out in the downward direction.

angles ϕ_0 and ϕ_n, the grating equation becomes

$$n\lambda = d|\cos\phi_0 - \cos\phi_n|. \quad (3)$$

Note that the complementary angles are measured from the surface on opposite sides of the point where the light is incident.

The track spacing is reported to be 0.32 μm for a Blu-ray disc,[4] so there should be a diffracted ray for incident angles less than about $\phi_0 = 10°$ for 635-nm light, according to Eq. (3). However, I was unable to see a diffracted ray. There are two plausible explanations for this difficulty. First, the diffracted ray would be very close to the very bright incident ray. For example, if the incoming ray is at $\phi_0 = 5°$, the diffracted ray should be at $\phi_1 = 171°$, which is only 4° away. (Recall that these angles are measured from opposite sides.) Second, the diffracted light may not be very intense for grazing incident angles.

Table II. Measured incident and diffracted angles for 532-nm light obliquely incident on a Blu-ray disc. In all cases, *n* =1.

ϕ_0	ϕ_1
20°	135°
25°	139°
30°	144°
35°	149°
40°	155°
45°	165°

Light with a shorter wavelength makes the measurement of the track spacing on the Blu-ray disc feasible. Laser ray boxes with green diode lasers exist, but I was unable to find a domestic supplier. Instead, a 532-nm laser pointer was used. The beam diameter was large enough that the laser pointer could be aimed slightly downward to show the paths of the incident, reflected, and diffracted light on the polar graph paper. An alternative method was to place a small glass rod with its axis horizontal in front of the laser beam. As illustrated in Fig. 4, the rod produces rays that are fanned out in the downward direction like a laser ray box. Only first-order diffracted rays were produced using the Blu-ray disc. Table II shows the measured angles of the incident and diffracted rays. For each pair of angles, the track spacing calculated using Eq. (3) is consistent with 0.32 μm. As the angle ϕ_1 approaches 180°, the diffracted ray gets very dim. This gives some credence to the suggestion that the diffracted ray expected at $\phi_1 = 171°$ for the red (635-nm) light wasn't visible because it was too dim.

The method described for measuring the track spacing for optical discs has some advantages. The experiment is simple to set up in a small space near the edge of a table. The paths of the incoming and diffracted rays are clearly visible, so the angles that they make can easily be measured directly. Therefore, no geometry is required to apply the condition for constructive interference.

References

1. Christian Nöldeke, "Compact disc diffraction," *Phys. Teach.* **28**, 484–485 (Oct. 1990).
2. James E. Kettler, "The compact disk as a diffraction grating," *Am. J. Phys.* **59**, 367–368 (April 1991).
3. PASCO scientific, Model SE-8505.
4. Tom D. Milster, "Horizons for optical data storage," *Opt. Photonics News* **16** (3), 30–33 (2005).

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