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TG 01/10
Physics HL 01

# Internal Assessment

## Determination of radial separation of pits on "The Remix" CD

### Introduction

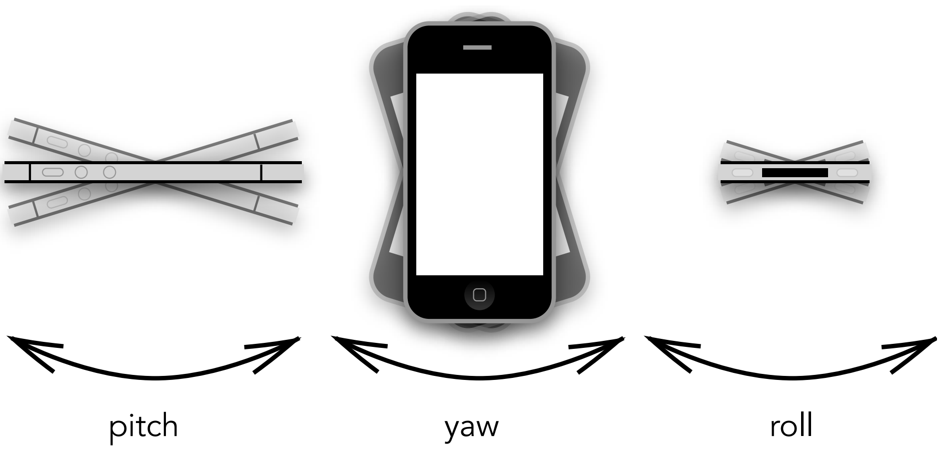
Aim: To find out the track width of Lady Gaga's "The Remix" compact disc.

A compact disc stores data in pits, along many tracks that travel along the shiny side of the disc, protected by a thin piece of plastic. The tracks are separated by a distance, which I intend to find out in this experiment.

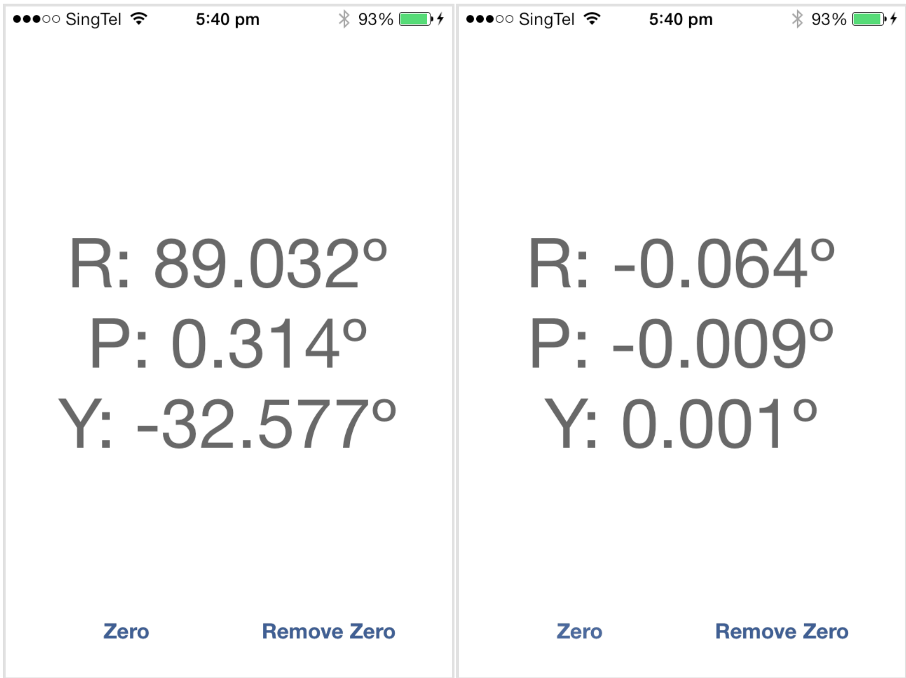
To determine this distance, I will use the disc to diffract a red laser light. The waves diffract after reflecting from the pits, which act as apertures. As there are many pits in a small space, they act as many sources of light, which produce light which interfere and produce a diffraction pattern.

I will measure the angle $\theta$ between the axis corresponding to the central maximum and the axis corresponding to the n maximum. Using the formula $d \sin \theta = n\lambda$, where $\lambda$ is the wavelength of the laser, the slit width d can be calculated.

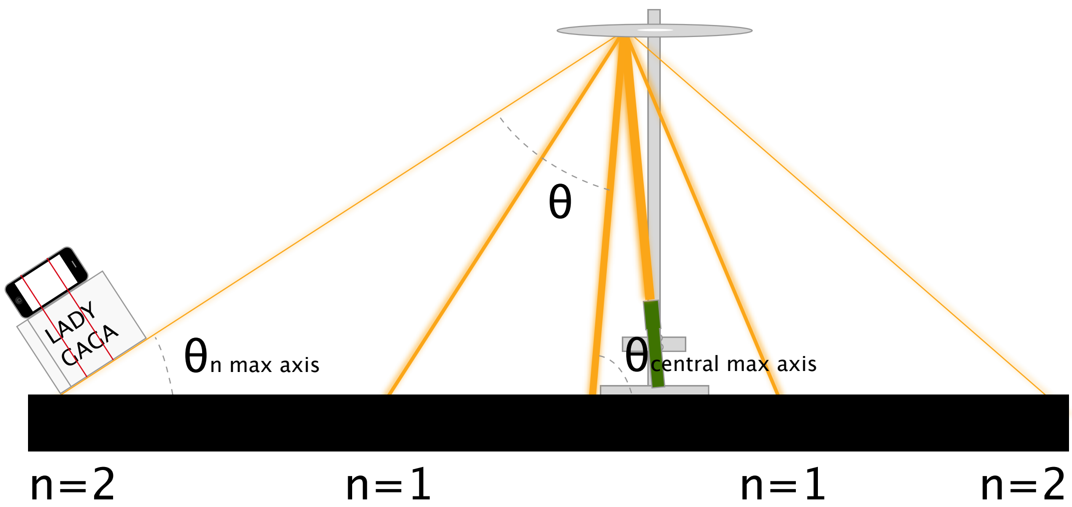
I will use my iPhone 4S, with its internal gyroscope and accelerometer, to measure the angle of the axis corresponding to the central maximum and the axis corresponding to the n maximum. The difference between this two values is $\theta$. I will use an app, Sextant, which I wrote a few months back for another physics experiment. It is a simple app that uses the device motion API, part of the CoreMotion framework provided by Apple, to get the device's attitude in real time. Among other things, the API gives the roll, pitch and yaw of the device.



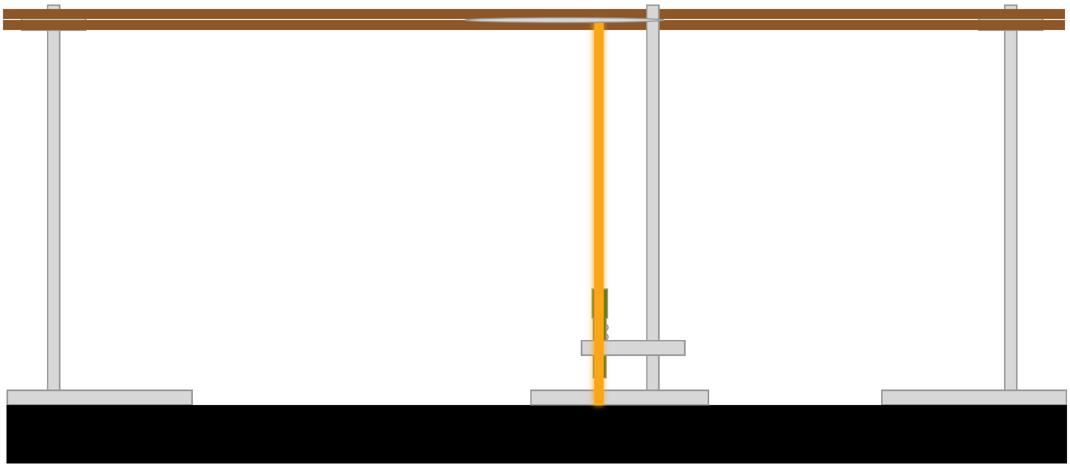
Before measuring the angle, we need to give Sextant a point of reference, which will be the plane of the table. Select two corners on the jewel case that will be put parallel to the beam. For this example, I will use the bottom left and right corners. Fasten the iPhone to the jewel case with rubber bands. To calibrate Sextant, place the two corners such that they are touching the table. Press Zero, which will cause Sextant to use the current attitude of the device as its point of reference. There will be a small amount of noise, which will cause the values to keep fluctuating. The screenshot on the left shows some values before Zero has been pressed, and the one on the right shows the values after that.



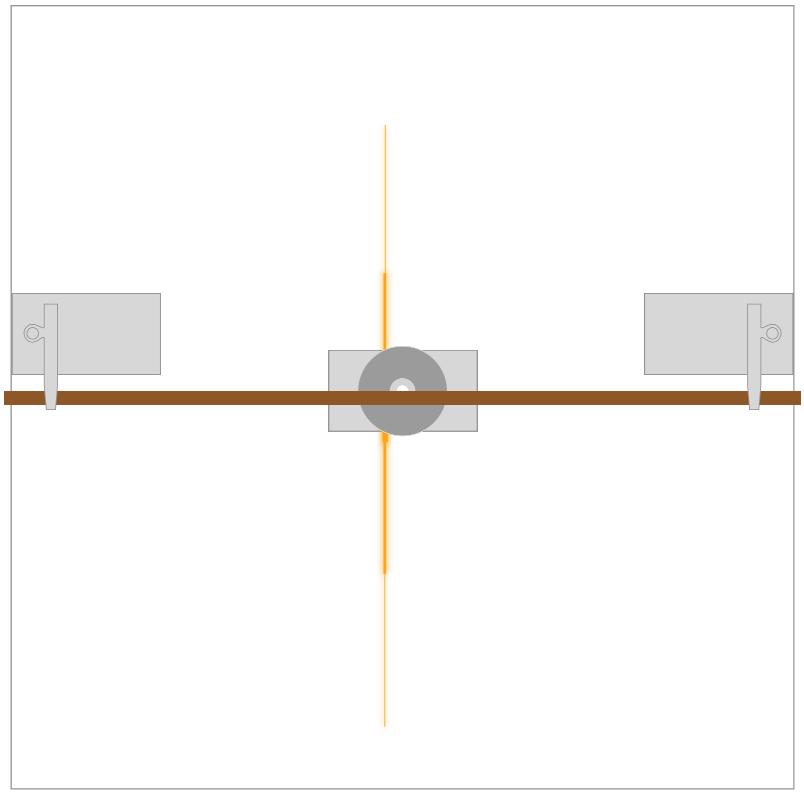

To measure the angle, the bottom left corner of the jewel case is placed on the point on the table where the maximum is. The case is then tilted until the laser point is visible on the bottom right corner of the case. As the jewel case has a straight edge and sharp corners, it makes it more convenient and accurate than using the phone's shorter side and rounded corners to measure this angle. The angle can then be read off the phone as the yaw value, labeled "Y" on the screen.



The laser pointer is clamped in a retort stand at around the center of the table. It should be clamped in such a way that the clamp presses on its switch, and the laser remains on until it is unclamped. The laser should also be clamped as low as possible, and pointing upwards to the shiny side of a CD, suspended by two meter rules clamped at both ends by two retort stands, as shown in the diagram below. If the laser is too high, it may block the diffracted rays coming off the surface of the disc. To minimise the effect of refraction by the plastic covering the pits on the angles measured, the laser should be pointing at almost right angles to the surface of the disc. However, it cannot be too close to being perpendicular, as the axis corresponding to the central maximum will not be able to reach the table, making it difficult to measure this angle.



The setup is arranged in a cross, with the plane of the laser beams roughly perpendicular to the rulers. This illustration shows a top view of the whole setup.



## Variables

- The number corresponding to a maximum $n$ (independent variable)
- The angle between the axis corresponding to the central maximum and the axis corresponding to the $n$ maximum, $\theta$ (dependent variable)
- Wavelength of the laser $\lambda$ (constant)
- The angle of the axis corresponding to the central maximum, $\theta_{central\ max\ axis}$
- The angle of the axis corresponding to the $n$ maximum, $\theta_{n\ max\ axis}$

## Apparatus

- 3 retort stand
- 2 meter rules
- 2 rubber bands
- Laser pointer
- CD
- CD jewel case
- iPhone with a gyroscope and accelerometer
- An iOS app that measures the device attitude. I will use Sextant, which I programmed myself.

## Results

Table 1: Raw data for the determination of radial separation of the pits on a CD.

Key: $\lambda$ = wavelength of the laser

*n* = the number corresponding to the maximum

$\theta_{central\ max\ axis}$ = the angle corresponding to the axis of the central maximum

$\theta_{n\ max\ axis}$ = the angle corresponding to the axis of the *n* maximum

| Trial | $\lambda$/μm | n | $\theta_{\text{central max axis}}$/° | $\theta_{\text{n max axis}}$/° |
|---|---|---|---|---|
| | (±10) | | (±0.3) | (±0.3) |
| 1 | 650 | 1 | -73.8 | -44.0 |
| 2 | 650 | 1 | -89.7 | -64.3 |
| 3 | 650 | 2 | -89.7 | -27.4 |
| 4 | 650 | 1 | 89.7 | 64.8 |
| 5 | 650 | 1 | -85.6 | -58.9 |
| 6 | 650 | 1 | 90.7 | 63.7 |
| 7 | 650 | 2 | -84.4 | -15.6 |
| 8 | 650 | 1 | -86.8 | -141.3 |
| 9 | 650 | 2 | -86.8 | -177.1 |
| 10 | 650 | 1 | 2.9 | 30.0 |
| 11 | 650 | 2 | 2.9 | 65.0 |

* The uncertainty of the angles $\theta_{\text{central max axis}}$ and $\theta_{\text{n max axis}}$ are estimated to be ±0.3° as when I was holding up the phone at the angle, the numbers on the screen were fluctuating about ±0.2°.

The angles $\theta_{\text{central max axis}}$ and $\theta_{\text{n max axis}}$ are recorded haphazardly as I did not have a fixed procedure when conducting the experiment, so they have to be normalized.

Table 2: Processed data for the determination of radial separation of the pits on a CD.

Key: $\theta_{central\ max\ axis}$ = the angle corresponding to the axis of the central maximum

$\theta_{n\ max\ axis}$ = the angle corresponding to the axis of the $n$ maximum

$\theta$ = the angle between the axis corresponding to the central maximum and the axis corresponding to the $n$ maximum

$d$ = the radial separation of the pits on a CD

| Trial | Normalized $\theta_{central\ max\ axis}$/ ° | Normalized $\theta_{n\ max\ axis}$/° | θ/° | θ/rad | d/m | % error |
|---|---|---|---|---|---|---|
| **1** | 73.8 | 44.0 | 29.8 | 0.520 | 1.31E-06 | 18 |
| **2** | 89.7 | 64.3 | 25.4 | 0.443 | 1.52E-06 | 5 |
| **3** | 89.7 | 27.4 | 62.3 | 1.09 | 1.47E-06 | 8 |
| **4** | 89.7 | 64.8 | 24.9 | 0.435 | 1.54E-06 | 4 |
| **5** | 85.6 | 58.9 | 26.7 | 0.466 | 1.45E-06 | 10 |
| **6** | 90.7 | 63.7 | 27.0 | 0.471 | 1.43E-06 | 11 |
| **7** | 84.4 | 15.6 | 68.8 | 1.20 | 1.39E-06 | 13 |
| **8** | 86.8 | 141.3 | -54.5 | -0.951 | -7.98E-07 | 150 |
| **9** | 86.8 | 177.1 | -90.3 | -1.58 | -1.30E-06 | 181 |
| **10** | 87.1 | 60.0 | 27.1 | 0.473 | 1.43E-06 | 11 |
| **11** | 87.1 | 25.0 | 62.1 | 1.08 | 1.47E-06 | 8 |
| **Average** | | | | | **1.45E-06** | **10** |

* Average is calculated without trials 8 and 9, because I cannot replicate the results.
* I did not plot a graph because the value of *d* can be calculated by averaging the numbers of *d*, and a graph would be redundant.

Sample calculations for Table 2, Trial 1

| Item | Formula used |
|---|---|
| **θ/°** | normalized $\theta_{central\ max\ axis}$ - normalized $\theta_{n\ max\ axis}$<br>= 73.8 ° - 44.0 °<br>= 29.8 ° |
| **θ/rad** | θ / 180 ° * π rad<br>= 29.8 ° / 180 ° * π rad<br>= 0.520 rad |
| **d** | (n * λ) / sin(θ)<br>= (1 * 0.000000650 m) / 0.497<br>= 0.00000131 m |
| **% error** | absolute difference between 1.6 μm and 1.31 μm / 1.6 μm * 100 %<br>= 0.29 μm / 1.6 μm * 100 %<br>= 18 % |

**Propagation of Uncertainties**

Table 3: Propagation of the uncertainties of processed data for the determination of radial separation of the pits on a CD.

| Trial | % uncertainty λ | absolute uncertainty θ/° | % uncertainty θ | absolute uncertainty θ/rad |
|---|---|---|---|---|
| **1** | 1.5 | 0.6 | 2 | 0.01 |
| **2** | 1.5 | 0.6 | 2 | 0.01 |
| **3** | 1.5 | 0.6 | 1 | 0.01 |
| **4** | 1.5 | 0.6 | 2 | 0.01 |
| **5** | 1.5 | 0.6 | 2 | 0.01 |
| **6** | 1.5 | 0.6 | 2 | 0.01 |
| **7** | 1.5 | 0.6 | 1 | 0.01 |
| **10** | 1.5 | 0.6 | -1 | -0.01 |
| **11** | 1.5 | 0.6 | -1 | -0.01 |

| Trial | absolute uncertainty sin θ | % uncertainty sin θ | % uncertainty d | absolute uncertainty d/m |
|---|---|---|---|---|
| **1** | 0.01 | 2 | 3 | 4E-08 |
| **2** | 0.01 | 2 | 4 | 6E-08 |
| **3** | 0.00 | 1 | 2 | 3E-08 |
| **4** | 0.01 | 2 | 4 | 6E-08 |
| **5** | 0.01 | 2 | 4 | 5E-08 |
| **6** | 0.01 | 2 | 4 | 5E-08 |
| **7** | 0.00 | 0 | 2 | 3E-08 |
| **10** | 0.00 | -0 | 1 | 2E-08 |
| **11** | 0.00 | -0 | 2 | 2E-08 |
| **Average** | | | **3** | **4E-08** |

Sample calculations for Table 3, Trial 1

| Item | Formula used |
|---|---|
| **% uncertainty λ** | absolute uncertainty λ / λ * 100 %<br>= 10 μm / 650 μm * 100 %<br>= 1.5 % |
| **absolute uncertainty θ** | 0.3 + 0.3<br>= 0.3 + 0.3<br>= 0.6 ° |

| Item | Formula used |
| --- | --- |
| **% uncertainty θ** | absolute uncertainty θ / θ * 100 %<br>= 0.6 ° / 29.8 ° * 100 %<br>= 2 % |
| **absolute uncertainty θ** | % uncertainty θ / 100 % * θ<br>= 2 % / 100 % * 0.520 rad<br>= 0.01 rad |
| **absolute uncertainty sin θ** | max(lsin(θ + absolute uncertainty θ) - sin θl, lsin(θ - absolute uncertainty θ) - sin θl)<br>= 0.01 rad |
| **% uncertainty sin θ** | absolute uncertainty sin θ / sin θ * 100%<br>= 0.01 rad / sin (0.520 rad) * 100 %<br>= 2 % |
| **% uncertainty d** | % uncertainty λ + % uncertainty sin θ<br>= 1.5 % + 2 %<br>= 3 % |
| **absolute uncertainty d** | % uncertainty d / 100 % * d<br>= 3 % / 100 % * 1.31 μm<br>= 0.04 μm |

## Conclusion and Evaluation

Table 4: Final value of *d*, with its uncertainties and errors.

| d/μm | % error | % uncertainty d |
| --- | --- | --- |
| 1.45 ± 0.04 | 10 | 3 |

The value of *d* calculated is within 10% of the literature value of 1.6 μm, with the percentage error more than the percentage uncertainty, which means there are more systematic errors than random errors. Thus, I am not very confident in the value *d*. This value of *d* should also be similar across all CDs, and not just limited to this "The Remix" disc that we used, as it is an international standard.

The maxima on the table were big oval shapes which got bigger as the distance from the CD increased. Deciding on the point to start measuring the angle theta was difficult as the laser point on the table was a large elongated shape, which forced us to estimate the center point of the shape. Because of this, the thetas corresponding to axis of the central maximum is likely to be the more accurate than the thetas corresponding to the axis of the n maximum. We could use another surface much closer to the CD to measure some points, especially the points where n=2, which were faint and very large on the table. This will reduce its size, enabling us to determine a point to start and end measuring theta from with much greater certainty.

Using an arm to hold up the phone and CD jewel case makes the angle measured shaky, as our arms are not very rigid. This makes it difficult to measure the angle, especially when it the number keeps jumping around. Some guesswork was then required to decide what the actual number was. That explains our rather high error of theta despite having a device that can measure to a precision of roughly ±0.03°. We could use a lever or something to angle it stably, giving us less noisy data to work with, reducing or eliminating the guesswork required.

We record the yaw values provided by the device motion API as theta. However, if the pitch and roll values (the other 2 axes it measures) is not 0, then the yaw values might not be as accurate as it should be. I did not think to keep the pitch and roll values at 0, so the yaw value could be off. We should have gotten the "zero" device attitude when the device is parallel to the plane of the diffracted rays, which we can obtain by putting a ruler between two of the points on the table. That will ensure that the pitch and roll values will be as close to 0 as possible when we measure the yaw, so that we get the most accurate value of theta possible.

The recording of data can certainly be improved. I could have used a fixed procedure for measuring the angles, instead of measuring the angles in any way I liked and getting angles that do not make sense and require processing to fix them. I did not have a fixed procedure to use at that time, because my friend and I came up with that procedure while experimenting with the equipment that we had. We were solving a problem we had with an older procedure, which was giving us horrendous results with percentage errors on the order of a few thousands to tens of thousands. Since we came up with that on the spot, we did not have time to write out a procedure and the raw data we were collecting seemed to work, until after we were done and went to analyse it. We could have noticed the 150% error we got and sat down to work out why it was so bad before continuing, and the negative angles should have alerted us that something was wrong. It is also about time management as we were working outside of class time.