Determination of Planck's constant using electroluminescence process

Aim: To determine the value of Planck's universal constant using LEDs.

Apparatus: LEDs, digital voltmeter, micro-ammeter, and ten turn linear potentiometer.

Principle: LED is a p-n junction and it works on the principle of electro-luminescence; a phenomenon in which materials emit light in response to the passage of electric current. The primary carriers in p and n-type semiconductors are holes and electrons respectively. When a junction is formed from these materials, free electrons near the junction diffuse across the junction into the P region and combine with holes. Filling a hole makes a negative ion and leaves behind a positive ion on the N side. These two layers of positive and negative charges form the depletion region; the region depleted of charge carriers. As electrons diffuse across the junction a point is reached where the negative charge repels any further diffusion of electrons; thus forming a potential barrier. External energy must be applied to get the electrons to move across the barrier of the electric field. The potential difference required to move the electrons through the electric field is called the barrier potential. Barrier potential, V_o of a PN junction depends on the type of semiconductor material, amount of doping and temperature. In an LED, the PN junction is used in forward bias condition which helps in injecting large number of electrons with additional potential energy required to overcome the barrier potential thus leading to large flow of current through the junction. The recombination of electrons in the conduction band with the holes of the valence band results in release of photons and the wavelength of the light emitted depends on the band gap of the semiconductor material used in the LED.

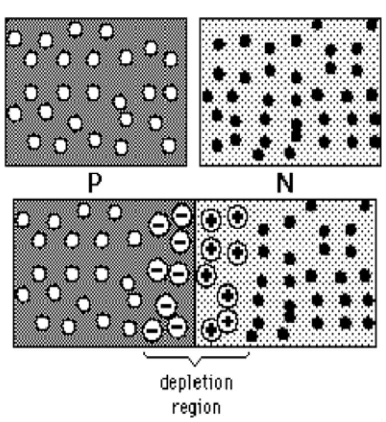

Fig. 1 Formation of Depletion Layer in a p-n junction

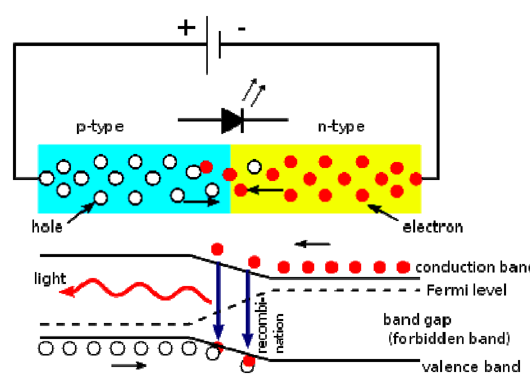

Fig. 2 The foward-bias of the p-n junction leads to large current. The energy diagram below shows the recombination of electrons and holes producing photons

From the conservation of energy,

$E=eV_o$ (electron) $=h\nu= h(c/\lambda)$ (photon)

$h=(eV_o\lambda)/c$ (1)

Where e and h are the charge of electron and Planck's constant respectively while λ and ν , are the wavelength or the color and the frequency of the photons emitted from the LED.

The Eq. (1) can also be expressed as $V_o = \frac{hc}{e} \lambda^{-1}$ (2)

Therefore, the value hc/e and hence the Planck constant, h can be obtained from the slope of V_o-λ^{-1} curve which can be obtained from the V_o values obtained for each LED from its V-I plots. The V-I plot for four different LED's is obtained and the V_o-λ^{-1}curve is obtained from the barrier potential V_o obtained from V-I plot of each LED. If the linear portion of the V-I plot is extrapolated back to x-axis the intercept represents the barrier potential (the potential above which, I becomes independent of V).

Circuit: The LED circuit is shown in Fig. 3 and it consists of 5V supply; a ten turn potentiometer to vary voltage across the LED from 0 to 5 V that is measured using voltmeter and an ammeter to measure current through the LED. A 33 kΩ resistor is connected in series with the LED (find out why).

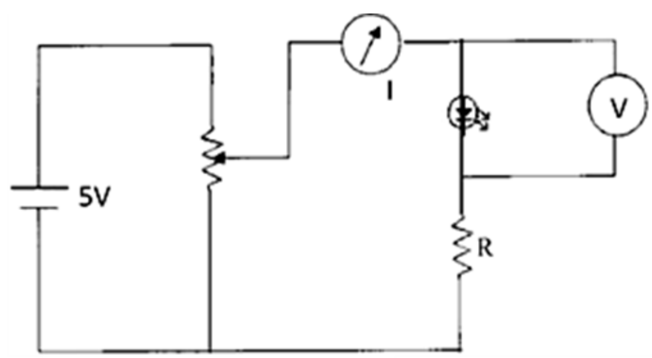

Fig. 3 Circuit diagram

Procedure:

1. Connect an LED (you have been given four LEDs) to the jack provided on the front panel and switch on the unit.
2. Vary the voltage V (decide the appropriate step size) across the LED and note the corresponding current I and tabulate as shown in Table 1 for V-I characteristic of LED.
3. Repeat step 2 for the remaining LEDs.
4. Plot the V (along x-axis)-I (along y-axis) characteristics of all the LEDs on a single graph sheet and obtain the V_o for each LED
5. Enter the values in Table 2.
6. Plot a graph of voltage V_o versus $1/\lambda$ for LED's of different wavelength and determine the slope (=hc/e) of the line. Calculate h using standard values of c and e.
7. Calculate the slope also using least square fit method:

   $slope = \frac{N\sum x_i y_i - \sum x_i \sum y_i}{N\sum x_i^2 - (\sum x_i)^2}$ where N is the number of points. From the slope

obtain the value of h.

Table-1 : I-V Characteristics of 4 different LEDs

	Colour		Colour		Colour		Colour	
Sl. No.	**V** (volts)	**I** (mA)	**V** (volts)	**I** (mA)	**V** (volts)	**I** (mA)	**V** (volts)	**I** (mA)

Table 2 : Barrier Potential Vs. inverse of wavelength of the photons emitted.

Sl. No.	LED color	Wavelength λ (nm)	**$1/\lambda$** (nm -1)	Barrier Potential **V_o**

Slope of the $1/\lambda$- V_o curve (hc/e) : S =
Coefficient (c/e) : C=
Planck Constant S/C : h=

Result: The value of Planck's constant was found to be ______________________

Conclusions

Hint for Error Analysis: Estimate the error in V at which I become nearly independent of V.

Questions

1. Suggest a method to measure h without using the value of any other universal constant.
2. Identify the sources of systematic errors and random errors
3. Speculate the consequences if h were zero in our universe.
4. How is h useful to engineers?
5. Can you make LED like device using metals?
6. Can we think of LED as a device which annihilates mass (electron) to give energy (photon)?
7. Principle explained above is rather over-simplified. Please look to a textbook on semiconductor devices (Streetman, S. M Ze) to obtain more information on energy diagram of LED.

Determining Numerical Aperture, Acceptance angle and optical power losses of Optical fibers for finding their suitability in telecommunications applications

Aims:

1. To determine the Numerical Aperture (NA) and acceptance angle ($_a$) of the given two different (1 meter and ½ meter cables) optical fibers to find their suitability in telecommunications applications.
2. Observing the optical power losses, when light are passing through two different (1 meter and ½ meter cables) optical fibers during, (a) when they are not coupled each other and (b) when they are coupled each other through an in-line adaptor.

Apparatus required:

Fiber optic LED light source, Fiber optic power meter, Fiber Optic (FO) cable 1 meter, FO cable ½ meter, In-line adaptor (to connect 2 cables), NA-Jig (L-shape with scale on one side and connector on other side).

Formula:

$$NA = \sin \ {}_a = \frac{W}{\sqrt{(4L^2+W^2)}} \text{ (No unit)}$$

where W - Diameter of the spot (m)

L - Distance between the fiber end and the screen (m)

$_a$- Acceptance angle (deg)

Procedures:

To determine the Numerical Aperture (NA) and acceptance angle ($_a$):

1. Connect one end of the 1 meter FO cable and the other end to the NA Jig as shown in the figure.
2. Plug the AC main. Light should appear at the end of the fiber on the NA Jig.

3. Notice the horizontally movable acrylic screen-printed plate attached with NA-Jig. This screen is drawn with concentric circles of 10, 15, 20, 25 and 30 mm diameters).
4. Now move the acrylic screen-printed plate to a distance L (say 5 mm) from the fiber end, view the spot and measure its diameter W.
5. Repeat the experiment for different distances L (say 10 mm, 15 mm, 20 mm, 25 mm and 30 mm). Note down the diameter values W of the corresponding spots.
6. Then calculate the NA and $_a$ using the above relations.
7. Now fix the ½ meter cable and repeat the same procedures to calculate the NA and $_a$.

To observe the optical power losses, when light are passing through two different (1 meter and ½ meter cables):

1. Connect one end of the 1 meter FO cable to the FO LED and the other end to the fiber optic power meter and observe the displayed value and estimate the power loss.
2. Connect one end of the 1 meter FO cable to the FO LED and the other end to the fiber optic power meter and observe the displayed value and estimate the power loss.
3. Connect both the FO fiber cables through the given in-line adaptor and then connect one end of this coupled FO cables to the FO LED and the other end to the fiber optic power meter and observe the displayed value and estimate the power loss.
4. Analyze the power losses estimated in the 3 above mentioned cases.

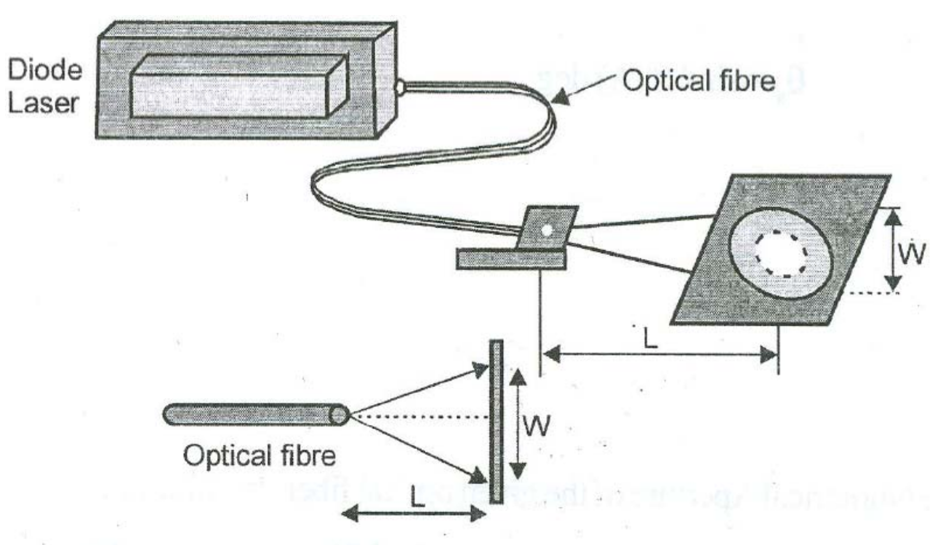

Figure: Set-up for NA measurement

To determine

NA and $_a$:

1) **For Optical fiber cable with length of 1 meter:**

Sl. No.	L	W	NA	$_a$
	mm	mm	No unit	deg
1				
2				
3				
4				
5				
6				
		Mean =		

2) **For Optical fiber cable with length of ½ meter:**

Sl. No.	L	W	NA	$_a$
	mm	mm	No unit	deg
1				
2				
3				
4				
5				
6				
		Mean =		

Calculations:

$$NA = \sin \quad {}_a = \frac{W}{\sqrt{(4L^2+W^2)}} \text{ (No unit)}$$

NA = **………………**

$\sin \quad {}_a$ = **NA**

$${}_a = \sin^{-1}(\text{NA}) \text{ deg}$$

Results

i) The Numerical Aperture of the given optical fiber (1 Meter) = …………….

ii) The acceptance angle for the given optical fiber (1 meter) = …………..... deg.

iii) The Numerical Aperture of the given optical fiber (1/2 Meter) = …………….

iv) The acceptance angle for the given optical fiber (1/2 meter) = …………..... deg.

v) The optical power loss, when light is passing through optical fiber cable (1 meter)……………

vi) The optical power loss, when light is passing through optical fiber cable (1/2 meter)……………

vii) The optical power loss, when light is passing through optical fiber cable (1/2 meter)……………

viii) The optical power loss, when light is passing through optical fiber cables (1 meter and ½ meter) when they are coupled each other through an in-line adaptor……………

Error Analysis:

Do the error analysis for observations related to NA and $_{a}$ measurements for both the FO cables.

Determination of the track width (periodicity) in a written CD

Aim: Determination of the track width (periodicity) in a given CD by a Laser diffraction method and then determine the amount of data stored on a given CD.

Apparatus Required:

Laser source, written CD-R, Planer screen and Scale.

Theory:

A standard CD is a fairly simple piece of plastic disk having 1.2 mm thick and 120 mm diameter. It can hold up to 80 minutes of uncompressed audio or 700 MB of data.

As shown in the Fig. 1, a CD have the following components, from the center outward: the center spindle hole (15 mm), the first-transition area (clamping ring), the clamping area (stacking ring), the second-transition area (mirror band), the program (data) area, and the rim. The inner program area occupies a radius from 25 to 58 mm.

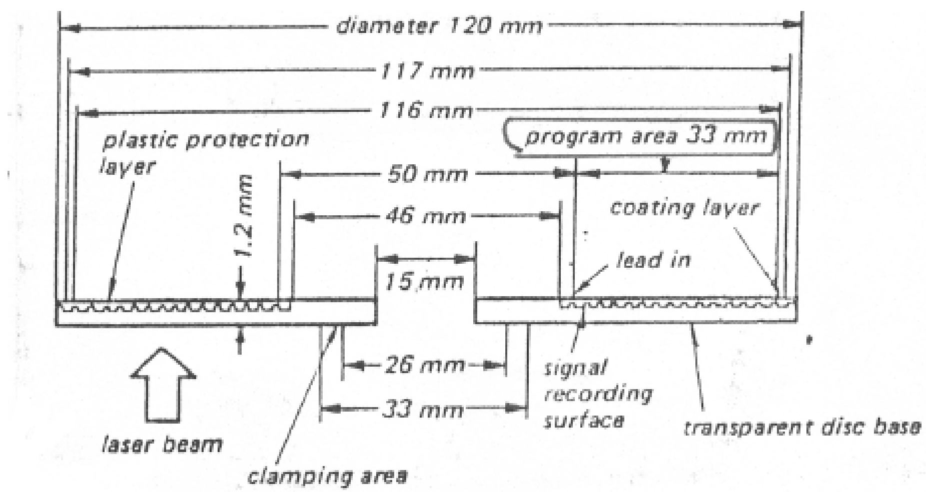

Fig. 1: A cross-sectional view of a CD skelton along with different components and their typical dimensions.

There are different types of CDs are available in the market and CD-ROM (called stamped CD), CD-R and CD-RW are the most widely used types. Here we try to determine the track width of a standard CD-R, using laser reflective diffraction method.

Just like all kinds of CDs, a CD-R disc is a sandwich of a number of layers. The polycarbonate disc contains a spiral groove (tracks), called the "pregroove" (because it is molded in before data are written to the disc), to guide the laser beam upon writing and reading information. The pregroove is molded into the top side of the polycarbonate disc, where the pits and lands would be molded if data were written; the bottom side, which faces the laser beam in the player or drive, is flat and smooth. **The distance between the spiral tracks, the pitch, is ____ µm. Our aim is to determine the pitch using light diffraction experiment.**
This polycarbonate disc is coated on the pregroove side with a very thin layer of organic dye (cyanine, azo or phthalocyanine). Then, on top of the dye is coated a thin, reflecting layer of silver, a silver alloy, or gold. Finally, a protective coating of a photo-polymerizable "lacquer" is applied on top of the metal reflector and cured with UV-light. Some discs are also topped, on lacquer layer, with additional layers that improve scratch resistance, increase handling durability or provide surfaces suitable **for labeling by inkjet or thermal transfer printers.** A cross-sectional view of a CD-R is shown in the Fig.2.

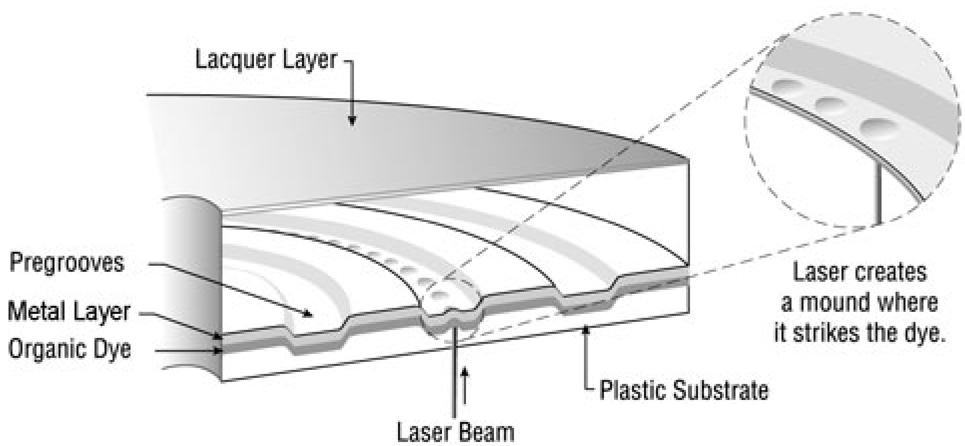

Fig.2: A cross-sectional view of a CD-R.

The laser of your CD-R drive heats the dye to a temperature of about 200 ^{o}C, irreversibly melting a pitted pattern into the recording layer. A plastic layer alongside the dye expands into the newly available space creating a pit pattern similar to that of a conventional CD. Your CD player reads this highly reflective pattern for playback. Because the plastic layer melts into the dye layer to set the patter.

Digital data is stored in CD as a series of these "pits". The areas between pits (i.e., unmelted area) are known as "lands". Each pit is approximately 100 nm deep by 500 nm wide, and varies from 0.85 µm to 3.5µm in length. Pits have the same light reflecting surface as the land, but pits reflect the read-laser's light in a diffuse and interferening way and thus look relatively dark compaired to the land areas.

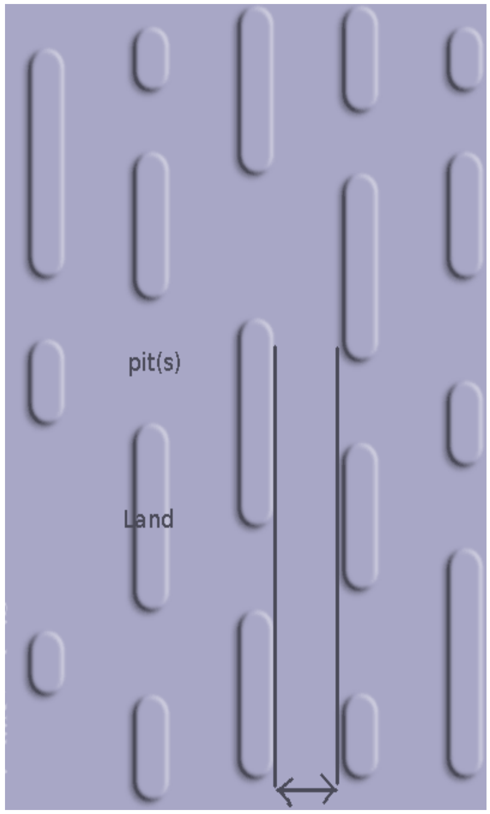

Fig.3: Data tracts and lands and pits in the written CD.

It is not simply so that a land is a "1" data bit, and a pit is a "0" data bit. A data bit is a "1" or "0" from the original data, but on a CD there are no data-bits but channel-bits. A channel bit is the smallest time unit used on a CD (=1/4,321,800 sec). A "1" channel bit = a time with change from land to pit, or from pit to land, a "0" channel bit = a time when there is no change, as shown in Fig.4. Channel bit length is computed just by dividing the speed by the bit rate. For example: 1.2 m/sec / 4321800 channel bit/sec = 277.662 nm.

Pit & Land Length varies a little depending on how fast the disk turns while recording. The scanning velocity during recording shall be between 1.20 m/s and 1.40 m/s with a channel bit rate of 4321800 channel bit/sec. The velocity variation for a disk when recorded shall be within 0.01 m/s. In other words, CDs are recorded at a constant velocity within 0.01/1.3 = 0.8% tolerance. Since the channel bit rate is held constant (4321800 channel bit/sec = 75 blocks/sec * 98 frames/block * 588 channel bits/frame.), then the density of the bits must vary with recording velocity. In other words, those 4321800 channel bits that encode 1 second of audio could be stored in as little as 1.2 linear meters or as much as 1.4 linear meters.

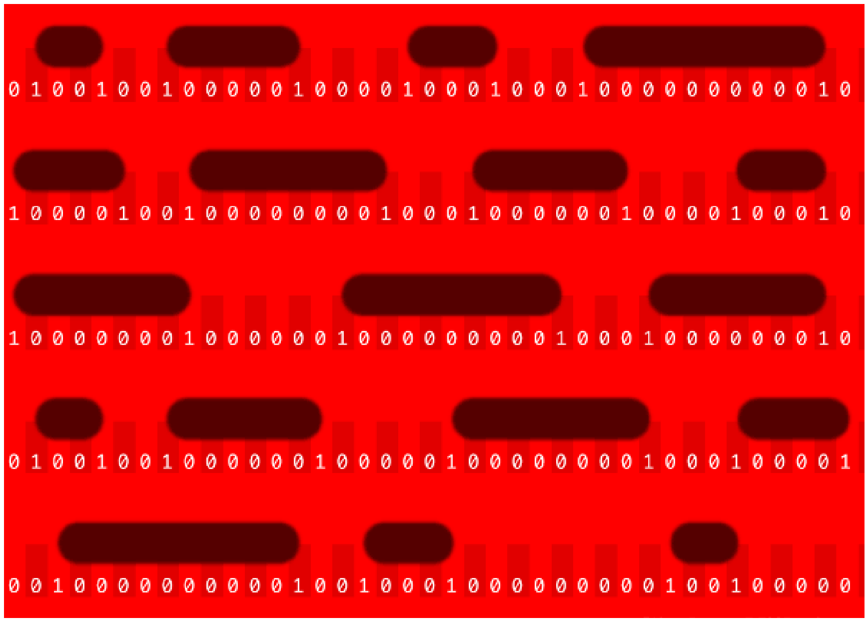

Fig.4: Mapping of bits with lands and pits.

The spiral of pits behaves in much the same way as a reflective diffraction grating. That is why you see beautiful rainbow colors when white light illuminates the CD. When a laser beam is reflected off the disc, a diffraction pattern is formed. If the angle of incidence is close to the normal, the condition for constructive interference is identical to that for a transmission diffraction grating.

In your previous cycle (Modern Physics lab), you may have determined the wavelength (W/L) of the laser using a grating (ruler). Now you can use the W/L of the laser to to measure the spacing between tracks on a compact disc (CD)! Thus, you may determine the maximum amount of information that can be stored on a CD.

The diffraction pattern that you see when you allow the *reflected* laser light to fall on a white wall can be used to infer the track width.

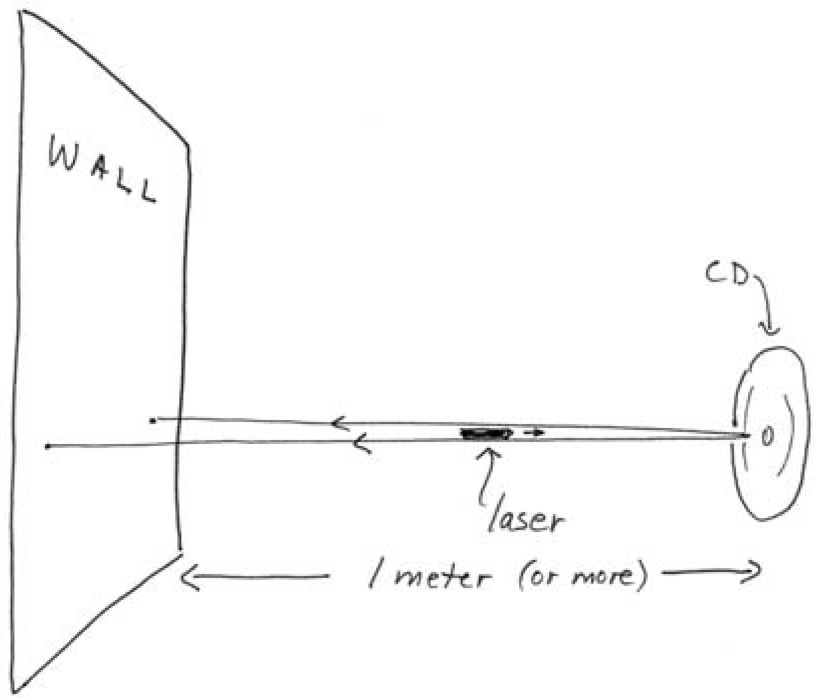

Fig.5: The schematic diagram of the experimental arrangement.

Formula used:

$n\lambda = \mathbf{d\ sin\theta}$ (For reflected diffraction pattern) ……………………………………..(1)

Where,

λ is the wavelength of the laser, θ is the angle of diffraction, n is the order of diffraction and d is the track width (to be determined). Hence, the track width can be determined by using the following equation,

$d = \lambda n / \sin\theta$ µm …………………………………(2)

Experimental Procedure:

1. The CD is held normal to the laser beam at a distance ~40cm such that the laser source lies between the screen and the CD.
2. The laser source is switched on and it is diffracted by the CD by the phenomenon of reflective diffraction.

3. A central spot with equidistant spots on either side will be noticed on the screen.
4. The distance 2L between the spots on either side of the central spot is measured corresponding to various orders (1,2,3….n).
5. The experiment is repeated for various values of D, the distance between the screen and the CD.

Observation Table: Given λ of laser =…………..

n	**D (cm)**	**2L (cm)**	**L (cm)**	**tanθ** =L/D	$\theta = \tan^{-1}(L/D)$	Sinθ	**Mean Sinθ**	**Track-width (d) (μm)**
1								
2								

Calculations:

d = λ n /Sinθ (**μm**)

Result & Conclusion:

The track width of the CD is ‘d’ **=………………. **μm

Applications:

Precautions:

1. Do not see the laser light directly.

Questions:

1. Given the inter-track spacing that you find, can you estimate the number of tracks on the CD and the total length of the spiral track?
2. From this total length, and an average bit-length of about 0.6 micron, estimate how many *bits* would fit on the CD?
3. Find the number of *bytes* (8 bits/byte).

Further study:

1. Do the same for DVD

2. Create Transmission Gratings from a CD and try the above experiment to determine the track width on the written CD.

3. Estimate the data size exist on the CD, by assuming standard value of data channel.

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THE END