General Physics Lab 10

Diffraction of Light

Objectives:

- To observe and analyze diffraction from a transmission grating and a CD

Equipment:

- Laser Pointer
- Diffraction Grating (1000 lines/mm)
- Blank CD
- Measuring Tape
- Modeling Clay
- Breadboard
- 4 LEDs
- Objects for Stacking
- Tape

Physical Principles:

Diffraction Grating

A diffraction grating has many, very closely-spaced slits (see Fig. 1). Coherent, monochromatic light rays of wavelength, λ, will interfere destructively everywhere except for special angles, θ_m, where the path length difference of adjacent rays is an integer number of wavelengths, i.e.,

$$d \sin(\theta_m) = m\lambda \,, \quad (m = 0, \pm 1, \pm 2, \dots) \,. \tag{1}$$

Here d is the spacing between adjacent slits and m is the integer order number.

Diffraction gratings are normally characterized by the spatial frequency, k, giving the number of slits (lines) per mm. For example, the grating included in your lab kit has k = 1,000 lines/mm.

This translates into,

$$d = \frac{1}{k} = \frac{1}{1000\ lines/mm} = 0.001\ mm/line \,. \tag{2}$$

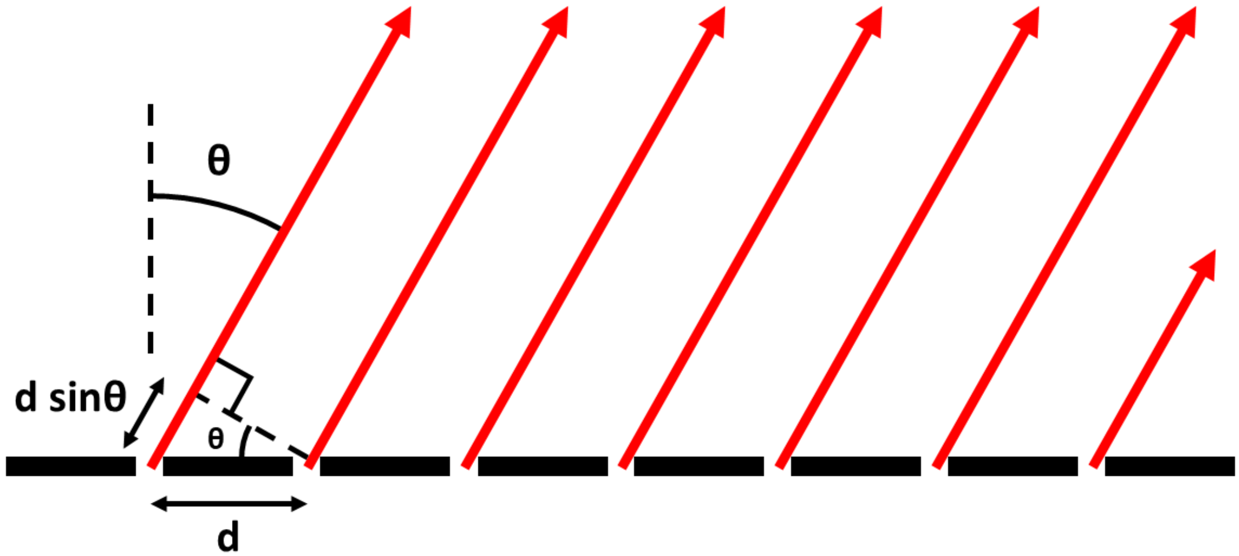


Fig. 1: Rays passing through a diffraction grating.

Since d is very small and

$$\sin(\theta_m) \propto \frac{1}{d}\ , \tag{3}$$

the angles, θ_m, cannot be considered small angles. In practice, this means that to determine θ_m you should measure both the lateral distance, y_m , (between a given bright spot on a screen and the central bright spot at $y_0 = 0$) and the screen distance, L, from the grating (see Fig. 2).

The angle can then be obtained from trigonometry as,

$$\theta_m = \tan^{-1}\left(\frac{y_m}{L}\right)\ . \tag{4}$$

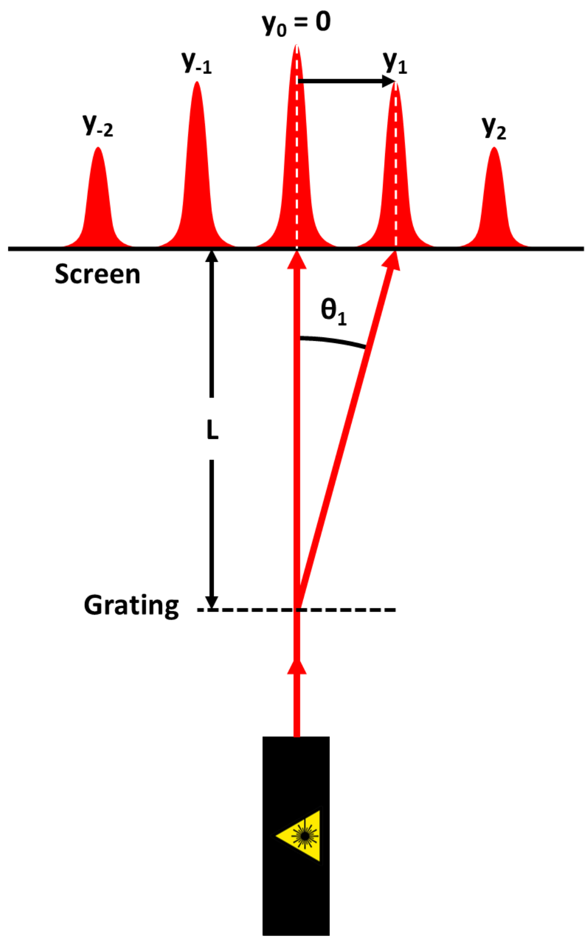


Fig. 2: Light passing through a diffraction grating will interfere constructively at specific locations on a screen.

Procedure:

Setup

1. Orient your diffraction grating so that the words on it read horizontal (see Fig. 3). Now, when you look through the diffraction grating at a light source, you should see a horizontal rainbow of colors.
2. Place 2 pairs of LEDs (4 total) in your breadboard, separated by the width of the diffraction grating frame (about 18 holes). Place each LED at the end of a row with the two leads in the last couple holes next to the center groove of the breadboard (see Fig. 4a).
3. Place the diffraction grating upright between the pairs of LEDs so that the bottom sits in the center groove of the breadboard, and it is held upright by the LEDs (see Fig. 4b). You can adjust the angle if necessary by shifting the LEDs. When you finish, the diffraction grating should be vertical (perpendicular to the breadboard) as shown in Fig. 4b and 4c.

Fig. 3: Rainbow Symphony Diffraction Grating

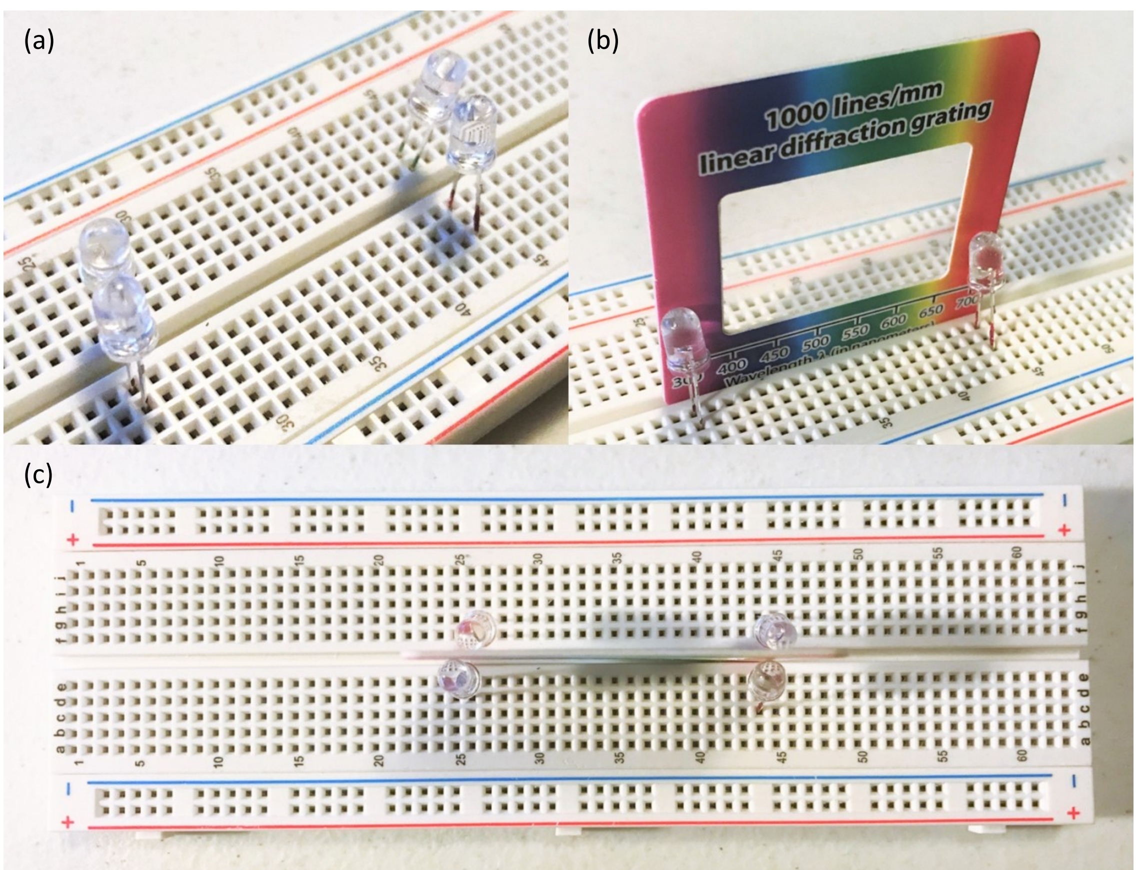


Fig. 4: Place 4 LEDs in a breadboard to make a stand for the diffraction grating.

WARNING: Never look directly into a laser or at its reflection from a mirror or shiny surface! The laser will reflect off the diffraction grating so be careful to avoid this reflection.

4. Load batteries into your laser pointer.
5. Form a clay holder for the laser pointer to hold it steady (see Fig. 5).
6. Set the laser pointer and holder on a flat surface (table, counter, etc.) so that the beam passes through the grating.
7. After passing through the grating, allow the beam to fall on a blank wall acting as the screen (see Fig. 6) with the distance between the grating and the screen, L ≈ 1 m (measure from the wall/screen to the center groove on the breadboard).
8. After setting the distance, L, tape down the breadboard so it will not move accidentally.

Fig. 5: Laser pointer in a clay holder

Fig. 6: Shine the laser through the diffraction grating at a wall. Tape down the grating to prevent it from moving.

Diffraction Grating Measurements

1. Calculate and record the slit spacing, $d_{grating}$, in units of m/line.
2. Record the distance from the diffraction grating to the screen, L.
3. Locate the undeflected central bright spot ($m = 0$, $y_0 = 0$).

4. Locate the two interference maxima on either side for m = ±1.
5. Eliminate the effects of asymmetry in your beam direction by determining the average distance, $y_{1\ ave}$, on the screen/wall. To do this, measure the total distance separating the centers of the bright regions at y_1 and y_{-1} and divide by 2 (see Fig. 7).

$$y_{1\ ave} = \frac{|y_1|+|y_{-1}|}{2} = \frac{total\ distance}{2}\ . \qquad (5)$$

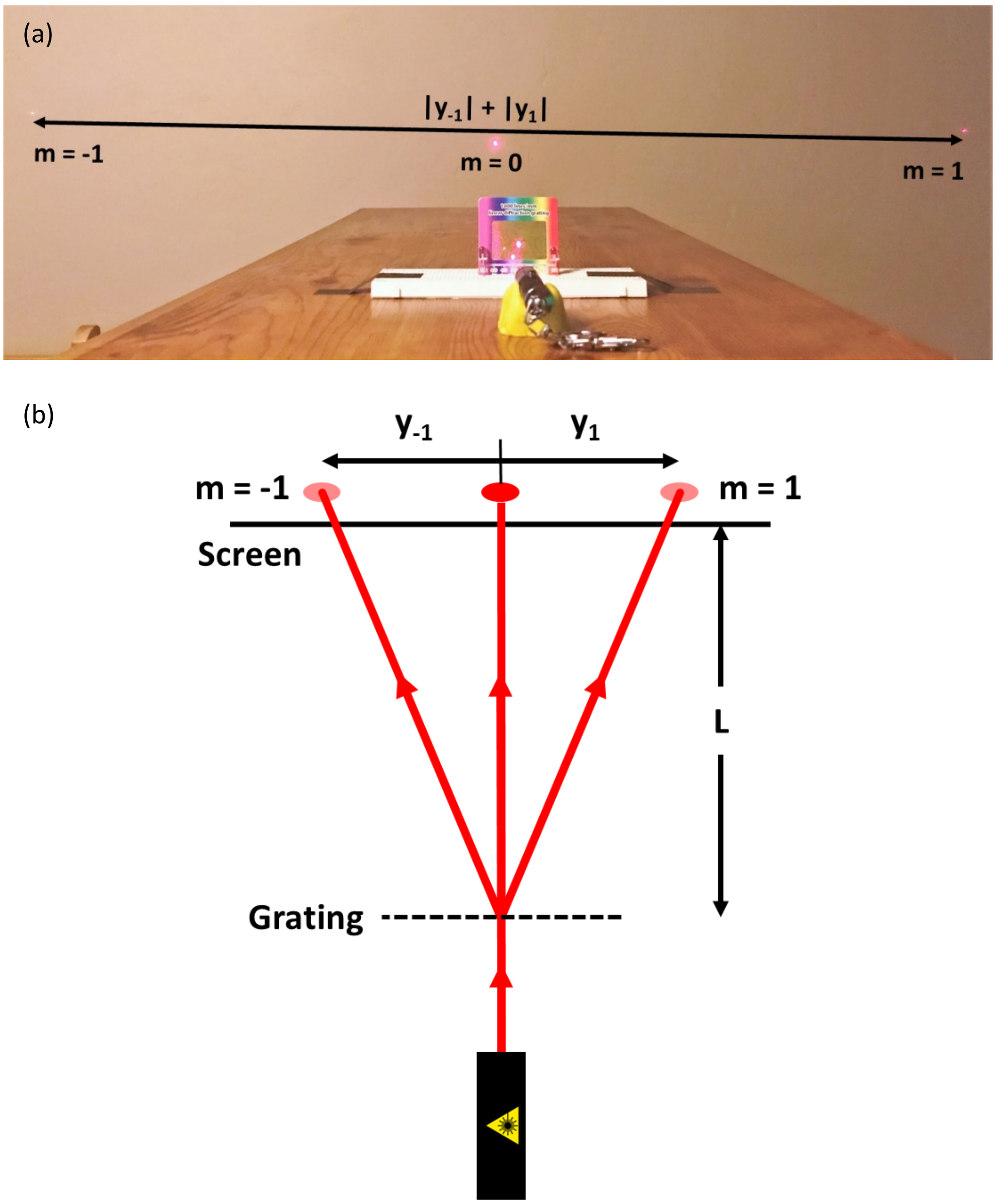


Fig. 7: Diffraction pattern displayed with maxima (m = -1, 0, 1). Total separation between the m = -1 and m = 1 maxima is $|y_{-1}| + |y_1|$. Divide this separation by 2 to get the average distance, $y_{1\ ave}$.

CD Diffraction Measurements

1. Without moving the breadboard stand, replace the diffraction grating with a blank CD (shiny side facing the wall). Adjust the LEDs to make the CD stand vertically on edge (see Fig. 8a). This way, light will reflect off the CD and onto the wall/screen. Each groove of the CD acts like a slit in a diffraction grating; the only difference is the light is reflected instead of transmitted.
2. Place the laser pointer between the CD and the wall and aim it at the CD. Elevate the laser to strike the CD on a side where the grooves are oriented vertically (see Fig. 8).
3. If the laser is not aimed exactly at the side of the disk, the maxima will be angled (one spot higher and the other lower). If that happens, just adjust the laser up/down along the side of the disk until the diffraction pattern levels out.

   Also, you can make the pattern more symmetrical by adjusting the laser until the central maxima (m = 0) hits the laser, or shines just above or to one side of it, before hitting the wall. This is why in Fig. 9 there is no central bright spot on the wall. It hit the laser instead of the wall.

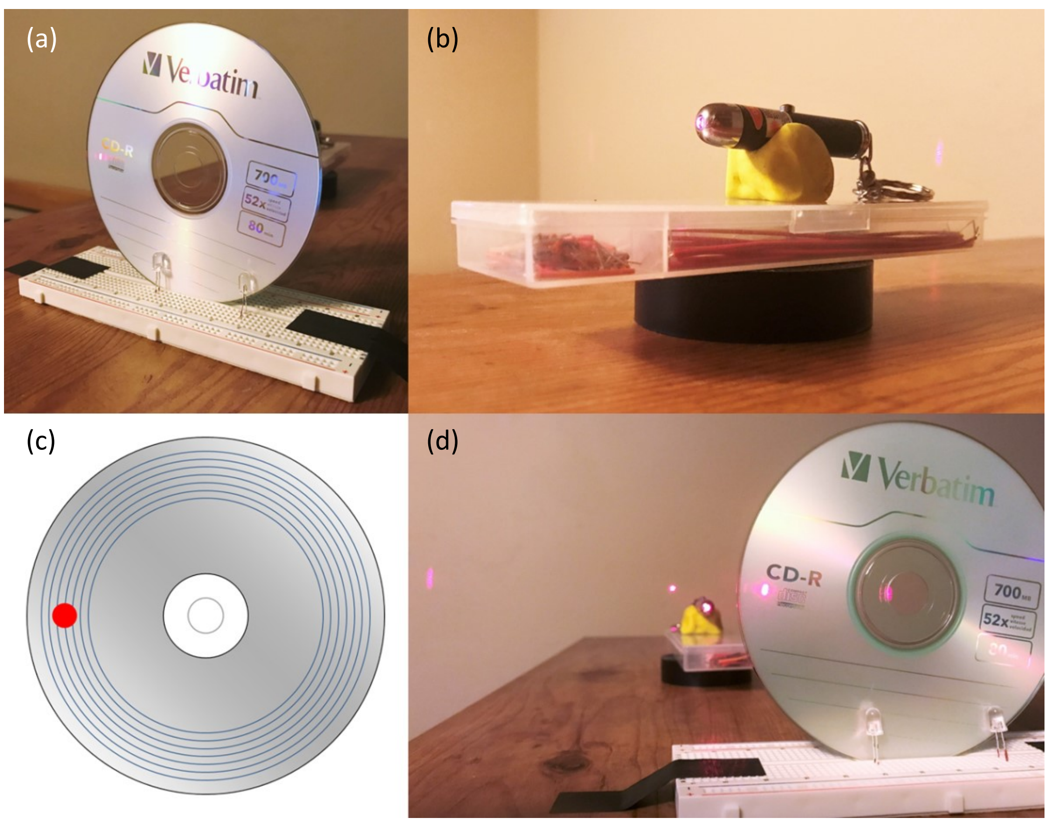
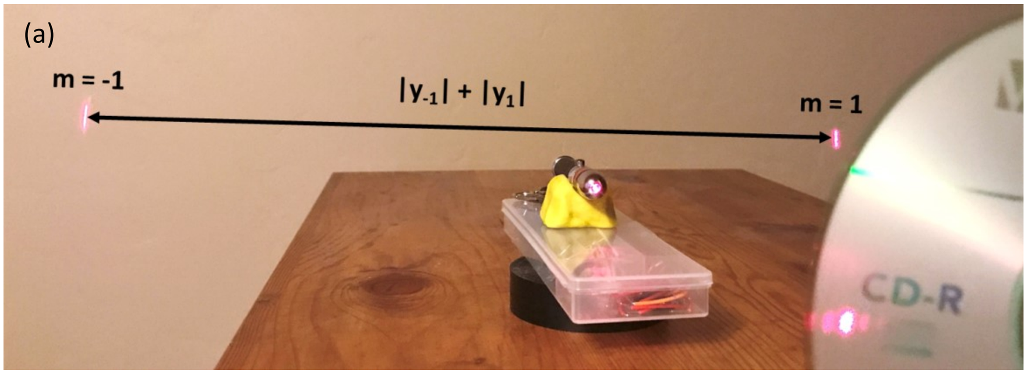


Fig. 8: (a) Replace the diffraction grating with a blank CD. (b) Elevate the laser pointer, (c, d) so that it will hit the CD on the side where the grooves are vertical.

4. Measure the distance, L, separating the CD and the wall/screen.
5. Again measure the total distance between the intensity maxima at m = ±1 and divide by 2 in order to get the average distance, $y_{1\ ave}$ (see Eq. 5).



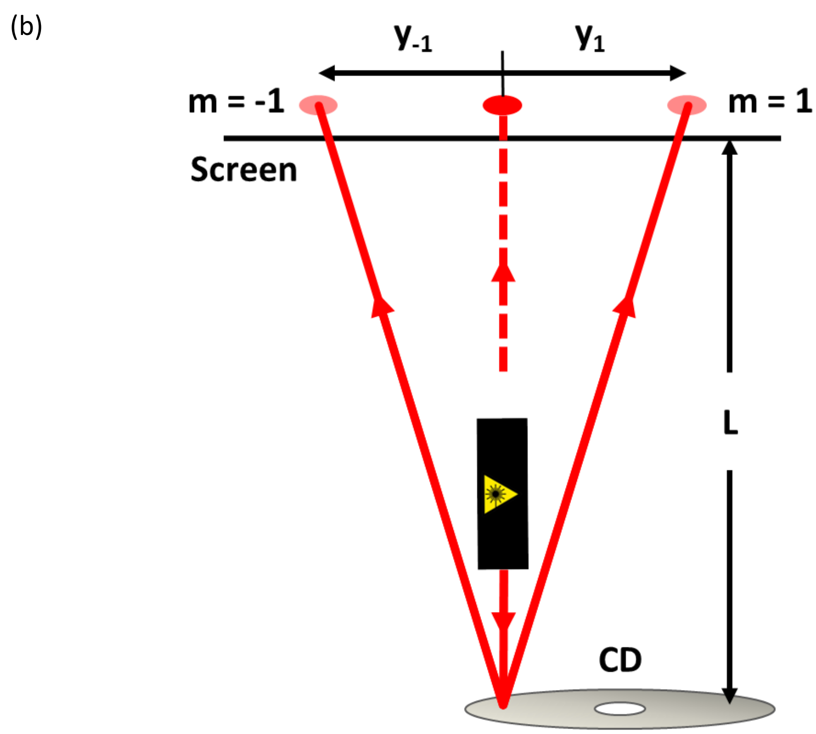


Fig. 9: CD diffraction pattern displayed with maxima (m = ±1). The central maxima (m = 0) is blocked by the laser. Total separation between the m = -1 and m = 1 maxima is $|y_{-1}| + |y_1|$. Divide this separation by 2 to get the average distance, $y_{1\ ave}$.

Analysis:

Diffraction Grating

1. Use Eq. (4) with $y_{1\,ave}$ and L to calculate θ_1 for the diffraction grating.
2. Use Eq. (1) to calculate the laser wavelength, λ_{meas}, recognizing that this is an estimated average over a range of wavelengths due to the bandwidth, $\Delta\lambda$, of the short coherence length from a short laser.
3. Use a percent difference to compare the measured wavelength, λ_{meas}, with the average of the wavelength values stated on your laser.

   Most lasers will list $\Delta\lambda$ = 630 nm - 680 nm, which yields λ_{ave} = 655 nm. However, some of the lasers may have a different wavelength range, so check the label on your laser pointer and use what it says. For example, some may be λ = 650 ± 10 nm. In that case, λ_{ave} = 650 nm.

   Don't forget to convert units from nanometers to meters.

$$\%Diff = \frac{|\lambda_{ave} - \lambda_{meas}|}{\lambda_{ave}} \times 100\%$$

CD Diffraction

1. Use Eq. (4) with $y_{1\,ave}$ and L to calculate θ_1 for the CD.
2. Use Eq. (1) with θ_1 and the wavelength, λ_{meas} (determined from the diffraction grating), to compute the distance, d_{CD}, between the CD grooves.
3. Look up the typical CD groove spacing, $d_{CD\,pred}$, at the following link:

   https://hypertextbook.com/facts/2001/InnaSokolyanskaya2.shtml

4. Use a percent difference to compare your measured groove spacing, d_{CD}, with the predicted value, $d_{CD\,pred}$.

$$\%Diff = \frac{|d_{CD\,pred} - d_{CD}|}{d_{CD\,pred}} \times 100\%$$