Study Guide and Review for Electricity and Light Lab Final

This study guide is provided to help you prepare for the lab final. The lab final consists of multiple-choice questions, usually two for each unit, and 4 work out problems that usually consist of multiple steps. The questions and problems will be taken from the pre-lab questions, some of the reading material from the lab theory section and from the work performed in the lab exercise. Sample questions and problems accompany this review. Answer to these questions and problems will be given at the end of this review.

Unit 15 – Introduction to Laboratory test Equipment
1. Know what a Digital Multimeter can measure and the proper way to read the displayed value.
2. Know how to use the meter to measure current and voltage.
3. On an oscilloscope, know what the horizontal and vertical divisions represent.
4. Be able to determine period, frequency, peak to peak voltage or RMS voltage of a signal if given a diagram of the signal or the number of divisions that were measured, along with the Time/div and Volts./div settings.
5. Know the relationship between period and frequency.

1 and 2

- The digital multimeter used in these labs is able to measure resistance in ohms, Direct Current, DC, voltages and currents, and Alternating Current, AC, voltages and currents.
- Voltage measurements are made with the probes of the multimeter in parallel or across the device or component; for example the voltage drop across a resistor.
- Current measurements are made with the multimeter in series with the device or component; for example the current through a resistor.
- Resistance measurements are measured across a component without the presence of voltage or current.

See Figure 15-1 in the manual to view the proper placement of the multimeter. The circled V and A represents the function the multimeter is set to measure.

- Each function, voltage, current or resistance, has different ranges that are selectable. The value for each range represents the maximum it can read before it registers and overload condition.
- The range values usually have some sort of multiplier, m or k, which respectfully represents $10^{-3}$ or $10^{3}$. The value displayed would be multiplied by the multiplier to get the reading into the standard units for the measured value. The standard units for voltage is volts, V, current is amps, A, and resistance is ohms, $\Omega$.

While the digital multimeter is capable of reliable DC voltages and resistance measurements, it is limited in its ability to measure AC voltages. This limitation is that it is designed to measure only sinusoidal waveforms and up to a frequency of a few thousand hertz.
While the inner workings of the Oscilloscope might be useful knowledge, it is not required to operate the oscilloscope.

The display of the oscilloscope has both a horizontal and vertical scale.

- The Time/Div knob controls the horizontal scale sensitivity and is used when making time based measurements of a waveform. The period of a waveform is a typical measurement made with an oscilloscope. This is accomplished by measuring the number of divisions along the horizontal axis and then multiplying it by the Time/Div setting.
- The Volts/Div knob controls the vertical scale sensitivity and is used to make voltage measurements of the waveform such as its peak to peak voltage or amplitude.
  Frequency has units of Hertz (Hz) and is the inverse of the period of the waveform.

**Uses for an Oscilloscope**

An oscilloscope is mainly used to measure time dependent voltage waveforms. When the period, which is the time between reoccurring events, of a waveform occur at rates of 100, 1000, 10000, etc. times a second, the oscilloscope makes measuring the period a simple task. The oscilloscope can also be used to measure both DC and AC voltages. While it is generally more cumbersome in size to a Digital Multimeter it can accurately measure AC voltages that are non-sinusoidal in nature.

The picture to the right is a typical oscilloscope display. This one is separated into 10 major horizontal divisions and 8 major vertical divisions. The center lines are further separated into fifths of a division.

The waveforms shown have amplitude of 4 vertical divisions and a period of 5.6 horizontal divisions.

If the Volts/div knob is set to 0.2 V and the Time/div knob is set to 50 µs then the measured peak to peak voltage is 0.2V * 4 = 0.8V and the measured period is 5.6 * 50 µs = 280 µs.

The frequency of the waveform is 1/period and has units of Hertz (Hz).

The root mean square voltage (RMS) of the waveform which is the voltage one would use in calculations using formulas such as ohms law is the peak to peak voltage / $2\sqrt{2}$

Therefore for the above waveform

- frequency = $1/280\times10^{-6}$s = 3570 Hz
- $V_{rms} = 0.8V / 2\sqrt{2} = 0.283$ V
Unit 16 – Electric Fields

1. Be familiar with Faraday’s concepts for lines of force.
2. Be familiar with how to draw a diagram to represents field strength for a uniform electric field in a region for x times E.
3. Know what equipotential lines are and their relation to electric field lines.
4. If given a diagram of field lines with various points labeled, be able to calculate the field strength in the area of the points and determine which has the strongest and weakest field strength.
5. Know how much work is required to move a charge along an equipotential line or surface and from one equipotential line to another.
6. Know what the electric field strength should be within a hollow conductor.

1 and 2
To aid in visualizing electric field lines Faraday developed concepts for the lines of force. In this lab we concentrated on a few of these concepts.

- The lines of force originate on positive charges and terminate on negative charges.
  This was indicated by drawing arrows on the electric field lines directed towards the negative surface.
- The density of the lines of force in a region or space is used to represent the electric field strength in that region of space.

The diagrams represents different field strengths.
If the two field lines in (a) represents a strength of 1E, then the eight field lines in (b) represents a larger field strength of 2E.

- Lines of force will not cross over or touch one another.

3
In this lab exercise points of the same voltage potential were measured and marked, a line was then drawn connecting these points thus constructing an equipotential line. A number of these lines were constructed for each of the two initial configurations. Electric field lines were drawn such that the field line is perpendicular to the equipotential line and they originated on the most positive equipotential line or surface and terminated on the least positive line or surface.

4
Field lines at a sharp point such as a tip will be more concentrated than the field lines along a flat surface. The strongest electric field for the figure shown to the right would be at the tip of the triangle. Where the field lines are uniform the field would likely be of an intermediate strength. As the field lines extend further away from the triangle and rectangle the field strength would weaken.

In this experiment the electric field was determined using equipotential lines and the distance between them so that \( E = \Delta V / \Delta x \).

5
It requires no expenditure of work to move a charge along an equipotential line, however to move a charge from one equipotential line to another requires work to be performed on the charge. The amount of work expended is \( W = qE\Delta d \).

6
A hollow conductor placed within a region where there is an electric field will have no electric field within the conductor itself. There would be a potential upon its surface that will be at the same potential along the surface. A charge will follow a path that requires the least work, traveling along the conductive surface and not through the hollow region, therefore within the hollow region of the conductor the electric field is zero, \( E = 0 \).
Unit 17 – Capacitance

1. Know what a unit of capacitance is called and where it is derived from.
2. Know what the area under a graph of current vs. time represents.
3. Be able to determine an equivalent capacitance for capacitors connected in series or parallel or a combination of the two.
4. If given a circuit, and a set of capacitors be able to determine a minimum and maximum value for the circuit.

1 & 2

A capacitor is a device made up of two or more isolated conductors called plates. When placing a potential across the capacitor plates, an equal but opposite charge is distributed upon the plates. Then removing the voltage, the capacitor will retain the charge. Capacitance is the ability to store a charge, and hence electrical potential energy.

Capacitance has units of coulombs / volts more commonly called the Farad, F. The charge stored on a capacitor is determined by \( Q = CV \) where \( C \) is the capacitance in Farads. Then plotting charge vs. the applied voltage, the slope of a linear line will yield capacitance.

In this lab, you determined the charge on a capacitor by discharging it through a resistor. The area under a graph of current vs. time gave you the charge in units of Amps seconds, A·s.

3. Capacitors in Series or Parallel

When capacitors are connected in series or parallel the can be reduced to a single equivalent capacitance. In the table below the equations to determine the equivalent capacitance are reviewed.

<table>
<thead>
<tr>
<th>Series</th>
<th>Parallel</th>
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<tbody>
<tr>
<td><img src="image" alt="Series Capacitors" /></td>
<td><img src="image" alt="Parallel Capacitors" /></td>
</tr>
</tbody>
</table>

The equivalent capacitance, \( C_{eqv} \), for capacitors in series is:

\[
\frac{1}{C_{eqv}} = \frac{1}{C_A} + \frac{1}{C_B} + \frac{1}{C_C}
\]

Note: For capacitors in series \( C_{eqv} \) will be smaller than the smallest capacitor value.

The equivalent capacitance, \( C_{eqv} \), for capacitors in parallel is:

\[
C_{eqv} = C_A + C_B + C_C
\]

4. Network of capacitors

In this unit you were asked to determine the minimum and maximum capacitance for a network circuit of capacitors.

The circuit to the left contains two capacitors in parallel, in series with another capacitor.

The equation for this circuit would be \( 1/C_{eqv} = 1/(C_A + C_B) + 1/C_C \)

If the three capacitors are given three unique values, let's call them 1, 2, and 3, They can be substituted for \( A=1, B=2 \) and \( C=3 \) to determine a equivalent capacitance value for the circuit. Then the capacitors can be rearranged \( A=1, B=3 \) and \( C=3 \) to find another capacitance value for the circuit. Lastly using \( A=2, B=3 \) and \( C=1 \) forms yet another combination for a capacitance value. From these three values a minimum and maximum value can be determined.
Unit 18 – DC Circuits

combination of the two.
1. Be able to determine equivalent resistance for resistors connected in series or parallel or some
2. Know Kirchoff’s Current and voltage rules.
3. Know the difference between a short and an open.
4. Be able to solve for three unknown currents in a circuit similar to the one used in the lab.
5. You could be given the information for a circuit operating normally and then the information of
   the same circuit with a fault. Be able to determine the fault and calculate the new expected
currents.

1 Resistors in Series and Parallel

<table>
<thead>
<tr>
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<th>Resistors in Parallel</th>
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<tbody>
<tr>
<td>To the left is a circuit of resistors in series. The 3 resistors can be replaced by a single equivalent resistor equal to</td>
<td>To the right is a circuit of resistors connected in parallel. The three resistors can be replaced by a single equivalent resistor equal to</td>
</tr>
<tr>
<td>$R_{equiv} = R_1 + R_2 + R_3$</td>
<td>$\frac{1}{R_{equiv}} = \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$</td>
</tr>
</tbody>
</table>

2 Kirchhoff’s Rules

**Kirchhoff’s 1st Rule; Current rule:**
The diagram to the right illustrates Kirchhoff’s 1st rule.
The algebraic sum of the currents entering a junction is equal to the algebraic sum of the currents leaving the junction.
Plainly speaking currents $I_1$ and $I_2$ enters a junction and passes through $R_3$ to become the current $I_3$, which is equal to $I_1 + I_2$. As the current $I_3$ leaves the junction to return to the batteries it becomes $I_1$ and $I_2$.

**Kirchhoff’s 2nd Rule; Voltage Rule:**
The diagram to the left illustrates Kirchhoff’s 2nd rule.
The algebraic sum of the change in potential encountered in a complete transversal of a loop in a circuit must be zero.
Plainly speaking and using the diagram you first start with a potential $V_1$ and as the current passes through the first resistor $R_1$, there is a voltage drop equal to $R_1I_1$ next the current through the resistor $R_3$ creates a voltage drop $R_3I_3$ Summing the voltages in this loop yields $V_1 - R_1I_1 - R_3I_3 = 0$.
The same method can be used for the second loop which yields the equation $V_2 - R_2I_2 - R_3I_3 = 0$
4 A sample solution
By combining the equations from rule 1 and 2 and given the voltages and resistances, the currents can be theoretically determined using simultaneous equations. A sample will be shown for $V_1 = V_2 = 5$ Volts. $R_1 = 500$ ohms, $R_2 = 250$ ohms, and $R_3 = 75$ ohms.

Since the two equations in rule 2 are equal to zero you can set them equal to one another. Then eliminate algebraically the common values and then solve for $I_1$ or $I_2$ in terms of the other.

Now in the current rule equation replace $I_2$ with the recently determine value of it in terms of $I_1$.

Now in the voltage rule equation which contains $I_1$ and $I_3$. Replace $I_3$ with the value determined for it in terms of $I_1$.And then solve for $I_1$.

Last solve for $I_2$ and $I_3$

$$5 - 500I_1 - 75I_3 = 0$$
$$5 - 250I_2 - 75I_3 = 0$$
$$I_1 + I_2 = I_3$$

$$5 - 500I_1 - 75I_3 = 5 - 250I_2 - 75I_3$$
$$500I_1 = 250I_2$$
$$I_1 + 2I_1 = I_3$$
$$3I_1 = I_3$$

$$I_1 = 6.90\, \text{ma}$$
$$I_2 = 13.8\, \text{ma}$$
$$I_3 = 20.7\, \text{ma}$$

3 Analyzing Shorts and Opens in DC Circuits
A component, that is shorted, has a resistance of zero ohms. A component, that is open, has a resistance of infinity.

How Shorts and Opens affect a series circuit
In the circuit to the left under normal operation has an equivalent resistance of 300 ohms. If a single resistor shorts, it will cause the equivalent resistance to drop to 200 ohms. If the resistor opens, it will cause the equivalent resistance to increase to infinity ohms.

How Shorts and Opens affect a parallel circuit
In the circuit to the right under normal operation has an equivalent resistance of 33.3 ohms. If a single resistor opens it will cause the equivalent resistance to increase to 50 ohms. If a resistor shorts, it will cause the equivalent resistance to drop to 0 ohms.
Unit 19 – Potentiometer

1. Know what emf and terminal voltage are and how they relate to each other.
2. Be able to determine the emf or terminal voltage of an unknown cell if given a standard cell emf and the unit length of a potentiometer settings for \(L_{sta}\) and \(L_{unk}\).
3. Be able to determine from a set of voltmeters which one draws the least or most current or which one has the least or most internal resistance when given their measured value of the terminal voltage of an emf source.
4. If given a graph of \(V_T\) vs. \(R_L\) be able to determine the internal resistance of a cell.
5. If given a graph of \(V_T\) vs. \(I\) be able to determine the internal resistance of a cell

1 EMF source and Terminal voltage

A source of Electromotive force is a device that has an intrinsic ability to do work electrically. A cell, a battery (a series of cells), and a generator are examples of emf sources. Any source of emf has an internal resistance. Schematically it is illustrated in the diagram to the right. The terminal voltage \(V_T\) is measured between the points A and B. The terminal voltage will change depending on the amount of current drawn from the emf source in accordance with the equation

\[
V_T = E - Ir
\]

In order to measure the true voltage potential of the emf source it must be done such that no current is drawn from the source. A potentiometer is a device that can accomplish this task. Basically a potentiometer is a length of resistive wire that has a wiper that can be adjusted along its length. A variable voltage potential is connected across the length of the wire; a galvanometer is connected to the wiper and the emf source is connected to the other end of the galvanometer. As a starting reference position, the wiper is set to an arbitrary length, in the experiment this length was between 0 and 100 and shown on an indicator. The galvanometer measures the current following into or drawn from the emf source by varying the voltage source across the length of the wire a null can be obtain on the galvanometer at this point no current is being drawn from the emf source. Replacing the emf source with a standard source that has a known potential value, \(E_{sta}\), and then adjusting the wiper to obtain a null on the galvanometer a length value can be obtained and lets call it \(L_{sta}\). The ratio of the lengths should equal the ratio of the potentials such that.

\[
\frac{L_{sta}}{L_{unk}} = \frac{E_{sta}}{E_{unk}}
\]

solving for \(E_{unk}\)

\[
E_{unk} = \frac{E_{sta} \times L_{unk}}{L_{sta}}
\]

Load resistance placed across the emf source draws current from the source therefore changing the terminal voltage of the emf source. The terminal voltage, \(V_T\), can be determined using the same equation as shown above by replacing \(E_{unk}\) with \(V_T\). The internal resistance of the cell can be determined using two methods which is discussed in the upcoming sections.
Voltmeters are used to measure voltage potential and all voltmeters have some internal resistance within them, thus they will draw current from the cell. The higher the internal resistance of the voltmeter the lower the current would be that is drawn from the cell. The following equations should give some insight into the relationship, let $R$ be the internal resistance of the voltmeter, $r$ the internal resistance of the emf source, $E$, then

$$I = \frac{E}{R + r}$$ and $$V_T = E - Ir$$

$E$ and $r$ are fixed values; the value of $R$ affects the current $I$ drawn from the emf source, which affects the terminal voltage $V_T$.

**4 Determining internal resistance from $V_T$ vs $R_L$ for an EMF cell**

The picture to the left shows a typical graph of terminal voltage, $V_T$ vs. load resistance, $R_L$ for an EMF cell. The internal resistance of the cell can be determined from the graph. The load resistance $R_L$ is equal to the internal resistance of the cell when $V_T = E/2$. By drawing a horizontal line from the y-axis at $E/2$ to the plotted line and then drawing a vertical line down to the x-axis the value where the vertical line passes through the x-axis is the internal resistance of the cell.

**5 Determining internal resistance from $V_T$ vs $I$ for an EMF cell**

The picture to the right shows a graph of terminal voltage $V_T$ vs. load current in ma. The line through the data points obeys the equation $V_T = E - Ir$. With the slope of the line being the internal resistance and the y-intercept is the true emf of the cell.
Unit 20 – Response of Passive Network Elements

1. Know how capacitive reactance, resistance and inductive impedance react as frequency increases.
2. Be able to determine capacitance or inductance if given $X_C$ or $Z_L$ at a certain frequency.
3. If given a diagram of an oscilloscope with two sinusoidal waveforms, be able to determine the phase angle between them. Part B
4. Be familiar with the phase relationship of current and voltage in a capacitor and an inductor.
5. Be able to calculate the time constant for a RC and RL circuit. You could be asked to determine it from a diagram from an oscilloscope.

Passive Network Elements

A passive network element absorbs electrical energy. There are three types of passive elements, resistors, inductors and capacitors.

Response to AC Voltage

An AC voltage is a voltage that varies over time. The most common type of AC voltage is the sinusoidal waveform (sine wave). For a resistor regardless if the voltage is DC or AC there is a direct proportion to the voltage across it and the current through it.

However, for a capacitor or an inductor the frequency of the voltage source plays a significant factor. Both the inductor and capacitor has a reactance to the AC voltage. Reactance is akin to resistance and has units of ohms.

Reactance is frequency dependent. For a capacitor, the capacitive reactance is

$$X_C = \frac{1}{2\pi f C}$$

Where C is the capacitance in Farads and f is the frequency of the voltage source in Hertz.

For an inductor the inductive reactance $X_L$ is calculated by:

$$X_L = 2\pi f L$$

Where and L is the inductance of the inductor in units of Henries, H.

Furthermore for the inductor the DC resistance of the wire which make up the inductor must be taken into consideration. When the DC resistance is combined with the reactance of the inductor, the effect it has on the voltage source is called impedance, $Z$. The impedance for an inductor $Z_L$ is calculated from the equation

$$Z_L = \sqrt{R_L^2 + X_L^2}$$

The graph shows how the reactance, impedance and resistance of each passive element respond to frequency.

The resistance of the pure resistor remains constant over frequency.

The impedance of the inductor is linearly proportional to the frequency.

The reactance of the capacitor is inversely proportional to the frequency.
3 Current and Voltage Phase relationship

The picture to the left will be used to represent the voltage and current through an inductor and a capacitor. The voltage and current will be denoted by the color of the waveform and will be different for the inductor and capacitor.

**Phase relationship of Voltage and Current for an inductor**

For an inductor the voltage is the red waveform and the current is the blue waveform. For an oscilloscope, time begins at zero on the left side of the picture and increases in time as the trace moves to the right. Therefore, from the picture the voltage comes before the current, hence the voltage leads the current in an inductor.

In the picture the capital N represents the number of divisions for a complete cycle of the waveform. Let's assign N as 3.2 divisions. Since there is 360° in a cycle each division is worth 360°/N = 360°/3.2 = 112.5°. The lower case n represents the phase angle between the current and the voltage and let's assign 0.8 divisions to n. By multiplying n by 112.5° there will be a 90° angle between the voltage and the current.

**Phase relationship of Voltage and Current for a capacitor**

For a capacitor, the voltage is the blue waveform and the current is the red waveform. In a capacitor the voltage lags the current.

**RL and RC time constants**

When a step wave such as a square-wave is applied across an inductor and a resistor, it takes a certain amount of time before the current rises or falls to its maximum or minimum levels. Generally, it takes about 5 time constants, τ. A time constant is the time it takes to rise from the zero or maximum current to 63% of the maximum or minimum current level. This is true for a resistor combined with either an inductor or a capacitor.

From the picture, the time constant for an RL circuit can be measured. First by counting the total number of vertical divisions the signal rises to, N. Then calculate 0.63N, and count up this number of divisions. From this point the number of horizontal divisions can be counted to the start of the signal, this yield n. Multiply n by the Time/Div setting will give the time constant τ.

In the picture to the left N = 6. Therefore 0.63N = 3.78 or 3.8. From the start of the trace to 3.8 division n=2 divisions. If the Time/Div knob is set to 5µs then the time constant τ = 10µs

For an inductor and resistor the time constant, τ can be theoretical determined by τ = L/R. Where L is the inductance in Henries and R is the total resistance in the circuit. In the case of our experiment, R consisted of R_L + R_S + R_generator.

In this case, a RC time constant is shown and the time constant τ being measured is the time it takes to fall from the maximum. Again, the total number of divisions for the signal is 6. However, either you can count from the top down 0.63N or count from the bottom up 0.37N, at this point the number of horizontal divisions to the start of the signal (where it begins to fall) is n. Then multiplying n by the Time/Div knob setting will yield the time constant τ.

From the picture n = 2.1 and if the Time/Div is set to 50µs then the
time constant \( \tau = 105 \mu s \).
The theoretical value of \( \tau = RC \). Where \( C \) is the value of capacitance in Farads and \( R \) is the total resistance in the circuit. In the scope of our experiment \( R = R_s + R_{\text{generator}} \). Note since there is no inductor you do not use \( R_L \).

**Unit 21 – AC Circuits**
1. Know how to calculate the resonant frequency and/or manipulate the equation to determine either inductance or capacitance.
2. Be able to determine the impedance of a RLC circuit at a given frequency.
3. Be able to determine the phase angle of a RLC circuit between current and voltage and whether the current leads, is in phase with, or lags the voltage.
4. Know why the impedance of a circuit is unique at resonance.

**Resonance and Impedance for a RLC AC Circuit**
A RLC circuit is a circuit which contains a resistor, inductor and a capacitor. The reactance for the capacitor and inductor is a function of the frequency of the voltage source as discussed in unit 20. There is a frequency where the inductive reactance is equal to the capacitive reactance. This frequency is called **resonance** and can be theoretically determined from the equation

\[
\omega_0 = \frac{1}{\sqrt{LC}}
\]

Impedance for an AC circuit is determined from the total resistance and reactance in the circuit where the impedance \( Z \) is equal to

\[
Z = \sqrt{(R + R_L)^2 + (X_L - X_C)^2}.
\]

From this equation, at resonance when \( X_L \) is equal to \( X_C \) the impedance of the circuit can be assumed to be purely resistive \( Z = R_L + R \), and if it is purely resistive then the current and voltage will be in phase with one another, which is also what defines an AC circuit at resonance.

**Voltage and Current phase relationship in a RLC circuit**
The phase relationship between current and voltage in a RLC circuit is dependent on the frequency of the voltage source, which affects the reactance of the inductor and capacitor. The phase angle can be calculated by the equation

\[
\phi = \tan^{-1}\left(\frac{X_L - X_C}{R_{\text{net}}}ight)
\]

Where \( R_{\text{net}} \) is the total resistance in the circuit.

When the frequency is less than the resonant frequency then \( X_L < X_C \). The phase angle \( \phi < 0 \) and the circuit is more capacitive therefore the current leads the voltage by the calculated phase angle.

At resonance the current and voltage are in phase, \( \phi = 0 \) and \( X_L = X_C \).

At frequencies greater than resonance \( X_L > X_C \) and \( \phi > 0 \). The circuit is more inductive and the current will lag the voltage by the calculated phase angle.
Unit 22 – Reflection and Refraction

1. Understand Law of reflection and Law of Refraction
2. Be able to determine the foci or radius of curvature for a curved mirror
3. Be able to determine the index of refraction
4. Know when to use critical angle equation and what the critical angle represents.
5. Be able to determine the index of refraction for different wavelengths of light as it passes through a prism. Also, be able to determine the velocity of the light through the prism.

Reflection

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<thead>
<tr>
<th>Flat surface</th>
<th>Concave surface</th>
<th>Convex surface</th>
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**Single incident ray reflection**
Above three reflective surfaces is represented. The normal indicated by the white dashed line is always perpendicular to the surface at the "point of impact" of the ray of light. If the incident light ray makes an angle \( \theta_i \) from the normal then the reflected ray is reflected at \( \theta_r \) from the normal where \( \theta_i = \theta_r \) and \( \theta_i, \theta_r \) are coplanar
This is the Law of Reflection

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**Multiple incident rays reflection**
In the pictures above the light is traveling parallel to the principle axis and is incident onto a spherical surface. The light will obey the law of reflection and each incident beam will be reflected from that surface. In the case of a concave surface the light will reflect through a focal point. For a convex surface the light will reflect away from a focal point that is extended into the surface.
The focal point is equal to 1/2 the radius of curvature of the spherical surface \( f = R/2 \)
**Index of Refraction**

The term index of refraction, $n$, is the ratio of the speed of a wave, such as light, in a vacuum, $c$, divided by the speed of the wave in another medium, $v$. For light $n = \frac{c}{v}$.

The term medium is any material which will allow the wave to pass through it, for light examples are glass, water, and air. Air and a vacuum both have an index of refraction of $n=1.00$. The velocity of a light wave through other mediums is less than that of the same light wave through a vacuum. Therefore, the index of refraction for mediums other than a vacuum is always greater than one $n > 1$.

**Refraction**

The first frame of the animation illustrates a ray of light traveling from one medium to another. When the light travels from a less dense medium to a denser medium at an angle $\theta_1$ from the normal (indicated by the dashed line), that ray will refract towards the normal inside the denser medium at an angle $\theta_2$. There is a direct relation to this phenomenon and it is called the Law of Refraction. The law of refraction obeys two rules:

1. $\theta_1$ and $\theta_2$ are coplanar and
2. $n_1 \sin \theta_1 = n_2 \sin \theta_2$

The second frame illustrates a ray of light traveling along the principle axis, it will pass through the piece of optics undeviated.

The third frame illustrates that when the ray of light is incident unto the curved surface at a normal to the surface it will pass through to the next medium without any deviation.

**Critical Angle**

At any interface for a dense medium to less dense medium there is an angle of incidence from the normal in which the ray of light will not pass through but instead travel along the surface of this interface. This angle is referred to as the critical angle.

The equation to determine the critical angle is $\theta_c = \sin^{-1} \left( \frac{n_2}{n_1} \right)$ and when $n_2$ is air or a vacuum then $\theta_c = \sin^{-1} \left( \frac{1}{n_1} \right)$

**Through a prism**

White light contains all the visible wavelengths of light, violet through red. As white light passes though a prism at an angle $\theta_i$ from the normal, the different wavelength will refract at different angles $\theta_r$ from the normal. From the laws of refraction this gives each wavelength a unique index of refraction in the material. Since $n = \frac{c}{v}$ the velocity of each wavelength is also unique. The velocity of a wave be it sound or light is equal to its frequency times its wavelength $v = f \lambda$. The frequency of the wave remains unchanged in the material therefore the wavelength must decrease in order for the equation to be true.
Through lenses

The diagram to the left shows a convex lens also known as a converging lens. When the light enters the lens parallel to the principle axis, indicated by the dashed line, it will refract towards the normal. Upon exiting the lens, the light will refract away from the normal and pass through the focal point of the lens, f.p., which lies along the principle axis.

The concave lens, also called the diverging lens is depicted in the diagram to the right. When the light enters the lens parallel to the principle axis, the light bends towards the normal inside the lens and then away from the normal as it leaves the lens. As the light leaves the lens it appears to be traveling along a line, which passes through the focal point of the lens on the opposite side from which it is exiting.
Unit 23 – Diffraction and interference

1. Know what diffraction and interference of light is. Know that the dark regions are where light is deconstructive and the bright regions are where light is constructive.

2. Know how to determine the slit width for a narrow slit aperture.

3. Know how to determine the slit spacing for 2 or multi slit apertures.

4. You could be given a picture that represents a diffraction or interference pattern like the one shown on page 126. Then asked to determine the slit width and slit spacing.

5. Be familiar with how to determine wavelength using the transmission grating.

Diffraction

Geometric optics, where light travels in straight lines, does not predict diffraction. Diffraction occurs because light is wavelike in nature. When light encounters a opaque barrier with a opening that is not too large relative to its wavelength it will bend around the opening to illuminate the area beyond the opening as if the opening was a source of light. This bending of light, or flaring, is called **diffraction**. If a monochromatic beam of light encounters an opening, a narrow slit, as described above a pattern is formed beyond the opening. This pattern will have a central bright band with alternating dark and bright bands on either side as shown in the figure below. This pattern is called a Fraunhofer diffraction pattern.

![Diffraction Pattern](image)

The distance from the peak of the central bright band to the first order dark band is indicated on the diagram by the letter x. This first dark band away from the central peak is the called the first order. Each subsequent dark band would be incremented up and named the 2nd order, 3rd order etc. There is a mathematical relationship between the variables involved in producing the diffraction pattern.

\[
x / D = (m\lambda) / a
\]

Where

- D is the distance from the slit to where the pattern is formed.
- x is the distance from the central peak to which ever dark band being used.
- m is the order (1, 2, 3) of the dark band being used.
- \( \lambda \) is the wavelength of the light source
- a is the slit width

D, x, a, and \( \lambda \) are in meters

In this lab the slit width, a, was determined from the given and measured variables.

If all the variables D, and \( \lambda \), were kept constant and the slit width was decreased the pattern would change from narrow sharp images with the orders close to the center peak to a pattern with wide diffused images with the orders further away from the center peak.
**Interference**

Interference from two slits

When light encounters an opaque barrier with two narrow slits that are close together each slit acts as a related light source. Each slit diffracts the light and at a distance away from the slits the pattern formed is a combination of the diffraction pattern created by each slit. When the two patterns combine and are in phase with one another they combine to create a bright region and this is called **constructive interference**. When the combine and are out of phase with one another they create a dark region which is called **destructive interference**. The mathematical relationship for the interference of light is

$$ \frac{m\lambda}{d} = \frac{y}{\sqrt{D^2 + y^2}} $$

Where D is the distance from the slits to the pattern, d is the separation between the slits, y is the distance between the central peak and each ordered peak and m is the order (i.e. 1st peak is 1, 2nd peak is 2 etc). The picture show a 1st order m=1 peak.

A wide spacing between slits can produce a pattern of sharp narrow bright spots separated by narrow dark regions. As the slit spacing decreases the number of bright spots decrease and they also become larger in size. The dark regions becomes larger as well.

**Interference from Multiple Slits**

The interference pattern form by increasing the number of slits while keeping the slit width and spacing between slits constant, changes such that the peaks become sharper and the dark regions more distinct. However the spacing between the center peak and its nth order peaks remain the same. With more slits a pattern within a pattern can be more easily observed. The picture below illustrates this.

The narrow peaks of the interference pattern created by the spacing between the slits lies under the wider pattern of a diffraction pattern that would be created by a single slit. Both the slit width and the slit spacing can be determine from this pattern when the proper measurements are made.

**REMININDER** To determine slit width measurements are made from the central blue peak to the blue valleys.

To determine spacing between slits the measurements are made from the central red peak to the next red peak which lies within the same blue peak.

Lastly a transmission grating is simple a multiple slit whose slit spacing is very narrow in relationship to the wavelength of the light source. The double slits used in this first part of the lab were on the order of 4 per mm while the transmission grating were on the order of 600 per mm. The pattern formed by a transmission grating will be a bright, sharp central peak with one and maybe two bright, sharp peaks to either side with distinctive dark regions.