INTERFERENCE AND DIFFRACTION OF LIGHT

STEP-UP PROGRAM SUMMER 2013

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Problem:
What are the principles behind the interference and diffraction of light? What are examples of these interactions and how can they be used beneficially?

Abstract:
The duality of light waves can sometimes be a difficult concept for high school level students to understand. To help demonstrate this dual personality the photoelectric effect often is used to show light acting as a particle (photons) and interference and diffraction can depict light’s wave nature. However, at a high school level these principles can be difficult to apply and describe in the classroom. This lesson plan focuses on the wave nature of light and utilizes real-world examples and straightforward activities to explain the complexities of interference patterns and the diffraction of electromagnetic waves.

Objectives:
1) Identify in which interference and diffraction will occur.
2) Describe how electromagnetic waves interfere with one another to create bright and dark fringes.
3) Solve problems using constructive and destructive interference equations.
4) Describe how electromagnetic waves diffract (bend) around objects and create bright and dark fringes.
5) Predict the locations of bright and dark fringes caused by diffraction using the diffraction equation.
6) Describe how diffraction is related to an optical instrument’s resolution.
7) Recognize real-world applications of interference and diffraction of light.
8) Describe the properties of lasers and their applications.

Anticipated Learner Outcomes:
After the completion of this unit the student should be able to:

1) Describe the conditions for the interference and diffraction of light to occur.
2) Explain the principles behind interference and diffraction of light mathematically and conceptually.
3) Describe the superposition of light waves and how interference patterns are produced.
4) Solve for the path difference, wavelength and angle for constructive and destructive interference.
5) Relate the equations \( \text{dsin}\theta_{\text{calc.}} = m\lambda \), and \( y = L\tan\theta_{\text{obs.}} \) to solve for the path angle of a diffraction grating.
6) Describe how interference and diffraction of light is used in modern research and technology.
7) Describe how lasers work and how they are used in real-world applications.

**Materials and Supplies:** (These are only suggested supplies; most demonstrations can be found in video form if needed)

1) Red laser pointers (one per group)
2) Green laser pointer (just for demonstration purposes)
3) Diffraction gratings with different grating sizes (I used 100 lines/mm, 300 lines/mm, 530 lines/mm, and 600 lines/mm, but as many and as varied of sizes that are available can be substituted) (one per group)
4) CD/DVD’s without the aluminum coating and cut in pieces about 3 cm x 3 cm in size. Refer to teacher’s answer key for the lab to demonstrate the easiest way to do this. (one per group)
5) Ring stands and clamps (one per group)
6) Rulers and Meter sticks (one per group)
7) Spectroscopes or diffraction gratings
8) Various light sources (LEDs, incandescent, fluorescent, halogen, sunlight, etc.)
9) Emission tube box and various emission tubes (hydrogen, helium, argon, neon, etc.)

**Plan:** (This plan is designed for nine days* with 50 minute periods but can be adapted for any schedule)

Sections of the lesson plan (especially the PowerPoints) can be added on to, deleted or modified to meet curriculum needs or time restraints. Everything in bold is either included in this document or is in a separate heading that should be included. Note about PowerPoints: I usually print out the PowerPoints as notes for my students (that is why they are wordy) and then have them highlight certain points and write extra notes. They can be edited to meet your note-taking teaching style.

**Day 1:**

1) Introduction to Interference. Refer back to sound waves and beats.
2) Begin the PowerPoint Presentation on **Interference**. Point out to students that different people use different language when speaking of the same thing. For example bright fringes can also be referred to as maxima or maximum, dark fringes are sometimes called minimum fringes and the central bright fringe is sometimes thought of as the zero-order bright fringe. Also point out that with dark fringes the order number is one less than described because it is a half-step. For example: the first dark fringe is in between the central bright fringe \( (m = 0) \) and the first bright fringe \( (m = 1) \) so the \( 1^{\text{st}} \) dark fringe \( (m + \frac{1}{2}) \) is \( (0 + \frac{1}{2}) \). This idea can be confusing for the students and should be emphasized.
3) Remind the students about the diffraction of waves (water waves around an island, sound waves around an open door, etc.).
4) Demonstrate diffraction grating and red and green laser; see **Interference and Diffraction Demonstrations**
1) Begin the PowerPoint Presentation **Diffraction**. With spectrosopes point out how useful a tool they are and even though the ones that are used in the classroom involve visible light there are many spectrometers that use other portions of the electromagnetic spectrum.

2) If time permits pass out **Introduction to the Interference and Diffraction of Light Worksheet**.

3) These questions can be done as a class, in groups, or individually. They can be reviewed by the teacher or students can direct the discussion. This can be given as homework or in class.

### Day 3:

1) Complete or review **Introduction to the Interference and Diffraction of Light Worksheet**
2) Demonstrate examples of Interference and Diffraction problems; see **Interference and Diffraction Demonstrations**
3) If time permits pass out **Interference and Diffraction Problems**.
4) These problems can be done as a class, in groups, or individually. They can be reviewed by the teacher or students can put the answers on the board. This can be given as homework or in class.

### Day 4:

1) Complete the Worksheet: **Interference and Diffraction Problems**.

### Day 5:

1) Review and Explain Procedures of the **Diffraction Grating Lab**.
2) Time remaining may be devoted to or unit projects.

### Day 6:

1) Review and Explain Procedures of spectroscopy; see **Interference and Diffraction Demonstrations**. A spectroscope lab can be done here, but most students should have done a spectroscope lab in chemistry. I have included YouTube videos which are good review of spectroscopy. I have also included some videos on diffraction, interference and lasers which would all make good reviews.

2) **Spectroscope Videos**: rhcrgvp channel
   a. **Astronomy-spectroscopy-1/3 (9:59)**: good basics on light and spectroscopy, speaks on Kirchoff’s Laws of the continuous, emission, and absorption spectrum (focus mainly on emission)
   b. **Astronomy-spectroscopy-2/3 (9:47)**: continuation of the series and speaks more on the continuous spectrum; relates temperature to the spectra and the Balmer series
   c. **Astronomy-spectroscopy-3/3 (8:03)**: last part of the series; most related to astronomy; speaks of Doppler Effect and red/blue shifts.

3) **Diffraction and Interference Videos**: 1vertasium channel
   (http://en.wikipedia.org/wiki/Veritasium)
   a. **The Original Double Slit Experiment (7:40)**: Starts off with the host asking people on the street – ”What is Light?”; Young’s Double Slit Experiment with sunlight; interference patterns created in water; debate over light as waves and particles – watch till the very end – remind the students of the duality of light
b. **How to Make Color with Holes (5:38):** Light basics; combining of electric and magnetic fields; butterfly wings and their structure of scales – like diffraction gratings; soap bubbles

4) **Laser Videos:** SmarterEveryDay channel (done by a Huntsville missile engineer and a Dutch laser expert) Remind the students that these are professionals and they are using Class 4 lasers so a standard laser pointer will not work. Also, remind students that laser training and safety is very important.

a. **How Lasers Work (in practice) – Smarter Every Day 33 (3:54):** open cavity laser

b. **Lasers vs. Balloons – Smarter Every Day 35 (4:28):** Class 4 laser is shone on different colored balloons (they all pop except the white one – the blue one does take longer); he explains why

c. **How to Light a Match Inside a Balloon – Smarter Every Day 36 (2:13):** Lights a match inside a white balloon with a Class 4 laser and the balloon does not pop.

5) **Holograms:**

a. **How It’s Made: Holograms from the Discovery channel (EVAN199)(4:50):** self-explanatory

Day 7:

1) See Team Trivia: **Interference and Diffraction** for instructions and questions. There is also a PowerPoint presentation if you have a SmartBoard with a clicker system.

Day 8:

1) **Unit projects are due.**
2) Have the students present their posters and flash charts to the class.
3) As the students are presenting ask them pertinent questions as a review.

Day 9:

1) Pass out **Interference and Diffraction Evaluation.**
2) The equations for the unit may or may not be provided.
3) The Evaluation can be counted as a quiz or a test.
4) The Evaluation should be graded at the teacher’s discretion

**National Standards:**

**Content Standard A:** As a result of activities in grades 9-12, all students should develop:
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

**Content Standard B:** As a result of activities in grades 9-12, all students should develop an understanding of:
- Structure and properties of matter
- Interactions of energy and matter

**Content Standard G:** As a result of activities in grades 9-12, all students should develop an understanding of:
- Science as a human endeavor
- Nature of scientific knowledge

**PS 4: MOTIONS AND FORCES**
Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. These effects help students to understand electric motors and generators.

PS 5: CONSERVATION OF ENERGY AND THE INCREASE IN DISORDER

a) All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.

PS 6: INTERACTIONS OF ENERGY AND MATTER

a) Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

b) Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.

c) Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.

Georgia Performance Standards (Physics):

SCSh1. Students will identify and investigate problems scientifically.
   a. Suggest reasonable hypotheses for identified problems.
   b. Develop procedures for solving scientific problems.
   c. Collect, organize and record appropriate data.
   d. Graphically compare and analyze data points and/or summary statistics.
   e. Develop reasonable conclusions based on data collected.
   f. Evaluate whether conclusions are reasonable by reviewing the process and checking against other available information.

SCSh2. Students will use standard safety practices for all classroom laboratory and field investigations.
   1. Follow correct procedures for use of scientific apparatus.
   2. Demonstrate appropriate technique in all laboratory situations.
   3. Follow correct protocol for identifying and reporting safety problems and violations.

SCSh3. Students will identify and investigate problems scientifically.
   g. Suggest reasonable hypotheses for identified problems.
   h. Develop procedures for solving scientific problems.
   i. Collect, organize and record appropriate data.
   j. Graphically compare and analyze data points and/or summary statistics.
   k. Develop reasonable conclusions based on data collected.
   l. Evaluate whether conclusions are reasonable by reviewing the process and checking against other available information.

SCSh6. Students will communicate scientific investigations and information clearly.
   a. Write clear, coherent laboratory reports related to scientific investigations.
   b. Write clear, coherent accounts of current scientific issues, including possible alternative interpretations of the data.
   c. Use data as evidence to support scientific arguments and claims in written or oral presentations.
   d. Participate in group discussions of scientific investigation and current scientific issues.

SCSh9. Students will enhance reading in all curriculum areas by:
a. Reading in All Curriculum Areas
- Read technical texts related to various subject areas

c. Building vocabulary knowledge
- Demonstrate an understanding of contextual vocabulary in various subjects.
- Use content vocabulary in writing and speaking.
- Explore understanding of new words found in subject area texts.

d. Establishing context
- Explore life experiences related to subject area content.
- Discuss in both writing and speaking how certain words are subject area related.
- Determine strategies for finding content and contextual meaning for unknown words.

SP3. Students will evaluate the forms and transformations of energy.

a. Analyze, evaluate, and apply the principle of conservation of energy and measure the components of work-energy theorem by
  - describing total energy in a closed system.
  - identifying different types of potential energy.
  - calculating kinetic energy given mass and velocity.
  - relating transformations between potential and kinetic energy.

b. Explain the relationship between matter and energy.

e. Demonstrate the factors required to produce a change in momentum.

SP4. Students will analyze the properties and applications of waves.

a. Explain the processes that results in the production and energy transfer of electromagnetic waves.

b. Experimentally determine the behavior of waves in various media in terms of reflection, refraction, and diffraction of waves.

c. Explain the relationship between the phenomena of interference and the principle of superposition.

e. Determine the location and nature of images formed by the reflection or refraction of light.

Background:

**Interference:**

When two waves with *equal wavelengths* cross paths, they will combine to form a resultant wave. The resultant wave has the same wavelength as the two interacting waves, but its displacement at any point equals the algebraic sum of the displacements of the component waves (superposition principle). The formation of the resultant wave is caused by the *interference* of the two individual waves. Interference can be destructive or constructive depending on if the displacements are in opposite or in the same directions.

Constructive interference is demonstrated when using *monochromatic* light (one wavelength/color), if the light waves combine to form a resultant wave with amplitude that is larger than the individual waves. For light, the resultant wave will be brighter than the two individual waves. In the case of destructive interference, the amplitude of the resultant wave is less than that of the individual waves and will result in dimmer light or no light at all (complete destructive interference).

For an interference pattern to be seen on a screen, the light waves reaching any point on the screen must have a phase difference that does not change in time. These waves are said to have *coherence* (the property by which two waves with the same wavelength will maintain a constant phase relationship). This is the reason that *lasers* (an instrument that produces an intense, parallel beam of coherent light) are a great light source for this lab. The monochromatic light passes through two very small and parallel slits. When the light from the two slits arrives at a point on a screen, constructive or destructive interference will occur. As a result, either a bright or dark band (fringe) will appear on the screen. See Figure 1.
When both waves of light move the same distance, they appear on the screen in phase and interfere constructively. The waves will also interfere constructively (bright fringes) if the difference between the distances traveled by each light source equals a whole wavelength. However, if the differences in the distances traveled by the light are equal to a half a wavelength, destructive interference (dark fringes) will occur.

Diffraction:

Diffraction refers to the behavior of waves bending around obstacles or that pass through small openings. Though light waves are able to diffract like other waves, it can be difficult to observe due to their very small wavelengths [visible light range: 700 nm (red) > \( \lambda > 400 \) nm (violet)]. If light were only a particle and did not diffract it would travel in straight lines and an interference pattern would not be observed in the double-slit demonstration (See INTERFERENCE and FIG. 2). The bending of light as it passes through each of the two slits can be explained through Huygens’ Principle* (any point on a wave front can be treated as a point source of waves). Since each slit serves as a point source of light, the light waves spread out from the slits and depart from the straight-line path.

Diffraction patterns result from constructive and destructive interference and therefore resemble interference patterns. However, in the case of interference the slits behave as point sources of light, whereas for diffraction, the actual width of a single slit is taken into consideration. The amount the light that will bend is determined by the relative size of the light’s wavelength compared to the size of the barrier or opening. If the opening is much greater than the light’s wavelength, the bending will be almost undetectable. However, if the size difference is small, the amount of light that will bend will be quite easy to view.

*This is an interesting link in learning to pronounce Huygens’ name: [http://frank.harvard.edu/~paulh/misc/huygens.htm](http://frank.harvard.edu/~paulh/misc/huygens.htm)
A diffraction grating is a device that uses the principles of diffraction and interference to separate light into its component colors producing an effect comparable to that of a prism. Diffraction gratings can be constructed to either transmit or reflect light. A transmission grating (light is able to pass through) is comprised of many equally spaced parallel slits. Reflection gratings can both be plane or concave and reflect the incident light at different angles to produce a diffraction pattern (the rainbow of colors that appear on the surface of a CD).

The condition for the bright fringes is the same in the diffraction grating as that of the double-slit example. However, angular separation of the bright fringes is usually much larger because the slit spacing is so small for a diffraction grating. The greater the number of lines per unit of length in a grating, the smaller the distance between the slits and the farther spread apart the individual wavelengths of light are.
The bright fringe formation is given by the equation for constructive interference:

\[ d \sin \theta = m \lambda \]

Eqn 1

\( d \) = distance between slits

\( \theta \) = angle of diffraction

\( \lambda \) = wavelength of light

\( m \) = the order number for the bright fringes

Let \( \theta \) represent the angle of diffraction of the beam with respect to the incident direction. Let \( d \) be the spacing between the two slits. The path difference between the two waves starting from the two slits, as in Fig. 4a and b, can be clearly shown to be \( d \sin \theta \). For these waves to constructively interfere the waves must arrive in phase; clearly the path difference has to be an integral multiple of the wavelength.

**CDs and DVDs as DIFFRACTION GRATINGS**

CDs and DVDs show a display of colors when white light falls on them. This is due to the digital information (alternating pits and smooth reflecting surfaces) on the discs forming closely spaced rows acting like reflecting diffraction grating. These rows are spaced 1.6 micrometers from one another on a CD and 0.74 micrometers on a DVD. These rows do not reflect nearly as much light as the portions of the disc that separate them. In these portions the light reflected undergoes constructive interference in certain directions. Therefore, when white light is reflected from the disc each wavelength of light can be seen at a particular angle with respect to the disc’s surface producing a light spectra.

CDs and DVDs have a protective polycarbonate coating which does not interfere in the reflective diffraction grating, but to create a transmission grating the metal layer must be removed and the physical diffraction grating retrieved. This is a crucial step if AFM images are to be produced (See AFM). DVDs are usually two layered which are fairly easy to separate. CDs are one layer and cannot be separated so other techniques must be applied. (See ADVANCED PREPARATIONS)

To listen to a CD, the laser light in the CD player is reflected consecutively from the thread of binary bits etched on the disc (alternating pits and smooth, reflecting surfaces). When the light reflects from the smooth surface it reaches the detector. However, when the light reflects from the pits it is out of phase and the intensity of the beam hitting the sensor is less (the depth for the pits is roughly about one quarter of the wavelength of the laser). Any change in the intensity of the reflected beam as it transitions from a pit to land or land to pit is converted to an electrical signal and coded as a binary 1. Electronic circuits connected to the detector translate the binary data into an electrical signal. The
signal is then amplified and results in a reconstruction of the original recorded sample. A DVD player works on the same principle, but uses a smaller wavelength laser and therefore can detect information that is coded in much smaller pits and smooth, reflecting surfaces. DVDs can hold more than seven times as much data as a CD.

**Spectroscopy:**

A spectroscope is a tool that is used to determine the composition of materials by breaking down the light emitted or absorbed by chemical elements into particular lines of color (spectra). Light (electromagnetic radiation) is created when an excited electron moves back to its lower energy level from a higher energy level. The photon of light that is released has an energy that matches exactly to the difference in energy between the two orbits. Every chemical element has its own unique “fingerprint” of these orbitals that can be used to identify the chemical composition.

**Continuous Spectra:**

Shows all the colors of the rainbow blended into one another in a band. They are usually produced by a luminous liquid or solid. Ex) glowing filament of an incandescent bulb.

**Absorption Spectra:**

Is a dark line spectra which is identified by the black bands of missing color present in a continuous spectra. They are generated when white light passes through a cooler gas located between the source of the continuous spectrum and the observer. The cooler gas absorbs those wavelengths that it would usually emit if it were the glowing source. It has the same spectral “fingerprint” that the cooler gas would if it were emitting a bright line spectrum. Think of it like a photo-negative.

**Emission Spectra:**

Or Bright line emission spectra, whose source is a glowing gas. This gas emits photons with very specific energies (frequencies or wavelengths) that are characteristic of the chemical element of which the gas is composed of. Stars and tubes of heated gas can produce this emission spectra. A continuous emission spectra is produced by the chemicals in hot, incandescent gas and displays bright bands of color on top of a continuous spectra. You can see this spectra when looking at florescent lights. The white coating on the bulb mixes the elemental lines of the gas inside the bulb to create the continuous spectra while the bright bands are produced from the gas inside.

![Fig. 5; Parts of a simple spectroscope](http://en.wikipedia.org/wiki/Spectrometer)
More on the Emission Line Spectra

Unlike a continuous spectrum source, which can have any energy it wants (all you have to do is change the temperature), the electron clouds surrounding the nuclei of atoms can have only very specific energies dictated by quantum mechanics. Each element on the periodic table has its own set of possible energy levels, and with few exceptions the levels are distinct and identifiable.

Atoms will also tend to settle to the lowest energy level (ground state). This means that an excited atom in a higher energy level must ‘dump’ some energy. The way an atom ‘dumps’ that energy is by emitting a wave of light with that exact energy.

In the diagram following, a hydrogen atom drops from the 2nd energy level to the 1st, giving off a wave of light with an energy equal to the difference of energy between levels 2 and 1. This energy corresponds to a
specific color, or wavelength of light -- and thus we see a bright line at that exact wavelength! ...an emission spectrum is born, as shown below:

![Energy Level Diagram](image1)

**Fig. 9;** An excited Hydrogen atom relaxes from level 2 to level 1, yielding a photon. This results in a bright emission line. http://loke.as.arizona.edu/~ckulesa/camp/spectroscopy_intro.html

Tiny changes of energy in an atom generate photons with small energies and long wavelengths, such as radio waves! Similarly, large changes of energy in an atom will mean that high-energy, short-wavelength photons (UV, x-ray, gamma-rays) are emitted.

**Absorption Line Spectra**

On the other hand, what would happen if we tried to reverse this process? That is, what would happen if we fired this special photon back into a ground state atom? That's right, the atom could absorb that 'specially energetic' photon and would become excited, jumping from the ground state to a higher energy level. If a star with a 'continuous' spectrum is shining upon an atom, the wavelengths corresponding to possible energy transitions within that atom will be absorbed and therefore an observer will not see them. In this way, a dark-line absorption spectrum is born, as shown below:

![Energy Level Diagram](image2)

**Fig. 10;** A hydrogen atom in the ground state is excited by a photon of exactly the 'right' energy needed to send it to level 2, absorbing the photon in the process. This results in a dark absorption line. http://loke.as.arizona.edu/~ckulesa/camp/spectroscopy_intro.html

**Fields that use Spectroscopy:**

**Astronomy:**

Most astronomers are not continuously looking through their large telescopes, because they are letting the telescopes collect light for a spectrograph. Since each type of atom (or ion) has its own wavelength that it can absorb or emit, they will produce a unique spectra. The temperature of a star varies, so the atoms in the outer, cooler layers of the star absorb light emitted from the inner, hotter layers. This produces a dark absorption line across the spectrum. This spectra is used to identify the make-up of atoms in a star. Unlike a
spectroscope used in school, astronomers do not take a color picture of the spectrum for the following reasons:

a) Color film is less sensitive than black and white.
b) Color film does not represent the continuous range of colors in a spectrum very well.
c) A graph showing brightness vs. wavelength has a lot more quantitative information

Thus astronomers make graphs of their spectra, with the y-axis showing the brightness, while the x-axis shows the wavelength. In the figure this graph is aligned just below the picture of the spectrum.

Not only can astronomical spectroscopy be used to figure out a star’s chemical composition it can also determine temperature, luminosity, density, distance, mass and relative motion using the Doppler Effect.

**Gemology:**

The way that transparent, colored gemstones absorb the visible light that passes through them is what determines their color. The color observed is directly related to the stones chemical make-up, spectroscopy is a very effective method for determining the chemistry of the gemstones.
Chemistry (also Physics and Biology):

Research scientists use spectroscopy often regardless of their field. The spectra can be used to identify the composition of the sample and the amounts of the chemicals in the sample, but other information can also be obtained. For example, information about atomic and molecular energy levels, chemical bonds, interactions of molecules and the shapes of the molecules can also be determined. Usually the spectrum is a plot of the intensity of the energies versus the wavelength, frequency, mass, momentum, etc. of the energy.

Types of Spectroscopy:

There are many types of spectroscopy used, but I just chose a few to discuss. The site: http://chemistry.about.com/od/analyticalchemistry/a/spectroscopy.htm is a good place to start to learn about other types. It would be a good extension to this unit to have the students report on the different types of spectroscopy and could replace the Unit Project if desired. Spectroscopy is used so much in research it is really an important topic.

Visible and Ultraviolet Spectroscopy:

Different compounds can be differentiated by their color. For example, chlorophyll is green and quinone is yellow. In this respect our eyes act as a spectrometer that detects and analyzes the light reflect from an opaque object or transmitted through a transparent one. To understand why some compounds have color and others do not, precise measurements of light absorption at various wavelengths in and near the visible part of the electromagnetic spectrum are required.

The visible region of the spectrum comprises photon energies of 36 to 72 kcal/mole, and the near ultraviolet region, out to 200 nm, extends this energy range to 143 kcal/mole. This is enough energy to excite a molecular electron to a higher energy orbital. Usually, energetically favored electron promotion will be from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO), and the resulting species is called an excited state. When sample molecules are exposed to light having an energy that matches a possible electronic transition within the molecule, some of the light energy will be absorbed as the electron is promoted to a higher energy orbital. An optical spectrometer records the wavelengths at which absorption occurs, together with the degree of absorption at each wavelength. The resulting spectrum is presented as a graph of absorbance (A) versus wavelength.

Fig. 13 a and b; Both images: http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/Spectrpy/UV-Vis/spectrum.htm#uv1
**Mass Spectroscopy:**

A mass spectrometer converts individual molecules to ions so an external electric/magnetic field can manipulate them and the characteristics of the molecules can be determined. The three main parts of a mass spectrometer are:

**d) The Ion Source** (a sample is ionized – us. Loss of an e-)

**e) The Mass Analyzer** (the ions are separated based on their mass and charge)

**f) The Detector** (the ions are measured and results displayed)

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**IR (Infrared):**

Photon energies associated with this part of the electromagnetic spectrum are not great enough to excite electrons, but may induce vibrational excitation of covalently bonded atoms and groups. The covalent bonds in molecules are not rigid sticks or rods, such as found in molecular model kits, but are more like stiff springs that can be stretched and bent. Molecules experience a large variety of vibrational motions, characteristic of their component atoms. Consequently, virtually all organic compounds will absorb infrared radiation that corresponds in energy to these vibrations. This allows researchers to obtain absorption spectra of compounds that are a unique reflection of their molecular structure.

One influence of the intensity of infrared absorptions, is that a change in dipole moment should occur for a vibration to absorb infrared light. Absorption bands associated with C=O bond stretching are usually very strong because a large change in the dipole takes place in that mode.

**Some General Trends:**
a) Stretching frequencies are higher than corresponding bending frequencies. (It is easier to bend a bond than to stretch or compress it.)
b) Bonds to hydrogen have higher stretching frequencies than those to heavier atoms.
c) Triple bonds have higher stretching frequencies than corresponding double bonds, which in turn have higher frequencies than single bonds. (Except for bonds to hydrogen.)

**Gas Phase Infrared Spectrum of Formaldehyde, H₂C=O**

Fig. 15; shows the IR spectrograph of Formaldehyde; http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/Spectrpy/InfraRed/infrared.htm

**Raman Spectroscopy:**

Raman Spectroscopy: a technique used to detect vibrational, rotational and other low frequency modes in a sample. When electromagnetic radiation is scattered by a molecule, the incident photon is destroyed and, at the same time, another photon of the scattered radiation is created. The scattering mechanisms are grouped based on the difference between the energies of the incident and scattered photons. If the incident energy equals the scattered this is referred to as Rayleigh scattering (most types of scattering). However if the incident is different than the scattered energy (inelastic scattering – KE is not conserved) then it is known as Raman scattering.

The photon is the incident particle and interacts with matter and the frequency of the photon is shifted to red (energy of photon decreases) or blue (energy of photon increases). The molecular bonds and chemical make-up determine the Raman shift and spectra.

The Raman Effect occurs when light is incident on a molecule and interacts with the electron cloud and the bonds of the molecule. A photon excites the electron in the molecule from the ground state to a virtual energy state. As the molecule relaxes a photon is emitted and the electron returns to a different vibrational state. The change in energy from the initial state and the new state leads to a shift in the emitted photon’s frequency.
If the final state is more energetic than the original, then the emitted photon will be shifted to a lower frequency to balance out the total energy of the system (Stokes shift). If the final state is less energetic, then the emitted photon will be shifted to a higher frequency (anti-Stokes shift). Some amount of deformation of the electron cloud is required for a molecule to exhibit a Raman effect.

Lasers and Holograms:

Lasers:

A laser (Light Amplification by Stimulated Emission of Radiation) is an instrument that converts light, electrical or chemical energy into coherent light. Coherence means that the light waves interfere constructively causing them to have become in phase with one another (in-step). This increases the amplitude and therefore the energy of the laser.

There are many types of lasers but they all use an active medium to which energy is added to produce coherent light. The active medium can be solid, liquid, or gas. The composition of the active medium determines the wavelength, or color, of the light produced by the laser.

The following explanation and images (Fig. 18 a-d) are from the National Ignition Facility (NIF) a part of the National Nuclear Security Administration. <https://lasers.llnl.gov/education/how_lasers_work.php>
a) High-voltage electricity causes the quartz flash tube to emit an intense burst of light, exciting some of the atoms in the ruby crystal to higher energy levels.

b) At a specific energy level, some atoms emit particles of light called photons. At first the photons are emitted in all directions. Photons from one atom stimulate emission of photons from other atoms and the light intensity is rapidly amplified.

c) Mirrors at each end reflect the photons back and forth, continuing this process of stimulated emission and amplification.

d) The photons leave through the partially silvered mirror at one end. This is laser light.
The laser flash that escapes through the partially reflecting mirror lasts for only about 300 millionths of a second, but is very intense. Early lasers could produce peak powers of some 10,000 watts. Modern lasers can produce pulses that are billions of times more powerful.

The 1,000-watt light used in modern lighthouses can be seen from 20 miles away. But beyond that distance, the light beam has spread out so much that it is difficult to see. A laser beam, however, will run straight and true for very long distances. A laser beam has been bounced off the moon to accurately measure the distance of more than 250,000 miles! The beam stays roughly the same size as it travels this vast distance. Coherence means that laser light can be focused with great precision.

Many different materials can be used as lasers. Some, like the ruby laser, emit short pulses of laser light. Others, like helium–neon gas lasers or liquid dye lasers, emit a continuous beam of light. The NIF lasers, like the ruby laser, are solid-state, pulsed lasers.

Lasers have many important applications. They are used in common consumer devices such as DVD players, laser printers, and barcode scanners. They are used in medicine for laser surgery and various skin treatments, and in industry for cutting and welding materials. They are used in military and law enforcement devices for marking targets and measuring range and speed. Laser lighting displays use laser light as an entertainment medium. Lasers also have many important applications in scientific research.

**Holograms:**

Holography is a technique that creates three-dimensional images. Interference and diffraction principles are used along with lasers, light intensity recording and suitable lighting of the recorded image to create a hologram. The image changes appearance as the position/orientation of the viewing system changes in the same way as if the object were still there (why the image appears 3-D).

Holography allows a light field, which is generally the product of a light source scattered off objects, to be recorded and later reconstructed when the original light field is no longer present, (the original object is absent). A good analogy is to think of holography like a sound recording. The sound field is created by vibrating objects (musical instruments or vocal cords) that is encoded in such a way that it can be reproduced later, without the original vibrating objects. The holographic recording itself is not an image; it consists of an apparently random structure of either varying intensity, density or profile.

![Fig. 19: Close-up photograph of a hologram's surface. The object in the hologram is a toy van. It is no more possible to discern the subject of a hologram from this pattern than it is to identify what music has been recorded by looking at a CD's surface. Note that the hologram is described by the speckled pattern, rather than the "wavy" line pattern. http://en.wikipedia.org/wiki/Holography](image)

When the hologram plate is illuminated by a laser beam identical to the reference beam which was used to record the hologram, an exact reconstruction of the original object wave front is obtained. An imaging system (an eye or a camera) located in the reconstructed beam 'sees' exactly the same scene as it would have done when viewing the original. When the lens is moved, the image changes in the same way as it would have done...
when the object was in place. A holographic image can also be obtained using a different laser beam configuration to the original recording object beam, but the reconstructed image will not match the original exactly. When a laser is used to reconstruct the hologram, the image is speckled just as the original image would have been. This can be a major drawback in viewing a hologram.

White light consists of light of a wide range of wavelengths. Normally, if a hologram is illuminated by a white light source, each wavelength can be considered to generate its own holographic reconstruction, and these will vary in size, angle, and distance. These will be superimposed, and the summed image will wipe out any information about the original scene, just as if you superimposed a set of photographs of the same object of different sizes and orientations. However, a holographic image can be obtained using white light in specific circumstances, e.g. with volume holograms and rainbow holograms. The white light source used to view these holograms should always approximate to a point source, i.e. a spot light or the sun. An extended source (e.g. a fluorescent lamp) will not reconstruct a hologram since its light is incident at each point at a wide range of angles, giving multiple reconstructions which will "wipe" one another out.

**Types of Holograms:** This is just a few types

**Transmission:**

These can be found on credit cards and money. They are called transmission because they should be lit from behind (like a slide in a slide projector). It can be difficult to light the hologram in this manner so a mirror or a foil backs the hologram. This is why the credit card hologram has a silvery appearance. The light can bounce off the mirrored backing and basically light the hologram from behind.

Fig. 20 a and b; a) on the left demonstrates the divisible properties of a hologram and b) on the right shows the basic setup for a transmission hologram. [http://science.howstuffworks.com/hologram.htm](http://science.howstuffworks.com/hologram.htm)
A rainbow hologram is a special type of transmission hologram as the light being used to illuminate them is split into a spectrum, the hologram representing the ‘correct’ color(s) from one angle, while at other angles seen in different colors of the spectrum (from deep blue to red). Transmission rainbow holograms can be large (>1m²) or small (<10mm²), can be made singularly, or mass-reproduced using a technique known as **embossing**. **Embossed holograms** are the ones usually seen on credit cards and packaging. The original hologram is made into a metal copy and duplicates are used to create millions of copies by embossing the pattern into soft aluminized plastic. This the most common form of holography because it can be made in great quantities quickly and cheaply.

**Reflection:**

For this type of hologram the object and reference beams are incident on the plate from opposite sides of the plate. The reconstructed object is then viewed from the same side of the plate as that at which the re-constructing beam is incident. With a reflection holography, the image is stored in a thick emulsion and can be viewed in white light. The simplest such hologram to make is the direct beam reflection hologram. In this case the direct beam through the film serves as the reference beam.

**Fig. 21;** Embossed holograms massed produced.


**Fig. 22;** Setup of a direct beam reflection hologram;

http://hyperphysics.phy-astr.gsu.edu/hbase/optmod/holog3.html

**Fig. 23;** An example of a reflection hologram; usually they are back painted so light is reflected

http://digilander.libero.it/crispers/holograms.html
Pulsed:

A moving object can be made to appear to be at rest when a hologram is produced with the extremely rapid and high-intensity flash of a pulsed ruby laser. The duration of such a pulse can be less than 1/1,000,000 of a second; and, as long as the object does not move more than 1/10 of a wavelength of light during this short time interval, a usable hologram can be obtained. A continuous-wave laser produces a much less intense beam, requiring long exposures; thus it is not suitable when even the slightest motion is present.

![Fig. 24; An example of a pulsed hologram; does not require the object to be completely stationary](http://www.holograms.bc.ca/home6b1.htm)

Sometimes the term hologram is used incorrectly. For example:

At the 2006 Grammy Awards the Pepper's ghost technique was used to project Madonna with the virtual members of the band Gorillaz onto the stage in a "live" performance. This type of system consists of a projector (usually DLP) or LED screen, with a very high resolution (1280×1024 or higher) and very high brightness (at least 5,000 lumens), a high-definition video player, a stretched film between the audience and the acting area, a 3D set/drawing that encloses three sides, plus lighting, audio, and show control. [13]

During Dr. Dre and Snoop Dogg's performance at the 2012 Coachella Valley Music and Arts Festival, a projection of deceased rapper Tupac Shakur appeared and performed "Hail Mary" and "2 of Amerikaz Most Wanted." [14][15]

![Fig. 25; A demonstration of how Tupac's image appeared – not a hologram](http://gizmodo.com/5903092/this-is-how-tupac's-hologram-that-wasnt-really-a-hologram-worked)
References:

Books and Interviews:


• Porter-Davis, Karen. Interview with Dr. Thomas Orlando. Department of Chemistry. Georgia Institute of Technology. Atlanta, Georgia. Summer 2013.


Websites:


INTERFERENCE AND DIFFRACTION
DEMONSTRATIONS

Diffraction Grating Demonstration:

Take the red laser pointer and shine it through a diffraction grating on the wall/white board in a darken room. Have the students attempt to explain what is occurring with the laser light. Have a student come up to the wall and point out the central bright fringe. Have them mark off the bright fringes with a marker (or if on a wall you can have them use red stickers – like Avery color coding labels). Then bring out the green laser and ask the students to predict how the green laser will diffract compared to the red laser (remind them about the wavelength size difference between red and green). Repeat the previous procedure with the green laser and have the student mark off the bright fringes (make sure you are pointing it in the same direction at the same level. After they are marked off turn on the lights and compare and discuss how the diffraction of light differs depending on wavelength.

Spectroscope Demonstration:

Pass out diffraction gratings and spectroscopes to each student or pairs of students. REMIND THE STUDENTS NOT TO TOUCH THE GRATING PART OF THE SLIDE. If you do not have any spectroscopes the diffraction gratings will do. As a class have the students look through the diffraction gratings and spectroscopes at different light sources (NOT THE SUN). It is best if you have several different sources like an emission box with neon, hydrogen and helium gas, but also incandescent, halogen and fluorescent sources. Open up a discussion of what students are seeing and if the sources of light all look the same and why they look different. Also, if you are using both diffraction gratings and spectroscopes have the students explain the similarities and differences (both split the light into a spectrum, but a spectroscope usually will provide a scale to measure the wavelength of the bands – also since spectroscopes have the grating enclosed it can be easier to see the spectra). If you are just using diffraction gratings, below are tips on how to help the students see the spectra.

a) Darken the room.
b) Hold the grating close to the eye and look through it at a light source.
c) Make sure that the gratings are turned so the grooves run vertically.
d) Look off to either side of the light source. This may take some practice.
e) If they are having problems seeing the spectra they may need to try holding grating different distances from their eye and/or closing the eye not in front of the grating.
INTRODUCTION TO THE INTERFERENCE AND
DIFFRACTION OF LIGHT WORKSHEET

Name: ____________________  Date: __________  Period: _______

1. Does interference of light only occur with visible light? If not, give an example.

2. Explain why light has a dual nature. Use examples to support your answer.

3. What results when visible light has constructive and destructive interference?

4. Define coherence.

5. What is a spectrometer? Name at least two uses.
6. What is the difference between transmission and reflective diffraction gratings?

7. What is necessary for an optical instrument to have high resolution or resolving power?

8. Which object would produce the most distinct diffraction pattern: your textbook, your house key or a strand of your hair? Explain why.

9. Would red or green light produce a wider diffraction pattern? Explain why.

10. What does the acronym, laser, mean? How does a laser differ from incandescent light (name at least three ways)? Name two uses for lasers.
INTRODUCTION TO THE INTERFERENCE AND DIFFRACTION OF LIGHT WORKSHEET

Teacher copy

Name: ____________________ Date: ________ Period: ______

1. Does interference of light only occur with visible light? If not, give an example.

No, interference can occur with all electromagnetic waves. One common example is with radio waves (affects cell phones, radios, television, etc.). X-rays are also good examples.

2. Explain why light has a dual nature. Use examples to support your answer.

This means that light can act as a wave but also as a particle (photon). The way light diffracts demonstrates wave characteristics (Huygens, Fresnel or Young's experiments), but the photo electric effect (other ex: Compton's or J.J. Thomsons' experiment can also be used) demonstrated how light can act as a particle as well.

3. What results when visible light has constructive and destructive interference?

For constructive interference the light waves will combine and produce bright fringes and with destructive interference the light waves will cancel (or reduce) to produce dark/dim fringes.

4. Define coherence.

The property by which two waves with identical wavelengths maintain a constant phase relationship. (Holt Physics book definition)

5. What is a spectrometer? Name at least two uses.

A spectrometer is a simple device that uses a diffraction grating to separate the light from a source into its monochromatic components. All elements have their
own unique “fingerprint” and so spectrometers are used in astronomy to
determine the make-up and temperatures of stars and galaxies, in gemology to
establish the composition of gems and stones, and in chemistry to ascertain the
chemical structure and make-up of chemical compounds and solutions.

6. What is the difference between transmission and reflective diffraction
gratings?

A transmission grating is made of a transparent substance, so that the diffracted
light goes through the grating and displays the pattern on the other side of the
object. A reflection grating is made of a reflective/opaque substance; so the
diffracted light bounces off and creates a pattern on the same side.

7. What is necessary for an optical instrument to have high resolution or
resolving power?

The angle between the resolved objects should be as small as possible. The
shorter the wavelength of the incident light or the wider the aperture (opening
through which light passes) the smaller the angle of resolution and the greater
the resolving power will be. The limiting angle of resolution in radians for an
optical instrument with a circular aperture is \( \theta = \frac{1.22 \lambda}{D} \)

8. Which object would produce the most distinct diffraction pattern: your
textbook, your house key or a strand of your hair? Explain why.

Your strand of hair. Its size is nearest the size of the wavelength of visible light.

9. Would red or green light produce a wider diffraction pattern? Explain why.

Red light; Longer wavelengths are diffracted more.

10. What does the acronym, laser, mean? How does a laser differ from
incandescent light (name at least three ways)? Name two uses for lasers.

Light Amplification by Stimulated Emission of Radiation; Lasers are
monochromatic, directional and coherent unlike incandescent light. Bar codes,
surgeries, optical tweezers, determining distances, CD/DVD players, scientific
research, etc.
INTERFERENCE AND DIFFRACTION PROBLEMS

Name: ___________________________ Date: __________________ Period: ______

Constructive Interference: \[ d \sin(\theta) = m \lambda \quad m = 0, \pm 1, \pm 2, \ldots \]

Destructive Interference: \[ d \sin(\theta) = (m + \frac{1}{2}) \lambda \quad m = 0, \pm 1, \pm 2, \ldots \]

Diffraction: \[ d \sin(\theta) = m \lambda \quad m = 0, \pm 1, \pm 2, \ldots \]

1. Light from a Helium-Neon laser falls on a double slit with a slit separation of \(2.03 \times 10^{-6} \text{ m}\), and the first bright fringe is seen at an angle of 18.16 ° relative to the central maximum. Determine the wavelength of the light source.

2. If the distance between two slits is \(3.33 \times 10^{-3} \text{ mm}\), determine the angle between the first-order and second-order bright fringes for the yellow spectra of a sodium lamp with a wavelength of 589 nm.

3. A pair of narrow parallel slits are illuminated by the blue component of a mercury vapor lamp with a wavelength of 435.8 nm. The angle from the central maximum to the first bright fringe is 16.2°. Determine the distance between the slits.

4. The distance between slits in a double-slit interference experiment is 0.055 mm. The second-order bright fringe is measured to have an angle of 3.45° from the central maximum. Calculate the wavelength of the light source.
5. Light with a wavelength of 574 nm falls on a double slit interference experiment (d = 2.5 mm). Calculate the angle between the central maximum and the second dark fringe.

6. Convert the following into d (distance between slits):
   a. 300,000 lines/m
   b. 2150 lines/cm
   c. 428 lines/mm

7. Light from a Krypton laser (λ = 416 nm) shines on a diffraction grating with 175,000 lines/m. Solve for the angle between the central maximum and the first-order maximum.

8. A grating with 1525 lines/cm is illuminated with light of wavelength 632.8 nm. What is the angle between the central maximum and the second-order maximum?

9. A diffraction grating has blue light with a wavelength of 475 nm shone on it. An angle of 11° is determined between the central maximum and first-order maximum. What is the distance between the slits?

10. Light from a Nitrogen laser (λ = 337.1 nm) shines on the surface of a diffraction grating that has 525 lines/mm. Determine the angles at which you would observe the first and second order maxima.
INTERFERENCE AND DIFFRACTION PROBLEMS

TEACHER’S COPY

Name: ___________________________ Date: __________________ Period: ______

Constructive Interference: \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \)

Destructive Interference: \( d(\sin \theta) = (m + \frac{1}{2})\lambda \quad m = 0, \pm 1, \pm 2, \ldots \)

Diffraction: \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \)

1. Light from a Helium-Neon laser falls on a double slit with a slit separation of \( 2.03 \times 10^{-6} \) m, and the first bright fringe is seen at an angle of 18.16° relative to the central maximum. Determine the wavelength of the light source.

\[
d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \rightarrow \lambda = \frac{d(\sin \theta)}{m} = \frac{(2.03 \times 10^{-6})\sin 18.16°}{1} \\
6.327 \times 10^{-7} \text{ m or 632.7 nm}
\]

2. If the distance between two slits is \( 3.33 \times 10^{-3} \) mm, determine the angle between the first-order and second-order bright fringes for the yellow spectra of a sodium lamp with a wavelength of 589 nm.

Convert: \( 3.33 \times 10^{-3} \) mm \( \rightarrow \) \( 3.33 \times 10^{-6} \) m and 589 nm \( \rightarrow \) 589 \times 10^{-9} m or 5.89 \times 10^{-7} m

\( 1^{\text{st}} \) order: \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \rightarrow \theta = \sin^{-1}(m\lambda/d) \rightarrow \theta = \sin^{-1}\left(\frac{(1)(589 \times 10^{-9})}{3.33 \times 10^{-6}}\right) \rightarrow 10.19° \)

\( 2^{\text{nd}} \) order: \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \rightarrow \theta = \sin^{-1}(m\lambda/d) \rightarrow \theta = \sin^{-1}\left(\frac{(2)(589 \times 10^{-9})}{3.33 \times 10^{-6}}\right) \rightarrow 20.72° \)

3. A pair of narrow parallel slits are illuminated by the blue component of a mercury vapor lamp with a wavelength of 435.8 nm. The angle from the central maximum to the first bright fringe is 16.2°. Determine the distance between the slits.

Convert: 435.8 nm \( \rightarrow \) 435.8 \times 10^{-9} m or 4.358 \times 10^{-7} m

\[
d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \rightarrow d = m\lambda/\sin \theta = \frac{[(1)(435.8 \times 10^{-9})]/\sin 16.2°}{1} \rightarrow 1.56 \times 10^{-6} \text{ m}
\]

4. The distance between slits in a double-slit interference experiment is 0.055 mm. The second-order bright fringe is measured to have an angle of 0.75° from the central maximum. Calculate the wavelength of the light source.

Convert: 0.055 mm \( \rightarrow \) 5.5 \times 10^{-5} m

\[
d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \rightarrow \lambda = \frac{d(\sin \theta)}{m} = \frac{(5.5 \times 10^{-5})(\sin 0.75°)}{2} \rightarrow 359.96 \times 10^{-7} \text{ m}
\]
5. Light with a wavelength of 574 nm falls on a double slit interference experiment (d = 0.25 mm). Calculate the angle between the central maximum and the second dark fringe.

\[ \text{Convert: } 574 \, \text{nm} \rightarrow 574 E^{-9} \, \text{m or } 5.74 E^{-7} \, \text{m} \]  
\[ \text{and } 0.25 \, \text{mm} \rightarrow 2.5 E^{-4} \, \text{m} \]

Remember the 2nd dark fringe is between the 1st and 2nd bright fringe so \( m = 1 \)

\[
\text{Some calculations lead to: } \theta = \sin^{-1}\left(\frac{(1)(574 \, E^{-9})}{(2.5 \, E^{-4})}\right) \approx 0.197^\circ
\]

6. Convert the following into \( d \) (distance between slits) in meters:

a. 300,000 lines/m \( \rightarrow (300,000)^{-1} \rightarrow 3.33 E^{-6} \, \text{m} \)

b. 2150 lines/cm \( \rightarrow (2150)^{-1} \rightarrow 4.65 E^{-4} \, \text{cm} \rightarrow 4.65 E^{-6} \, \text{m} \)

c. 428 lines/mm \( \rightarrow (428)^{-1} \rightarrow 2.34 E^{-3} \, \text{mm} \rightarrow 2.34 E^{-6} \, \text{m} \)

7. Light from a Krypton laser (\( \lambda = 416 \, \text{nm} \)) shines on a diffraction grating with 175,000 lines/m. Solve for the angle between the central maximum and the first-order maximum.

\[ \text{Convert: } 416 \, \text{nm} \rightarrow 416 E^{-9} \, \text{m or } 4.16 E^{-7} \, \text{m} \]  
\[ \text{and } 175,000 \, \text{lines/m} \rightarrow 5.71 E^{-6} \, \text{m} \]

\[
\text{Some calculations lead to: } \theta = \sin^{-1}\left(\frac{(1)(416 \, E^{-9})}{(5.71 \, E^{-6})}\right) \approx 4.18^\circ
\]

8. A grating with 1525 lines/cm is illuminated with light of wavelength 632.8 nm. What is the angle between the central maximum and the second-order maximum?

\[ \text{Convert: } 1525 \, \text{lines/cm} \rightarrow 6.56 E^{-4} \, \text{cm} \rightarrow 6.56 E^{-6} \, \text{m} \]  
\[ \text{and } 632.8 \, \text{nm} \rightarrow 632.8 E^{-9} \, \text{m or } 6.328 E^{-7} \, \text{m} \]

\[
\text{Some calculations lead to: } \theta = \sin^{-1}\left(\frac{(2)(632.8 \, E^{-9})}{(6.56 \, E^{-6})}\right) \approx 11.12^\circ
\]

9. A diffraction grating has blue light with a wavelength of 475 nm shone on it. An angle of 11^\circ is determined between the central maximum and first-order maximum. What is the distance between the slits?

\[ \text{Convert: } 475 \, \text{nm} \rightarrow 475 E^{-9} \, \text{m or } 4.75 E^{-7} \, \text{m} \]

\[
\text{Some calculations lead to: } d = \frac{(1)(475 \, E^{-9})}{\sin 11^\circ} \approx 2.49 E^{-6} \, \text{m}
\]

10. Light from a Nitrogen laser (\( \lambda = 337.1 \, \text{nm} \)) shines on the surface of a diffraction grating that has 525 lines/mm. Determine the angle at which you would observe at the second order maximum.

\[ \text{Convert: } 337.1 \, \text{nm} \rightarrow 337.1 E^{-9} \, \text{m or } 3.371 E^{-7} \, \text{m} \]  
\[ \text{and } 525 \, \text{lines/mm} \rightarrow 1.905 E^{-6} \, \text{m} \]

\[
\text{Some calculations lead to: } \theta = \sin^{-1}\left(\frac{(2)(337.1 \, E^{-9})}{(1.905 \, E^{-6})}\right) \approx 20.73^\circ
\]
DIFFRACTION GRATING LAB

MATERIALS:

Diffraction gratings, a CD/DVD with aluminum coating removed, laser pointer, ring-stand with clamp, and white screen (or poster board)

PROCEDURE:

Use the information on the diffraction gratings to compare the calculated angle of diffraction with the measured one (first order maximum). Use a CD/DVD as a diffraction grating and determine the distance between the grooves.

DATA:

<table>
<thead>
<tr>
<th>Grating</th>
<th>d (meters)</th>
<th>y (meters)</th>
<th>L (meters)</th>
<th>( \theta ) calculated</th>
<th>( \theta ) observed</th>
<th>% Error</th>
</tr>
</thead>
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<tr>
<td>100 lines/mm</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>300 lines/mm</td>
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<tr>
<td>530 lines/mm</td>
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</table>

DIFFRACTION EQUATIONS

\[ d \sin \theta_{\text{calc.}} = m \lambda \] and \[ y = L \tan \theta_{\text{observed}}. \]

- \( d \) = distance between slits
- \( \theta \) = path angle
- \( m \) = order number
- \( \lambda \) = wavelength of light

Wavelength of laser (\( \lambda \)): _________________ m
For the CD/DVD:

Calculate the $\theta_{\text{diffraction}}$ for the first order maximum using the measured $y$ and $L$. Then using the calculated angle solve for $d$ using $d \sin \theta_{\text{calc}} = m \lambda$. Compare it to the $d$ measured from the AFM image of the CD/DVD using the % Error equation.

<table>
<thead>
<tr>
<th>$y$ (meters)</th>
<th>$L$ (meters)</th>
<th>$\theta_{\text{diffraction}}$</th>
<th>$d_{\text{calculated}}$ (meters)</th>
<th>$d_{\text{measured}}$ (meters)</th>
<th>% Error</th>
</tr>
</thead>
</table>

Fig1a. AFM image: Sample: Memorex CD 750 MB; blank; scan size 10 micrometer  
2a. AFM image: Sample: Sony DVD-R 4.7 GB; Blank, scan size 5.0 micrometer
INTERFERENCE AND DIFFRACTION
REVIEW PROJECT

Instructions:
You are to create a Flash Chart (A heavy-duty paper notebook insert) or Poster as a review guide for Refraction, Lenses and Optical Phenomenon. This project will be due on ________________. There will be a 10 pt deduction for every school day the project is late without proper excuse.

The Flash Chart/Poster should include:

a) A title and a brief overview of the entire unit.

b) Divisions for each section (three sections: Interference, Diffraction and Lasers) in the unit.

c) Each section division should include:

1) The section objectives (summary)
2) All important terms and their definitions
3) All equations used in the section with example problems for each
4) At least two visuals (charts, graphs, diagrams, pictures, etc.) that relate to the section.

d) All Flash Charts should be typed (only exception – the calculations) and placed on colored paper (no notebook paper). Posters can be designed on poster board or through the website http://edu.glogster.com. Content quality, readability (organization), neatness and creativity will all be considered.
# FLASH CHART RUBRIC

Name: ___________________________ Date: _____________ Period: _____

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<td>Appropriate Title Given with Grammatical Errors</td>
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<tr>
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<td>Requirement not Met/Less than 50% of Equations Defined Correctly</td>
<td>50 – 74% of Equations Defined Correctly</td>
<td>At least 75% of Equations Defined Correctly</td>
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<td>At least Two Meaningful Visuals for Each Section</td>
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<td>TYPED FLASH CHARTS</td>
<td>Requirement not Met/Less than 75% of Flash Chart is Typed (sans calculation)</td>
<td>At least 75% of Flash Chart is Typed (sans calculations)</td>
<td>All of the Flash Chart is Typed (messy calculations)</td>
<td>All of the Flash Chart is Typed (sans calculations but they are written neatly)</td>
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<td>CONTENT QUALITY</td>
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<td>Content Quality is Very Good</td>
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<td>ORGANIZATION/NEATNESS</td>
<td>Majority of Flash Chart is Unorganized</td>
<td>Some Sections of the Flash Chart are Unorganized</td>
<td>Flash Chart is Organized</td>
<td>Flash Chart is Very Organized</td>
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<td>CREATIVITY/PERCEIVED EFFORT</td>
<td>Very Little Perceived Effort</td>
<td>Some Perceived Effort</td>
<td>Creative Touches Were Added/Some Perceived Effort</td>
<td>Meaningful Creative Touches Were Added/A lot of Perceived Effort</td>
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Bonus Points: ________________________

Total Score: ________________________
# RUBRIC FOR POSTER/BROCHURE/VIDEO/COMIC BOOK

Name(s): ________________________  Project: ______________  Period(s): ____

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Total Points: ____________/100

Teacher Comments:
TEAM TRIVIA: INTERFERENCE AND DIFFRACTION

Instructions: Divide class into groups of 3 or 4. Pass out 4 note cards (with letters A, B, C, and D on one card each) to each group OR if you have a clicker system with your Smartboard give each group a remote (there is a ppt with these questions on them). Allow students to use scrap paper and calculators. You may provide equations to each group as well. Read the question and all the choices allowed to the class and let each group send up a representative with their answer. Every group should get a chance to answer (this is not a first come first served game). At the end of the multiple choice round pass out the Bonus Round Sheet to each group to work on (you may establish an appropriate time limit). Tally up each groups’ points. I usually give 1st place 6 pts on their evaluation, 2nd place 5 pts, etc. (you can award your winners any way that you like).

1. Projected on a screen is a two-slit interference pattern, the fringes are evenly spaced on the screen
   a) Only for small angles
   b) Only for large angles
   c) Only at 45°
   d) never

2. Which of the following is a monochromatic and coherent light source?
   a) LED
   b) Fluorescent
   c) Laser
   d) Incandescent

3. Which is not a type of hologram that was discussed?
   a) refraction
   b) transmission
   c) pulsed
   d) embossed

4. What is the function of a spectrometer?
   a) To eliminate light dispersion
   b) To reduce constructive interference
   c) To separate light from a source into its monochromatic components
   d) To produce coherent light
5. All lasers use a substance called the ________________ to which energy is added to produce coherent light.
   a) Gas-ion barrier
   b) Stimulated emission
   c) Photon beam
   d) Active medium

6. Instruments that have high resolution are created to
   a) Reduce interference
   b) Eliminate coherence of light waves
   c) Enhance dispersion
   d) Maximize diffraction patterns

7. In a double slit experiment, the angle between the central maximum and the second bright fringe is 2°. The slit separation is 3.8 E-5 m. What is the wavelength of the light source?
   a) 5.3 E-7 m
   b) 6.6 E-7 m
   c) 5.9 E-8 m
   d) 6.4 E-8 m

8. To meet the needs to form an interference pattern a(n) ________________ is usually used as a light source.
   a) Halogen bulb
   b) Mercury vapor lamp
   c) Laser
   d) Light Emitting Diode

9. Which of the following changes would increase the resolution of a telescope?
   a) Observing light at a low wavelength, increasing the aperture
   b) Observing light at a low wavelength, decreasing the aperture
   c) Observing light at a high wavelength, increasing the aperture
   d) Observing light at a high wavelength, decreasing the aperture

10. Extra point question: The inelastic scattering (KE is not conserved) of a photon is called
    a) Rayleigh Scattering
    b) Tyndall Scattering
    c) Raman Scattering
    d) Mie Scattering
INTERFERENCE AND DIFFRACTION

BONUS ROUND

Group Member Names: _____________________________ Date: __________ Period: ____

Group #: _________

1. If you had two incandescent light bulbs as your light source would interference occur? Explain your answer.

2. Who first demonstrated interference in light waves from two sources in 1801?

3. In a double slit interference pattern the 1st order bright fringe appears 0.25 cm from the central maximum. The distance between the slits is 0.5 mm and the wavelength is 463 nm. What is the angle?

4. The colors formed on a soap bubble are caused mainly by ________________________________.

5. Why is blue light used for illumination in an optical microscope?

6. In a double slit experiment the slits are separated by 0.3096 mm and has a light with a wavelength of 589 nm. What is the angle of the 4th order minimum from the central maximum?
ANSWER KEY: INTERFERENCE AND DIFFRACTION BONUS ROUND

Group Member Names: _____________________________ Date: _________ Period: ____

Group #: __________

1. If you had two incandescent light bulbs as your light source would interference occur? Explain your answer.

No interference occurs. The sources must be coherent (maintain a constant phase change with respect to each other) and light waves from an ordinary source such as a light bulb undergo random phase changes in time intervals shorter than a nanosecond that our eyes cannot follow such rapid changes and therefore no interference is observed. Also, the source should be monochromatic (single wavelength). *You can create a set-up that makes the light bulbs coherent.

2. Who first demonstrated interference in light waves from two sources in 1801?

Thomas Young

3. In a double slit interference pattern the 1st order bright fringe appears 0.25 cm from the central maximum. The distance between the slits is 0.5 mm and the wavelength is 463 nm. What is the angle?

Convert: 0.25 cm → 2.5 E -3 m, 0.5 mm (not needed to solve problem) → 5 E -4 m, and 463 nm → 463 E -9 m or 4.63 E -7 m

\[ d \sin \theta = m \lambda \]
\[ m = 0, \pm 1, \pm 2, \ldots \]
\[ \theta = \sin^{-1}(m \lambda / d) \]
\[ \theta = \sin^{-1}(1(463 E -9)/(5 E -4)) = 0.05^\circ \]

4. The colors formed on a soap bubble are caused mainly by __________________________. Interference patterns (reflection and refraction do occur in soap bubbles but the colors are formed because different wavelengths interfere

5. Why is blue light used for illumination in an optical microscope?

Less diffraction results from the short wavelength of blue light

6. In a double slit experiment the slits are separated by 0.3096 mm and has a light with a wavelength of 589 nm. What is the angle of the 4th order minimum from the central maximum?

Convert: 0.3096 mm → 3.096 E -4 m and 589 nm → 589 E -9 m or 5.89 E -7 m

Remember the 4th dark fringe is between the 3rd and 4th bright fringe so m = 3

\[ d \sin \theta = (m + \frac{1}{2}) \lambda \]
\[ m = 0, \pm 1, \pm 2, \ldots \]
\[ \theta = \sin^{-1}((m + \frac{1}{2}) \lambda / d) \]
\[ \theta = \sin^{-1}((3 + \frac{1}{2})(589 E -9)/(3.096 E -4)) \rightarrow 0.38^\circ \]
INTERFERENCE AND DIFFRACTION EVALUATION

Please circle your answers for mathematical problems and you must show your work to earn any partial credit.

Constructive Interference: \[ d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \]

Destructive Interference: \[ d(\sin \theta) = (m + \frac{1}{2})\lambda \quad m = 0, \pm 1, \pm 2, \ldots \]

Diffraction: \[ d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \]

\[ y = L\tan \theta \]

1) A neon-laser with a wavelength of 633 nm is pointed at a diffraction grating 3000 lines/cm. Find the angle where the first bright fringe occurs?

2) In a double slit interference experiment the second order maximum is observed at an angle of 8.53° from the central maximum. The wavelength of the light source is 500 nm. Calculate the slit’s separation.

3) Your car has two headlights. What sort of interference pattern do you expect to be seen from them? Explain.
4) Light with a wavelength of 650 nm is shone on a grating. The angle between the zero and third order bright fringe is 31.5°. A) Calculate the spacing between the slits on the grating. B) Calculate the number of lines/m on the grating.

5) A diffraction grating having 400,000 lines/m has a 600 nm light source shone on it. Calculate the angle between the zero maximum and the first order maximum.

6) A prism separates colors of light by ___________________________. A diffraction grating separates colors of light by ___________________________.

7) The second order maximum fringe is obtained at an angle of 19°. The grating has 300 lines/mm. What is the wavelength of the light?

8) Describe the changes in a single-slit diffraction pattern as the width of the slit is decreased.
9) Two slits are 0.05 mm apart. A laser of wavelength 633 nm is incident to the slits. A) Calculate the angle of the third dark fringe.

10) Monochromatic light ($\lambda = 441$ nm) is shone upon a narrow slit. On a screen 2 m away, the distance between the second diffraction minimum and the central maximum is 1.5 cm. What is the width of the slit?
**ANSWER KEY: INTERFERENCE AND DIFFRACTION EVALUATION**

Name: ____________________________________ Date: __________________ Period: _____

Please circle your answers for mathematical problems and you must show your work to earn any partial credit.

**Constructive Interference:** \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \)

**Destructive Interference:** \( d(\sin \theta) = (m + \frac{1}{2})\lambda \quad m = 0, \pm 1, \pm 2, \ldots \)

**Diffraction:** \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \)

\[ y = L \tan \theta \]

1) A neon-laser with a wavelength of 633 nm is pointed at a diffraction grating 3000 lines/cm. Find the angle where the first bright fringe occurs?

Convert: 633 nm \( \rightarrow \) 633 E\(-9\) m or 6.33 E\(-7\) m; 3000 lines/cm \( \rightarrow \) 3.33 E\(-4\) cm \( \rightarrow \) 3.33 E\(-6\) m

**1st order:** \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \) \( \rightarrow \) \( \theta = \sin^{-1}(m\lambda/d) \)

\[ \theta = \sin^{-1}([1(633 \text{ E-9})]/(3.33 \text{ E-6}))) \]

\[ 10.96° \]

2) In a double slit interference experiment the second order maximum is observed at an angle of 8.53° from the central maximum. The wavelength of the light source is 500 nm. Calculate the slit’s separation.

Convert: 500 nm \( \rightarrow \) 500 E\(-9\) m or 5 E\(-7\) m

\( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \) \( \rightarrow \) \( d = m\lambda/\sin \theta \)

\[ d = [(2)(500 \text{ E-9})]/ \sin 8.53° \]

\[ 6.74 \text{ E-6 m} \]

3) Your car has two headlights. What sort of interference pattern do you expect to be seen from them? Explain.

None. Headlights are not coherent sources (cannot produce sustained interference patterns)

Bonus points: the headlights are so far apart in comparison to the wavelength emitted that even if they were made into coherent sources, the interference maximum and minimum would be too closely spaced to be observed.
4) Light with a wavelength of 650 nm is shone on a grating. The angle between the zero and third order bright fringe is 31.5°.  A) Calculate the spacing between the slits on the grating.  B) Calculate the number of lines/m on the grating.

Convert: 650 nm → 650 E -9 m or 6.5 E -7 m

A) \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \) → \( d = m\lambda / \sin \theta \) → \( d = [(3)(650 \ E -9)]/ (\sin 31.5^\circ) \) → 

\[ 3.73 \ E - 6 \ m \]

B) \((3.73 \ E - 6 \ m)^{-1} \to 267,947.98 \text{ lines/m} \to 2.7 \ E +5 \text{ lines/m} \]

5) A diffraction grating having 400,000 lines/m has a 600 nm light source shone on it. Calculate the angle between the zero maximum and the first order maximum.

Convert: 600 nm → 600 E -9 m or 6 E -7 m; 400,000 lines/m → 2.5 E -6 m

1st order: \( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \) → \( \theta = \sin^{-1}(m\lambda / d) \) → \( \theta = \sin^{-1}((1)(600 \ E -9))/(2.5 \ E -6)) \)

13.89°

6) A prism separates colors of light by __refraction_________________. A diffraction grating separates colors of light by __interference______________.

7) The second order maximum fringe is obtained at an angle of 19°. The grating has 300 lines/mm. What is the wavelength of the light?

Convert: 300 lines/mm → 3.33 E -3 mm → 3.33 E -6 m

\( d(\sin \theta) = m\lambda \quad m = 0, \pm 1, \pm 2, \ldots \) → \( \lambda = d(\sin \theta)/m \) → \( \lambda = (3.33 \ E -6)(\sin 19^\circ)/2 \) → 

\[ 5.42 \ E - 7 \ m \text{ or } 542 \text{ nm} \]

8) Describe the changes in a single-slit diffraction pattern as the width of the slit is decreased.

The bands get wider and dimmer. Longer wavelengths will produce fringes with greater spacing on the screen because the spacing is directly proportional to the wavelength.
9) Two slits are 0.05 mm apart. A laser of wavelength 633 nm is incident to the slits. A) Calculate the angle of the third dark fringe.

Convert: 0.05 mm → 5 E -5 m; 633 nm → 633 E -9 m or 6.33 E -7 m

Remember the 3rd dark fringe is between the 2nd and 3rd bright fringe so m = 2

d(sin\(\theta\)) = (m + \(\frac{1}{2}\)). m = 0, ±1, ±2,... \(\theta = \sin^{-1}(\frac{(m + \frac{1}{2})\lambda}{d})\) → \(\theta = \sin^{-1}(\frac{(2 + \frac{1}{2})(633 E -9)}{(5 E -5)})\) \(\approx 1.81^\circ\)

10) Monochromatic light (\(\lambda = 441\) nm) is shone upon a narrow slit. On a screen 2 m away, the distance between the second diffraction minimum and the central maximum is 1.5 cm. What is the width of the slit?

Convert: \(\lambda = 441\) nm → 441 E -9 m or 4.41 E -7 m; 1.5 cm → 0.015 m

L = 2 m \ y = 0.015 m \ m = (1 + \frac{1}{2}) \ \theta = ? \ d = ?

First find angle: \ y = L\tan\theta \ \theta = \tan^{-1}(y/L) \ \theta = \tan^{-1}(\frac{0.015}{2}) = 0.43^\circ\)

Remember the 2nd dark fringe is between the 1st and 2nd bright fringe so m = 1

d(sin\(\theta\)) = (m + \(\frac{1}{2}\)). m = 0, ±1, ±2,... \(d = (m + \frac{1}{2})\lambda/\sin\theta \ d = [(1 + \frac{1}{2})(441 E -9)]/\sin 0.43^\circ\) \(d = 8.81 E -5\) m
DIFFRACTION OF LIGHT

Diffraction, Lasers and Holograms

http://dansdata.blogsome.com/2006/12/19/light-bulb-diffraction/
DIFFRACTION

• Diffraction: the spreading of waves into a region behind an obstruction.

• Diffraction patterns are less spread out-and therefore less visible-when light passes through a wider slit. This is due to the slit no longer resembles a point source. The light from broad sources is responsible for the sharp shadows produced by obstacles.

All images: http://en.wikipedia.org/wiki/Diffraction
Light spreads out, or diffracts, from the narrow slit opening, to form a diffraction pattern on the screen.

The diffracted beams from two slits interfere to make narrow bands of light and dark, interference fringes on the screen.

The effect of increasing the number of slits is to narrow and brighten the bright fringes. Smaller bright fringes between the major fringes disappear as more slits are used.

All images: http://www.daviddarling.info/encyclopedia/D/diffraction.html
A shadow is formed where light rays cannot reach. The light from broad sources is responsible for the sharp shadows produced by obstacles.

Sharp shadows can be created by a small light source nearby or by larger source farther away.

One result of diffraction is that sharp shadows are not produced due to interference.

Usually, there is a dark part on the inside and a lighter part around the edges of the shadow.

**Umbra**: a total shadow

**Penumbra**: a partial shadow; it appears where some of the light is blocked.
A diffraction grating uses diffraction and interference to disperse light into its component colors with an effect similar to that of a glass prism.

- \(d \sin \theta = m \lambda\)
- \(m = 0, \pm 1, \pm 2, \ldots\)
Diffraction of a green and red laser.

Diffraction of a white light source.
• **Resolution**: ability of an optical instrument to resolve detail in the object that is being imaged. It depends on wavelength and aperture width.

• The **resolution** of an optical instrument can be limited by factors such as flaws in the lenses or misalignment. However, there is a **max** to the resolution of any optical instrument due to **diffraction**.

• **Resolving power** is the ability of an optical instrument to separate two images that are close together. It is greater for short wavelengths.
Diffraction increases as the imaging lens iris is closed.

Resolution/contrast decrease as the diffracted dots approach each other because they begin to blend together.

All images: http://www.edmundoptics.com/technical-resources-center/imaging/electronic-imaging-resource-guide/?&pagenum=2
LASERS: Light Amplification by Stimulated Emission of Radiation

• A laser is a device that converts light, electrical energy, or chemical energy into coherent light.

• There are many types of lasers but they all use an active medium to which energy is added to produce coherent light.

• The active medium can be solid, liquid, or gas. The composition of the active medium determines the wavelength, or color, of the light produced by the laser.

Red (635nm), green (532nm) and blue (445nm) laser pointers; http://en.wikipedia.org/wiki/Laser_pointer
LASERS

• **Unlike incandescent light sources that emit electromagnetic waves at different times and in different directions, lasers produce an intense, nearly parallel beam of coherent light.**

• **Because the light waves are in phase in a laser, they interfere constructively at all points. (increases amplitude → energy)**

HOW A LASER WORKS

1. Electron is pumped to a higher energy level.

2. Pumping level is unstable, so the electron quickly jumps to a slightly lower energy level.

3. Electron relaxes to a lower energy state and releases a photon.

4. Light and an electron in an excited energy level...

5. ...produces two photons of the same wavelength and phase.

6. Mirror reflects photons.
USES OF LASERS

• A laser can measure large distances, because it can be pointed at distant reflectors and detected again.

• Lasers improve information storage and retrieval.

• Lasers are used in CD and DVD players.

• Lasers are used in medical procedures.

• Lasers are used in scientific research.
CD/DVD RAINBOW

• If you had a completely blank CD/DVD, one without the spiral or spiral of bumps, it would be a perfect mirror. The bumps are what give a CD its rainbow colors!
• The discs disperse light into its component colors in a manner similar to that of a diffraction grating. Constructive interference occurs due to the various reflecting surfaces.
• Light rays bend (diffract) when they reflect off of the surface and separate into different wavelengths. We see each wavelength as a different color.

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html
A disc has a single spiral track of data, circling from the inside of the disc to the outside. The data track is approximately 0.5 microns wide, with 1.6 microns separating one track from the next.

All images:  http://electronics.howstuffworks.com/cd1.htm
CD/DVD Player Components

The CD/DVD player has the job of finding and reading the data stored as bumps on the disc. Considering how small the bumps are, the disc player is an exceptionally precise piece of equipment. The drive consists of three fundamental components:

A **drive motor** spins the disc. This drive motor is precisely controlled to rotate between 200 and 500 rpm depending on which track is being read.

A **laser and a lens system** focus in on and read the bumps.

A **tracking mechanism** moves the laser assembly so that the laser's beam can follow the spiral track. The tracking system has to be able to move the laser at micron resolutions.

http://electronics.howstuffworks.com/cd4.htm

http://www.stebbing.co.nz/resource_pages/cddvdworks.html
The tracking system, as it plays the CD/DVD, has to continually move the laser outward. As the laser moves outward from the center of the disc, the bumps move past the laser faster -- this happens because the linear speed of the bumps is equal to the radius times the speed at which the disc is revolving (rpm). Therefore, as the laser moves outward, the spindle motor must slow the speed of the CD. That way, the bumps travel past the laser at a constant speed, and the data comes off the disc at a constant rate.

http://express.howstuffworks.com/express-cd.htm
The laser focuses on the track of data bumps and shoots the laser beam through the polycarbonate layer so that it reflects off the aluminum layer. The reflected light activates a special on/off switch, called an opto-electronic switch. This then takes in the binary information and translates it into an audio format.

In the CD/DVD player, each string of 1s and 0s corresponds to an electrical signal (a voltage). The DAC (digital-to-analog converter) turns the numbers into voltages. The voltages change 44,000 times per second! The amplifier sends the voltages to the speakers where they turn into a series of sounds. Voltage samples (base-10 value) from 4-bit codes
USING A CD/DVD AS A DIFFRACTION GRATING

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html

Photograph taken by Porter-Davis and Balachandran at Georgia Tech (Summer 2008)
AFM Images of CD/DVD (unrecorded)

Images taken by Porter-Davis and Balachandran at Georgia Tech (Summer 2008) on portable AFM (NNIN)
AFM IMAGES OF RECORDED CD, DVD AND BLU-RAY

Images taken by Porter-Davis and Balachandran at Georgia Tech (Summer 2008) on portable AFM (NNIN)
SPECTROMETERS

• Every substance produces different light frequencies and patterns which act like a chemical fingerprint.

• Using this idea, unknown samples can be analyzed using spectrometers then compared to known patterns to determine the sample’s make-up.
HOW SPECTROMETERS WORK

• A simple device that begins with a way of collecting light from a sample and guiding that light onto a diffraction grating. The diffraction grating then directs light onto mirrors, which lead the light to either a flat surface to show the spectrum or a charged coupled device (CCD) chip, which can record the light pattern.
TYPES OF SPECTROMETERS

- **Spectroscope**: uses a diffraction grating to separate electromagnetic radiation (light) into its component wavelengths. The spectroscope can be used to measure absorption or emission spectra.

Spectroscopes are used in Astronomy to determine the make-up of stars.

http://amazing-space.stsci.edu/resources/explorations/groundup/lesson/basics/g23/

http://www.uwplatt.edu/chemep/chem/chemscape/labdocs/catofp/measurep/spectro/spectrs3.htm


TYPES OF SPECTROMETERS

- **Raman Spectroscopy**: a technique used to detect vibrational, rotational and other low frequency modes in a sample.

- Based on Raman scattering which is an inelastic scattering (KE is not conserved) of a photon.

- The photon is the incident particle and interacts with matter and the frequency of the photon is shifted to red (energy of photon decreases) or blue (energy of photon increases).

- The molecular bonds and chemical make-up determine the Raman shift and spectra.
TYPES OF SPECTROMETERS

• Fourier Transform Infrared Spectroscopy (FTIR): is a technique which is used to interpret an infrared spectrum of absorption, emission or Raman scattering of a sample. The FTIR gathers spectral data in a wide range at the same time and then the computer takes the data to infer the absorption at each wavelength.

Raman and FTIR are complementary to one another. They both detect changes in vibration and rotation at the molecular level. But while FTIR measures the amount of IR light absorbed, Raman measures the amount of light scattered.
HOLOGRAMS

• Holography depends on the coherent nature of laser light to create an interference pattern that produces a 3-D image when illuminated by a light source. Four main types: transmission, reflection, pulsed and embossed

• Many pairs of beams form an extremely complicated interference pattern on film, one that can be produced only if the phase relationship of the 2-wave pairs is constant throughout the exposure of the film. This condition is met through the use of light from a laser because of the coherence of laser light.

The holograms found on credit cards and other ordinary objects are embossed holograms mass-produced by stamping the pattern onto foil.

Close-up photograph of a hologram's surface (a toy van). Can not tell what it is similar to trying to identify what music has been recorded by looking at the surface of a CD. The hologram is defined by the speckle pattern, rather than the "wavy" line pattern.

http://en.wikipedia.org/wiki/Holography

Image courtesy Dreamstime; http://science.howstuffworks.com/hologram10.htm

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http://en.wikipedia.org/wiki/Holography

Image courtesy Dreamstime; http://science.howstuffworks.com/hologram10.htm
SOME TYPES OF HOLOGRAMS

• **Transmission:** they should be lit from behind (like a slide in a slide projector). It can be difficult to light the hologram in this manner so a mirror or a foil backs the hologram.

• **Embossed:** are a type of transmission hologram; most common; can be massed produced quickly and cheaply; The original hologram is made into a metal copy and duplicates are used to create millions of copies by embossing the pattern into soft aluminized plastic.

• **Reflection:** the object and reference beams are incident on the plate from opposite sides of the plate. The reconstructed object is then viewed from the same side of the plate as that at which the re-constructing beam is incident.

• **Pulsed:** instead of a steady laser being directed on the image a rapidly pulsed laser is used. This reduces the need for vibrational tables.
If you tear a hologram in half, you can still see the whole image in each piece. The same is true with smaller and smaller pieces.

The interference fringes in a hologram cause light to scatter in all directions, creating an image in the process. The fringes diffract and reflect some of the light (inset), and some of the light passes through unchanged.
Basic transmission hologram:
1) The laser points at the beam splitter, which divides the beam of light into two parts.
2) Mirrors direct the paths of these two beams so that they hit their intended targets.
3) Two beams pass through a diverging lens and becomes a wide band of light rather than a narrow beam.
4) Object beam, reflects off of the object and onto the photographic emulsion.
5) The reference beam, hits the emulsion without reflecting off of anything other than a mirror.

Example of a transmission hologram; usually can only be reconstructed using a laser but a particular type of transmission hologram, known as a rainbow hologram, can be viewed with white light.

http://science.howstuffworks.com/hologram.htm/printable
1- **Channel**: You can see several views of kitten and "movement" of background. Although hologram was recorded on flat media, you can see full 3D illusion of the object.

**Multi-Channel**: "Channels" mean different images, recorded on the same hologram. Such images appear in a hologram one after another during observation. There are two channels within this picture.
**NSS: PHYSICAL SCIENCE**

- **MOTIONS AND FORCES**
  - Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

- **CONSERVATION OF ENERGY AND THE INCREASE IN DISORDER**
  - All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.

- **INTERACTIONS OF ENERGY AND MATTER**
  - Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.
  - Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.
  - Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.
GPS: PHYSICS

SP4. Students will analyze the properties and applications of waves.
- a. Explain the processes that result in the production and energy transfer of electromagnetic waves.
- b. Experimentally determine the behavior of waves in various media in terms of reflection, refraction, and diffraction of waves.
- c. Explain the relationship between the phenomena of interference and the principle of superposition.
- e. Determine the location and nature of images formed by the reflection or refraction of light.

SP3. Students will evaluate the forms and transformations of energy.
- a. Analyze, evaluate, and apply the principle of conservation of energy and measure the components of work-energy theorem by
  - describing total energy in a closed system.
  - identifying different types of potential energy.
  - calculating kinetic energy given mass and velocity.
  - relating transformations between potential and kinetic energy.
- b. Explain the relationship between matter and energy.
- e. Demonstrate the factors required to produce a change in momentum.
REFERENCES

Books:

Websites:


REFERENCES


REFERENCES


INTERFERENCE AND DIFFRACTION OF LIGHT
1) Projected on a screen is a two-slit interference pattern, the fringes are evenly spaced on the screen

- A) Only for small angles
- B) Only for large angles
- C) Only at 45°
- D) never
2) Which of the following is a monochromatic and coherent light source?

- A) LED
- B) Fluorescent
- C) Laser
- D) Incandescent
3) Which is not a type of hologram that was discussed?

A) refraction
B) transmission
C) pulsed
D) embossed
4) What is the function of a spectrometer?

A) To eliminate light dispersion
B) To reduce constructive interference
C) To separate light from a source into its monochromatic components
D) To produce coherent light
5) All lasers use a substance called the ________________ to which energy is added to produce coherent light.

A) Gas-ion barrier
B) Stimulated emission
C) Photon beam
D) Active medium
6) Instruments that have high resolution are created to

- A) Reduce interference
- B) Eliminate coherence of light waves
- C) Enhance dispersion
- D) Maximize diffraction patterns
7) In a double slit experiment, the angle between the central maximum and the second bright fringe is $2^\circ$. The slit separation is $3.8 \times 10^{-5}$ m. What is the wavelength of the light source?

- A) $5.3 \times 10^{-7}$ m
- B) $6.6 \times 10^{-7}$ m
- C) $5.9 \times 10^{-8}$ m
- D) $6.4 \times 10^{-8}$ m
8) To meet the needs to form an interference pattern a(n) ____________________ is usually used as a light source.

   A) Halogen bulb
   B) Mercury vapor lamp
   C) Laser
   D) Light Emitting Diode
9) Which of the following changes would increase the resolution of a telescope?

- A) Observing light at a low wavelength, increasing the aperture
- B) Observing light at a low wavelength, decreasing the aperture
- C) Observing light at a high wavelength, increasing the aperture
- D) Observing light at a high wavelength, decreasing the aperture
10) The inelastic scattering (KE is not conserved) of a photon is called

- A) Rayleigh Scattering
- B) Tyndall Scattering
- C) Raman Scattering
- D) Mie Scattering
INTERFERENCE OF LIGHT
LIGHT WAVES COMBINE WITH EACH OTHER

- Interference takes place only between waves with the same wavelength.

- **Monochromatic**: light waves that have the same wavelength.

- **Constructive**: light becomes brighter

- **Destructive**: light becomes dimmer
INTERFERENCE

- Waves must have a constant phase difference for interference to be observed.
- Crest 1 + Crest 2 = phase difference of $0^\circ$ and said to be in phase.
- Crest 1 + Trough 2 = phase difference of $180^\circ$ and said to be out of phase.
- When the phase difference between two waves is constant and the waves do not shift relative to each other as time passes, the waves are said to have coherence.
DEMONSTRATING INTERFERENCE

- Light from a single source is passed through a narrow slit and then through two narrow parallel slits. The slits serve as a pair of coherent light sources because the waves emerging from them come from the same source.

- If monochromatic light is used, the light from the two slits produces a series of bright and dark parallel bands (fringes).
Results of Young's Experiment

Top View of Experimental Set-Up

Slit

Laser

Front View of Screen

Low frequency
Large spacing between bright bands.

High frequency
Small spacing between bright bands.

http://www.chk.ac.th/physic/wbi/Class/light/U12L1b.html
PREDICTING THE LOCATION OF INTERFERENCE FRINGES

- **Path difference**: the difference in the distance traveled by two interfering light waves.

- **Constructive**: \( d \sin(\theta) = m\lambda \)

- **Destructive**: \( d \sin(\theta) = (m + \frac{1}{2})\lambda \)  
  (odd # \(\lambda\))

- **Order number \((m)\)**: the number assigned to interference fringes with respect to the central bright fringes)
IRIDESCENCE

- Objects that show a rainbow of colors which can change depending on our point of view, are considered iridescent.
- Iridescence is from the Latin word, "iris," meaning rainbow.
- Iridescence is caused by "structural colors" rather than pigment molecules.

http://www.flickr.com/photos/atlapix/1236129334/
Examples of Interference in Nature

Peacock Feather  Abalone Shell  Iridescent Opal

Figure 9

http://www.microscopyu.com/articles/polarized/interferenceintro.html
http://www.itp.uni-hannover.de/~zawischa/ITP/multibeam.html
**CAUSE OF IRIDESCENCE**

- Constructive and destructive interference of different wavelengths of light produces different colors when viewed at different angles of incident light.

- Seen with thin-films (Soap Bubbles, Oil on Water) or with diffraction gratings (pearls, CDs).

- Colors seen are due to:
  - index of refraction
  - thickness of the film/grating
  - wavelength of light
  - angle of incidence
PHASE CHANGES AT BOUNDARIES

A Free End boundary is similar to light entering a material with an index of refraction lower than the incident material. No phase shift occurs.

A Fixed End boundary is similar to light entering a material with an index of refraction higher than the incident material. An 180° phase shift occurs.

Only reflected waves can have phase shifts – Refracted waves do not.
THIN-FILMS

- A thin film is a layer of material ranging from fractions of a nanometer to several micrometers in thickness. Electronic semiconductor devices and optical coatings are the main applications benefitting from thin film construction.
As the film gets thin at the top it becomes black because its thickness is less than the wavelength of the visible light.
Interference Structures in Butterfly Wings

Magnified View of Wing Scales

Morpho Butterfly

Scale Ridges

Wing Scale Base Lamella

Ridge Plates

Air Spaces

Attachment to Lamella

Figure 3

http://www.microscopyu.com/articles/polarized/interferenceintro.html
CONSTRUCTIVE INTERFERENCE
AND THIN-FILMS

- Ex) soap bubble or oil on water
- Light reflecting from the top has phase shift
- Light reflecting from the bottom has no phase change.
- Destructive interference would occur for most colors.
- But, if the thickness of the film is $\frac{1}{4} \lambda$ (of a certain color of light) the light would travel an extra distance of $\frac{1}{2} \lambda$.
- This color’s $\lambda$ is in phase with the top reflected wave $\rightarrow$ film appears this color (Constructive Interference).
INSIDE A SOAP BUBBLE

http://www.webexhibits.org/causesofcolor/15E.html
THICKNESS OF FILM DETERMINES COLOR

Red light reflected from the top surface interferes constructively with red light from the bottom surface, so the film looks red. Light of the other colors experiences destructive interference.

$n_{\text{air}} = 1$
$n_{\text{oil}} = 1.5$
$n_{\text{water}} = 1.33$

Color is perceived as Red

Thickness of Film is $\frac{1}{4}$ the $\lambda$ of Red Light
DESTRUCTIVE INTERFERENCE AND THIN-FILMS

- Ex) non-reflective coatings and colors are seen on silicon wafers with a SiO$_2$ thin-film.
- Since $n_{\text{substrate}} > n_{\text{film}} > n_{\text{air}}$ both the top and bottom reflected waves have $180^\circ$ phase shift.
- Most colors of light will constructively interfere.
- But, if the thickness of the film is $\frac{1}{4} \lambda$ (of a certain color of light) the light would travel an extra distance of $\frac{1}{2} \lambda$.
- This color’s $\lambda$ is out of phase with the top reflected wave and cancels (Deconstructive Interference).
- The color seen is a mix of the other frequencies.
THICKNESS OF FILM DETERMINES COLOR

Light reflecting from the bottom surface travels an extra distance of \( \frac{1}{2} \) the \( \lambda \) of green light. Green light reflected from the top surface interferes destructively with green light from the bottom surface. Most of the light in the middle region of the visible spectrum is transmitted and not reflected. Since some violet and red light is reflected the coating is perceived as purple.

\[
\begin{align*}
\text{n}_{\text{air}} &= 1 \\
\text{n}_{\text{SiO}_2} &= 1.463 \\
\text{n}_{\text{silicon}} &= 3.96
\end{align*}
\]
SPECTRUM APPLET

http://www.cs.rit.edu/~ncs/color/a_spectr.html
<table>
<thead>
<tr>
<th>Film Thickness (Å)</th>
<th>Color of Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>tan</td>
</tr>
<tr>
<td>700</td>
<td>brown</td>
</tr>
<tr>
<td>1000</td>
<td>dark violet to red violet</td>
</tr>
<tr>
<td>1200</td>
<td>royal blue</td>
</tr>
<tr>
<td>1500</td>
<td>light blue to metallic blue</td>
</tr>
<tr>
<td>1700</td>
<td>metallic to very light yellow-green</td>
</tr>
<tr>
<td>2000</td>
<td>light gold or yellow - slightly metallic</td>
</tr>
<tr>
<td>2200</td>
<td>gold with slight yellow-orange</td>
</tr>
<tr>
<td>2500</td>
<td>orange to melon</td>
</tr>
<tr>
<td>2700</td>
<td>red-violet</td>
</tr>
<tr>
<td>3000</td>
<td>blue to violet-blue</td>
</tr>
<tr>
<td>3100</td>
<td>blue</td>
</tr>
<tr>
<td>3200</td>
<td>blue to blue-green</td>
</tr>
<tr>
<td>3400</td>
<td>light green</td>
</tr>
<tr>
<td>3500</td>
<td>green to yellow-green</td>
</tr>
</tbody>
</table>

The appearance of color is due to the constructive and destructive interference of light. The wavelengths of light in SiO₂ which undergo destructive interference is given by:

\[ \lambda_k = \frac{(5.84t)}{(2k + 1)} \]

Where:
- \( \lambda \) = wavelength
- \( t \) = oxide thickness
- \( k = 0, 1, 2, ... \) (and which give solutions in the visible light spectrum)

The color of light seen is the eyes response to the amplitude of the wavelengths remaining.
Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.

Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.

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REFERENCES

Books:

Websites:


REFERENCES


REFERENCES

<http://www.oakridgemicro.com/tech/tfb.htm#up>

http://www.ehow.com/about_5372347_spectrometer.html#ixzz2VvsNbxju>
TEACHER INSTRUCTIONS FOR DIFFRACTION LAB

MATERIALS

CDs, DVDs, diffraction gratings of various sizes, laser pointers, screen/poster board, tape, rulers/meter-sticks, clamps, AFM images of a CD and DVD gratings (provided), razor blades, tweezers, packing tape (for making the diffraction gratings from the CDs/DVDs)

ADVANCED PREPERATIONS

RETRIEVAL OF PHYSICAL DIFFRACTION GRATINGS FROM CDs AND DVDs

DVDs

1) Identify the two layers and take a razor blade and carefully slice between them. They should separate fairly easily.
2) Discard the protective polycarbonate coating.
3) Take large pieces of tape (packing tape works well) and gently press the tape onto the reflective surface and then rip the tape off. Continue this until the majority of the metal coating is removed. (Sometimes small pieces of metal are difficult to remove – this is not a problem just use a portion that is clear for the large scale experiment or for imaging purposes).
4) Cut into 3 cm x 3 cm sections (large enough that they can be clamped and used with a laser pointer)

Clockwise from top left

1) Split along the edge
2) Separate into 2 layers
3) Peel off the reflecting layer with tape
4) You now have a transmission grating

CDs

1) An unpainted CD is required (CD-R’s and CD-RW’s work well)
2) Take large pieces of tape (packing tape works well) and gently press the tape onto the top surface (the side that can be written on) and then rip the tape off. Continue this until the majority of the metal coating is removed. (There are two layers of metal – the top layer is the one that can be written on, the lower layer is the reflective layer – both must be removed).
SAFETY INFORMATION

LASERS

Most lasers used in high school laboratories are the continuous wave, low power (0.5 - 3.0 mW.) lasers. The main danger is possible damage to the retina if a student looks directly into the beam or non-diffused reflection. Remind the students of this and direct them to be very careful when using the lasers.

RAZOR BLADES

The blades are quite sharp and could cut or puncture a student. The teacher may want to handle the process of opening the DVDs prior to the student’s lab.

DIRECTIONS FOR THE ACTIVITY

1) Discuss interference, diffraction and diffraction gratings.
2) Demonstrate diffraction with different types of gratings.
3) Divide the class into two – four student groups.
4) Review the general procedures of the lab and remind the students about the safety concerns when using lasers.
5) After the data is collected from the CD and DVD gratings discuss the size of these gratings and how small a distance the grooves are from one another. Ask the students if they are able to measure the grooves with a ruler or able to see the grooves under an optical microscope (if an optical microscope is available demonstrate this for the class).
6) Explain to the students that objects on the micro- and nano-scale must have special equipment to be viewed. Discuss the basic concept of the AFM (make sure the students understand that the images that they see are not photographs but digital interpretations of the topography of the object).
7) Depending on time and equipment restraints there are three options for the second part of the lab:

   Use the hard copies of the images provided and with a ruler measure the distance between tracks. Have the students perform the calculations to determine the distance between tracks and compare to the other data obtained.

Step 1: Prepare CDs and DVDs to use as diffraction grating (see above)

Step 2: Gather materials and set up each group for the lab

Step 3: Explanation of Diffraction Grating Setup
Obtain a laser and fix it to a stand such that the laser is held horizontally and securely using a clamp. If you do not have enough ring stands then one student can hold the laser in place.

Use another stand to position the diffraction grating in front of the laser such that the light from the laser is incident normally on the grating. Place the grating as close to the laser as possible.

Use a blank wall/white board/poster board as the screen so that the diffraction pattern can be observed clearly. It is preferable that the room be dark so that it is easy to observe the diffraction pattern. The laser should be positioned about a meter (or less) away from the screen.

Switch on the laser and look for the central non-diffracted beam spot on the screen. The first order maxima should be visible on either side of the central spot. The second and third order can also be observed but may not be as bright as the first order image. A student from each group should mark these spots.

**Step 4: Diffraction pattern using the CD/DVD**

Use same procedure as diffraction gratings, however:

*If the images are not on a horizontal on the screen rotate the CD and change its orientation until you get the images on a horizontal line. Note that the tracks are spiral in a CD or DVD and so the spacings are not exactly parallel. The treatment for a plane transmission grating can be applied to a CD or DVD grating to a good approximation. This is also why the first and second order images may not be exact spot images of the laser beam.*

**Picture and Diagram of the experimental set up**

---

**DIFFRACTION EQUATIONS**

\[ d \sin \theta_{\text{calc.}} = m \lambda \quad \text{and} \quad y = L \tan \theta_{\text{obsr.}} \]

- \( d \) = distance between slits
- \( \theta \) = path angle
- \( m \) = order number
- \( \lambda \) = wavelength of light

---

Central bright fringe

\[ m = 1 \]
Step 5: Measurement and Analysis

Diffraction Gratings:

1) After the set-up and the fringes are marked:
   a) Measure the distance of the first order maxima from the central spot on either side and calculate its average (y). Either side should give a very close value.
   b) Measure the distance of the laser to the screen (L).
   c) Use the label on the laser to identify the wavelength of the laser beam that is used (\(\lambda\)).
   d) Convert the diffraction grating size to distance between slits in meters. Ex) 100 lines/mm \(\rightarrow\) 1/100 = 0.01 mm/line \(\rightarrow\) 1 E -5 m/line
   e) Remind students to have their calculators set in degrees and not radians.

   Since the angle of diffraction for the first order is not really small (about 22 °), the approximation that \(\sin \theta = \tan \theta\) is not valid. Evaluate \(\tan \theta\) using the equation given in Step 4; if the first order image is too spread out on the screen on either side try reducing the distance of the screen to the laser setup.

\[ x = \text{distance from maximum on screen} \]

\[ d = \text{distance from grating to screen} \]

\[ \lambda_{\text{laser}} = \text{wavelength of laser} \]

\[ \theta_{\text{diffraction}} = \text{calculated angle of diffraction} \]

\[ d = \text{grating separation (average track spacing)} \]

To find \(\theta_{\text{calc}}\) use the values for \(d, \lambda,\) and \(m = 1\) with equation 1.

**Equation 1:** \(d \sin \theta_{\text{calc}} = m \lambda. \ m = 0, \pm 1, \pm 2, \ldots \ \Rightarrow \ \theta_{\text{calc}} = \sin^{-1}(m\lambda/d)\)
To find $\theta_{\text{observed}}$ measure distance from grating to screen ($L$) and the first order distance from central bright fringe ($y$) and then by using equation 2 calculate the angle ($\text{observed}$).

Equation 2: $y = L \tan \theta_{\text{observed}} \Rightarrow \theta_{\text{observed}} = \tan^{-1}(y/L)$

**Calculate Percent Error:** Have the students compare the observed and calculated angles by using percent error. I have gotten pretty good results with this. The main error is that the students did not convert $d$ correctly. $|O - A|/A \times 100\%$ (O is the observed angle value and A is the calculated value)

**Step 6: Track Pitch of the CD/DVD**

Repeat the same procedure for a CD/DVD. With the DVD, it may be difficult to observe the second and the third order images; it is also advisable to move the laser arrangement much closer to the screen so that the first order image is closer to the central non-diffracted spot. Measure $y$ and $L$ using the same procedure in Step 5. Using equation 2 calculate the angle and then use that angle and the wavelength of the laser and $m = 1$ to calculate $d$. Then measure spacing between tracks on the given AFM images (remind the students to convert values from their ruler to the nano-scale), this will be $d_{\text{measured}}$. Have the students calculate percent error with $O$ as the measured $d$ and $A$ as the calculated $d$.

**Fig1a. AFM image** : Sample : Memorex CD 750 MB; blank; scan size 10 micrometer

**1b. Line scan of the image**
Calculations for the CD image:

Scale factor: 7.2 cm = 10 micrometers; 1 cm = 1.39 micrometers
4 x track pitch = 4.4 cm = 6.12 micrometers
track pitch = 1.53 micrometers

(Note that the grating element is the combined width of the opaque and transparent lines in a regular grating; so measure the distance between tracks as including the width of the track – See arrow in scan)

Calculations for the DVD image:

Scale factor: 7.2 cm = 5 micrometers; 1 cm = 0.694 micrometer
3x track pitch = 3.4 cm = 2.36 micrometers
track pitch = 1.13 cm = 0.787 micrometer
DIFFRACTION GRATING LAB

TEACHER’S COPY

MATERIALS:

Diffraction gratings, a CD/DVD with aluminum coating removed, laser pointer, ring-stand with clamp, and white screen (or poster board)

PROCEDURE:

Use the information on the diffraction gratings to compare the calculated angle of diffraction with the measured one (first order maximum). Use a CD/DVD as a diffraction grating and determine the distance between the grooves.

DATA:

Wavelength of laser (λ): ________________ m

DIFFRACTION EQUATIONS

\[ dsin\theta_{\text{calc.}} = m\lambda \quad \text{and} \quad y = Ltan\theta_{\text{observed}}. \]

- \( d \) = distance between slits
- \( y \) = distance from central to 1st bright fringe
- \( \theta \) = path angle
- \( m \) = order number

<table>
<thead>
<tr>
<th>Grating</th>
<th>( d ) (meters)</th>
<th>( y ) (meters)</th>
<th>( L ) (meters)</th>
<th>( \theta_{\text{calculated}} )</th>
<th>( \theta_{\text{observed}} )</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 lines/mm</td>
<td>( 1 \times 10^{-5} )</td>
<td></td>
<td></td>
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<tr>
<td>300 lines/mm</td>
<td>( 3.33 \times 10^{-6} )</td>
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<tr>
<td>530 lines/mm</td>
<td>( 1.89 \times 10^{-6} )</td>
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<tr>
<td>600 lines/mm</td>
<td>( 1.67 \times 10^{-6} )</td>
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For the CD/DVD:

Calculate the $\theta_{\text{diffraction}}$ for the first order maximum using the measured $y$ and $L$. Then using the calculated angle solve for $d$ using $d \sin \theta_{\text{calc.}} = m \lambda$. Compare it to the $d$ measured from the AFM image of the CD/DVD using the % Error equation.

<table>
<thead>
<tr>
<th>$y$ (meters)</th>
<th>$L$ (meters)</th>
<th>$\theta_{\text{diffraction}}$</th>
<th>$d_{\text{calculated}}$ (meters)</th>
<th>$d_{\text{measured}}$ (meters)</th>
<th>% Error</th>
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Fig1a. AFM image: Sample: Memorex CD 750 MB; blank; scan size 10 micrometer

2a. AFM image: Sample: Sony DVD-R 4.7 GB; Blank, scan size 5.0 micrometer