Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Chapter 9 – Waves and Light						
Day 1 Refraction (9.1, 9.2)	**E2.1** use appropriate terminology related to the wave nature of light, including, but not limited to: **diffraction, dispersion, wave interference, nodal line, phase, oscillate, polarization,** and **electromagnetic radiation** [C]	**Do Now** *Diagnostic Assessment* - Hand out assessment as students walk in - Find out how much students remember from SPH3U (use modified unit test from SPH3U) - If possible try to complete at end of previous day's class	20 min	Diagnostic Assessment	Diagnostic	SPH3U SNC2D Optics Unit
		Unit Hook Write question on the board: *How can we use properties of light to create technologies that enhance our lives?* Use Think Pair Share to discuss. Possible answers: X-rays, MRI, CT scans, photocells, lasers, infrared cameras, night vision goggles, sunglasses, CFLs, LEDs, CD, DVDs, Fibre optics, holograms, GPS etc.	5 min		Formative (Discussion)	Nelson Physics 12 - Unit 4 - Chp. 9 & 10
		Introduce Unit Project - In teams of 4, prepare and deliver a 3-5 min oral presentation - Discuss topics, may choose own topic - Review rubric - analysis of principles of light, assess impact to society, careers - Choose own group and topic, sign up on Day 3 - Presentation on Day 9	10 min	***Unit Project Handout***		Nelson Physics 12 - Unit 4 - Chp. 9 & 10
		Activity *Lab - PhET Bending Light (Java applet)* - Create a worksheet with guiding questions - Work in pairs with elbow partner to complete lab	25 min	- Worksheet - Book computer lab - Need computers with Java and Internet access - Use PhET Simulation Lab	Formative	http://phet.colorado.edu/en/simulation/bending-light

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
		Consolidation/Exit Ticket Match terminology to definitions: Periodic wave, Universal wave Equation, Law of Reflection, Refraction, Snell's Law, Dispersion, Total Internal Refraction, Fibre Optics etc.	10 min	Fill in the blanks handout	Formative	Nelson Physics 12 - Sections 9.1, 9.2
		Homework (Problem Set) Page 443 # 1-8, 12, 16, 20-21 Page 458 # 1-8	5 min		Formative	Nelson Physics 12 - Sections 9.1, 9.2

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Day 2 Diffraction (9.3)	**E2.2** conduct inquiries involving the **diffraction** and **interference** of waves, using ripple tanks or computer simulations [PR]	**Do Now** *Page 458 #10. Write out answers and hand in. This will test if students did the homework or not, of course bright students will be able to do this if they didn't do the homework.*	5 min	Blank paper	Formative	Nelson Physics 12 - Sections 9.3
		Take up homework Check if there are any questions from previous day's homework	5 min	Take up on board (if needed)		Nelson Physics 12 - Sections 9.1, 9.2
		Hook - Observation Stations Students to rotate through two stations *Station 1:* Ripple tank to observation diffraction Complete page 1 of worksheet *Station 2:* Interference from two speakers Complete page 2 of worksheet Note: I did not create the worksheet.	15 min	- Ripple tank - Two speakers - Use computer simulations if equipment not available	Formative (Observation)	Nelson Physics 12 - Section 9.3 - *Station 1:* Investigation 9.3.1, p. 487-488 - *Station 2:* Mini-Investigation lab, p. 464 - Computer Simulation http://phet.colorado.edu/en/simulation/wave-interference
		Direct Instruction Go through the derivations and sample problems p. 461, 466, 467 on board. Provide time to complete practice problems on p. 461, 467	15 min			
		Activity Homework problems - p 468-469 #1-7 Complete as group activity. Split class into 7 groups (table groups if easier). Each group to complete one question on chart paper and present answers to class.	20 min		Formative	Nelson Physics 12 - Section 9.3

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
		Homework Complete the questions you did not do.	5 min		Formative	Nelson Physics 12 - Section 9.3
		Consolidation - Summarize Lesson verbally	5 min			
		Exit Ticket 1. Name one thing you learned today. 2. Name one thing you would like to know more about.	5 min	***Exit ticket***	Formative	

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Day 3 Double Slit Concepts (9.4)	**E2.3** conduct inquiries involving the **diffraction, refraction,** polarization, and **interference of light waves** (e.g., shine lasers through **single, double, and multiple slits**; observe a computer simulation of **Young's double-slit experiment**; measure the index of refraction of different materials; observe the effect of crossed polarizing filters on transmitted light) [PR]	**Do Now** *Terminology Review Worksheet* - Hand out worksheet as students walk in - Take up answers, have students go up and fill in the blanks on the SmartBoard - Announce Chp. 9 Quiz on Day 5	5 min	***- Terminology Review Worksheet*** ***- SmartBoard***	Formative	Nelson Physics 12 - Review of 9.1, 9.2, 9.3
		Take up homework Check if there are any questions from previous day's homework	5 min	Take up on board (if needed)		
		Hook Write question on the board: *Is light a wave or particle?* - Use Think Pair Share (TPS) to discuss and take up answers. - Extension: Use debate format as an alternative to TPS (depends on class/group dynamics)	5 min		Formative (Discussion)	Nelson Physics 12 - Section 9.4
		Direct Instruction Watch and discuss Dr. Quantum video	10 min	YouTube Video		http://www.youtube.com/watch?v=DfPeprQ7oGc
		Activity *Lab - PhET Quantum lab (Java applet)* - Complete question 1 together as a class - Work in pairs with elbow partner to complete lab	30 min	***- PhET Lab Handout*** - Book computer lab - Need computers with Java and Internet access - Use PhET Simulation Lab	Formative	http://phet.colorado.edu/en/simulation/quantum-wave-interference

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
		Homework (to hand in) Complete questions 2-9 (required) Challenge questions 10-17 (optional)	5 min		Formative	
		Consolidation - Summarize Lesson verbally	5 min			
		Exit Ticket 1. Name one thing you learned today. 2. Name one thing you would like to know more about.	5 min	***Exit ticket***	Formative	

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Day 4 Double Slit Math (9.5)	**E2.4** analyse **diffraction** and **interference** of water waves and light waves (e.g., with reference to two-point source interference in a ripple tank, thin-film interference, multiple-slit interference), and **solve related problems** [PR, AI]	**Do Now** *Hand in PhET Quantum Lab* - Hand out worksheet as students walk in - Write a note about Young's double-slit experiment. Create a a fill in the blank worksheet. Take up answers.	5 min	- Young's double-slit experiment note - SmartBoard	Formative	Nelson Physics 12 - Section 9.4
		Take up homework Check if there are any questions from previous day's homework	5 min	Take up on board (if needed)		Nelson Physics 12 - Section 9.4
		Direct Instruction Show proofs and derivations for the formulas used pp. 479-482.	10 min			Nelson Physics 12 - Section 9.5
		Activity Homework problems - p 484 #2-8 Complete as group activity. Split class into 7 groups (table groups if easier). Each group to complete one question on chart paper and present answers to class.	30 min	- Chart Paper - Markers	Formative	Nelson Physics 12 - Section 9.5
		Homework Complete the questions you did not do.	5 min		Formative	Nelson Physics 12 - Section 9.5
		Consolidation - Summarize Lesson verbally - Review content covered in Chapter 9 - Review quiz expectations (20 min, multiple choice, fill in the blanks etc.)	15 min			

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Chapter 10 – Applications of the Wave Nature of Light						
Day 5 - Quiz - Diffraction Gratings (10.3)	**E3.1** describe and explain the **diffraction** and **interference of water waves in two dimensions**	**Chapter 9 Quiz** - Closed book, put all notes away, need a pen or pencil - No talking - 20 minutes If you finish early read section 10.3 of textbook	20 min	Quiz (did not create)	Summative	Nelson Physics 12 - Chapter 9
		Hook Watch and try to explain why this works. Laser show videos (if equipment available, replicate in the classroom as a demonstration)	5 min	YouTube Video from Thomas Altman	Formative	http://www.youtube.com/watch?v=Imz7IYEJZJ4 http://altmanscience.com/Lasers.html
		Direct Instruction - Discuss how a spectrometer works - Discuss how this relates to CDs or DVDs - Show proofs (maxima, minima) and derivations for the formulas used pp. 523.	10 min			Nelson Physics 12 10.3
		Activity Complete worksheet courtesy of Robert Tevlin.	30 min	Worksheet from Roberta Tevlin Day 1.5	Formative	http://roberta.tevlin.ca/12U%20Course/1)%20Wave%20Nature%20of%20Light/Wave%20nature%20Main.htm
		Consolidation - Summarize Lesson verbally	5 min			
		Exit Ticket 1. Name one thing you learned today. 2. Name one thing you would like to know more about.	5 min	***Exit ticket***	Formative	

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Day 6 - Polarization (10.5) - Thin Film and Single Slit Interference (10.1, 10.2)	E3.2 describe and explain the diffraction, refraction, **polarization,** and **interference of light waves** (e.g., r**educed resolution caused by diffraction, mirages caused by refraction, polarization caused by reflection and filters, thin-film interference in soap films and air wedges, interference of light on CDs)** E3.3 use the concepts of refraction, diffraction, **polarization,** and **wave interference** to explain the **separation of light into colours** in various situations (e.g., light travelling through a prism; **light contacting thin film, soap film, stressed plastic between two polarizing filters)**	**Return Quizzes** Take up questions that everyone missed. Post answers. Tell students to see me after class if there are specific questions they want to discuss.	5 min	Marked Quizzes	Formative	Nelson Physics 12 - Chapter 9
		Click questions (or individual white board questions) 5 multiple choice questions to review previous day's content (need to create)	5 min	Take up on board (if needed)	Formative	Nelson Physics 12 10.3
		Direct Instruction Complete observation lab, hand in by end of class	5 min			
		Activity - Observation Stations Students to rotate and make observations for each station Station 1: Reflection (Mirror and laser/light beam) Station 2: Thin film (soap) on glass Station 3: Thin film (oil) on water Station 4: Interference of light on CDs Station 5: Newton's Rings and Air Wedges Station 6: Anti-reflective coatings on glasses, windshields, cellphone cameras Station 7: Polarizing camera filter (or sunglasses) Station 8: LCD displays and Polarization Complete observations on worksheet Note: I did not create the worksheet. If finished early, start homework.	45 min	- Mirror - Light beam - glass - beaker with water - soap - oil - CDs - Newton's Rings - Air Wedges - Old glasses with anti-reflective coating - polarizing camera filter or sunglasses - LCD display (picture frame)	Formative (Observation)	Nelson Physics 12 - Section 10.1, 10.2, 10.5
		Homework p. 511 #1-3,5 p. 519 #1-3,7-10 p. 537 #1-2,5-6,11-12	5 min		Formative	Nelson Physics 12 - Section 10.1, 10.2, 10.5

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
		Consolidation - Summarize Lesson verbally	5 min			
		Exit Ticket 1. Name one thing you learned today. 2. Name one thing you would like to know more about.	5 min	***Exit ticket***	Formative	

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Day 7 Electromagnetic Radiation (10.4) Projects work period (1/2 period)	**E3.4** describe, in qualitative terms, the production of **electromagnetic radiation** by an oscillating electric dipole (e.g., a radio transmitter, a microwave emitter, an X-ray emitter, electron energy transitions in an atom)	**Do Now** *Page 537 #7. Write out answers and hand in. This will test if students did the homework or not, of course bright students will be able to do this if they didn't do the homework.*	5 min	Blank paper	Formative	Nelson Physics 12 - Section 10.1, 10.2, 10.5
		Take up homework Check if there are any questions from previous day's homework	5 min	Take up on board (if needed)	Formative	Nelson Physics 12 - Section 10.1, 10.2, 10.5
		Hook Write question on the board: *What is an example of electromagnetic radiation? I can think of ten, how many can you come up with?* - Use Think Pair Share (TPS) to discuss and take up answers.	5 min		Formative (Discussion)	Nelson Physics 12 - Section 10.4
		Direct Instruction Show image of electromagnetic spectrum Discuss practical examples	10 min	Image of Electromagnetic Spectrum		Nelson Physics 12 - Page 527
		Consolidation - Summarize Lesson verbally - Handout Unit 4 - Chp. 9 & 10 Review Package so students can start their review - Review content covered in Chapter 9 and 10 - Review quiz expectations (60 min, multiple choice, fill in the blanks etc.)	5 min	Review Package		
		Homework (to hand in) p. 531 #1-6, 10-11	5 min		Formative	Nelson Physics 12 - Section 10.4
		Activity *Work period to complete group projects.*	40 min		Formative	

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Day 8 Group Presentations	**E1.1** analyse, with reference to the **principles** related to the wave nature of light, a **technology** that uses these principles (e.g., Xeon lights, spectroscopes, polarized sunglasses) [AI, C] **E1.2** assess the **impact on society and the environment** of technologies that use the wave nature of light (e.g., **DVDs, polarized lenses, night vision goggles, wireless**	**Group Presentations** - Review format, ground rules, respect for each other - Questions: each person to come up with a question to ask. I will call on you randomly. Every person will ask at least one question. Complete and hand in worksheet. - peer evaluation - presentation skills only (not content)	5 min	Question Worksheet	Summative	
		Timeline 7 groups @ 10 min per group 3-5 min presentation 5 min for questions/comments	70 min			Nelson Physics 12 - Unit 4 - Chp. 9 & 10

Day / Topic	Curriculum Expectations	Agenda	Timing	Materials Needed	Assessment/ Evaluation	Reference
Day 9 Review	**E1.** analyse technologies that use the wave nature of light, and assess their impact on society and the environment; **E2.** investigate, in qualitative and quantitative terms, the properties of waves and light, and solve related problems; **E3.** demonstrate an understanding of the properties of waves and light in relation to diffraction, refraction, interference, and polarization.	**Take up homework** Check if there are any questions from previous day's homework	5 min	Take up on board (if needed)	Formative	Nelson Physics 12 - Section 10.4
		Activity *Work period to review/study for summative test.* If there are any misconceptions or particular topics that need to be reviewed, do as a class, otherwise it is a work period. Students should use this opportunity to ask any questions they have or work on the review package if they haven't started yet.	70 min		Formative	Nelson Physics 12 - Unit 4 - Chp. 9 & 10
Day 10 Summative Test		Unit 4 - Chp. 9 & 10 Summative - Closed book, put all notes away, need a pen or pencil - No talking - 60 minutes If you finish early read start Diagnostic for next unit	60 min	***Unit Test***	Summative	Nelson Physics 12 - Unit 4 - Chp. 9 & 10
		Unit 5 Diagnostic - Closed book, put all notes away, need a pen or pencil - No talking - 15 minutes If you finish early read or do quiet work	15 min	Diagnostic Assessment	Diagnostic	

Applications of “Light” in the real world

Task:

In teams of 4, prepare and give a **3-5 min oral presentation** (i.e. video, skit, poem, song, for ask Ms. Lu about an alternative format) on one of the following topics. Your team must sign up for a topic (posted in class).

Requirements:

Your presentation must include a description of your situation, a description of the applications of light involved (and a diagram) and any technological advancement.

In addition, you must prepare and submit electronically to Ms. Lu 2 multiple choice questions about the physics of your topic. Select questions will be included in our unit test.

For your selected topic, you will need to:

- Analyse, with reference to the principles related to the wave nature of light, how your technology uses these principles
- Assess the impact on society and the environment or your technology that uses the wave nature of light
- Discuss and explain careers that would use this technology

Topics:

#	Topic	Textbook Reference	Page
1	Electromagnetic waves used in applications such as lidar and photoelasticity	10.6	538-539
2	Light nanotechnology and counterfeit preventions	10.7	540-541
3	Global Positioning Systems	10.8	542-543
4	CD and DVD Storage Capacity	Investigation 10.3.1	547
5	Optical Pattern Analysis	Unit task 4	556
6	Select own topic with teacher’s approval		

Group Members:

	Mark	Level 1	Level 2	Level 3	Level 4
Group Participation [C]	/4	Three members do not participate.	Two members do not participate.	One member does not participate.	All members participate equally
Effectiveness of Presentation [C, A]	/4	Does not communicate situation background, current technology and physics. Little effort has been made to make presentation effective.	Somewhat communicates situation background, current technology and physics. One or more requirements may be missing. Presentation appears not to be rehearsed / prepared in advance.	Does an okay job of communicating situation background, current technology and physics. Some attention to detail and effort made to make presentation effective.	Effectively communicates situation background, current technology and physics. Presentation has been obviously rehearsed; effort has been put into making the presentation effective and / or entertaining.
Description of Physics [K/U]	/4	Physics description inaccurately models situation.	Physics description somewhat models situation.	Physics description does an okay job modeling the situation.	Physics description accurately models situation.
Impact on Society [T/I]	/4	Description inaccurately discusses the impact on society.	Description somewhat addresses the impact on society.	Description does an okay job explaining the impact on society.	Description accurately explains the impact on society.
Career Applications [A]	/2	Does not discuss careers that would use this technology.	Explains careers that would use this technology at a high level. No examples provided	Explains careers that would use this technology at a high level. Provides generic examples.	Thoroughly explains careers that would use this technology. Provides detailed examples.
Multiple Choice Questions [T/I]	/2	No questions are submitted.	Questions are inadequate or missing. Will not be used on a test.	Questions are okay, may or may not be appropriate for test.	Questions are excellent and effective evaluation tools. 4 possible answers are provided. Includes solutions and explanations.
TOTAL	**/20**				
Comments:					

Name:___________________________

Date:___________________________

______ 22K	______ 11T	______ 2A	______ 3C

Unit Test

Strand: The Wave Nature of Light

Expectations:
E1. analyse technologies that use the wave nature of light, and assess their impact on society and the environment;
E2. investigate, in qualitative and quantitative terms, the properties of waves and light, and solve related problems;
E3. demonstrate an understanding of the properties of waves and light in relation to diffraction, refraction, interference, and polarization.

PART 1 – FILL IN THE BLANKS – 10 MARKS

______ 10K

Directions: Fill in the blanks.

1. A wave with a repeated pattern over time or distance is called

   _________________________.

2. The index of refraction is the ratio of the speed of light in

   _________________________ to the speed of light in _________________________.

3. The nodal line is a line or curve along which _________________________

   interference results in _________________________ displacement.

4. A diffraction grating consists of a _________________________ number of closely

   spaced _________________________ slits that produces interference patterns.

5. Three ways that polarized light can be produced from unpolarized light are:

   _________________________, _________________________, and

   _________________________.

Name:___________________________

Date:___________________________

5K

PART 2 - MATCHING – 5 MARKS

Directions: Beside each definition, write the letter of the term from the right hand column. Use each term only once.

	Definition	Term
______________________	1. The bending of light as it travels at an angle from one medium to another.	A. Dispersion
______________________	2. The separation of a wave into its component parts according to a given characteristic.	B. Iridescence
______________________	3. The bending and spreading of a wave when it passes through an opening.	C. Reflection
______________________	4. The phenomenon that occurs when two waves in the same medium intersect.	D. Incoherence
______________________	5. A change in direction of a light ray after meeting an obstacle.	E. Interference
		F. Refraction
		G. Diffraction
		H. Interference

Name:___________________________

Date:___________________________

5K

PART 3 – TRUE AND FALSE – 5 MARKS

Directions: For each question below, circle **True** or **False**.

True False 1. Newton's Particle Theory of Light states that light particles travel in straight lines with a maximum velocity and therefore have kinetic energy.

True False 2. At Brewster's angle, the refracted ray and reflected ray are parallel to each other.

True False 3. Specular reflection is the reflection of light from a surface where all the reflected rays are directed in many different directions.

True False 4. A light beam diffracting around a small solid disc will create a bright spot in the centre of the disc's shadow.

True False 5. Electromagnetic waves consist of magnetic and electric fields that are parallel to each other and to the direction of propagation, and oscillate in phase.

Name:___________________________

Date:___________________________

PART 4 – MULTIPLE CHOICE – 5 MARKS

Directions: Circle the most correct answer.

__ 2K

1. The colours in anti-reflective coatings on eyeglasses, solar cells, and the colours seen as sunlight shines on a soap bubble, can be explained by
   A. Light interfering as it reflects within a thin film
   B. Light diffracting within a thin film
   C. Light dispersing across a thick film
   D. Light polarizing inside a thin film

2. To increase the distance of the first dark fringe from the central maximum in a single-slit diffraction pattern, you should
   A. Use more intense light
   B. Use light of a longer wavelength
   C. Use light of a higher frequency
   D. Replace the slit with a wider opening

__ 3T

3. All light waves have a speed of $3.0 * 10^8$ m/s. What is the wavelength of light that has a frequency of $5.0 * 10^{14}$ Hz?
   A. $6.0 * 10^{-5}$
   B. $6.0 * 10^{-6}$
   C. $6.0 * 10^{-7}$
   D. $1.5 * 10^6$

4. Light travels from air into a transparent material that has an index of refraction of 1.3. The angle of refraction is $45°$. What is the angle of incidence?
   A. $23°$
   B. $45°$
   C. $50°$
   D. $67°$

5. A double-slit experiment uses two slits 0.35 mm apart to produce an interference pattern on a screen 1.5 m from the slits. The distance between adjacent bright spots in 2.4 mm. What is the wavelength of the incident light?
   A. 0.56 µm
   B. 0.56 mm
   C. 0.84 µm
   D. 0.84 mm

Name:___________________________

Date:___________________________

PART 5 – SHORT ANSWER – 13 MARKS

Directions: Show your work.

___ / 3T

___ / 1C

1. Determine the critical angle for light inside a diamond at the diamond-air boundary. The diamond has an index of refraction of 2.42.

2. Most computer LCD projectors emit polarized light of red, green, and blue. You project the image of a white screen from the LDC project. When you hold a polarizing filter in front of the projector lens, the "shadow" case by the filter is bright green.

___ / 1T

A. Explain why the shadow is green.

___ / 2A

___ / 1C

B. Predict what would happen if you rotated the polarizing filter by 90°.

Name:___________________________

Date:___________________________

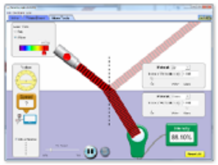
PART 5 – SHORT ANSWER – 13 MARKS - CONTINUED

Directions: Show your work.

3. Explain the key differences between Newton's particle theory of light and Huygen's principle. Provide examples to illustrate your point.

____ 4T

____ 1C



Refraction PhET Lab

Purpose: To investigate the behaviors and characteristics of light when it bends due to refraction. These properties and characteristics will be true for all other EM waves - and sound as well.

Questions:
What happens to the speed of light as it goes from air to water?
- Hypothesis:

What happens to the frequency of light as it goes from air to water?
- Hypothesis:

What happens to the wavelength of light as it goes from air to water?
- Hypothesis:

Procedure:
Go online and search for "phet bending-light", or go to the PhET website http://phet.colorado.edu/en/simulation/bending-light, and run the sim. Mess around with the controls and tools provided on the Intro tab; your first tasks are:
- Learn how to turn the beam on and off,
- Learn how to change the beam to a wave,
- Learn how to change the angle of the beam.

Write down the steps you needed to do to accomplish each task.

You will be systematically learning about changing angles in **refraction**
- Which beam is best suited for measuring angles, the ray or wave?
- Which tool should you select for measuring angles, the protractor or intensity meter?

-Using this setup and tool, you will investigate and discover:
- How the **angle of refraction** compares to the **angle of incidence**, measured from the **normal**, when going from air to water,
- How changing the **index of refraction** of the bottom material changes the angle of refraction,
- How changing the index of refractions of both materials changes the angle of refraction. What conditions produce no refraction? What conditions produce maximum refraction?

Write down the steps you needed to do to accomplish each task, and in a table, record your observations for each.

Investigate the materials further: set the *top* material to be water, and the *bottom* one to be air. Systematically investigate and discover:
- How the angle of refraction compares to the angle of incidence, measured from the normal, when going from water to air,
- At what angle of incidence does something different happen that did not occur in the first investigations? Describe what happens to the refracted beam at this **critical angle**.
- How changing the index of refraction of the bottom material changes the angle of refraction,
- How changing the index of refraction of the bottom material changes when the critical angle appears,
- How changing the index of refractions of both materials changes the angle of refraction. What conditions produce no refraction? What conditions produce maximum refraction?

Write down the steps you needed to do to accomplish each task, and in a table, record your observations for each.

You are now ready to investigate the beam itself. Click on the More Tools tab, and change your beam to a wave.
- Using the speed tool, investigate the connection between the **index of refraction** of the bottom material and the **speeds of the beams** in air and in the bottom material.

Write down the steps you needed to do to accomplish this task, and in a table, record your observations; what equation connects the above two variables?

- Using the time tool, investigate the connection between the **index of refraction** of the bottom material and the **frequency of the beam** in that material compared to the beam in air. Observe the **wavelength of the beam** in the material compared to its wavelength in air (you may slow down or pause the sim for this).

Write down the steps you needed to do to accomplish each task, and in a table, record your observations.

BONUS:
- Using the equation you found for the index of refraction, find the index of refraction of **mystery materials A & B**. Search online and theorize what these materials might be.
- Investigate and report what effect **changing the color** (wavelength) of the beam has on any of the refraction behaviors you already recorded.

Conclusion:
What were your hypotheses, and were they validated by the results of your investigations? If not, what did you learn? Summarize what conditions are necessary for refraction to occur, and how changing those conditions changes the amount of refraction. What conditions cause exceptional behavior?

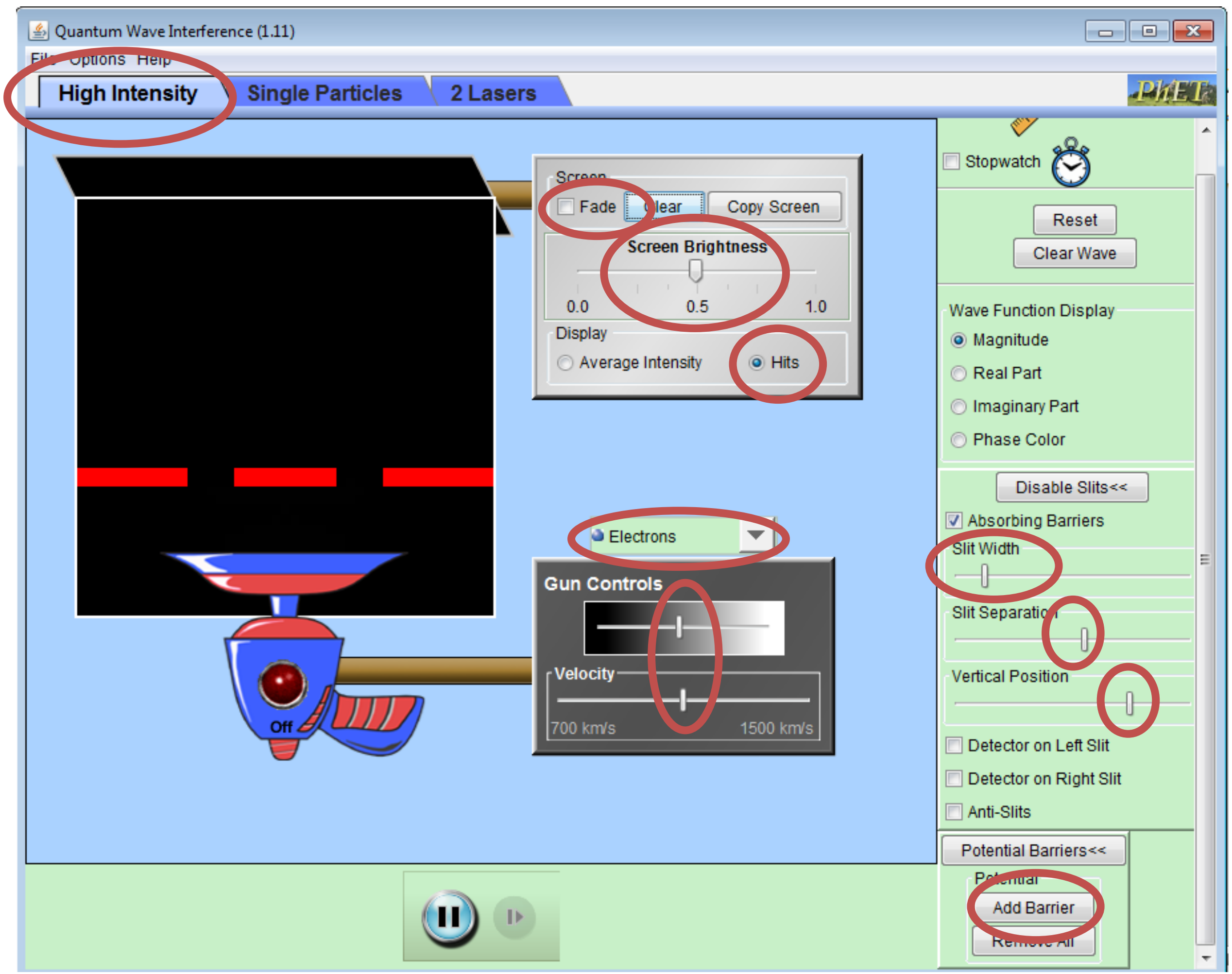
PhET's Quantum Wave Interference Simulation

http://phet.colorado.edu/en/simulation/quantum-wave-interference

Select settings as follows:

Hit the **Run Now** button. Set up the simulation (using controls from top to bottom):

- high intensity
- screen: hits, medium brightness, no fade
- particles: electrons
- slits: 1/10 width, ½ separation, ¾ vertical (this produces three clear maxima)
- add a potential barrier to block the right slit
- gun: ½ intensity (middle of slider), ½ velocity (default)



Electron Interference **Name ________________**

An electron gun is set to fire a couple hundred electrons per second. The screen at the back detects the electrons that make it through the slit(s).

1) The right slit is blocked off. If the gun is fired for two seconds you will see about 200 electrons spread over
   a) in a narrow region opposite the slit
   b) mostly on the left half of the screen
   c) only on the left half of the screen
   d) spread evenly over the whole screen

   Prediction and Reason: …………………………………………………………..

   Sketch the Result:

2) If the experiment is repeated the screen will look
   a) exactly the same
   b) almost the same
   c) very different

   Prediction and Reason: …………………………………………………………..

   Sketch the Result:

3) The right slit is opened and the left slit is blocked. Sketch the pattern that will form.

   How does this pattern compare to the previous one?

4) Both slits are uncovered. The screen will show about 400 electrons that hit
   a) evenly across the screen
   b) in one concentrated region fading to the edges
   c) in two concentrated regions. The middle will have few hits.
   d) in three concentrated regions. The middle will have many hits.

   Prediction and Reason: …………………………………………………………..

   Sketch the Result:

   How does this pattern compare to the two single slit patterns?

5) The intensity is reduced so that there will only be one electron going through the slits at a time. The next electron will land

a) anywhere on the screen
b) almost anywhere but most likely in the middle third
c) most likely in the middle or near 0.6 nm or 3.6 nm
d) most likely near 1.2 nm or 3.0 nm

Prediction and Reason: ……………………………………………………………..

Result: …

6) When the intensity of the gun is altered so that only one electron is travelling at a time. What will the pattern look like? You will see

a) one spread out region that is the sum of the two spread out regions from each slit
b) three spread out regions because an individual electron acts like a wave
c) three spread out regions because the electrons ricochet off the slit edges

Prediction and Reason: ……………………………………………………………..

Result: ………………………………………………………………………………….

7) A detector is added to the left slit. This will be able to detect whether the electrons went through the left side or the right slit. It will not block the electrons.

Sketch the Result:

How does this pattern compare to the two single slit patterns?

8) If you turn the detector off then electron goes through

a) the left slit
b) the right slit
c) either the left or right, but we can't know which
d) both slits
e) neither slit

Prediction and Reason: ……………………………………………………………..

Result:

9) The wavelength of an electron is given by $\lambda = h/mv$. If the electrons move faster, then the

a) pattern will get brighter
b) pattern will get fainter
c) bright spots will move closer together
d) bright spots will move further apart

Prediction and Reason: …………………………………………………………..

Result:

10) How will the pattern for just a single slit change as the slit width is decreased? It will become

a) fainter all over but the same size
b) fainter all over and narrower
c) fainter directly opposite the slit
d) fainter where it diffracts around the slit

Prediction and Reason: …………………………………………………………..

Result:

11) You can't detect a person's wavelength because

a) people are not waves, that's only for sub microscopic particles
b) the wavelength is ridiculously big
c) the wavelength is ridiculously small

Prediction and Reason: ……………………………………………………………………….

12) A person's mass is on the order of 100 kg. Typical human speeds are on the order of 10^0 m/s and h is on the order of 10^{-33} Js. A human's wavelength is similar to the size of a

a) cell b) atom c) nucleus d) proton e) something else

Prediction and Reason: ……………………………………………………………..

13) Go to the simulation at http://phet.colorado.edu/new/simulations/sims.php?sim=Quantum_Wave_Interference. Select helium atoms as your particle. On the screen settings choose 'hits', not average intensity and disable the fade option. Add double slits.

a) At the default settings, how far is the first maximum from the center? Use the ruler.

b) What are the slit separations and speed of the helium at this setting?

c) What is the wavelength of helium at this speed?

d) Calculate how far the slits must be from the screen?

e) Alter the settings until you get the clearest pattern of central three maxima. Describe in detail what you must do and why to achieve this.

14) The real electron experiment was preformed by A Tonomura in 1989. The electrons were accelerated by a potential difference of 5 x 10^4 m/s V. Do the following calculations non-relativistically. (Details can be found at http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm.)

a) How fast were these electrons moving?

b) How fast is that compared to the speed of light? 42 %.

c) How long would they take to cross the 1 m apparatus?

d) What was the wavelength of these electrons?

e) Should relativistic equations be used?

f) How was the slit set-up in this experiment different from the simulation?

15) The experiment demonstrating interference of buckminsterfullerene, C60, had the molecules moving at 210 m/s. Each molecule has an atomic mass of 720 atomic units and a diameter of 1 nm. The molecules passed through slits with widths of 50 nm and separations of 100 nm. After the slits, the molecules travelled 1.25 m before being detected. (More details can be found at http://www.quantum.univie.ac.at/research/matterwave/c60/index.html.)

a) What is the mass of one molecule?

b) What is the momentum?

c) What is its wavelength?

d) How does this wavelength compare the size of the molecule?

e) How does this wavelength compare the size of the slits?

f) How far apart would the slits be for the interference of light with a ratio like this?

g) How far apart would the fringes be separated if the screen was 5 m from the slits?

h) How far from the center would the first maximum be?

i) How was the slit set-up different from the simulated experiment?

16) The two-slit experiment illustrated several fundamental concepts in quantum mechanics. Explain what each of these is and how they are demonstrated in the experiments:

a) Intrinsic Randomness
b) Measurements Affect Reality
c) Superposition
d) Heisenberg's Uncertainty Principle

17) Google "Dr. Quantum double slit". This should take you to a very popular and well-animated version of the electron two-slit experiment. Unfortunately it has the physics seriously wrong in a few places. Describe these.

Using Phet's Quantum Wave Interference as an Interactive Lecture Demonstration

The Quantum Wave Interference simulation is a fantastic resource for making quantum mechanics tangible to students. The point of this particular lesson is to take students step by step through a series of 'experiments' that confront them with the basic conflict between the wave model and particle model. I like to do this with electrons rather than light because the electrons are more obviously particles than photons are. The demonstration shows their wavelike behaviour.

Go to http://phet.colorado.edu/new/simulations/sims.php?sim=Quantum_Wave_Interference.

Hit the **Run Now** button. Set up the simulation (using controls from top to bottom):

- high intensity
- screen: hits, medium brightness, no fade
- particles: electrons
- slits: 1/10 width, ½ separation, ¾ vertical (this produces three clear maxima)
- add a potential barrier to block the right slit
- gun: ½ intensity (middle of slider), ½ velocity (default)

Note: the simulation shows the probability wave – it would be nice if it could be turned off. Don't draw attention to the wave. If students ask about it, praise them for noticing it and say that it will be covered later.

The rest of this file is similar to the four pages that the student gets, but with extra information and the answers to the questions in **bold**. As you go through the concept questions make the students write down an answer and a short reason. Then have them discuss their answers with their nearest neighbours. Then you can have a full-class discussion or go straight to the simulation. After they see what happens you can help them consider what the results mean. Give them time to write down their new ideas. This process has been shown to help students form the mental models needed in physics. The last four to six questions can be assigned for homework.

1) An electron gun is set to fire a couple hundred electrons per second. The screen at the back detects the electrons that make it through the slit(s).
The right slit is blocked off. If the gun is fired for two seconds you will see about 200 electrons

a) in a narrow region opposite the slit
b) mostly on the left half of the screen
c) only on the left half of the screen
d) spread evenly over the whole screen

After the predictions are made, hit the button on the gun and hit it again two seconds later.

The shading above shows the average distribution because it was easier for me to do this on the computer. However, students should draw the dots to emphasize the randomness.

Copy the screen using the copy screen option so it can be compare to later results.
2) If the experiment is repeated the screen will

a) exactly the same
b) almost the same
c) very different

Clear the screen using the button to the right of the screen. Fire electrons for two seconds. Copy the screen. The two screens should be similar, but not identical.

3) The right slit is opened and the left slit is blocked. Sketch the pattern that will form.

How does this pattern compare to the previous one?

Clear the screen. Move the potential barrier to the left slit. Fire electrons. Copy the screen. The pattern is similar to the first two, but reflected about the middle of the screen.

4) Both slits are uncovered. The screen will show about 400 electrons that hit

a) evenly across the screen
b) in one concentrated region fading to the edges
c) in two concentrated regions. The middle will have few hits.
d) in three concentrated **regions. The middle will have many hits.**

How does this pattern compare to the two single slit patterns?

Clear the screen. Clear the barrier. Fire for two seconds. Copy the screen.

The pattern for two slits is not a sum of the patterns from the two individual slits! Draw attention to the nodal regions. With two slits open, they receive fewer electrons than with one open. Adding electrons has resulted in fewer electrons in these places.

What does it look like? It is like the interference pattern you would get from water/light/sound waves passing through two slits.

What could be interfering? It could be electrons jostling each other, with ones that pass through the left slit bumping into those on the right slit. That's what water molecules do.

Suggest looking at the pattern when there is only one electron in the device at a time. Turn the intensity to almost zero. You should see an electron arrive only once or twice a second.

5) The intensity is reduced so that there will only be one electron going through the slits at a time. The next electron will land

a) anywhere on the screen
b) almost anywhere but most likely in the middle third
c) most likely in the middle or near 0.6 nm or 3.6 nm
d) most likely near 1.2 nm or 3.0 nm

Turn the gun on and leave it running while you have the students argue about this. It will take quite a while before the result is obvious.

Add a ruler and divide the screen into parts and assign the parts to particular groups. They can cheer when an electron lands in their spot. Make sure that it isn't fair, i.e. some groups get a region with nodes and others get a maximum. Eventually, they will see that the pattern is random but not even.

This shows a fundamental principle in quantum mechanics.

<u>A) Intrinsic Randomness</u>: We cannot know what will happen in a specific instant, but we can have a very good idea of what will happen if it is repeated many times. We have to give up causes and effects.

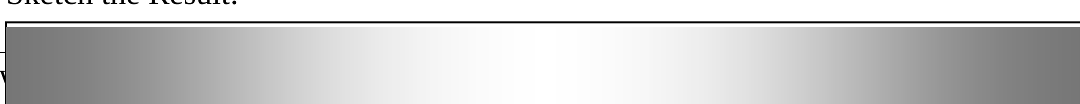
6) When the intensity of the gun is altered so that only one electron is travelling at a time. What will the pattern look like? You will see

a) one spread out region that is the sum of the two spread out regions from each slit
b) three spread out regions because an individual electron acts like a wave
c) three spread out regions because the electrons ricochet off the slit edges

Once the simulation has been running long enough, they see that that the answer is either b or c. However, if it were due to ricocheting, the pattern should be a sum of the two individual ones. Draw attention to the nodal regions again. Suggest looking more closely to see which slit it went through.

7) A detector is added to the left slit. This will be able to detect whether the electrons went through the left side or the right slit. It will not block the electrons.

Sketch the Result:



How does this pattern compare to the two single slit patterns?

Turn the gun up a bit to speed things along.

The pattern has changed! It is the sum of the two individual patterns, the pattern that you would suspect from particles fired through two slits.

The simulation doesn't let us record which slit it went through, nor does it tell us how the detecting is done. They have to believe you when you say that no matter how it is done, no matter how careful you are, once you can tell which slit they went through they behave like particles and there is no intereference.

This experiment shows two key points, common throughout quantum mechanics, not just the two-slit experiment.

- **B)** **<u>Measurements Affect Reality</u>: What you measure fundamentally changes the results of your measurement. No matter how gently and carefully you observe the electron - you affect it.**

- **C)** **<u>Superposition:</u> If we don't know what state an object is in, then it is in a combination or superposition of those states and these possibilities can interfere with each other. If there are two indistinguishable paths - their probabilities can interfere. The electron can be in more than one place at a time. It can go through both slits.**

8) If you turn the detector off then electron goes through
- a) the left slit
- b) the right slit
- c) either the left or right, but we can't know which
- d) both slits
- e) neither slit

This pattern is a result of the interference of something that passes through both slits but the interpretation of this is debatable.

The electron is always detected as a whole electron. However, when it is not being detected its location is probabilistic and the probabilities are described extremely precisely by the Schrodinger Wave Equation. The electron's probability wave – not a smeared out electron - went through both slits and interfered with itself. The fuzzy blob coming out of the gun represents this probability wave as we imagine it. However, it can never be directly observed. What we observe is either an electron or no electron. The <u>interpretation</u> of what happens between the gun and the screen is still under debate. The main explanations are Copenhagen, many-worlds, sum over paths (Feynman) and the Bohm wave guide. Most phycisists don't bother themselves with this, they just accept that QM works and get on with their work.

9) The wavelength of an electron is given by $\lambda = h/mv$. If the electrons move faster, then the
- a) pattern will get brighter
- b) pattern will get fainter
- **c) bright spots will move closer together**
- d) bright spots will move further apart

This is not easy to see with the simulation. Set the gun on maximum intensity and the lowest speed. Slowly increase the speed and watch the probability wave, not the pattern for the clearest result.

At the lowest speeds you can only see three maxima. As you increase the speed, the pattern spreads less and you can see the next maxima as well.

The wavelength is smaller, therefore the pattern is spread out less. This is like blue light vs. red light. x =λ L/d.

10) How will the pattern for just a single slit change as the slit width is decreased? It will become

a) fainter all over but the same size
b) fainter all over and narrower
c) fainter directly opposite the slit
d) fainter where it diffracts around the slit

Set the gun on maximum intensity and medium speed. Cover the right slit with a potential barrier. Look at the probability wave not the pattern on the screen for the clearest result.

As the slits get narrow, the intense direct wave gets reduced, but the edge effects remain. By removing most of the direct wave (which behaves most like a particle), the diffraction effects (wave-like behaviour) are more noticeable.

This is an example of another key aspect of quantum mechanics.

D) <u>Heisenberg's Uncertainty Principle</u>: They more you know about where the electron is (narrow slit) the less well you know its momentum (where it goes after the slit); $\Delta x\ \Delta p < h/2\pi$. This is a fundamental limit (like faster than light travel) and not a restriction of our technical abilities (like faster than sound travel was a century ago).

Show the video clip of a real electron experiment from Japan. **So far, they have had to accept very weird results from a programmed simulation. It is important to show the real thing**. http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm **Click on movie clip 1. It is a short video - lasting only a minute. The students can examine the details later as homework**.

11) You can't detect a person's wavelength because

a) people are not waves, that's only for sub microscopic particles
b) the wavelength is ridiculously big
c) **the wavelength is ridiculously small**

A person's momentum will be much, much more than an electron's and so their wavelengths will be proportionately smaller.

12) A person's mass is on the order of 100 kg. Typical human speeds are on the order of 10^0 m/s and h is on the order of 10^{-33} Js. A human's wavelength is similar to the size of a

a) cell b) atom c) nucleus d) proton e) **something else**

The wavelength is on the order of 10^{-33} m. The objects aren't nearly small enough. Cells are measured in micrometres (10^{-6} m), atoms are nanometres (10^{-9} m), nuclei in picometres (10^{-12} m) and protons are femptometres (10^{-15} m). **The human wavelength, is close to the Planck length, which is the length that**

results from combining h, G and c so they produce units in m. The length is given by the square root of hG/c^3. and is10^{-35} m.

We can't show people intereference but we can show very large molecules interfering. Show data of buckyball (buckminsterfullerene, C60) interference.

http://www.quantum.univie.ac.at/research/matterwave/c60/index.html

Go down one page to show how the shape resembles a soccer ball. The next page shows a photo of the lab and equipment. The next page shows the results with and without the grating. Point out the extra two maxima with the grating.

13) Go to the simulation at http://phet.colorado.edu/new/simulations/sims.php?sim=Quantum_Wave_Interference. Select helium atoms as your particle. On the screen settings choose 'hits', not average intensity and disable the fade option. Add double slits.

a) At the default settings, how far is the first maximum from the center? Use the ruler.
   Around 1.1 nm.
b) What are the slit separations and speed of the helium at this setting?
   1.2 nm, 0.15 km/s
c) What is the wavelength of helium at this speed?
   $\lambda = h/mv = 6.63 \times 10^{-34}$ Js /4.00 x 1.66×10^{-27} kg x 150 m/s = 0.67 nm
d) Calculate how far the slits must be from the screen?
   $L = x_1 d/\lambda$ = 1.1 nm x 1.2 nm/0.67 nm = 2.0 nm. This agrees with the measurement on the simulation.
e) Alter the settings until you get the clearest pattern of central three maxima. Describe in detail what you must do and why to achieve this.
   Make the slits as narrow as possible to increase the size of the nodes, so the maxima are more distinct. Make the slit separation about twice the size of the slit widths. If d is too small, the central maximum dominates and it turns into a single slit pattern. If d is too large, the interference weakens and the central maximum starts to disappear. Increasing the vertical distance separates the maxima more, but they soon go off the screen, the middle setting is best. Similarly, decreasing the speed will in crease the wavelength and spread the pattern more, but the middle setting is best.

14) The real electron experiment was preformed by A Tonomura in 1989. The electrons were accelerated by a potential difference of 5 x 10^4 m/s V. Do the following calculations non-relativistically. (Details can be found at http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm.)

a) How fast were these electrons moving?
   Use kinetic energy equals electric energy and you get a speed of 1.(3) x 10^8 m/s if calculated non-relativitistically. v = sqrt(2qV/m) = sqrt(2 x 1.6 x 10^{-19} C x 5 x 10^4 V/9.11 x 10^{-31} kg). Site gives 1.2 x 10^8 m/s. To one digit these are the same.
b) How fast is that compared to the speed of light? 42 %.
   Site says about 40%.
c) How long would they take to cross the 1 m apparatus?
   t = d/v = 7.(9) ns.
d) What was the wavelength of these electrons?
   Use the De Broglie equation. λ = h/p = 6.63 x10^{-34} Js/(9.11 x 10^{-31} kg x 1.3 x 10^8 m/s) = 5.(6) x 10^{-24} m.
e) Should relativistic equations be used?
   Gamma is 1.1, so if we are only concerned with one digit there is no problem. For two digits we should use relativity.
f) How was the slit set-up in this experiment different from the simulation?
   The slit was formed by an "electron biprism" …"which consists of two parallel plates and a fine filament at the center. The filament is thinner than 1 micron (1/1000 mm) in diameter. " You can demonstrate something similar by putting a straight pin in the path of a laser pointer beam.

15) The experiment demonstrating interference of buckminsterfullerene, C60, had the molecules moving at 210 m/s. Each molecule has an atomic mass of 720 atomic units and a diameter of 1 nm. The molecules passed through slits with widths of 50 nm and separations of 100 nm. After the slits, the molecules travelled 1.25 m before being detected. (More details can be found at http://www.quantum.univie.ac.at/research/matterwave/c60/index.html.)

a) What is the mass of one molecule?
   720 x 1.660 x 10^{-27} kg = 1.195 x 10^{-24} kg.
b) What is the momentum?
   1.195 x 10^{-24} kg x 210 m/s = 2.51 x 10^{-22} kg m/s
c) What is its wavelength?
   h/p = 2.65 x10^{-12} m = 0.00265 nm
d) How does this wavelength compare the size of the molecule?
   1/500! The wavelength is much smaller than the object itself.
e) How does this wavelength compare the size of the slits?
   1/50, 000! We often say that to demonstrate interference you need a wavelength comparable to the slit separation. What we really mean is that this is what is needed to demonstrate it easily.
f) How far apart would the slits be if you were demonstrating the interference of light with a ratio like this?
   d = 5 x 10^{-7} m x 50,000 = 2.5 cm.
g) How far apart would the fringes be separated if the screen was 5 m from the slits?
   If the screen was 5 m away the fringes would be separated by a tenth of a millimetre. This could be detected but not easily!
h) How far from the center would the first maximum be?
   $x_1 = \lambda L/d$ = 2.65 x 10^{-12} m x 1.25 m/1.00 x 10^{-7} m = 3.31 x 10^{-5} m.
i) How was the slit set-up different from the simulated experiment?
   A diffraction grating of many slits was used to intensify the interference.

16) The two-slit experiment illustrated several fundamental concepts in quantum mechanics. Explain what each of these is and how they are demonstrated in the experiments:

a) Intrinsic Randomness

We cannot know what will happen in a specific instant, but we can have a very good idea of what will happen if it is repeated many times. We have to give up causes and effects on an individual basis. We don't know where the next electron will land but we know what the pattern of 100 electrons will be.

b) Measurements Affect Reality

What you measure fundamentally changes the results of your measurement. No matter how gently and carefully you observe the electron - you affect it. A detector at one slit destroys the interference pattern of two slits.

c) Superposition

If we don't know what state an object is in, then it is in a combination or superposition of those states and these possibilities can interfere with each other. If we don't try to detect which slit the electron goes through then electron can be in more than one place at a time. The probability of where it goes is a result of its amplitude of going through both slits.

d) Heisenberg's Uncertainty Principle

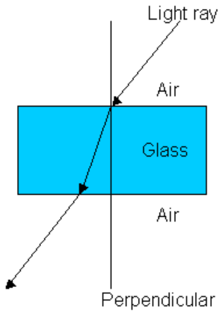
The smaller the uncertainty in position - the greater the uncertainty in momentum - $\Delta x \ \Delta p < h/2\pi$. This is a fundamental limit (like faster than light travel) and not a restriction of our technical abilities (like faster than sound travel was a century ago). They better you know where the electron was (narrow slits) the less well you know its momentum (where it goes after the slit) and its position at the screen becomes less predictable.

17) Google "Dr. Quantum double slit". This should take you to a very popular and well-animated version of the electron two-slit experiment. Unfortunately it has the physics seriously wrong in a few places. Describe these.

The biggest error, is that the double slits appear to give a single slit interference pattern with the central maximum twice as wide as the others. The next most serious, is that when the electrons are sent through one slit they show almost no diffraction. If the diffraction patterns don't overlap, they can't interfere. It shows the electron smearing out and splitting into two, which can leave you imagining that this is what interferes. However, the interference pattern is due to the interference of probability not smeared out matter.

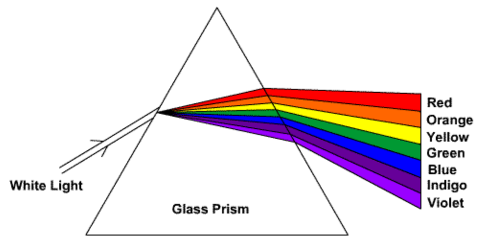
Directions: Underneath each diagram, write the letter or term from the right hand column. Use each term only once.

The bending of light as it travels at an angle from one medium to another.



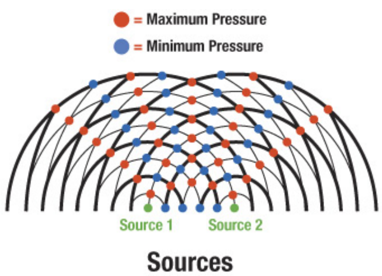
1.________________________

The separation of a wave into its component parts according to a given characteristic.



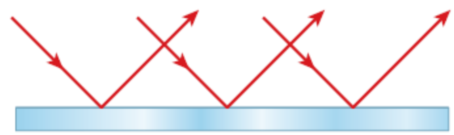
2.________________________

The phenomenon that occurs when two waves in the same medium intersect.



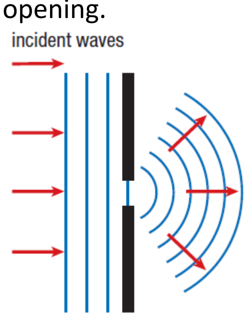
3.________________________

A change in direction of a light ray when it meets an obstacle where the incoming ray and the outgoing ray are on the same side of the obstacle.



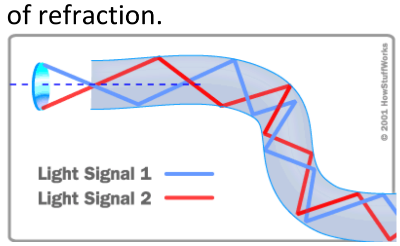
4.________________________

The bending and spreading of a wave when it passes through an opening.



5.________________________

An effect that occurs when light encounters a boundary between a medium with a higher index of refraction and one with a lower index of refraction.



6. ________________________

A. Dispersion

B. Iridescence

C. Reflection

D. Incoherence

E. Interference

F. Refraction

G. Diffraction

H. Total Internal Reflection

Newton's Particle Theory of Light

- Light travels in ________________ or "**corpuscles**"

- Particles travel in ________________ lines with ________________ velocity and have ________________ energy
- Light ________________ a medium or ether to travel in
- Explains ________________ and ________________ but NOT ________________

Huygens' principle (1678)

All points on a wave can be thought of as new sources of ______________

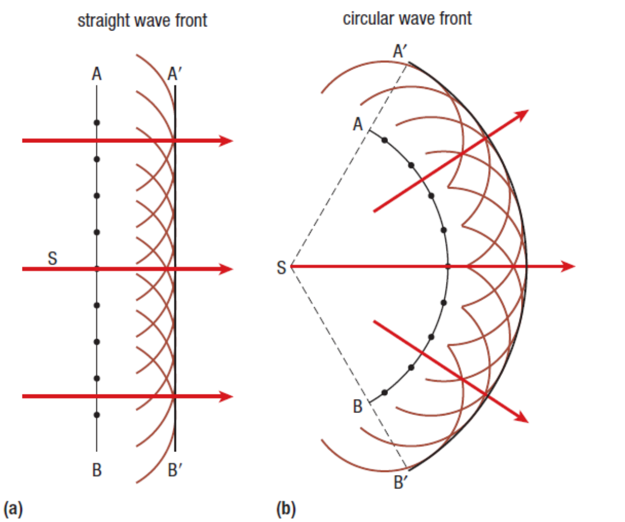
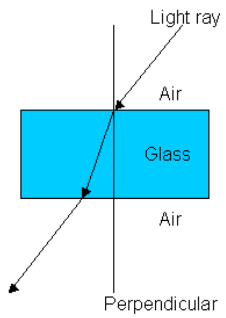


Figure 1 (a) In Huygens' construction of a straight wave front, the wave front is a straight line even though it is defined by circular waves. (b) In Huygens' construction of a spherical wave, the new wave front is drawn tangent to the circular wavelets radiating from the point sources on the original wave front.

- Light travels ________________ the ether
- Explained ________________, ________________ and ______________

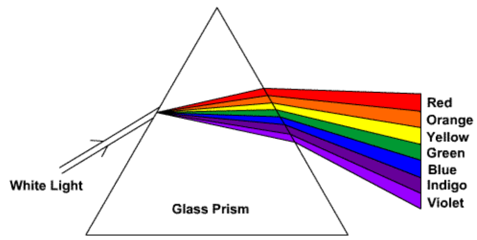
Directions: Underneath each diagram, write the letter or term from the right hand column. Use each term only once.

The bending of light as it travels at an angle from one medium to another.



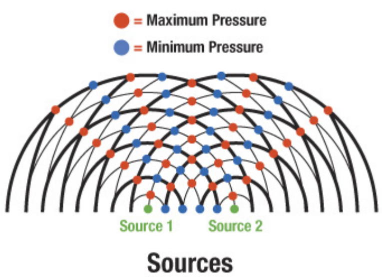
1.____Refraction______

The separation of a wave into its component parts according to a given characteristic.



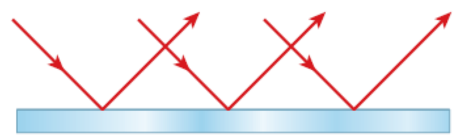
2.____Dispersion______

The phenomenon that occurs when two waves in the same medium intersect.



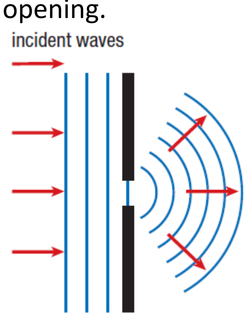
3.____Interference____

A change in direction of a light ray when it meets an obstacle where the incoming ray and the outgoing ray are on the same side of the obstacle.



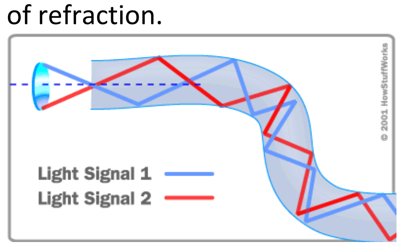
4.____Reflection______

The bending and spreading of a wave when it passes through an opening.



5._____Diffraction_____

An effect that occurs when light encounters a boundary between a medium with a higher index of refraction and one with a lower index of refraction.



6._Total Internal Reflection_

A. Dispersion

B. Iridescence

C. Reflection

D. Incoherence

E. Interference

F. Refraction

G. Diffraction

H. Total Internal Reflection

Newton's Particle Theory of Light

- Light travels in __**particles**__ or "**corpuscles**"

- Particles travel in __straight__ lines with __maximum__ velocity and have __kinetic__ energy
- Light __does not need__ a medium or ether to travel in
- Explains __diffraction__ and __reflection__ but NOT __refraction__

Huygens' principle (1678)

- All points on a wave can be thought of as new sources of __**spherical waves**__

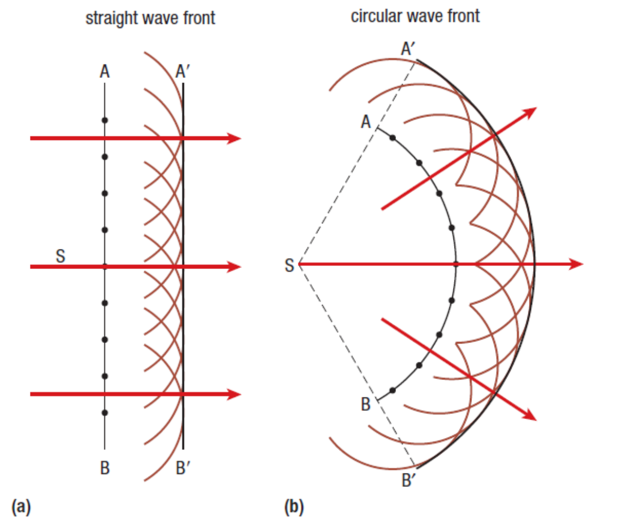


Figure 1 (a) In Huygens' construction of a straight wave front, the wave front is a straight line even though it is defined by circular waves. (b) In Huygens' construction of a spherical wave, the new wave front is drawn tangent to the circular wavelets radiating from the point sources on the original wave front.

- Light travels __through__ the ether
- Explained __reflection__, __refraction__ and __diffraction__

Date: ______________________ Student Name: ______________________

Exit Ticket

Answer and hand in the following questions:

1. Name one thing you learned today.

2. Name one thing you would like to know more about.

Date: ______________________ Student Name: ______________________

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