TOPIC 1.2: Waves in Two Dimensions

Students will be able to:

S3P-1-08 Describe and give examples of two-dimensional waves.

S3P-1-09 Compare and contrast a wavefront and a wave ray.

S3P-1-10 Describe, demonstrate, and diagram the reflection of plane (straight) and circular waves.
Include: linear and parabolic reflectors

S3P-1-11 Describe, demonstrate, and diagram the refraction of plane (straight) waves.

S3P-1-12 Derive Snell's Law using the relationships between wavelength, velocity, and the angles of incidence and refraction.

S3P-1-13 Experiment to demonstrate Snell's Law.

S3P-1-14 Describe, demonstrate, and diagram diffraction of water waves.

S3P-1-15 Describe, demonstrate, and diagram how constructive and destructive interference produce an interference pattern from two point sources.

S3P-1-16 Derive the path difference relationship for the interference pattern from two point sources $\left|\overline{P_nS_1} - \overline{P_nS_2}\right| = \left(n - \frac{1}{2}\right)\lambda$.

General Learning Outcome Connection

Students will...

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

Specific Learning Outcomes

S3P-1-08: Describe and give examples of two-dimensional waves.

S3P-1-09: Compare and contrast a wavefront and a wave ray.

Skills and Attitudes Outcomes

S3P-0-2f: Record, organize, and display data, using an appropriate format.

Include: labelled diagrams, tables, graphs

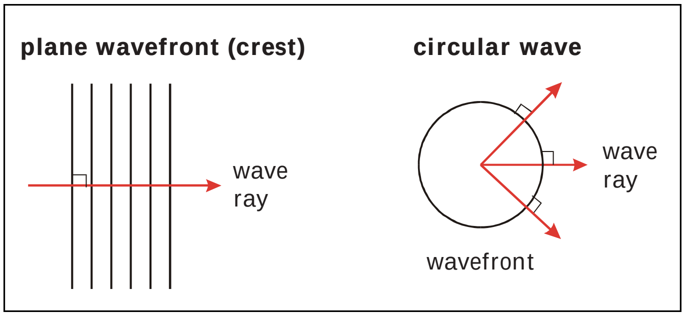
Suggestions for Instruction

Notes to the Teacher

In the previous topic, waves on a string or spring were used to outline the properties of waves in one dimension. A useful example of waves in two dimensions is water waves. It is recommended that students observe waves in two dimensions and highlight the characteristics of their behaviour. Students can use ripple tanks or the teacher can demonstrate water waves using a ripple tank placed on an overhead.

Distinguish between wavefronts and wave rays. A wavefront is a series of connected particles moving in phase with one another. The wave ray represents the direction of motion of a point on the wavefront. The direction of motion of the wave ray is perpendicular to the wavefront at that point.

Class Activity



Waves in ripple tanks can be used to illustrate two-dimensional waves. It is useful to videotape wave phenomena and play back the tape in slow motion or frame by frame. In a ripple tank apparatus, the wave crest acts like a converging lens and the crest is projected on a screen below as a bright area. A ruler and stopwatch could be placed in view while videotaping.

You can generate a straight wave in a ripple tank by dipping a wooden dowel into the water. Students can generate circular waves in a ripple tank by dipping a single finger into the water, or by using an eyedropper to drop water droplets into the ripple tank.

Demonstration

Strike a tuning fork and place it near an open beaker of water to generate waves in the beaker.

Senior Years Science Teachers' Handbook Activities

KWL (*Senior Years Science Teachers' Handbook*, page 9.8): Students research the impact of waves on the shorelines of lakes, oceans, and harbours, and the impact of wakes from boats on spawning fish or wildlife (e.g., the nesting areas of loons). Various research benefits, problems, and costs can be addressed.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2i: Select and integrate information obtained from a variety of sources.

Include: print, electronic, and/or specialist sources, resource people

S3P-0-3c: Identify social issues related to science and technology, taking into account human and environmental needs and ethical considerations.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

SUGGESTIONS FOR INSTRUCTION

Students use an Anticipation Guide (*Senior Years Science Teachers' Handbook*, page 9.20) for an article that researches the problems, benefits, and costs that accompany society's use of one of the following: microwaves, radio waves, X-rays.

Students use Article Analysis Frames and Research Notes frames to organize information from various sources. (See *Senior Years Science Teachers' Handbook*, Developing Concepts Using Graphic Displays, and Writing to Learn Science, page 11.30.)

Students use Compare and Contrast Frames for wavefront and wave ray.

SUGGESTIONS FOR ASSESSMENT

Teacher Observations

Students draw and label a diagram of a straight wave and a circular wave.

Students identify wavefronts and wave rays, and relate these to events in the ripple tank.

Students describe and give examples of two-dimensional waves.

Research Report (Oral or Written)

Students report on common natural waves.

General Learning Outcome Connection

Students will...

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

Specific Learning Outcome

S3P-1-10: Describe, demonstrate, and diagram the reflection of plane (straight) and circular waves.

Include: linear and parabolic reflectors

Suggestions for Instruction

Notes to the Teacher

Outcomes S3P-1-08–S3P-1-10 are closely connected to outcomes S3P-2-06–S3P-2-09 in the Nature of Light topic (wave model of light). It is recommended to first examine the characteristics of waves in general and then later (in Topic 2) extend these ideas to light. However, some teachers may prefer to introduce the wave nature of light at this time. At this point, the teacher can decide whether to limit the description of these wave characteristics in terms of water waves or extend these characteristics to light waves.

Students should be able to draw diagrams of the observed phenomena, identify the focal points (for parabolic reflectors), and label the normal angle of incidence and angle of reflection for each case.

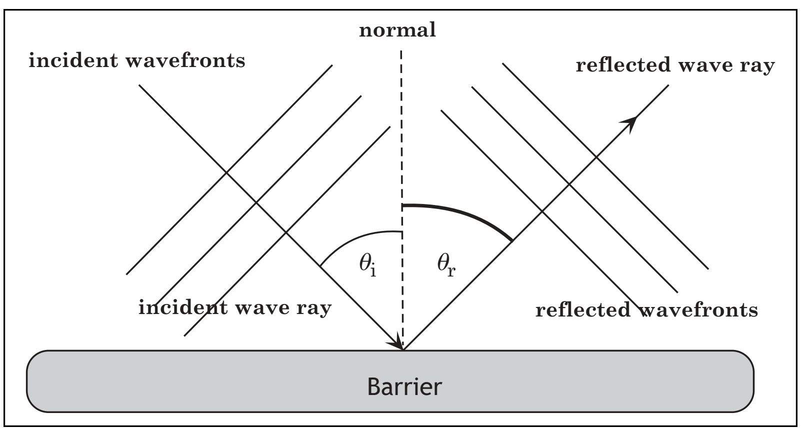
Student Activity

Students perform a lab with pulses in a ripple tank; use computer simulations; videotape and replay waves in a ripple tank in slow motion or frame by frame.

All the above activities will support the implementation and adaptation of the Law of Reflection under various conditions.

Senior Years Science Teachers' Handbook Activities

Students use the Three-Point Approach to build the concepts of reflection of waves in various conditions.



Reflection of Plane Wave

SKILLS AND ATTITUDES OUTCOME

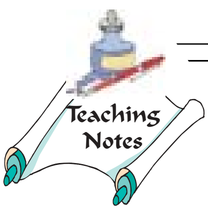
S3P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Performance Assessment/Student Demonstration

Students diagram and label reflection of straight waves from linear reflectors.

Students diagram and label reflection of circular waves from linear and concave reflectors.

Visual Displays

Students work in a team to do a lab with pulses in a ripple tank, and prepare a visual display of their observations.

SUGGESTED LEARNING RESOURCES

Multimedia

Physics: Cinema Classics videodisc Disk C: Waves (1), Chapter 53, Water: Plane Surfaces; Chapter 54, Water: Curved Surfaces

Video Encyclopedia of Physics Demonstrations (1992) videodisc

Software

Logal: Ripple Tank Core 1: It's All Done by Mirrors

General Learning Outcome Connection

Students will...

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

Specific Learning Outcome

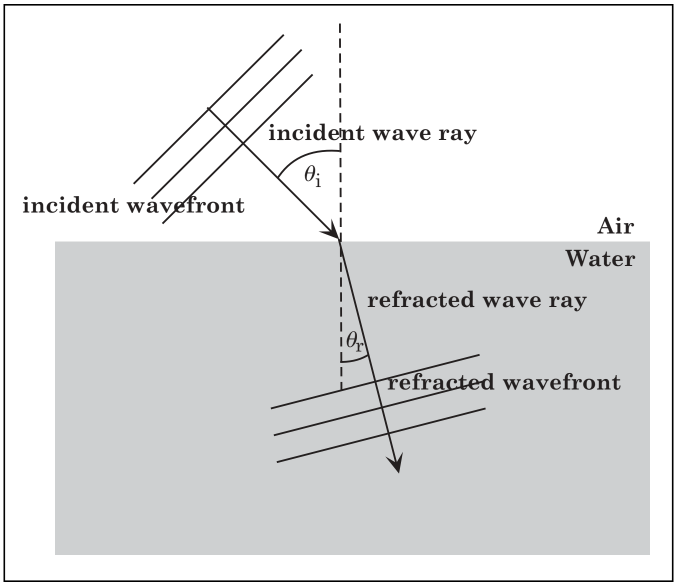
S3P-1-11: Describe, demonstrate, and diagram the refraction of plane (straight) waves.

Suggestions for Instruction

Notes to the Teacher

Outcomes S3P-1-08–S3P-1-11 are closely connected to outcomes SP3-2-06–SP3-2-09 in the Nature of Light topic (wave model of light). At this point, the teacher can decide whether to describe these wave characteristics in terms of water waves, or to extend these characteristics to light waves.

Use a ripple tank placed on an overhead to show refraction of straight waves as the waves go from shallow water to deep water and from deep water to shallow water. To create a refractive medium, use a flat piece of glass to change the depth of the water. Diagram the path of the incident wave hitting a different medium, passing through this medium, to exit back into the initial medium. This activity lends itself to understanding the theoretical basis of refraction and that the change in direction of motion of the wavefront is the result of the change in velocity of the wave.



According to the wave model, the wavefront slows down as it enters from a less optically dense medium to a more optically dense medium. This causes the refracted wavefront to travel in a different direction.

Senior Years Science Teachers' Handbook Activities

Students complete Compare and Contrast Frames for reflection and refraction.

SKILLS AND ATTITUDES OUTCOME

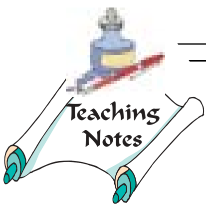
S3P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts (GLO D4)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students draw and label diagrams of wavefronts passing through the surface of two media. Diagrams should include the angle of incidence, the normal, the angle of refraction, and the wave ray.

Students draw and label diagrams of wave rays passing through the surface of two media. Diagrams should include the angle of incidence, the normal, the angle of refraction, and the wavefront.

SUGGESTED LEARNING RESOURCES

Multimedia

Cinema Classics videodisc Disk C: Waves (1), Chapter 61; Chapter 62

Software

Logal: Ripple Tank Exploration 2: Two Media

Applets (Websites)

<http://www.physics.nwu.edu/ugrad/vpl/index.html>

<http://www.phys.hawaii.edu/~teb/java/ntnujava/>

<http://www.physics.nwu.edu/ugrad/vpl/index.html>

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena (GLO A1)

SPECIFIC LEARNING OUTCOME

S3P-1-12: Derive Snell's Law using the relationships between wavelength, velocity, and the angles of incidence and refraction.

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

Outcomes S3P-1-12–S3P-1-13 are closely connected to outcomes S3P-2-06–S3P-2-09 in the Nature of Light topic (wave model of light). At this point, the teacher can decide whether to describe these wave characteristics in terms of water waves, or to extend these characteristics to light waves.

Demonstrate or have students complete lab activities related to waves in ripple tanks. Videotapes of wave phenomena are useful when played back in slow/stop action sequence. Derive Snell's Law from the geometry of the wavefronts (see Appendix 1.5: Derivation of Snell's Law).

Students will relate the visual representation of refraction to the symbolic mode.

Senior Years Science Teachers' Handbook Activities

Students use Compare and Contrast Frames for reflection and refraction.

Students apply a Category Concept Map for Snell's Law of Refraction.

Students write process notes for solving Snell's Law problems.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students solve problems using Snell's Law.

Students diagram refraction using wavefronts.

Given a diagram of the wavefronts travelling from one medium to another, students label the angles of incidence and refraction, and derive Snell's Law. (See "Working with Snell's Law and Wavefronts" in Appendix 1.5: Derivation of Snell's Law.)

SUGGESTED LEARNING RESOURCES

Multimedia

Physics: Cinema Classics videodisc Disk C: Waves, Chapter 62, Water (refraction example)

General Learning Outcome Connection

Students will…

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

Specific Learning Outcome

S3P-1-13: Experiment to demonstrate Snell's Law.

Skills and Attitudes Outcomes

S3P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

Suggestions for Instruction

Notes to the Teacher

Outcomes S3P-1-11–S3P-1-16 are closely connected to outcomes S3P-2-06–S3P-2-12 in the Nature of Light topic (wave model of light). Teachers can decide whether to describe these wave characteristics strictly in terms of water waves, or to extend these characteristics to light waves. In particular, the experiment on refraction and Snell's Law could be done:

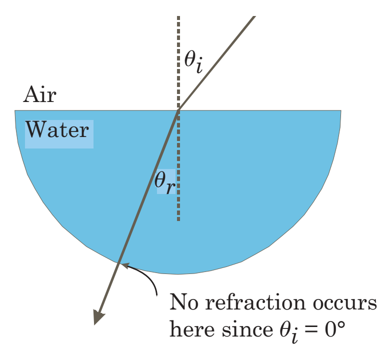
- at this point with water waves
- at this point with light
- or, it could be completed later with light

For Nature of Light outcome S3P-0-1, the phenomenon we call refraction can be explained by the statement: "as waves travel from deep water to shallow water, the direction of motion of the wavefront changes because the speed of the wavefront changes." The degree of this change in the direction of motion depends on the degree to which the speed of the wavefront changes. Scientific laws, in particular Snell's Law, identify this regularity and summarize it concisely.

Class Activity

Snell's Law can be investigated using periodic waves in a ripple tank that travel from one depth of water to another. Use a flat, glass plate to change the depth of water. Students trace the wave pattern on a screen below the ripple tank (or on any other screen) and then measure the angles of incidence and refraction.

There are several labs to investigate Snell's Law using light rays. The typical lab uses a glass block or cheese box filled with liquid as the refracting medium (see diagram below). The student observes pins and traces the path of the incident and refracted rays on paper. Then, the student records several angles of incidence and angles of refraction and displays these in a data table. Students then analyze and interpret the data to determine the linear relation between $\sin\theta_i$ and $\sin\theta_r$.



SKILLS AND ATTITUDES OUTCOMES

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs

S3P-0-1e: Differentiate between how scientific theories explain natural phenomena and how scientific laws identify regularities and patterns in nature.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students solve problems using Snell's Law.

Asking and Answering Questions Based on Data

Students make predictions using Snell's Law (e.g., speed of the waves in water).

Students prepare a lab report on Snell's Law. (See *Senior Years Science Teachers' Handbook*, page 14.12.)

General Learning Outcome Connection

Students will…

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

Specific Learning Outcome

S3P-1-14: Describe, demonstrate, and diagram diffraction of water waves.

Suggestions for Instruction

Notes to the Teacher

Outcomes S3P-1-14–S3P-1-16 are closely connected to outcomes S3P-2-06–S3P-2-09 in the Nature of Light topic (wave model of light). At this point, the teacher can decide whether to describe these wave characteristics in terms of water waves, or to extend these characteristics to light waves. In particular, diffraction can be dealt with:

- water waves at this point
- light at this point
- light at a later time

Teacher Demonstration

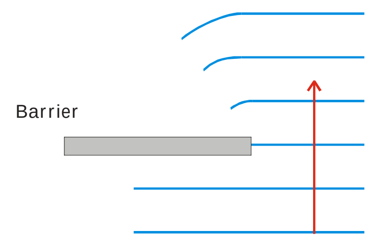
The teacher speaks to the class from outside the room with the door open, and students notice that the voice can be heard inside the classroom.

This simple demonstration points out the ability of sound waves to "diffract" around corners. We can expect that very little audible sound would pass directly through the walls.

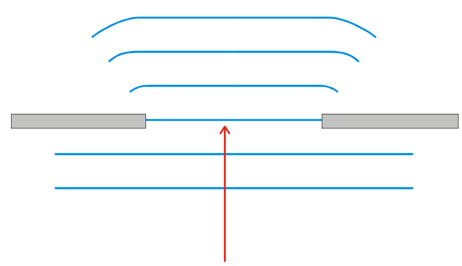
Student Activity

Using ripple tanks, students can generate diffraction, or they can view diffraction on video/DVD. Use different-size wavelengths and vary the slit opening to demonstrate the different diffraction patterns.

Students visually note the phenomenon of diffraction.



Diffraction as plane waves pass the edge of a straight barrier.



Diffraction as plane waves pass through an opening in a barrier.

SKILLS AND ATTITUDES OUTCOME

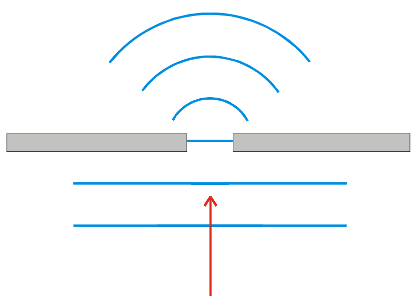
S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

SUGGESTIONS FOR INSTRUCTION



When the slit width and the wavelength are approximately equal in value, then the diffraction pattern will be the most pronounced.

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students diagram different diffraction patterns.

Students diagram diffraction patterns for various slit widths and various wavelengths.

SUGGESTED LEARNING RESOURCES

Multimedia

Cinema Classics videodisc Disk D: Waves (11), Chapter 11, Water Waves—Ripple Tank; Chapter 21, Water Waves—Ripple Tank

General Learning Outcome Connection

Students will...

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop
(GLO A2)

Specific Learning Outcomes

S3P-1-15: Describe, demonstrate, and diagram how constructive and destructive interference produce an interference pattern from two point sources.

S3P-1-16: Derive the path difference relationship for the interference pattern from two point sources

$$\left|\overline{P_nS_1} - \overline{P_nS_2}\right| = \left(n - \frac{1}{2}\right)\lambda.$$

Suggestions for Instruction

Notes to the Teacher

The two-point interference pattern is used in Topic 2, The Nature of Light, to derive Young's relationship to find the wavelength of light. Most textbooks will derive this relationship at that time. Since the derivation is lengthy and quite challenging for students, it is suggested that it be completed in two steps. The first step involves identifying the geometrical relationships of a wave pattern in general. The path difference can be calculated through simple constructions and by counting wavelengths. Later, this relationship for path difference provides the basis for Young's derivation.

Use circular waves generated in a ripple tank to observe the two-point interference pattern. Alternately, a videodisc or computer simulation can be used to view the interference pattern.

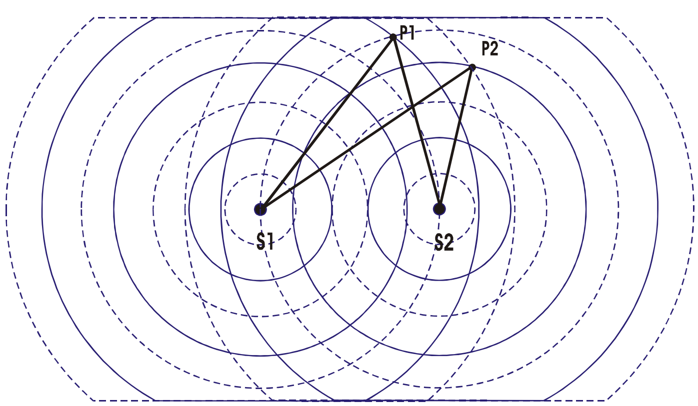
Copy the waves from a single point source pattern to a transparency. If two transparencies of this circular wave pattern are overlapped, patterns for different source separations can be quickly demonstrated. These patterns on the transparencies can be quickly copied to produce test items or questions (see Appendix 1.6: Circular Wave Patterns).

Teacher Demonstration

Moiré acetates are used to show interference patterns on the overhead (see Appendix 1.8 for various patterns).

Student Activity

Given an interference pattern from two point sources, students will map the nodal patterns. A nodal point is found at the intersection of a crest and a trough. In the diagram, the crests are represented by a solid line and the troughs are represented by a dotted line. Therefore, label a node at the point where a solid and dotted line intersect. Students can number the nodal point from the perpendicular bisector as P_1, P_2, et cetera. By counting the number of wavelengths from each source, the path length difference, $P_1S_1 – P_1S_2$, can be determined.



SKILLS AND ATTITUDES OUTCOMES

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SUGGESTIONS FOR INSTRUCTION

For example, the number of crests from S_1 to P_1 is 3 (count the solid lines from S_1 to P_1). The number of crests from S_2 to P_1 is 2½. Therefore,

$$P_1S_1 - P_1S_2 = (3\lambda - 2\tfrac{1}{2}\lambda) = \tfrac{1}{2}\lambda,$$

and for a point on nodal line number 2,

$$P_2S_1 - P_2S_2 = 1\tfrac{1}{2}\lambda,$$

and so on.

$$P_3S_1 - P_3S_2 = 2\tfrac{1}{2}\lambda.$$

(Note: in the diagram, only P_1 and P_2 are shown.)

In general,

$$P_nS_1 - P_nS_2 = (n - \tfrac{1}{2})\lambda.$$

That is, the line from P_1 to S_1 is longer by $(n - \tfrac{1}{2})\lambda$.

(A student template for this activity can be found in Appendix 1.7: Interference Pattern from Two Point Sources.)

***Senior Years Science Teachers' Handbook* Activities**

Students use the Compare and Contrast Frame for constructive and destructive interference.

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students diagram interference patterns and label nodal and antinodal lines.

Students identify areas of constructive and destructive interference from two point sources, and draw in nodal and antinodal lines.

Group/Peer Assessment

Students produce a written task for a partner where questions on different interference patterns are posed as well as questions on calculations of path difference. Rubrics for evaluation have to be negotiated in advance.

SUGGESTED LEARNING RESOURCES

Multimedia

Cinema Classics videodisc Disk D: Waves (11), Chapter 11, Water Waves—Ripple Tank

Applets (Websites)

<http://socrates.berkeley.edu/~cywon/>

<http://www.mta.ca/faculty/science/physics/suren/Applets.html>

<http://www.physicsweb.com> [waves in two dimensions]

NOTES