AMERICAN METEOROLOGICAL SOCIETY

The Maury Project

DEEP-WATER OCEAN WAVES

TEACHER'S GUIDE

The Maury Project

This guide is one of a series produced by The Maury Project, an initiative of the American Meteorological Society and the United States Naval Academy. The Maury Project has created and trained a network of selected master teachers who provide peer training sessions in precollege physical oceanographic education. To support these teachers in their teacher training, The Maury Project develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of the trained master teachers in your state or region, please contact:

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Forward

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities and in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further reading.

If we except the tides, and ... those that may be created by the wind, we may lay it down as a rule that all the currents of the ocean owe their origin to difference of specific gravity between sea water at one place and sea water at another; for wherever there is such a difference, whether it be owing to difference of temperature or to difference of saltiness, etc., it is a difference that disturbs equilibrium, and currents are the consequence.

Matthew Fontaine Maury
from The Physical Geography of the Sea. 1855.

Introduction: Deep-Water Ocean Waves

Deep-water ocean waves are waves occurring at the ocean surface which are unaffected by the ocean bottom. Most deep-water waves originate as disturbances of the still water surface by wind. Air flowing in contact with the water surface first generates small ripples called capillary waves. The capillary waves roughen the ocean surface and promote the transfer of energy from wind to water. Consequently the size of the waves increases. As a wave passes by, the original still water surface is restored by Earth’s gravitational attraction or, for the smallest ripples, by surface tension.

Because wind is almost always acting on the sea surface, the patterns of waves observed on the ocean surface are complex and ever changing. However, these patterns can be investigated by reference to the characteristics of ideal waves. The pattern exhibited by an ideal ocean wave can be uniquely described by a number of characteristics including length, height, period, and speed. These characteristics are determined by the factors that generate the wave.

Waves in the area of generation and still under the force of generation are called forced waves or sea. The size of waves produced by the wind increases with wind speed, wind duration, and fetch, the distance over which the wind blows. The size of waves produced by the wind does have limits. Eventually, the wave becomes unstable and breaks, forming whitecaps. In a fully developed sea, the wind energy input is balanced by energy lost by the breaking waves.

Waves that have traveled beyond the area of generation are called free waves or swell. Once formed, these waves may travel very long distances. As the waves travel, they transfer energy through ocean waters without a significant horizontal transport of the water itself. Because deep-water waves do not interact with the ocean bottom as they travel, their speed is independent of the water depth.

The speed of a deep-water wave is related to its wavelength. Because longer waves travel faster than shorter waves, swell leaving the same area of generation eventually sort themselves into groups of similar waves traveling together. When these groups of waves interact, they work together either to form a new series of wave groups (constructive interference), or to form wave free regions separating these groups (destructive interference).

Although there is interest in ocean waves as a source of pollution-free renewable energy, present day research is more focused on the physical influence of ocean waves, including their impact on ocean mixing and circulation. Breaking waves are also being investigated as an important mechanism contributing to the exchange of energy and material across the air-sea interface.

Basic Understandings

Ocean Waves

1. An ocean wave is a pattern of rising and falling water level that is transmitted along the sea surface.

2. Ocean waves transmit energy outward from an initial disturbance without the physical transport of water.

3. The patterns of rising and falling water observed on the ocean surface are complex and ever changing. However, these patterns can be investigated through the use of the characteristics of ideal waves.

Ocean Wave Characteristics

1. The pattern exhibited by an ideal ocean wave can be described uniquely by a number of characteristics including wave height, wavelength, period, and speed.

2. The highest point of each wave is the **wave crest**, and the lowest point is the **wave trough**.

3. The vertical distance between the wave crest and trough is the **wave height**. The greater the wave height, the greater is the associated **wave energy**.

4. The horizontal distance between two successive wave crests, or two successive wave troughs, is the **wavelength**.

5. The time it takes for two successive wave crests (one wavelength) to pass a fixed point is the **wave period**. Once a wave forms, its period remains constant.

6. How fast a wave is moving, the **wave speed**, can be determined by dividing the wavelength by the period.

7. Wave characteristics including wave height, wavelength, period, and speed are determined by the factors that generate the wave.

Generating Waves

1. Wind is the most common factor disturbing the still water surface and generating ocean waves. The disturbed water surface is restored to a still condition by gravity or, for the smallest ripples, by surface tension.

2. Wind is almost always acting on the sea surface to form waves. Air flowing over the water surface first generates small ripples, called **capillary waves**, which are small enough to be restored by surface tension.

3. Roughening of the water surface by capillary waves increases the transfer of the wind's energy to the ocean surface. As ripples grow to waves with wavelengths of centimeters and greater, the restoring force changes from surface tension to gravity.

4. The size of waves produced by the wind increases with wind speed, wind duration, and the distance over which the wind blows (**fetch**).

5. The increase in the size of waves produced by the wind has limits. When the ratio of wave height to wavelength, called the **steepness** of an ocean wave, exceeds 1 to 7, the wave breaks and forms **whitecaps**.

6. In a **fully developed sea**, the wind energy input is balanced by energy lost by the breaking waves and the waves have reached their maximum size.

7. Waves located in the area of generation and still under the force of generation are called **forced waves** or **sea**. Waves that have traveled out of the area of generation are called free waves or swell.

8. Unusually high deep-water waves, called **rouge waves**, may form in areas where waves generated by strong storms encounter oncoming currents.

Waves in Motion

1. Waves transfer energy through ocean waters without significant horizontal transport of the water itself.

2. A side view of the ocean surface with a wave moving from left to right would show water particles near the surface moving in clockwise circles called orbits. If the wave moves from right to left the orbits are counterclockwise.

3. The diameter of the orbits of the water particles at the surface is equal to the wave height.

4. The diameter of the orbits of the water particles gradually decreases with increasing depth below the surface until orbital motion ceases at a depth of one-half the wavelength.

Waves in Deep Water

1. Waves that occur in water which is deeper than one-half their wavelength are not affected by the ocean bottom. They are called **deep-water waves**.

2. Deep-water waves do not interact with the ocean bottom because the orbital motions of deep-water waves do not extend to depths greater than one-half their wavelength. Their speed is independent of the water depth.

3. Once a wave forms, its period remains constant. Hence, the speed of an individual deep-water wave is determined by its wavelength. The greater the wavelength, the greater is the wave speed.

4. Because waves of long wavelengths travel faster than smaller waves, swell leaving the same area of generation eventually sort themselves into groups of similar waves traveling together called **wave trains**.

5. When wave trains interact, they work together either to form a new series of wave groups (constructive interference), or to form wave-free regions separating these groups (destructive interference).

6. The speed of these wave groups, called **group speed**, is about one-half the speed of the individual waves. An individual wave can be observed passing through a wave group before disappearing into the wave-free region, and then reappearing at the back end of another wave group.

Wave Research

1. Breaking waves are being investigated as an important mechanism contributing to the exchange of energy and material across the air-sea interface.

2. Although there is still interest in ocean waves as a source of pollution-free renewable energy, current research is more focused on the influence of ocean waves, including their impact on ocean mixing and circulation.

Activity: Making Waves

Introduction

Waves that move across the ocean surface without being affected by the ocean bottom are called deep-water waves. Deep-water waves form as a result of wind disturbing the water surface and come in many shapes and sizes. They range in length from hundreds of meters, for the ship-swamping waves of nautical legend, down to a fraction of a centimeter, for the smallest ripples. All these waves exhibit several common characteristics and relationships that can be used to study and understand deep-water ocean waves.

The following activity investigates deep-water ocean waves by generating a simulated wave and observing it as it progresses across the water surface. The goal is to investigate the characteristics of these ocean waves and the water motions associated with them.

Materials

Cardboard paper-towel tube, marker pen, sheet of paper, metric ruler, scissors, clear tape, tack, watch.

Objectives

After completing this investigation, you should be able to:

* Describe the major characteristics of deep-water ocean waves.

* Describe the water motions associated with deep-water ocean waves.

Investigations

Measuring the Characteristics of Moving Waves

1. Hold the ***Wave Tube*** (built according to the ***Construction Instructions***, page 10) horizontally by its paper sleeve with its window on top. Look through the viewing window and rotate the cardboard cylinder by its edge. The window represents a view of a strip of ocean surface and the moving dark lines represent the highest parts of each wave, called the wave crests. Continue to rotate the tube to simulate a succession of individual waves crossing the ocean surface. During one complete rotation, the maximum number of wave crests visible in the window is (***<u>one</u>***), (***<u>two</u>***), (***<u>three</u>***), (***<u>four or more</u>***).

2. Ocean waves have characteristics that can be measured and then used to describe the waves. One of these characteristics is *wavelength*, the horizontal distance between any two successive wave crests. To determine the wavelength of the waves on your tube, use the ruler to measure the distance in centimeters between two successive wave crests visible in the window. Use a scale of one centimeter of the ruler represents one meter on the ***Wave Tube*** and record the wavelength in meters in the ***Wave Characteristics Table***, page 9. The wavelength measured between any other pair of successive wave crests on the tube would be (***the same***), (***different***) .

3. Ocean waves are also described by the time required for two successive wave crests (a distance of one wavelength) to pass a fixed point. This is the *wave period*. To determine the wave period, mark a point on the viewing window. Rotate the tube at a constant rate of about one-half turn each second and use your watch to measure the time required for two successive wave crests to pass this mark. On the tube, as on the ocean, it may be easier and more accurate to record how long it takes ten waves to pass a point and then divide by ten to obtain the average period. Try this and record the average wave period in seconds in the table.

4. Ocean waves are also characterized by *wave speed*. The speed of each wave is determined by the distance it travels divided by the time it takes to travel that distance. Having already determined that the wave period is the time it takes your wave to travel a distance of one wavelength, you can now determine your wave speed by dividing the wavelength in meters you previously recorded in the table by the wave period in seconds you also recorded. Record this result in the table as the wave speed in meters per second.

5. You can use this wave speed to determine the amount of time it would take one individual wave to travel a fixed distance. Measure the length of the window on the tube in centimeters. Again use a scale of one centimeter of the ruler represents one meter on the ***Wave Tube*** and record the distance in meters in the ***Wave Characteristics Table***. Divide this distance by the previously recorded wave speed to determine the time it would take one individual wave to travel the length of the window of the tube. Record this time in the table. Now rotate the tube at the same constant rate as before of about one-half turn per second to simulate a succession of individual waves crossing the ocean surface. Use your watch to measure how long it actually takes one wave to travel the length of the window. Record this time also in the table. Compare this measured time with your initial calculated time. The results are (***similar***), (***very different***).

Observing Water Motions of Moving Waves

6. Hold the ***Ocean Motion Maker*** (built according to the ***Construction Instructions***, page 10) horizontally by its paper sleeve. Look at the round end with the tack and paper attached and rotate the tube. The top edge of the paper represents sea level. Rotate the cardboard tube and observe the changing height of the water level. The motion of the paper's top edge displays the vertical motion of the water surface as a wave passes a fixed point. When at its highest point, the *wave crest* is passing the fixed point. When at its lowest point, the *wave trough* is passing. The vertical distance between the highest and lowest point, or crest and trough, is called the *wave height*. When only one wave crest and one wave trough have passed the fixed point, one-half wavelength has passed. When a crest, a trough, and a second crest have passed the fixed point, (***one-half***), (***three-quarter***), (***one***) wavelength has passed.

7. The tack on the motion maker represents a particle of water at the surface of the ocean. As a wave passes, the motion of this particle describes a (***vertical straight line***), (***circle***).

8. To investigate how waves move along the surface of the ocean without taking the same mass of water along with it, have five volunteers line up with their motion makers facing the audience. As viewed from the audience, the tack for the first volunteer on the far left should be located straight up, or at the 12 o'clock position on the face of a clock. From left to right, the tacks for the rest of the volunteers should be at the: 9 o'clock; 6 o'clock; 3 o'clock; and 12 o'clock position to start. Count out loud, slowly and repeatedly, "one, two, three, four" while all of the volunteers turn their motion makers clockwise a quarter turn in unison at each count. Note the progression of the wave crest across the ocean surface and the direction of motion of the water molecules. Stop and repeat for a counterclockwise rotation. If the particles of water are rotating clockwise, the audience will see the wave moving from (***left to right***), (***right to left***). If the particles of water are rotating counterclockwise, the wave is moving from (***left to right***), (***right to left***).

9. Examine the ***Wave Motion Diagram*** page 9. On this side view of the ocean surface, the waves are moving from left to right. To investigate this motion, align a piece of paper's long end along the average sea level line and the left short end along the vertical line on the left side of the diagram. Mark the paper's long edge at the horizontal distances at which the wave reaches its crest, sea level, trough, next sea level and next crest. Label these intervals in terms of fractions of one wavelength. Each mark is equal to an interval of about (***1/3***), (***1/4***), (***1/5***) wavelength.

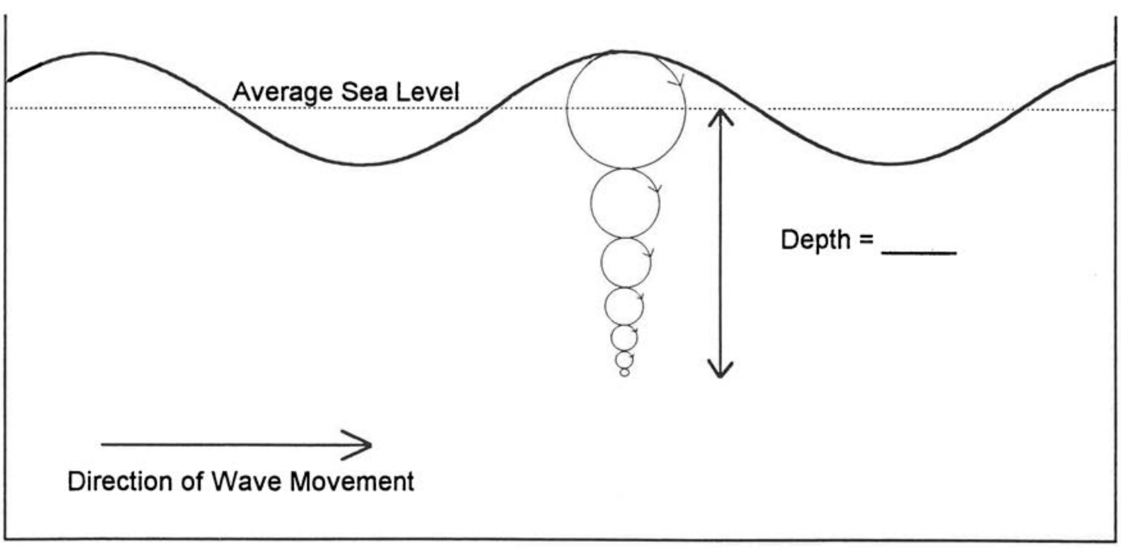
10. As the wave moves across the water surface on the diagram, particles of water are set in circular motion, called orbits, by the energy of the passing wave. The diameter of these orbits gradually decreases with depth below the surface. At some depth, the circular motion ceases. Use your calibrated paper to measure the depth below average sea level at which orbital motion ceases. Express this depth as some fraction of the wavelength and record it on the blank in the diagram. The depth at which orbital motion ceases is about (***1/4***), (***1/2***), (***3/4***) wavelength.

11. If the water is deep enough, the orbital motion associated with ocean surface waves will not interact with the bottom. Such waves are referred to as deep-water waves. According to the Wave Motion Diagram, a deep water-wave occurs in water that is deeper than (***1/8***), (***1/4***), (***1/2***) its wavelength.

Wave Characteristics Table

Wave Source	Wave Tube
Wavelength (m)	
Wave Period (sec)	
Wave Speed (m/sec) = wavelength/period	
Window Length (m)	
Calculated Time (sec)	
Measured Time (sec)	

Wave Motion Diagram



Construction Instructions

Wave Tube

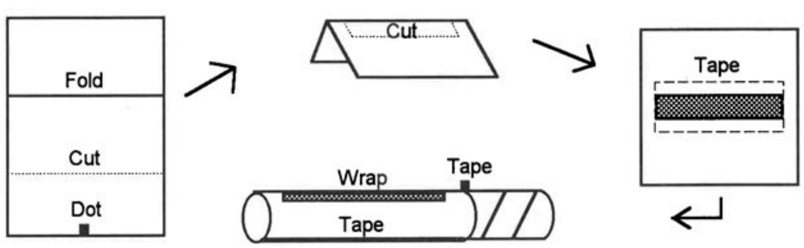
1. With the marker pen, make about a 0.5 cm wide dot halfway across the bottom (short side) of the piece of paper. Cut off the bottom 12 cm of the piece of paper (the portion with the dot) and retain for later use.

2. Fold the remaining piece of paper in half (long sides together). On the folded side, cut out a 0.5 cm wide strip horizontally across the paper, leaving a 1 cm margin on either end of the folded edge. Unfold the paper.

3. Cover the entire missing strip with one piece of clear tape on the front side of the paper and another on back to form a viewing window.

4. On the outside of the cardboard tube, use the marker pen to darken the seam that spirals along the length of the tube. Wrap the paper loosely around the tube, long sides together, to form a paper sleeve. Tape the seam. The paper sleeve should now rotate freely around the tube.

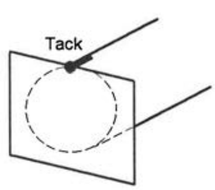
5. Align a tube end with a sleeve end and lightly trace a reference line on the tube around the other sleeve end. For a reference point, fold a 8-cm piece of tape in half, short sticky sides together, leaving about 2 cm on either end to attach to either side of the reference line.



Ocean Motion Maker

1. Stick a tack through the center of the dot on the remaining piece of paper.

2. Tape the metal shaft of the tack to the outside edge of the tube so that the paper hangs freely as it covers the tube opening.



Information Sources

Ahrens, C.D., 1994. Meteorology Today, *An Introduction to Weather, Climate, and the Environment*, 5th. ed. West Publishing Co., St Paul, MN.

Cullen, V. (ed.), 1993, Coastal Science & Policy I, *Oceanus* Vol. 36(1), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1993, Coastal Science & Policy II, *Oceanus* Vol. 36(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1991, Naval Oceanography, *Oceanus* Vol. 33(4), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1992, Physical Oceanography, *Oceanus* Vol. 35(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Duxbury, A.C. and Duxbury, A.B., 1994. *An Introduction to the World's Oceans*, 4th. ed. Wm. C. Brown Publishers, Dubuque, IA.

Golden, F. (ed.), 1989, The Oceans and Global Warming, *Oceanus* Vol. 32(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Gross, M. Grant, 1992. *Oceanography, A View of the Earth*, 6th. ed. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Open University, 1991, *Case Studies in Oceanography and Marine Affairs*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Ocean Circulation*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Seawater: Its Composition, Properties and Behavior*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Waves, Tides and Shallow-Water Processes,* Pergamon Press, Tarrytown, NY.

Ryan, P.R. (ed.), 1990, Marine Education, *Oceanus* Vol. 33(3), Woods Hole Oceanographic Institute, Woods Hole, MA

Thurman, H.V., 1992, *Essentials of Oceanography*, 4th. ed. Merrill Publishing Co., Columbus, OH