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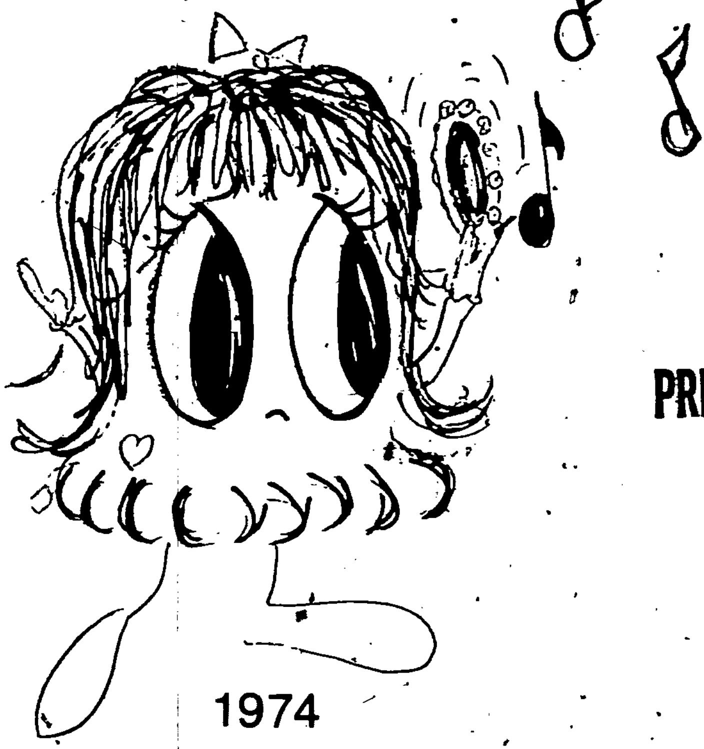
ABSTRACT

This minicourse was prepared for use with secondary physics students in the Dallas Independent School District and is one option in a physics program which provides for the selection of topics on the basis of student career needs and interests. This minicourse was aimed at providing students with a knowledge of the technical descriptions of music, the differences between music and noise, and the ways in which various instruments produce sounds. The minicourse was designed for independent student use with close teacher supervision and was developed as an ESEA Title III project. A rationale, behavioral objectives, student activities, and resource packages are included. Student activities and resource packages involve defining noise and music, taping sounds and noises, investigating careers in music, learning the vocabulary of sound and music, investigating vibrating strings, air columns and surfaces, exploring the role of temperature in sound transmission and making a noise pollution tape. (GS)

CAREER-ORIENTED PRE-TECHNICAL PHYSICS

Physics of Musical Instruments

MINICOURSE



PRELIMINARY EDITION

1974

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CAREER-ORIENTED PRE-TECHNICAL PHYSICS

Physics of Musical Instruments

Minicourse

ESEA Title III Project

1974

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March 25, 1974

This Mini Course is a result of hard work, dedication, and a comprehensive program of testing and improvement by members of the staff, college professors, teachers, and others.

The Mini Course contains classroom activities designed for use in the regular teaching program in the Dallas Independent School District. Through Mini Course activities, students work independently with close teacher supervision and aid. This work is a fine example of the excellent efforts for which the Dallas Independent School District is known. May I commend all of those who had a part in designing, testing, and improving this Mini Course.

I commend it to your use.

Sincerely yours,

Nolan Estes

Nolan Estes
General Superintendent

mfs

CAREER ORIENTED PRE-TECHNICAL PHYSICS TITLE III ESEA PROJECT

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CAREER ORIENTED PRE-TECHNICAL PHYSICS

THE PHYSICS OF MUSICAL INSTRUMENTS

RATIONALE (What this minicourse is about):

If you asked ten people, "What is music?", you would likely receive as many different answers. This is because music is a qualitative word and people with different tastes have different ideas about what music is. However, all of the definitions offered would probably include some reference to the human voice, to one of three major groups of musical instruments, or to some electronic device used to generate sound. Although the idea of what music is yields to personal preferences, there are some technical physics standards that allow us to describe music and help us to distinguish it from noise. In this minicourse, you will have an opportunity to learn something about these technical descriptions of music, about some differences between music and noise, and about some of the ways various instruments produce sounds.

In addition to RATIONALE, this minicourse contains the following sections:

1) TERMINAL BEHAVIORAL OBJECTIVES (Specific things you are expected to learn from the minicourse).

2) ENABLING BEHAVIORAL OBJECTIVES (Learning "steps" which will enable you to eventually reach the terminal behavioral objectives).

3) ACTIVITIES (Specific things to do to help you learn).

4) RESOURCE PACKAGES (Instructions for carrying out the learning Activities, such as procedures, references, laboratory materials, etc).

5) EVALUATION (Tests to help you learn and to determine whether or not you satisfactorily reach the terminal behavioral objectives):

   a) Self-test (s) with answers, to help you learn more.

   b) Final test, to help measure your overall achievement.

TERMINAL BEHAVIORAL OBJECTIVES:

When you have successfully completed this minicourse, you will be able to:

1) demonstrate a knowledge of the criteria scientists traditionally use for the difference between music and noise by writing a definition of each.

2) define several basic terms used in the study of the physics of music.

3) explain how sounds are produced by the vibration of strings, air columns, and surfaces.

4) list various factors which affect sound production and transmission.

5) show your understanding of the mathematical relationships between frequency, wave length, and speed of sound waves by solving simple related problems.

6) describe in a general way how the human ear transmits sound messages to the brain.

7) list some of the negative (deleterious) biological effects of sound.

ENABLING BEHAVIORAL OBJECTIVE #1:	ACTIVITY 1-1	RESOURCE PACKAGE 1-1
Distinguish between music and noise by writing a definition of each and by giving at least two examples of each.	Study Resource Package 1-1.	"Definitions of Noise and Music"
	ACTIVITY 1-2	RESOURCE PACKAGE 1-2
	Listen to the tape in Resource Package 1-2.	"Taped Sounds and Noises"
	ACTIVITY 1-3	RESOURCE PACKAGE 1-3
	Without looking at either of the previous activities, write the definition of noise and music, and give at least two examples	"Careers in Music"

ENABLING BEHAVIORAL OBJECTIVE #1:	ACTIVITY 1-3 (continued)	
(For a statement of this objective, see page 2 of this minicourse)	of each. Check your work, using Resource Packages 1-1 and 1-2. Read Resource Package 1-3.	
ENABLING BEHAVIORAL OBJECTIVE #2:	ACTIVITY 2-1	RESOURCE PACKAGE 2-1
Write the meaning of at least twelve (12) terms associated with the physics of muscial instruments.	Read Resource Package 2-1.	"Vocabulary of Sound and Music"
ENABLING BEHAVIORAL OBJECTIVE #3:	ACTIVITY 3-1	RESOURCE PACKAGE 3-1
Explain, orally or in writing, how various muscial instruments use vibrating strings, air columns, membranes, or surfaces to produce sounds. Also, demonstrate sound production to your class or teacher, using one example of each of these types of vibrators. Further, tell how factors such as length, tension, size, shape, and density of materials affect sound.	Complete Resource Package 3-1.	"Investigating Vibrating Strings"
	ACTIVITY 3-2	RESOURCE PACKAGE 3-2
	Complete Resource Package 3-2.	"Investigating Vibrating Air Columns"
	ACTIVITY 3-3	RESOURCE PACKAGE 3-3
	Complete Resource Package 3-3.	"Investigating Vibrating Surfaces"
	ACTIVITY 3-4	RESOURCE PACKAGE 3-4
	Complete Resource Package 3-4.	"Self-test"
	ACTIVITY 3-5	RESOURCE PACKAGE 3-5
	Check your answers, using Resource Package 3-5. Should you have questions about these answers, perhaps you should review the material with your instructor.	"Self-test Answers"

ENABLING BEHAVIORAL OBJECTIVE #4:

Demonstrate a knowledge of the mathematical relationships between the wave length, frequency, and speed of sound by solving correctly at least eight (8) of ten (10) related problems. These problems will require consideration of air temperature effects upon speed.

ACTIVITY 4-1

Study Resource Package 4-1.

RESOURCE PACKAGE 4-1

"Temperature and Speed of Sound Waves"

ACTIVITY 4-2

Complete Resource Package 4-2.

RESOURCE PACKAGE 4-2

"Self-test"

ACTIVITY 4-3

Check your results, using Resource Package 4-3.

RESOURCE PACKAGE 4-3

"Self-test Answers"

ENABLING BEHAVIORAL OBJECTIVE #5:

Write a short paragraph describing how the human ear receives and transmits sound signals.

ACTIVITY 5-1

In an encyclopedia, physics textbook, biology book, or whatever book, find a drawing and an explanation of the operation of the human ear. Study this. In addition, ask your teacher for a model of the human ear to study.

ACTIVITY 5-2

Complete Resource Package 5-2.

RESOURCE PACKAGE 5-2

"Investigating Sound Transmission"

ENABLING BEHAVIORAL OBJECTIVE #6:

List and describe some of the physiological and psychological effects of sounds on organisms.

ACTIVITY 6-1

In your school library or the public library, use the Reader's Guide to Periodic Literature to locate at least two (2) recent articles on the general subject

ENABLING BEHAVIORAL OBJECTIVE #6:

(For a statement of this objective, see page 4 of this minicourse.)

ACTIVITY 6-1 (cont.)

of noise pollution. Write a simple report of these articles. The report should include: bibliographical data, sources of noise pollution, instances of sound damage to organisms, who is doing research into problems of noise, where noise pollution research is being conducted, etc.

ACTIVITY 6-2

Listen to the tape from Resource Package 6-1 and complete Resource Package 6-2. Using your notes from the library articles and using the information given in Resource Packages 6-1 and 6-2, compile a list of at least eight (8) noise sources that are considered to be a problem to society. Describe the potential hazards that each of these pollution sources poses.

RESOURCE PACKAGE 6-1

"Noise Pollution Tape"

RESOURCE PACKAGE 6-2

"Noise Pollution"

ACTIVITY 7-1

Complete Resource Package 7-1.

RESOURCE PACKAGE 7-1

"Self-test"

ACTIVITY 7-2

Check your answers, using Resource Package 7-2.

RESOURCE PACKAGE 7-2

"Self-test Answers"

FINAL EVALUATION

ACTIVITY 8-1

If you feel you are ready, ask your instructor for the Final Evaluation Resource Package.

RESOURCE PASSAGE 1-1

DEFINITIONS OF NOISE AND MUSIC

Webster's Third New International Dictionary includes the following among its definitions:

noise - a sound that results from irregular vibrations in matter and produces an unpleasant sound.

music - sounds that have rhythm, melody, or harmony and that result from regular vibrations in matter.

You realize, of course, that certain contemporary music might give Mr. Webster cause for more than just a little reflection on his definitions! Don't you think that certain electronic music, for example, might make these definitions invalid? And isn't music quite like food, in that it can be largely a matter of taste? For reasons such as those discussed here, a musician's definition of music might be:

music - music is a combination of sound and silence, organized in terms of time.

RESOURCE PACKAGE 1-2

TAPED SOUNDS AND NOISES

Ask your teacher for the tape for Resource Package 1-2. You will need a pencil and paper to record your responses to taped questions and for taking notes.

RESOURCE PACKAGE 1-3

CAREERS IN MUSIC

Music-related careers are a sub-set of the career field of Fine Arts and Humanities. Musical training frequently begins at an early age, and is generally supervised part-time or full-time by a private music teacher. Of course, public schools offer music courses; and many music institutes, community colleges, 4-year colleges, and universities offer strong music programs.

Competition is keen in the music field. Some specialty areas are: music-related salesperson, performer (instrumental and/or vocal), teacher and composer (radio, television, motion pictures). In some sections of the nation, the employment outlook is not particularly good because the field seems to be overcrowded.

RESOURCE PACKAGE 2-1

VOCABULARY OF SOUND AND MUSIC

Look at the following terms; realize that the definitions are acoustically (sound) oriented. Refer to your textbook for further explanation of these terms.

1) beat - a cyclic increase and decrease of loudness (intensity) resulting from the interference of sound waves.

* 2) definite pitch - definite pitch is produced by vibrations of the same frequency; indefinite pitch is produced by vibrations of variable frequencies.

* 3) dynamics - musical sound possesses some degree of loudness and softness; this is known as dynamics to musicians and as intensity to physicists.

4) frequency - the rate at which a sounding body vibrates, usually measured in cycles per second (1 hertz = 1 cps).

5) fundamental tone - the tone produced by an object vibrating in its simplest way (fundamental mode).

6) intensity - the measure of energy of a sound wave (loudness depends upon intensity; and intensity increases with wave amplitude).

7) loudness - the effect which sounds of varying intensity and frequency have on the auditory (hearing) system.

* 8) metered music - metering is the organization of music to produce relationships of strong and weak beats over an underlying pulse.

* 9) music - music is organized sound and silence in time.

* 10) musical design - design is the unity and variety in the organization of sound and silence.

* 11) musical event - the manner in which sound and silence is organized defines a musical event.

* 12) musical form - the relationships in the organization of musical events define the form of a musical structure.

* 13) musical relationships - relationships exist when two or more pitches are combined; pitch relationships may be organized horizontally (successive pitches) and/or vertically (simultaneous pitches).

14) note - a sound produced by a body vibrating at a fixed, defined frequency.

15) overtone - a tone whose vibration rate (frequency) is a whole number multiple of its fundamental mode.

16) pitch - the auditory property of sound resulting from the physical characteristics and the frequency of a vibrating body. Example: Female voices are generally pitched higher than the bass voices of males.

* 17) pulse - pulse is the smallest perceivable ongoing cycle of sound tension and release in both metered and unmetered music.

* 18) rhythm - rhythm is the patterning of sounds and silences over an underlying pulse.

19) scale - a ladder-like series of notes, ordered in terms of frequency.

20) sound - an energy form transmitted through matter as a wave and caused by a vibrating body.

* 21) structure - structure is aural (sound) design in music. Structuring music is the process of establishing relationships as individual sounds combine to produce larger musical events.

* 22) style - musical style is the reflection of varied emphases in the inter-relationships of musical elements, as music evolves in historical periods and cultural environments.

* 23) texture - texture is the nature of horizontal-vertical inter-relationships of rhythmic and tonal factors in music.

* 24) timbre - timbre is the distinctive quality of tone determined by the sum of all of the tone's accoustical (sound) characteristics.

25) tone - the sound produced when an object vibrates in regular fashion; tone combines such characteristics as quality, richness, timbre, pitch, intensity, etc.

26) transmitting medium - the material through which the sound wave <u>propagates</u> (travels).

27) wave length - the distance between any wave point and the identical point exactly one cycle later; i.e., the crest-to-crest distance, trough-to-trough distance, etc.

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* Musician's definitions

RESOURCE PACKAGE 3-1

INVESTIGATING VIBRATING STRINGS

Please do not write in this Resource Package. Use other paper to record data and to answer questions.

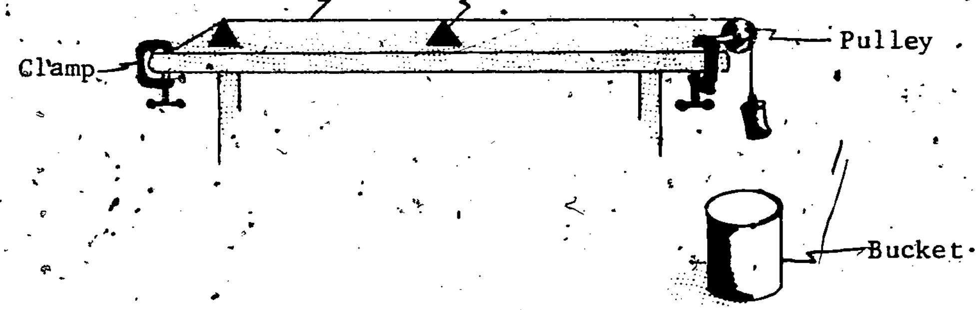
You may work alone or as a part of a small group (say, two to four people).

Purpose: This investigation is designed to let you evaluate sounds generated by vibrating strings made of different materials, of different lengths, and under different tensions (stretch forces).

Procedure: Use a sonometer. If you do not have a sonometer, set up the following items as shown in Fig. 1, next page: You will need:

- 2 "C" clamps
- 1 pulley (that can be extended over the edge of the table)
- 2 or more pieces of string or wire, each of different material and approximately three (3) meters long
- 1 spring balance
- 1 bucket (into which water, sand or rocks can be placed to serve as tension forces on the string or wire)
- 1 meter stick
- 2 triangular blocks (wooden or metal pieces) with fairly sharp edges, to support the string at specific points (to act as do the bridges of a guitar)
- some tuning forks, pitch pipes, and/or stroboscope.

Clamp one end of the string to one side of a table. On opposite side of the table, clamp a pulley wheel so that it extends beyond the edge of the table. Bring the free end of the string over the pulley and tie it securely to the bail (handle) of the bucket. Add material to the bucket so that the string is just tight enough to make a sound when plucked with your finger. Place the two triangularblock bridges under the string, as far apart as possible. Your set-up should look something like Fig. 1:



"POOR BOY" SONOMETER
Fig. 1

The vibrating string: Tension is varied by changing amount of water or other weight in can (bucket). Length is changed by moving triangular blocks (bridges).

Record your observations on a data chart, such as the sample below. You should run at least eight (8) trials, four (4) for each type of string or wire. Trial #1 should use the apparatus arrangement described above. In the data chart, "Material of String or Wire" could be cotton string, waxed twine, steel wire (22-gauge is a good size), brass wire, nylon cord, plastic or gut guitar string, etc. "Length" will be the distance between the bridge points. "Weight of Bucket and

Contents" may be in newtons* or pounds.

Caution: Do NOT try to use a lightweight spring balance; ask your teacher for a heavy-duty one.

Frequency is the principal physical determinate of pitch and can be recorded quantitatively (numerically), if you have tuning forks or pitch pipes or a stroboscopic light with which to compare your vibrating string (wire). Otherwise, pitch can be qualitatively recorded as "higher than #1" or "lower than #2, #3, or #4," etc.

For Trial #2, change ONLY the weight in the bucket (should be increased). For Trial #3, leave the apparatus IDENTICAL to Trial #2, but shorten the distance between the bridges.

For Trials #4, #5, and #6, use a different vibrator material and repeat the procedures of Trials #1 through #3. If you are interested, investigate other types of vibrator materials and/or other vibrator conditions.

Caution: Do not get your face or hands "in line" with the string. If it were to break under tension, the "whip-like" action of the ends of the fractured vibrator could injure you.

DO NOT OVERLOAD THE BUCKET!

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* If you don't recognize this, ask your instructor about w = mg = newtons = mass ($9.8\ m/sec^2$) = kg ($9.8\ m/sec^2$); read about metric forces in your text; and refer to Schaum's workbook (See REFERENCES, last page of this minicourse).

Sample of Data Chart:

	Material of Vibrator String or Wire	Vibrator Length	Weight of Bucket and Contents	Vibrator Frequency
Trial #1				
Trial #2				
Trial #3				
etc.				

Conclusion: Respond to the following; then submit your data and your responses for evaluation:

1) How did the sound of different strings compare, when tension and length were the same? How do you account for your answer?

2) For each vibrator, was pitch affected by tension?

3) How was pitch affected by vibrator length?

4) a. At what point along the vibrator did the displacement (distance of vibrator from its plucked position) seem greatest?

   b. At what point(s) did the displacement seem least?

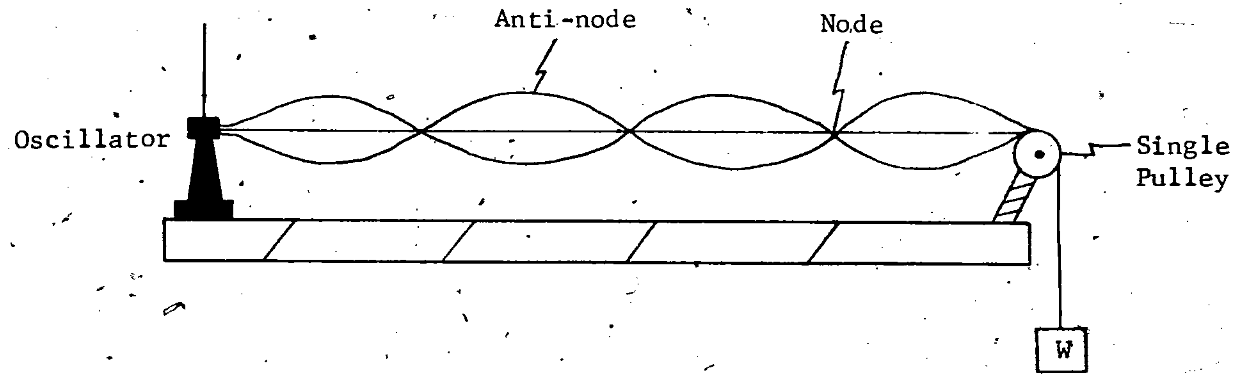
5) Write a general statement about the relationships between pitch and the length, tension, and massiveness of a vibrating string.

6) List some instruments whose sound is produced by vibrating strings. List also some methods used to pluck the instrument or to otherwise make its strings vibrate.

7) Suppose you tune an instrument to a specific frequency (pitch). As you are playing, the temperature of the instrument may change. (In a stringed instrument, for example, a metal string's tension can change with temperature -- have you ever noticed how electric power lines sag on a hot day?). If the instrument temperature changes, how might this affect the performance and what do performers do about this problem?

<u>Optional Activities</u>:

If you have an electric string vibrator, arrange it as shows:



STANDING WAVES IN A STRING

1) Hang a light weight on the string. Slowly add additional weights until a <u>standing wave</u> is seen in the string.

   a. Measure the wave length (node-to-alternate-node distance).

   b. Sketch the setup and label:

      1) nodes

      2) anti-nodes

      3) "crest"

      4) "trough"

      5) amplitude

2) Increase the string tension by adding more weight. When a new standing wave exists, measure its length.

3) How does string tension affect wave length?

4) If the oscillator frequency is fixed (it will be <u>either</u> 60 Hz or 120 Hz), what is the wave speed in the string when it is under the tension for Part 1? ...for Part 2?

5) How does wave speed vary with tension?

6) Submit your sketches, answers, and comments for evaluation.

RESOURCE PACKAGE 3-2

INVESTIGATING VIBRATING AIR COLUMNS

As always, record data and responses on a separate sheet of paper to be submitted for evaluation.

Purpose: To determine the factors which affect the pitch (frequency) of a vibrating column of air.

Equipment:

4 cold drink bottles of the same size and shape (10 oz. Dr. Pepper bottles are good to use)
4 cold drink bottles of assorted shapes and sizes
some toy whistles, "horns," or like kinds of vibrating air-column instruments (a "Flutaphone" is fine)
some tuning forks (the frequency range from C-128 to A-215 is good to use)
tape from Resource Package 1-2

Procedure: Practice blowing across the top of one of the bottles until you can get a smooth, consistent tone each time you blow. Make a data chart something like the one on the next page.

Now, take the four (4) bottles that are alike. Leave one empty, and partially fill the other three (3) with water (each to a different level). Blow across the neck of each bottle. Sound a tuning fork (or a tone from the tape in Resource Package 1-2); slowly add water to (or remove water from) one of the bottles until it produces the same tone as does the tuning fork or tape. You will have tuned the bottle to a designated pitch (frequency).

Next, beginning with the empty bottle, measure and record its air column (the distance from the lip of the bottle to its bottom, if empty, or to the surface of its liquid). Also, record the frequency of the bottle's sound, ~~such as 128~~ cps, or C-128 cps, or simply "higher than #2," or "higher than #1," or "#3", etc.

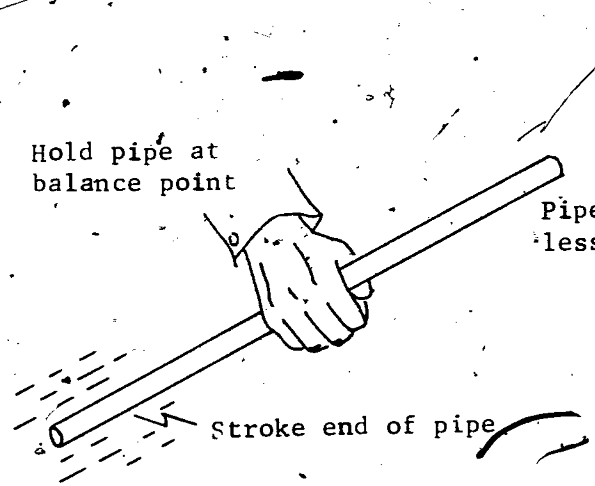
Sample Data Chart

Trial #	Type of Bottle	Length of Air Column (cm)	Frequency (cps)
1)			
2)			
3)			
etc.			

Next, take the four (4) bottles of different shapes and fill them with water until the column of air is the same length in each. Blow across the neck of each of these bottles. Is there a difference in pitch? Can you conclude that shape or size does, or does not, affect pitch? Does how hard you blow make any apparent difference in pitch? ... in intensity?

When generating sounds with the drink bottles; you are using what is sometimes called a "closed pipe" because one end is closed. Pipe organs employ closed sounding pipes.

Sounding pipes can also be open at both ends. To investigate this, stroke the end of an open pipe to make it sound. You should start off by supporting the pipe with one hand at its balance point (center of gravity) and at the same time stroking one end of the pipe with a friction material to make the pipe vibrate. A good "squeaky" effect can be obtained by using a chamois sprinkled with powdered resin or other sticky substance. A wet sponge also does well. See the diagram below.

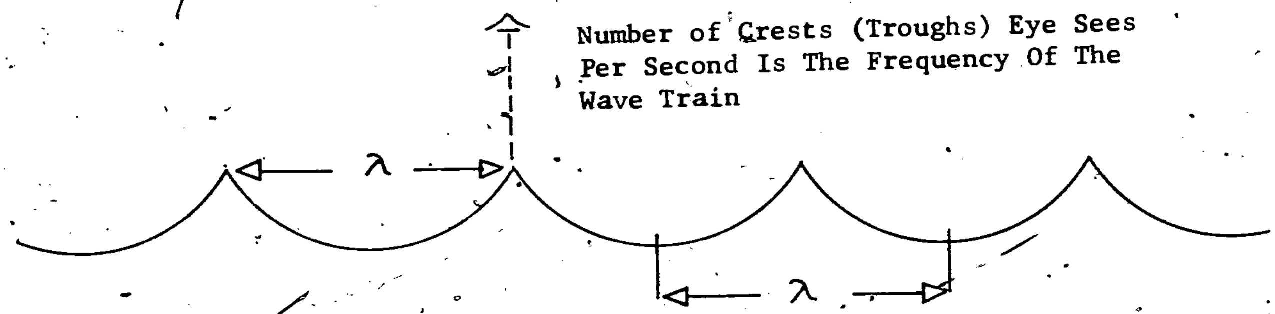


The speed of sound in air is over 330 meters per second at 0° C, this is nearly 1100 feet per second at 32° F. At a room temperature of 22° C (about 72° F), sound travels faster (about 345 m/s).

Sound can be simply defined as a form of mechanical energy which propagates (travels) as a wave form. Sound, then, is energy in motion through a material medium; and all sound is produced by an oscillator (vibrator) which transfers energy to the medium by setting the medium's particles (molecules) into vibratory motion.

You are referred to the minicourse, Physics of Communication, for a more complete treatment of sound as energy in a wave form. For our purposes here, it will suffice to say that sound obeys the physics of all kinds of wave transport of energy. For all waves, a simple mathematical relationship exists

...etween wave speed (v), oscillator frequency (f), and wave length (λ): $v = f\lambda$ (See Fig.1)



WATER WAVES
Fig. 1

Lambda (λ) is the Greek letter commonly used to represent wave length. For example, if a tuning fork oscillates at 200 Hz (200 cps) and if sound travels 1200 ft/sec, then the wave length is:

$$v = f\lambda$$

$$1200\ \frac{ft}{sec} = 200 \cdot \frac{cycles}{sec} \cdot (\lambda)$$

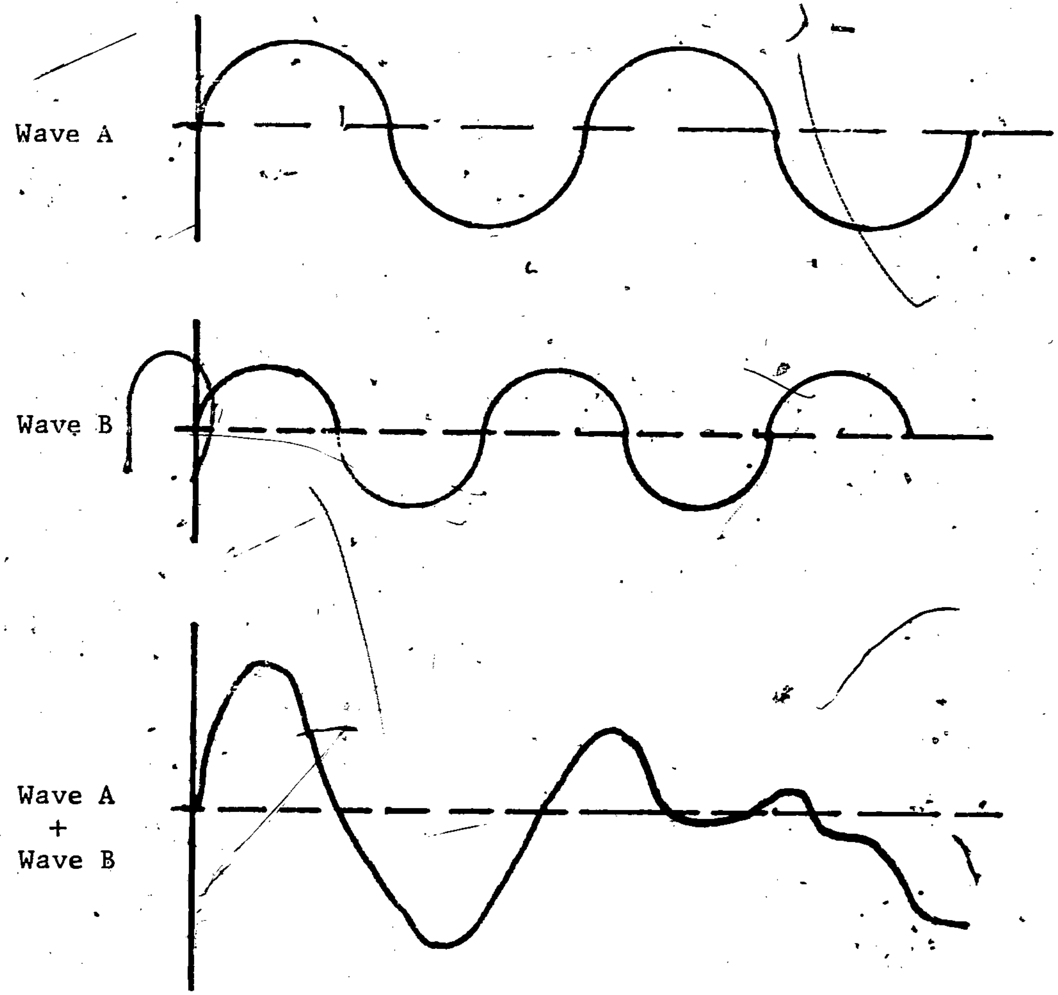
$$6\ ft = \lambda$$

Notice that cycles is NOT a diminsional unit, such as ft or sec; therefore, cycles is simply dropped from the dimensions of λ.

The frequencies associated with various musical pitches have been measured. However, there is not universal agreement among scientists and musicians as to just what frequency represents a given pitch. Therefore, a tuning fork from the physics lab marked C-256 may not be in tune with a piano's middle C. The American Federation of Musicians has adopted 440 hertz as the frequency of A above middle C, and musicians build their scales on this base. Consequently, the musical scale C has a frequency of C = 261.63 Hz associated with it, instead of the scientific frequency of 256 Hz.

Each musical note has a frequency that is in a fixed ratio to other notes. When two or more notes sounded together produce a pleasing sound, we say that the sounds are consonant or in harmony. Dissonant or discordant sounds occur when two or more notes sounded at the same time produce an unpleasant effect.

Another property of waves is that of superposition. Simply speaking, this means that when waves meet (arrive at the same space point at the same instant), their effects combine. (See Fig. 2.) Notice that the waves at some points "add together" and at other points "cancel out" each other.



SUPERPOSITION OF WAVES
Fig. 2

One special effect resulting from superposition is the <u>beat</u> effect. If two wave trains of slightly different frequencies are detected at a given space point, their cyclic addition and subtraction effects result in a periodic alternation of loud and soft sounds known as a <u>beat</u>. When one horn player in a group sounds <u>flat</u>, what you hear is this beat effect. The rate of this beat can be found mathematically by subtracting the frequency of the lower instrument from that of the higher:

$$f_{\text{Higher Pitched}} - f_{\text{Lower Pitched}} = f_{\text{Beats}}$$

For example: $516 \frac{\text{cycles}}{\text{sec}} - 512 \frac{\text{cycles}}{\text{sec}} = 4$ beats/sec.

Try striking adjacent (side-by-side) white and black keys on a piano; a flat tone results.

For a musical group, the difference in the sounding frequencies of two instruments determines their differences in pitch; therefore, the beat will increase or decrease as the pitch of an instrument is tuned nearer to or farther from the pitch to be matched.

Now, continue this investigation using a toy horn or a whistle. Because the instruments you may use can differ from lab to lab, it is not possible to give detailed directions. However, you should blow to produce sounds with the instrument's tube pipe, both open and closed. How do the sounds compare when the end is covered and when it is not? Is there a difference between the sounds when you blow hard and when you blow gently? You can lengthen the open tube part by rolling a sheet of paper snugly against the end of the pipe. Does this change the sound?

Conclusion:

1) If you have open and closed pipes of the same length, which one will have a lower fundamental (b... c) pitch?

2) How did the pitch produced by the closed pipe (bottle) change as the amount of water in the bottle was increased?

3) Does the shape or diameter of the pipe (bottle) affect the pitch?

4) List some ways that the length of the vibrating column of air is changed in band instruments.

5) What differences did you observe in the sounds produced by either open or closed pipes when you varied the air speed (force) with which you blew?

RESOURCE PACKAGE 3-3

INVESTIGATING A VIBRATING SURFACE

Purpose: To feel (as well as to hear) sound waves produced by a vibrating surface.

Procedure and Observations: Rapid back and forth movement (vibration) of a surface produces the longitudinal* mechanical waves we call sound waves. In longitudinal waves, the particles of the transmitting medium alternately compress (press close together) and rarefact (move apart). These two regions of a longitudinal wave cycle are sometimes simply referred to as the compression and the rarefaction.

Obtain this equipment:

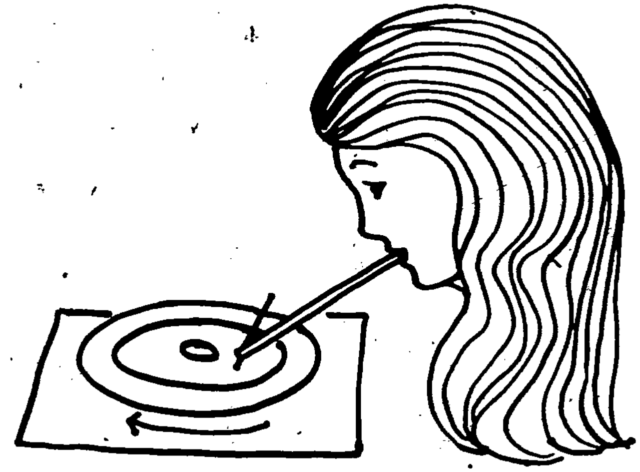
78-rpm record and record player
steel sewing needle
sheet of heavy paper
long pencil with a good eraser
tape player and tape from Resource Package 1-2

Modern record players have an electric motor and an electric amplifier; the sounds they produce have good fidelity (resemble the real thing), have volume (can be loud), have range (reproduce both high and low frequency sounds; i.e., very soprano and very bass), etc. The first phonographs, however, operated by hand or by a wind-up spring; and the sound from these first phonographs was simply relayed mechanically from the rough grooves of the record to a circular disc (or cone-shaped horn), which, in turn, caused the air to vibrate. Let's see how these old record players worked. Place the

* See The Physics of Communication or The Physics of Toys minicourses for further explanation of longitudinal waves.

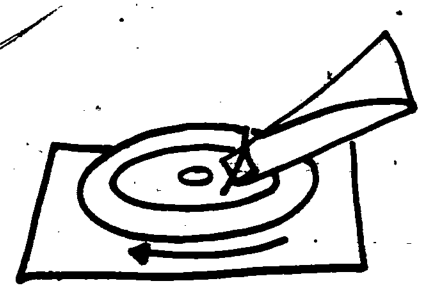
78-rpm record on the turntable. Make sure that the speed indicator is set for 78 rpm.

Push the needle through the eraser of the pencil at an angle, as shown in Fig. 1. Hold the pencil lightly between your teeth while the needle point touches a groove in the record. Now turn on the record player. Does "needle sound" reach your ears? If so, how might the needle vibrations be transmitted to your hearing organs? Stop up your ears; can you hear "needle sounds"?



HUMAN PHONOGRAPH
Fig. 1

Now roll a sheet of stiff paper into a cone, as shown in Fig. 2. Flatten the pointed end, fold about 1 inch of it over, and push the needle through the folded portion at such an angle that the needle can be held in the grooves of the record, as shown in Fig. 2. Turn on the record player. Does "needle sound" reach your ears? If so, what is the transmitting medium?



"POOR BOY" LOUDSPEAKER
Fig. 2

Play parts of the tape from Resource Package 1-2; use a high volume. Hold your hand 2 to 3 inches above the speaker. What do you feel? What is causing this feeling? Place a sheet of thin paper (tissue paper, copy paper, etc.) on top of the speaker. Can you see any movement? Sprinkle cork dust, chalk dust, lycopodium powder, salt, or the like, onto the paper covering the speaker of the tape player. What do you see?

Conclusions:

1) Discuss any change of energy forms involved in the record-to-record player reproduction of sound.

2) List, in order, the objects through which acoustical (sound) vibrations passed from the record grooves to your ears when the pencil was between your teeth.

3) Was the sound clearer using the pencil or using the paper cone?

4) Recall what you felt when you placed your hand near the tape player's speaker. Can you explain how a sudden loud noise, such as the firing of artillery or other explosion can rupture an ear drum?

SELF-TEST

Write answers on separate paper; please don't write in this Resource Package.

1) Increasing the tension on a string of constant length will ________ (raise, lower) the pitch produced.

2) A thicker string vibrates ________ (faster, slower) than a thinner like string of the same length under the same tension.

3) A longer string will produce a ________ (higher, lower) pitch than a shorter one, all other conditions being equal.

4) A string vibrating in its fundamental mode, shows its greatest displacement (amplitude) at the ________ (ends, center).

5) List four (4) instruments whose sound is produced by bowing or by picking its strings.

6) Closed pipes (or bottles) produce ________ (lower, higher) pitches than identical pipes open at both ends.

7) Pitch physically depends mostly upon the ________ (amplitude, frequency) of vibrations.

8) When you change the length of a vibrating column of air, you change the ________ (speed, wave length) of the sound.

9) Two ways that vibrating air columns in musical instruments are changed in length are (1) ________ and (2) ________.

10) What physical factors affect pitch from a pipe instrument?

11) Using bottles as you did in this investigation, could you produce any tones that are not produced by a piano?

12) When you play a record, rough surfaces in the grooves cause the ______________ to move, transmitting movements (vibrations) to an amplifier.

13) Why do you suppose you were instructed to use 78-rpm records in this exercise, rather than 45-rpm or 33 1/3-rpm?

14) What might be done to make the rolled-paper cone a more effective "sounder" or speaker?

15) Can you think of different or unusual uses of sound wave energy? List some of them.

RESOURCE PACKAGE 3-5

SELF-TEST ANSWERS

1) raise

2) slower

3) lower

4) center

5) violin, viola, cello, bass, harp, guitar, banjo, mandolin, etc.

6) lower

7) frequency

8) wave length

9) valves, slide, etc.

10) air column diameter, blowing force, temperature of the air, etc.

11) Bottles can produce pitches that fall between the <u>fixed</u> "notes" on a piano

12) needle (or playing arm)

13) Because the grooves are much larger than the ones on 45- and 33 1/3-rpm records; hence, the needle vibration amplitudes are greater.

14) Make it larger. Support it by a thread, instead of holding it. Put a weight on the needle to "track" it better in the groove, etc.

15) There are cleaning devices that use sound waves (such as those for jewelry, false teeth, etc.). Sound has been used in prisoner-of-war camps to break down the will of prisoners. Sound waves are used to measure distances, and ships SONAR gear is an acoustical device

for measuring ocean depth. Sound is used to cook food (sound ovens), etc.

If you missed more than three (3) of these fifteen (15) questions, you should review the previous resource packages before you proceed. If you have any special problems, consult your instructor.

RESOURCE PACKAGE 4-1

TEMPERATURE AND SPEED OF SOUND WAVES

As you learned earlier, the relationship between wave length, speed, and frequency is expressed by the formula:

Speed (v) = frequency (f) times wave length (λ);

and your investigations have revealed that the frequency of a vibrating object is subject to a number of variables, such as density (massiveness), kind of material, length, and tension. Your investigations revealed also that for a hollow pipe, its length, its diameter, open or closed ends, blowing force, etc., affect the sound waves generated.

Now we explore the role that temperature plays in the transmission of sound. It has been mentioned already that sound waves increase in speed as temperature rises. This increase is predictable, and you will study the equation which describes the dependency of sound speed upon temperature.

Do you remember how fast sound travels in air at 32° F or 0° C? Such waves move at nearly 1,100 feet per second, or over 332 meters per second. For each degree of Fahrenheit temperature increase the speed of sound increases about 2 ft/sec, or about 0.6 m/sec for each degree Centigrade (Celsius).

Let's assume the temperature in your classroom is 70° F and then calculate the speed of sound at that temperature.

Assume the speed of sound at 32^{o} F $= 1,090$ ft/sec

The temperature increase is $(70 - 32)\ ^{o}F = 38\ F^{o}$

The speed increase/F^{o} $= 2$ ft/sec

$$(38\ F^{o})\ 2\ \text{ft/sec}/F^{o} = (38 \times 2)\ \text{ft/sec}$$

$$(38\ F^{o})\ 2\ \frac{\text{ft}}{\text{sec}\ F^{o}} + 1090\ \text{ft/sec} = 1,166\ \text{ft/sec}$$

On a hot day at 38^{o} C (almost 100^{o} F), what is the speed of sound, measured in m/sec?

Assume the speed of sound at 0^{o} C $= 332$ m/sec

The temperature increase is $(38 - 0)\ C^{o} = 38\ C^{o}$

The speed increase/C^{o} $= 0.6$ m/sec

Therefore,

$$(38 \times .6)\ \frac{\text{m}}{\text{sec}} + 332\ \text{m/sec} = 354.8\ \text{m/sec}$$

This knowledge of the variation of the speed of sound with temperature has many technical applications. In meterology (science of weather), this knowledge is useful in determining the distance to an explosion or to a lightning display. In musicology (science of music), this knowledge can be used to determine how the pitch of a musical instrument would change with temperature. Consider these examples:

1) You see the flash of an explosion in the distance. Nine seconds later you hear its sound. The air temperature is 10° C. <u>How far away was the explosion?</u>

First, assume that the speed of sound is 332 m/sec at 0° C. Then, knowing the temperature is 10 C° higher, we can calculate the sound speed. Last, since distance = (rate) x (time), we know that the distance to the explosion = sound speed (9 seconds):

Speed of sound at 0° C	= 332 m/sec
Increase in speed per C degree	= 0.6 m/sec
Increase in temperature	= 10° C
Therefore, speed of sound at 10° C	$= (10\ C^{o} \times .6)\frac{m/sec}{C^{o}} + 332$ m/sec
	= 338 m/sec

If 9 seconds passed, then the

distance is 338 m/sec x 9 sec = 3,042 meters

2) An open pipe 0.83 m long vibrates in its fundamental mode and produces a fundamental frequency of 200 hertz at 0° C. What will be its frequency at 40° C?

First, we must know that a pipe open at both ends always has a fundamental wave length which is equal to twice the pipe length. (If open at only one end, then the fundamental wave length is always 4 times the pipe length.) Therefore,

Wave length (λ) of open pipe	= 2 times length of pipe
	= 2 x 0.83 m
	= 1.66 m

From the wave relationship, $v = f\lambda$

$$v(\text{at } 40^{o}\ C) = 332\ m/sec + (40\ C^{o} \times \frac{0.6\ m/sec}{C^{o}})$$

$= 356\ m/sec$

Solving the wave relationship, $f = \frac{v}{\lambda}$

$= \frac{356\ m/sec}{1.66\ m}$

$= 214.4$ hertz at 40^{o} C

3) If the frequency of a vibrating string remains constant at 440 hertz while the temperature drops from 20^{o} C to 0^{o} C, what will be the wave length (λ) at 0^{o} C?

$v(\text{at } 20^{o}\ C) = 332\ m/sec - (20\ C^{o} \times 0.6\ \frac{m/sec}{C^{o}})$

$= 320\ m/sec$

$= 440\ Hz$

$\lambda = \frac{v}{f}$

$= \frac{320\ m/sec}{440\ cycles/sec}$

$= .73$ meters at 0^{o} C

You may need to refer to these examples to solve the problems in Resource Package 4-2. For a more definitive treatment, use Schaum's workbook (See the REFERENCES section on the last page of this minicourse).

SELF-TEST

Solve these problems on a separate sheet.

1) A tuning fork makes 284 vibrations per second in air. What is its wave length at 25° Celsius?
2) What will be the frequency of a 4.15 meter wave at 0° Celsius?
3) A pipe closed at one end has a fundamental-tone wave length equal to four (4) times the pipe length. If the pipe is 1.75 meters long, what is the frequency of its fundamental tone when the temperature is 30° C?
4) The air temperature is 20° C when you see a flash of lightning. Five seconds later you hear the thunder. How far away was the lightning?
5) How long will it take the sound of a cannon to travel 8,000 meters when the air temperature is 15° C?
6) A pipe open at both ends sounds its fundamental with a wave length equal to twice the length of the pipe. How long is the pipe if it produces a fundamental of C-128 hertz at 0° C?
7) What is the frequency of a vibrating body that produces a wave of 4 meters at 60° C?
8) How far away is a gun that you hear 2 seconds after you see the "fire flash" if the air temperature is 18° C?
9) How long would it take sound to travel 1,000 meters at 2° C?

10) A pitch of C-512 hertz will have what wave length at an air temperature of 20° C?

11) If a tree falls in an uninhabited forest, is there any sound?

RESOURCE PACKAGE 4-2

SELF-TEST ANSWERS

If you miss two (2) or more of these problems, you should review the four (4) preceding Resources Packages.

Answers:

1) $\lambda = \frac{v}{f}$ = (332 + .15) m/s /284 Hz = <u>1.22 meters</u>

2) $f = \frac{v}{\lambda}$ = 332 m/sec /4.15 m = <u>80 hertz</u>

3) $f = \frac{v}{\lambda}$ = (332 + 18) m/sec /7m = <u>50 hertz</u>

4) speed x time = distance; (332 + 12) m/s x 5 sec = <u>1720 meters</u>

5) time = distance/speed; 8,000 m/ (332 + 9) m/sec = <u>23.4 seconds</u>

6) <u>pipe length</u> = $\frac{\lambda}{2}$; $\lambda = \frac{v}{f}$ = 332 m/sec /128 Hz = 2.59 m; <u>pipe length</u> = $\lambda/2$ = $\frac{2.59 \text{ m}}{2}$ = <u>1.3 m</u>

7) $f = \frac{v}{\lambda}$ = (332 + 36) m/sec /4m = <u>92 hertz</u>

8) distance = speed (time); (332 + 10.8) m/sec x 2 sec = <u>685.6 meters</u>

9) time = distance/speed = 1,000 m / (332 + 1.2) m/sec = <u>3 seconds</u>

10) $\lambda = \frac{v}{f}$ = (332 + 12) m/sec /512 Hz = <u>.67 meters</u>

11) Yes. Sound is a kind of mechanical energy in motion; it exists whether or not there is anyone around to detect it. The falling tree causes air compressions and rarefactions as it strikes the earth in a vibrating fashion.

RESOURCE PACKAGE 5-2

INVESTIGATING SOUND TRANSMISSION

Because sound waves result in vibrating particles of matter, their transmission depends on the type of matter through which they pass.

<u>Purpose</u>: To compare sounds transmitted through various materials.

<u>Procedure, Part I</u>: You will need:

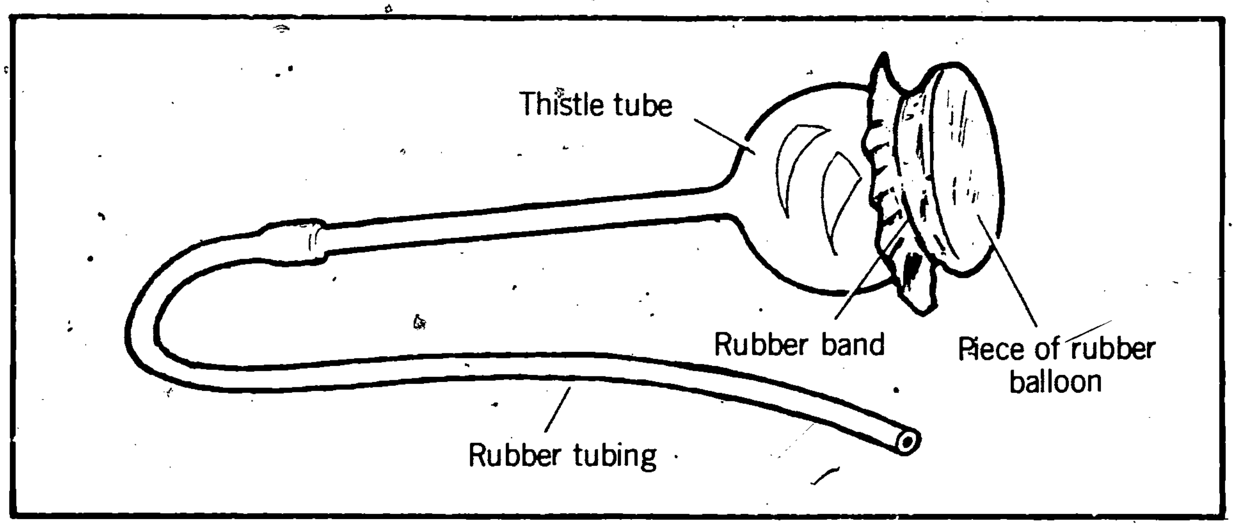
- vacuum pump
- bell jar
- alarm clock

Set up the vacuum pump apparatus. Ask the teacher to check all valves, connections, etc. Place the alarm clock on the pump table, taking care not to cover the vacuum pump exhaust hole. With the alarm ringing, place the clock under the bell jar and quickly start the pump. Repeat this operation once or twice. On a separate sheet of paper, simply describe your Part I observations.

<u>Procedure, Part II</u>: You will need:

- metal pan or bucket at least a foot in diameter
- 2 stones
- balloon
- rubber band
- thistle tube
- rubber tubing (2 to 3 ft)
- tuning fork and striking hammer
- wooden rod
- iron rod
- aluminum rod
- plastic rod (rods of other materials can be substituted)

Stretch a piece of rubber balloon over the bulb of a thistle tube and fasten it with a rubber band just behind the lip of the thistle tube bulb. Push a piece of rubber tubing over the other end of the thistle tube. The final assembly should look like Fig. 1.

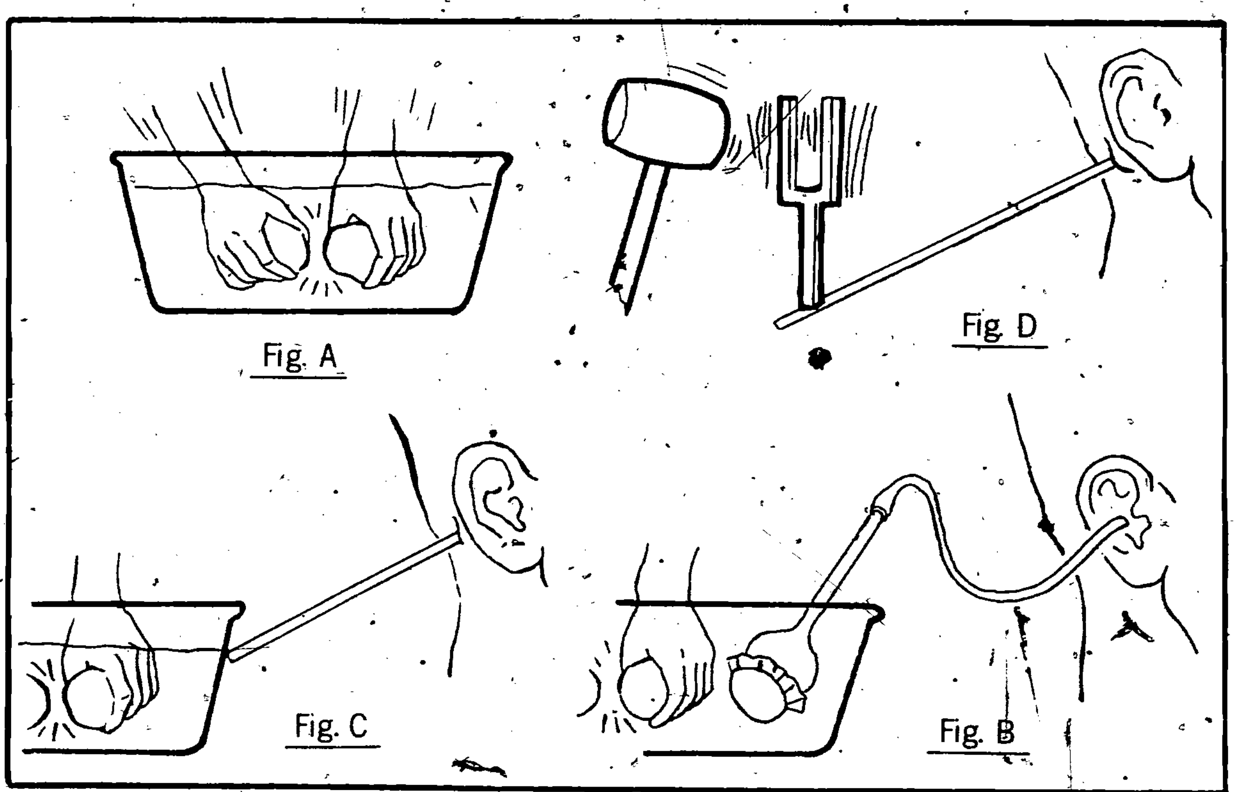


"POOR BOY" STETHOSCOPE
Fig. 1

Put water in the metal pan or bucket and have another person bump two stones together under water, as shown in Fig. 2A. Listen to the sound. Next, place the large end of the thistle tube under water and hold the rubber tube to one of your ears (This procedure is shown in Fig. 2B). Listen for the bumping of the stones. Record a description of this sound and compare it with the sound you heard with the procedure of Fig. 2A.

Now, place one end of an iron rod against the wall of the water container. Place the other end of the iron rod against the bone just behind your ear (See Fig. 2C). Record the sound of the bumping of the stones again. Repeat the above, using the different rods (wood, aluminum, plastic, etc.).

Finally, strike a tuning fork with a striking hammer and place the tuning fork against one end of the iron rod. Place the other end of the iron rod against the bone in back of your ear (See Fig. 2D). Record your observational comparisons of the iron rod, the wooden rod, the aluminum rod, and the plastic rod, for this last procedure.



SOUND TRANSMISSION
Fig. 2

Analysis:

1) Was the sound of the stones bumping less distinct when you used the tube in your ear? Why?

2) Were you able to hear with the iron rod against the bone behind your ear? Through which rod could you hear best? Next best? Worst? Can you sense the relationship between the design of hearing aids which fit snugly behind the ear and against the ear bone, and the rods you used in this investigation?

3) Was there a difference in the sound of the tuning fork's transmission through the various rods?

Conclusion: Make a general statement about sound transmission: Does it travel when no air is present? Does it travel through a liquid? Does it transmit through metal, plastic, wood? Which of these transmitting media is most dense (heaviest per unit volume)? Can you see a relationship between medium density and sound transmission?

Discuss any questions with your teacher. Submit your notes and responses for evaluation.

RESOURCE PACKAGE 6-1

NOISE POLLUTION TAPE

Ask your teacher for a tape player and for the tape on noise pollution. You will need a pencil and paper, too.

Listen to the tape, and then complete ACTIVITY 6-2.

RESOURCE PACKAGE 6-2

NOISE POLLUTION

Noise has become more than a nuisance and occasional health hazard. Noise has emerged as possibly the <u>third most crucial pollution problem</u> in our mechanized society. Most citizens are concerned about air pollution and water pollution, but few are even aware that noise is the <u>ear pollutant</u> which poses severe occupational hazards to large segments of industrial workers.

In the earlier days of the Industrial Revolution, evidence of noise dangers arose. In 1830, English doctors were reporting that noise was the cause of deafness in blacksmiths. By 1860, a recognized occupational hazard was the hearing loss common to those in the boilermaker trades.

Modern technology often saturates the worker with noise on the job and also surrounds him with it during his leisure hours. Surely, noise pollution is a concern for all citizens and especially for those workers in certain vocational and technological areas. Hearing loss is only an obvious symptom of noise pollution. Noise pollution can also result in changes in respiration rate, blood pressure, heartbeat, and oxygen consumption.

Noise-hazardous environments are prevalent in chemical and clothing (textile) manufacture, in heavy machinery and lumber products manufacture, in shipbuilding and heavy construction, in aircraft construction and operation and maintenance, etc. Such devices as power mowers, power saws, power hedgecutters, portable air compressors and welders, pneumatic pavement and rock drills, bulldozers, motorcycles, snowmobiles, outboard boat motors, and electronic amplifiers can be prime sources of noise pollution.

Efforts to legislate for safe and harmonious noise levels in our Nation have come mostly from organized labor. Although as many as an estimated five million workers in the United States are experiencing unsafe noise conditions, not much will likely be done about this condition until public pressure causes Congress to take action.

Turn in the following for evaluation:

1) Prepare a short bibliography on noise pollution (a half-dozen or so references).
2) Recall the last 24 hours of your life. List those <u>devices</u> and <u>environmental</u> factors which may have exposed you to unncessary and unsafe noise.
3) The Clean Air Act of 1970 <u>authorized</u> $30 million dollars for an investigation of noise and its effects upon the public. However, less than 1/15th of this amount was actually budgeted for fiscal year 1971-1972. Do you feel this was wise governmental "non-spending"? Write a short paragraph or two defending your feeling.

RESOURCE PACKAGE 7-1

SELF-TEST

Answer the following questions on separate paper. Please do not write in this Resource Package.

1) Noise is generally considered to be sound produced by _______ _______, while musical sounds are generally considered to be produced by _______ _______.

2) Name three (3) of the characteristics of sound a person employs in making a subjective determination of what is sound and what is noise.

3) What are three (3) harmful emotional or physical effects of too much sound?

4) List four (4) sources of serious sound pollution.

5) Name and describe three (3) major anatomical (body) parts or sections of the human ear and list briefly the role each plays in the hearing process.

6) Name two (2) ways that the pitch produced by a vibrating string may be raised.

7) How will the pitch of an open pipe be changed when one end of the pipe is closed?

8) What are two (2) factors that affect the frequency of both a closed and an open pipe?

9) When sound is produced by a vibrating membrane, how can the volume of sound be increased?

10) Name two (2) common musical instruments that use: vibrating strings, vibrating air columns, or vibrating membranes (or surfaces).

11) What is the wave length of a sound when frequency is 126 hertz at 0° C?

12) How far away is the source of a sound which requires 7 seconds to reach the hearer when the temperature is 30^{o} C?

13) What type substance transmits sound best? Under what conditions is no sound transmitted?

14) Give the meaning of each of these terms:

a) fundamental tone

b) wave length

c) music

d) transmitting medium

e) sound

f) intensity

g) frequency

If you have answered 32 of the 40 individual parts of these questions correctly, and if you feel that you are ready to take the final test, ask your teacher for it.

RESOURCE PACKAGE 7-2

SELF-TEST ANSWERS

1) irregular vibration; regular vibration.

2) any 3 of these: loudness or intensity, familiarity, regularity, pitch or frequency, location, reverberation, individual difference, time of day, etc.

3) any 3 of these: deafness, higher blood pressure, irritability, temper, sleeplessness, mental illness

4) Lists will vary, but might include: sirens, air conditioners, air hammers, motorcycles, etc.

5) outer ear (collects sound); middle ear (transfers sound to small bones); inner ear (converts physical movement into nerve signals to brain).

6) increasing tension, shortening length, etc.

7) It will be lowered.

8) length, diameter, transmitting medium, temperature, etc.

9) increase surface area, isolate membrane or surface so it is not muffled, increase amplitude of vibration, etc.

10) Lists may vary, but could include: string -- violin, harp, cello, piano, banjo, etc.
air column -- trumpet, bass horn, French horn, oboe, bassoon, etc.
surface or membrane -- drums, cymbals, xylophones, marimbas, bells, etc.

11) $\lambda = \frac{v}{f} = \frac{332 \text{ m/sec}}{126 \text{ Hz}} = 1.84$ meters

12) distance = speed x time = 332 + (30 x .6) m/sec x 7 sec = 2,450 meters

13) a more dense material; when there is no transmitting medium

14) See Resource Package 2-1 for definitions.

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