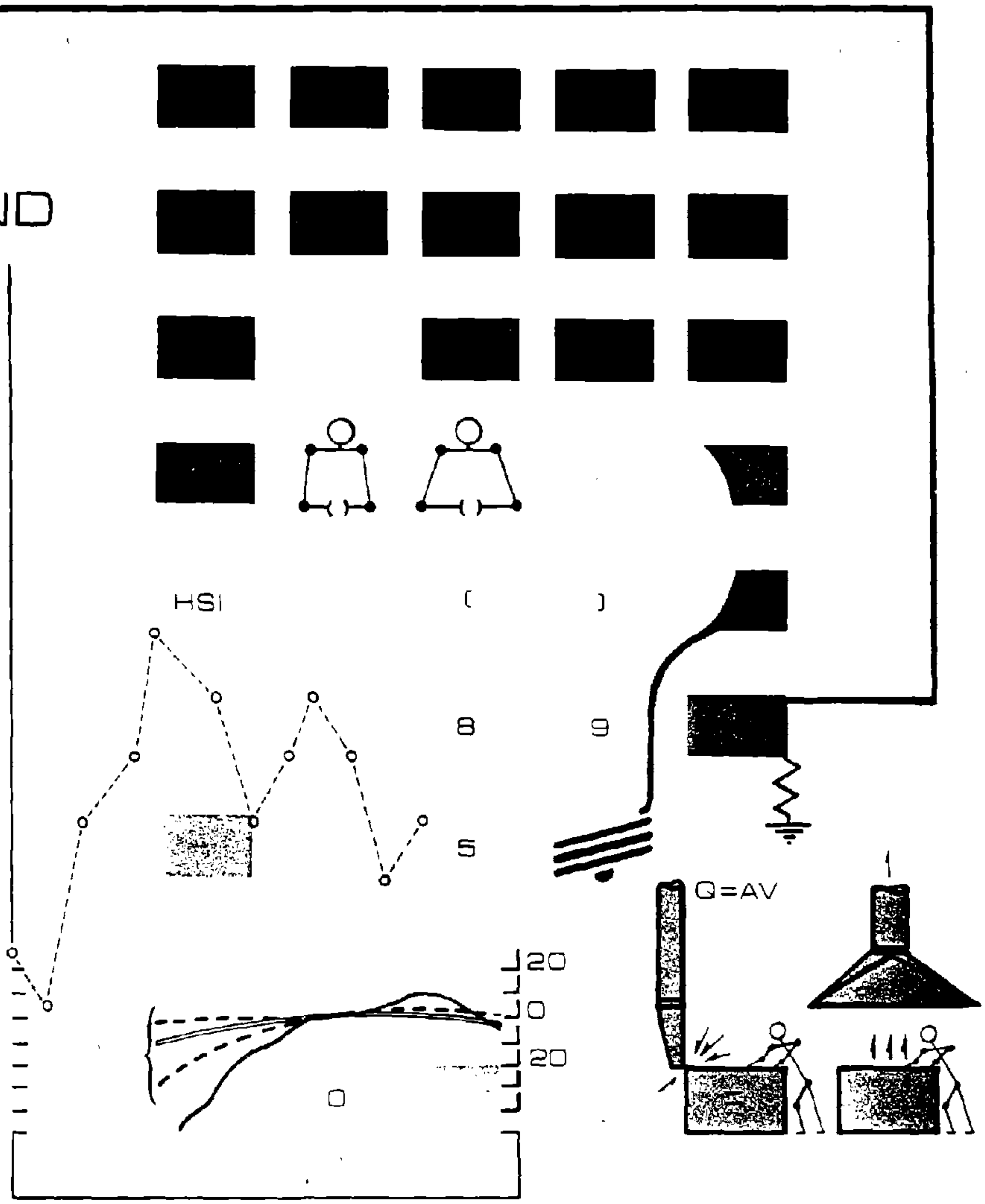
552

INDUSTRIAL HYGIENE
ENGINEERING & CONTROL

SOUND



Instructor Manual

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

INTRODUCTION TO INDUSTRIAL HYGIENE ENGINEERING AND CONTROL (552)

This is a modularized course designed for use as a one, two, or three week short course or as a one or two semester academic course at either the undergraduate or graduate level. It examines the fundamentals for design of controls to eliminate or satisfactorily deal with occupational health hazards. Lectures, augmented by problem solving sessions, are intended to assist the trainee in selecting, designing, and applying control methods in the work environment. Primary attention is given to industrial ventilation, noise and vibration control, heat stress, and industrial illumination as well as new engineering topics.

The training course manual has been specially prepared for the trainees attending the course and should not be included in reading lists of periodicals as generally available.

Module 4 — Instructor's Manual

SOUND

Division of Training and Manpower Development
National Institute for Occupational Safety and Health

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control

Cincinnati, Ohio

November 1978

FACULTY AND STAFF

DIVISION OF TRAINING AND MANPOWER DEVELOPMENT

Dr. Alan D. Stevens	Director
James S. Ferguson	Deputy Director
Dr. N. Jack Berberich	Chief, Curriculum Development Branch
Edward D. Leininger	Chief, Direct Training Branch
Dr. Thomas C. Purcell	Chief, Educational Resource Development Branch
Stephen G. Bayer	Training Instructor
Dr. David E. Clapp	Safety Engineer/Instructor
John M. Blankenhorn	Industrial Hygienist
Larry W. DeArmond	Training Technician
Steven N. Dereniuk	Chemist
Horace E. Dimond	Safety Engineer
Ruth A. Duffy	Secretary
Pauline J. Elliott	Visual Information Specialist
Denise Gerth	Secretary
Joyce Huff	Secretary
Bernadine B. Kuchinski	Occupational Health Nurse Consultant/Educator
Judith A. Kuethe	Secretary
Laura Love	Secretary
Carl H. Moline	Industrial Hygienist
Sharon Moreland	Secretary
Dr. Paul D. Pedersen	Medical Officer
William H. Perry	Industrial Hygiene Chemist
Jane A. Raber	Grants Assistant
Dr. Pantelis G. Rentos	Training Grant Program Officer
Richard C. Robbins	Motion Picture Specialist
Joann R. Schloemer	Consulting Nurse
Raymond C. Sinclair	Television Production Specialist
Linda Smith	Secretary
Anne M. Stirnkorb	Visual Information Specialist
Marsha Striley	Secretary
David S. Thelen	Training Grants Coordinator
Linda Tull	Secretary
James B. Walters	Public Health Advisor
Kathleen Watkins	Staff Assistant
Robert B. Weidner	Senior Industrial Hygiene Consultant
William J. Weis	Manpower Specialist
Donna Welage	Staff Assistant
Roger L. Wheeler	Electronics Engineer
Glenda M. White	Audio Visual Production Officer
John M. Yacher	Chemical Engineer/Training Officer

FOREWORD

The material presented in this document is designed for use in a college or university classroom and is directed to students at an advanced level of study in industrial hygiene. The course may also be utilized in total or in part as the basis for short course offerings.

This material was developed under sponsorship of the National Institute for Occupational Safety and Health, Division of Training and Manpower Development, Cincinnati, Ohio, (Contract CDC–210–75–0076). Serving as Project Officer for the development of this material was Robert B. Weidner, J.D., Branch Chief, Division of Training and Manpower Development.

The lesson plans and accompanying text entitled *Industrial Hygiene Engineering and Control* were prepared by the staff of Management Resource Associates, Monroeville, Pennsylvania. Serving as authors were Bruce B. Byers. Ronald J. Hritz, and James C. McClintock. Also assisting, as consultants to the development of the materials, were Ralph J. Vernon, Ph.D., and Richard B. Konzen, Ph.D., of Texas A&M University.

Art work for the text was prepared by Carole D. Byers. Manuscript preparation was the responsibility of Elaine S. Holmes.

TABLE OF CONTENTS

INTRODUCTION

Purpose of the Course

The course materials are designed for presentation to students at the baccalaureate or graduate level of study in Industrial Hygiene. The materials presuppose that the student has completed introductory courses in recognition, measurement, and evaluation of occupational health hazards. The materials are designed in such a manner that they are applicable as a two-semester course or a three-week intensive study short course. In addition, the materials may be divided to provide courses of a shorter duration. Since the course is divided into self-contained modules, each module can be used as the basis for the development of a course. (e.g., Module 2, Industrial Ventilation can be utilized as a one-semester offering or a one-week short course.)

The emphasis in each module is the control of occupational hazards. However, this emphasis does not preclude the inclusion of recognition, measurement and evaluation topics within the module. Summary material covering these important areas is included where appropriate within each module. This inclusion is based upon the authors' belief that problem identification and definition are important steps that must be taken before adequate control can be implemented.

Content

The materials are divided into eight (8) self-contained modules. Each module is divided into units and lessons. For the most part, the lessons are based upon a one-hour class session for presentation. The modules that are included, as well as the *minimum* time available to cover the modules are:

Module	*Title*	*Minimum Time*
1	Introduction to Industrial Hygiene Engineering and Control	7 Hours
2	Industrial Ventilation	31 Hours
3	Thermal Stress	4 Hours
4	Sound	7 Hours
5	Industrial Illumination	3 Hours
6	Nonionizing and Ionizing Radiation	8 Hours
7	Ergonomics	5 Hours
8	Other Topics	7 Hours
		Total Time 72 Hours

The time allotted is a minimum time that does not include allowance for testing and review of problems and exercises. Based upon the expereinces gained in a pilot test of the materials. the time allotted above provides for only a brief coverage of the topics included. For thorough coverage of each subject, the allotted time should be increased to at least 120 hours. In any case, the time required is dependent upon the level of detail and completeness of coverage of each topic that is desired.

Course Prerequisites

The students should have taken courses in recognition, measurement and evaluation of occupational health hazards. At a minimum, the students should have completed the following NIOSH sponsored courses or their equivalent:

—Recognition, Evaluation and Control of Occupational Hazards
—Industrial Hygiene Measurements

In addition, the students should have completed education in undergraduate mathematics through the calculus and undergraduate science including general and organic chemistry, physics, and biology. Additional engineering courses such as fluid mechanics and thermodynamics will be helpful to the student.

Components of the Course

The Course Manual is designed to provide the technically competent instructor with the basic educational materials from which to conduct the training sessions. It is not the purpose of the Course Manual to provide a complete skill and knowledge package from which the instructor can obtain the technical competency necessary to conduct training, since such competence is assumed to be an attribute of any instructor chosen to teach in the program. Should the instructor wish to brush up on certain skills and knowledge, the references cited as well as the accompanying text, *Industrial Hygiene Engineering and Control*, will provide a basis for this undertaking.

The course is organized with three (3) basic elements. These elements are:

1. Module—A complete, self-contained package of educational materials that is directed toward the attainment of skills and knowledge in a subject area. These modules can be presented as a stand-alone course or can be combined in various ways to construct courses for use with selected groups of students.

2. Unit—A self-contained package of educational materials that is directed toward attainment of a subset of skills and knowledge in a subject area. The unit does not necessarily lend itself to use as a stand-alone package since certain segments of the skills and knowledge presented depend upon completing previous units within the module.

3. Lesson—Generally, an artificial segmentation of a unit for administrative purposes. Lesson segments are normally one hour in length and, as far as is practical, cover a logical subset of knowledge or skills. Lessons allow for the scheduling of the training in various educational environments.

Instructor's Manual—The Module Plan

The module plan contains the following components:

1. Unit and Lesson Topic Outlines—This outline presents the topics covered within the module and the schedule for presentation of these topics. This information provides a concise and organized summary of the subject material in the module.

2. Terminal Objectives—General competency statements related to the skills and knowledge that should be possessed by the student upon completion of

the module. The skill objectives relate to the manipulative, computational, or decision-making skills that the student should attain upon completion of the module. The knowledge objectives relate to the subject knowledge that the student requires in order to perform the required skills. These objectives serve as a basis upon which an evaluation can be made of the student's mastery of the subject material included in the module.

3. Self-Tests—Postmodule self-tests along with the correct answers to these tests are included with each module.

4. References—A list of reference material can be consulted by the instructor or students.

Instructor's Manual—The Unit Plan

The unit is made up of a number of specific components and contains the lesson content outline. The components of the unit plan are:

1. Performance Objectives—Skill and knowledge objectives related to the subject matter included within the unit. These objectives are written in behavioral terms (i.e., an observable activity or result that can be evaluated quantitatively, as specified, and which is conducted or obtained under specific conditions). The objectives that are presented within the unit plan are of a more specific nature than those terminal objectives or competency statements that are specified by the module plan. The performance objectives presented within the unit might be thought of as enabling objectives; i,e., they represent the skills and knowledge that the student must attain in order to complete the requirements of the terminal objectives for the module.

2. Unit Activities—Activities that the student must perform to complete the unit. Reading assignments, reference materials, and outside activities are presented.

3. Required Facilities, Equipment, and Materials—Materials—The required facilities, equipment and materials that should be available for presentation of the unit. The equipment and materials listed are divided into those which are educational and those which are content oriented (e.g., 16 mm projector vs. pitot tube).

4. Content Outline—Presents an organized outline of the topics to be covered during the presentation of the unit. The content outline is divided into the lesson outlines necessary for completion of the units.

   In addition, the content outline contains instructions to the instructor and reference to slides and overlays that should be used in conjunction with the lecture. These instructions present the sequence of instructor activities, such as when to present a given slide, when a demonstration is required, or when an instructor's experience might be of value.

   Since the course is designed to be taught by technically competent instructors, the material in the lesson content outline is of a topical nature with only that explanation present that should be emphasized to the student. It is expected that the instructor's skill and knowledge will allow for the depth of presentation and emphasis required. The instructor is encouraged to present material relevant to experience, wherever possible, in order to provide the students with a referent to the subject.

5. Demonstration Outlines—Appropriate outlines for classroom and laboratory demonstrations and sample problems to be presented to the class. The demonstrations are designed to present an outline of the procedural steps that are important in performing the particular measurement, design, or calculation. Steps that are critical or that may lead to common errors are emphasized in the demonstration outlines.

6. Practice Exercises—A series of practice exercises that can be given to the student. These practice exercises can be used as either classroom or laboratory exercises or as homework assignments. Solutions to problems involving calculations are also provided.

Audio Visual Aids

A set of slides, which are referenced in the lesson outlines, have been prepared and are available for use in presenting the course.

MODULE 4

SOUND

INSTRUCTOR'S MANUAL

Unit and Lesson Topic Outline				
Sound				Module 4

The topics listed below are included within this module. The recommended time to be allotted for each topic is also given. Depending upon the particular class, this time may vary slightly; however, the total time for the entire module should not exceed the time given.

Unit	Lesson	TOPIC	Time/Hrs.	COMMENTS
1		Physics of Sound		
	1	Physics of Sound - (Introduction)	1	Defines sound, sound wave, sound pressure, sound power, sound intensity.
	2	Physics of Sound	1	Discusses decibels, sound pressure level, sound power level, and sound intensity level, plus discussion of directivity factor.
	3	Physics of Sound	1	Discusses sound in a room, absorption coefficient, noise reduction, and transmission loss.
2		The Ear and the Effects of Sound		
	1	The Ear and the Effects of Sound	1	Discusses the anatomy and physiology of the ear, the threshold of hearing, and annoyance of noise.
3		Vibration		
	1	Vibration	1	Discusses vibration, causes of and methods of controlling. Includes discussion of the effects of vibration on man.
4		Noise Control		
	1	Noise Control (Introduction)	1	Discusses controlling noise in an existing facility, at the source, and along the path; introduces enclosures.
	2	Noise Control (Continued)	1	Concludes discussion of enclosures and discusses controlling noise at the receiver.
				Total Module Time--7 Hours

Terminal Objectives	
Sound	Module 4

The objectives presented represent the competencies that the student should possess upon completion of the module. All objectives are directed toward the student's attaining certain levels of skills and knowledge.

Terminal Objectives

1. Given the following equations:

   a. $$SWL = SPL - 10Log_{10}\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] - 10.5 - T$$

   where SWL denotes sound power lèvel, SPL denotes sound pressure level, Q denotes directivity factor, r denotes distance in feet from a source and R denotes room constant, and T denotes correction for temperatūre and atmospheric condition

   b. $$R = \frac{\sum_{i=1}^{n} S_i \bar{\alpha}}{1 - \bar{\alpha}}$$ where R denotes room constant, S_i denotes the surface area of the i^{th} surface, and $\bar{\alpha}$ denotes the average adsorption coefficient

   c. $$\bar{\alpha} = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\sum_{i=1}^{n} S_i}$$ where $\bar{\alpha}$ denotes the average absorption coefficient, S_i denotes the surface area of the i^{th} surface, and α_i denotes the absorption coefficient of the i^{th} surface

   d. $$r_c = \sqrt{\frac{Q \sum_{i=1}^{n} S_i \bar{\alpha}}{16\pi(1-\bar{\alpha})}}$$ where Q denotes directivity factor, S_i denotes the surface area of the i^{th} surface, $\bar{\alpha}$ denotes the average absorption coefficient, and r_c denotes the critical distance

   and the following tables or charts:

   a. absorption coefficients of building materials
   b. sound field behavior in a reverberant toom
   c. adding decibels

   and the following information:

   a. room dimensions
   b. material covering surface area of room
   c. directivity factor of a given machine
   d. sound power levels of a given machine by center frequency
   e. distance of worker from sound source

   the student will be able to calculate

   a. the sound pressure level at r, the distance the worker is from the sound source
   b. the sound pressure level at the critical distance
   c. the sound pressure level at the walls of the room.

Terminal Objectives	
Sound	Module 4

1. Then given a new set of absorption coefficients, the student will be able to calculate the new sound pressure levels at

   a. r, the distance of worker from source
   b. walls
   c. the critical distance

   From the above comparisons, the student will be able to determine if the worker was helped by making the room more absorbent.

2. Given the following equations:

   a. $SWL = SPL - 10Log_{10}\left[4\pi r^2 + \frac{4}{R}\right] - 10.5 - T$

   (see Objective 1 for denotation of symbols)

   b. $R = \frac{\sum_{i=1}^{n} S_i \bar{\alpha}_i}{1 - \bar{\alpha}}$ (see Objective 1 for denotation of symbols)

   c. $\bar{\alpha} = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\sum_{i=1}^{n} S_i}$ (see Objective 1 for denotation of symbols)

   d. $r_c = \sqrt{\frac{Q\sum_{i=1}^{n} S_i \bar{\alpha}_i}{16\pi(1-\bar{\alpha})}}$ (see Objective 1 for denotation of symbols)

   e. $TL_{com} = 10Log\ 10\sum_{i=1}^{n} S_i - 10Log\sum_{i=1}^{n} S_i 10^{-TL_i/10}$

   where TL_{com} denotes transmission loss of combined partitions or walls, S_i denotes the surface area of the i^{th} surface, and TL_i denotes the transmission loss of the i^{th} surface.

   f. $NR = TL - 10Log_{10}\left(\frac{1}{4} + \frac{Sw}{R}\right)$

   where NR denotes noise reduction, TL denotes transmission loss, R denotes the room constant of the secondary room, and Sw denotes the surface area of the partition between two rooms or spaces

   g. $SPL_{wall\ secondary\ surface} = SPL_{wall\ sound\ source\ surface} - NR$

   where SPL denotes sound pressure level and NR denotes noise reduction

Terminal Objectives	
Sound	Module 4

2\.

and the following charts:

a. absorption coefficients of building material
b. adding decibels
c. transmission loss
d. sound field behavior in a reverberant field

and the following information:

a. room dimensions

   (1) primary room (noise source room)
   (2) secondary room (room adjoining noise source room)

b. directivity factor of a given machine(s)
c. sound power level(s) of a given machine(s) by frequency
d. material covering surfaces in

   (1) primary room
   (2) secondary room

e. distance of worker in secondary room from wall of adjoining sound source room

the student will be able to calculate

a. sound pressure level near walls of sound source room
b. sound pressure level near walls of secondary room
c. sound pressure level at r distance, where worker is standing in secondary room

3\. Given a diagram of the inner ear, with the following labels:

a. ear drum (tympanic membrane)
b. ossicular chain

   (1) malleus
   (2) incus
   (3) stapes

c. scala vestibuli
d. scala tympani
e. oval window
f. round window
g. cochlear duct
h. organ of corti
i. hair cells
j. basilar membrane
k. cochlear nerves

Terminal Objectives	
Sound	Module 4

3.

the student will be able to place arrows showing how sound travels through the inner ear and

a. show where high a low frequency sound are picked up
b. explain how the floor of scala vestibuli moves causing an effect on the organ of corti
c. explain how wave motion in a liquid is transformed into an electrical impulse
d. discuss how excessive sound damages the hair cells

4. Given the following:

a. $f_n = 3.13 \frac{1}{S_{st}}$ where f_n denotes natural frequency and S_{st} denotes static deflection of an isolator

b. transmissibility curves (single degree of freedom curves with damping factors assuming constant stiffness if isolators with respect to frequency and have noise reduction in decibels)

the student will be able to:

a. compute the transmissibility of an isolator, given the driving force affecting a machine's support and the force that is desired to affect the machine support
b. compute the natural frequency from the transmissibility curve, given a damping factor
c. compute the static deflection required of the isolator, once given the natural frequency

5. Upon request, the student will be able to list the three methods available to control vibration noise and give examples in writing, using diagrams, of each control method.

6. Given the following formula or equation:

$$SWL = SPL - 10\text{Log}_{10} \left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] - 10.5 - T$$ (see Objective 1 for denotation of symbols)

and a list of conditions under which the vendor of a particular machine calculated the machine's sound pressure level at given frequencies (i.e., the specifications of r, Q, and R), the student will be able to calculate if the machine in the new plant environment will meet a specific noise criteria level.

Terminal Objectives	
Sound	Module 4

7. Given the following equations:

   a. $f_{co} = \frac{C}{2D}$ where f_{co} denotes a cut-off frequency, C denotes the velocity of sound in a gas, and D denotes the inside diameter of a pipe downstream of a valve

   b. $C - 1127 \sqrt{\frac{t + 273}{300} \cdot \frac{29}{M}}$ where C denotes the velocity of sound in a gas, t denotes temperature in C^o, and M denotes molecular weight

   and given a pressure reducing valve table and the following information:

   a. pressure upstream of the valve
   b. pressure downstream of the valve
   c. mass flow rate
   d. temperature of the gas
   e. molecular weight of the gas
   f. the inside diameter of the pipe downstream of the valve

   the student will be able to construct the sound power level noise spectrum that is required to select a muffler. The correction factor will not be required in the solution of this problem (i.e., P_2/P_1 will be greater than 1.9).

8. Given the following equation:

   $$SWL = SPL - 10Log_{10}\left[\frac{Q}{4\pi r^2} - \frac{4}{R}\right] - 10.5 - T$$ (see Objective 1 for denotation of symbols)

   a table indicating sound pressure levels at each octave band frequency, at a specified distance, the specific criteria to meet at each criterion, the required noise reduction, and the allowance for noise variation at each frequency; and a data information sheet containing:

   a. dimensions of a large room
   b. r, distance worker is from the machine
   c. Q, directivity factor of the machine
   d. the wall, floor, and ceiling construction material with absorption coefficients
   e. the dimensions of the proposed enclosure
   f. the construction material of the enclosure with absorption coefficients

   the student will be able to compute the reverberant build-up at each frequency as a result of the enclosure and required transmission loss at each frequency of the enclosure construction material.

Terminal Objectives	
Sound	Module 4

8. Note: The following equations will not be given to the student:

$$R = \frac{\sum_{i=1}^{n} S_i \alpha_i}{1 - \bar{\alpha}}$$ (see Objective 1 for denotation of symbols)

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\Sigma S_i}$$ (see Objective 1 for denotation of symbols)

9. Given that the objective is to build an office in the center of a manufacturing area and the following information:

   a. dimensions of the manufacturing area
   b. the material on the floor, walls, and ceiling of the manufacturing area (with absorption coefficients at each octave band frequency)
   c. dimensions of the proposed office, with average absorption coefficients at each frequency
   d. sound pressure levels, at a specified distance, criteria noise level, and allowance for noise variation at each frequency

   the student will be able to compute the required transmission loss of the office walls, ceiling, and floor.

   Note: No equations will be given to the student.

10. Given the following equation:

$$NR = 10\text{Log}_{10} \frac{A_2}{A_1}$$

   where NR denotes noise reduction, A_1 denotes the total of absorption units of a room before the treatment and A_2 denotes the total of absorption units of the same room after treatment

   and the following information:

   a. dimensions of the room
   b. construction of ceiling, walls, and floor before treatment (with absorption coefficients)
   c. construction of ceiling, walls, and floor after treatment (with absorption coefficients)

   the student will be able to compute the noise reduction achieved by treating the walls, floor, and ceiling.

   Note: No other equations will be given to the student.

UNIT 1

PHYSICS OF SOUND

Performance Objectives		
Lesson	Physics of Sound	Module 4 Unit 1

1 — 1. Upon request, the student will be able to describe in writing, as well as graphically illustrate, the movement of air molecules associated with the generation of sound. Correct performance involves:

   a. written definition of sound
   b. identification (labeling) of areas of compression and rarefraction in his own illustration of the movement of air.

1 — 2. Given a series of lists, each containing no less than four definitions, the student will be able to correctly select the definition of

   a. compression of air molecules
   b. rarefraction of air molecules
   c. sound waves

1 — 3. Given a list of no less than four statements, the student will be able to select the statement that best describes wave-like motion.

1 — 4. Given an illustration of a sound wave, the student will be able to recall and label the following:

   a. areas above and below atmospheric pressure
   b. axis indicating distance or time
   c. wavelength

1 — 5. Given a frequency and temperature, the student will be able to compute the wavelength of sound propogated in an air medium.

1 — 6. Given a list containing at least four expressions, the student will be able to select the expression that shows the relationship between velocity, density, and elasticity.

or

Given a list of at least four statements, the student will be able to select the statement that best describes the change in velocity of sound due to either an increase or a decrease in either elasticity or density of the medium.

1 — 7. Given a list of at least four statements, the student will be able to select the statement that best describes how the velocity of sound in an air medium is affected by the temperature of the air.

1 — 8. Given a frequency, the student will be able to compute the period of one complete cycle of pressure change.

1 — 9. Given a list of expressions, the student will be able to select the expression that shows the relationship between wavelength, velocity, and period.

Lesson	Physics of Sound	Module 4 Unit 1

1 9. or

Given a list of statements, the student will be able to select the statement that best describes the change in wavelength when velocity remains constant, but the frequency of the sound source either increases or decreases.

1 10. Given a series of lists each containing no less than four statements or definitions, the student will be able to select the statements or definitions associated with

a. sound power
b. sound pressure
c. sound intensity

1 11. Given a list of at least four statements, the student will be able to select the statement that best describes the relationship between sound pressure and the frequency of sound.

1 12. Given a list of at least four statements, the student will be able to select the statement that best describes how sound intensity and sound power are related (inverse square law) when a sound measuring device moves away from a constant sound power source in a free field.

1 13. Given a list of the following equations:

a. $W = I4\pi r^2$ where W denotes sound power, I denotes sound intensity, and r denotes distance from a sound source

b. $I = \frac{P^2}{\rho C}$ where I denotes intensity, P denotes sound pressure, ρ denotes density, and C denotes velocity

and that $\rho = .0012\ gm/C^3$ and that C = 344 M/S and the following information

a. sound power of a machine
b. r, distance of worker from a machine

the student will be able to predict the sound pressure produced by a machine at distance r in a free field. To be successful, the student must be able to derive the following relationship:

$$P = \sqrt{\frac{3.5W \times 10^2}{r^2}}$$

where W denotes sound power and r denotes distance of worker from sound source in a free field.

Performance Objectives

Lesson	Physics of Sound	Module 4 Unit 1
2	14.	Given a list of at least four statements, the student will be able to select the statement that best describes complex sound.
2	15.	Given a series of lists each containing at least four statements, the student will be able to select the statements that best describe a. fundamental frequency b. harmonic
2	16.	Given a list of at least four statements, the student will be able to select the statement that best describes "Fourier analysis."
2	17.	Given a list of at least four statements, the student will be able to select the statement that best describes the relationship between the upper and lower limits of any of the following bands: a. Octave band b. 1/2 octave band c. 1/3 octave band
2	18.	Given a list of at least four statements, the student will be able to select the statement that best describes a decibel.
2	19.	Given a list of sound powers, sound intensities, and sound pressures, and a list of reference sound power, sound intensity, and sound pressure, the student will be able to compute a. sound pressure level b. sound power level c. sound intensity level
2	20.	Given a list of either sound power levels, sound pressure levels, or sound intensity levels, the student will be able to compute the overall sound power level, sound pressure level, or sound intensity level.
2	21.	Given a sound power level, r, a distance from a sound source and a table for T, correction factor for temperature, the student will be able to compute the sound pressure at distance r.
2	22.	Given a list of at least four statements, the student will be able to select the statement that best describes directivity factor.
2	23.	Given a list of numbers, the student will be able to select the number associated with a picture of a given sound radiation pattern (e.g., a machine located in the corner, sitting on the floor).

Lesson	Performance Objectives	
	Physics of Sound	Module 4 Unit 1
2	24. Given the following information: a. sound power of a machine at several frequencies b. sound power reference c. r, distance of worker from machine d. Q, the directivity factor of the machine e. temperature and atmospheric conditions--with correction factor chart the student will be able to compute the sound pressure level at distance r. No formula will be provided.	
3	25. Given a list of at least four statements, the student will be able to select the statement that best describes what happens to sound in a room.	
3	26. Given a diagram, the student will be able to label from recall the a. near field b. inverse square law field c. reverberant field	
3	27. Given a list of at least four statements, the student will be able to select the statement that best describes the behavior of sound pressure in the reverberant field.	
3	28. Given a list of at least four statements, the student will be able to select the statement that best describes the critical distance.	
3	29. Given a list of at least four definitions, the student will be able to select the best definition of the absorption coefficient.	
3	30. Given a list of statements, the student will be able to select the statement that best describes what happens to the energy that is absorbed into a surface.	
3	31. Given the dimensions of a room or surface and the absorption coefficient associated with the surfaces, the student will be able to compute the average absorption coefficient of the room or surface.	
3	32. Given a list of at least four statements, the student will be able to select the statement that best describes the term, "room constant."	
3	33. Given a list of statements, the student will be able to select the statement that best describes what happens to the room constant when the walls are made more absorbent but the surface area remains the same.	
3	34. Given a list of room dimensions and absorption coefficients, the student will be able to compute the room constant for that room. No formula will be provided.	

Performance Objectives		
Lesson	Physics of Sound	Module 4 Unit 1

3 35. Given the following:

a. room dimensions
b. average absorption coefficient
c. directivity factor
d. sound power of a machine

the student will be able to compute the sound pressure level at the walls of the room. This involves computing the average distance of the walls from the sound source.

3 36. Given the following information:

a. directivity factor
b. average absorption coefficient
c. room dimensions

the student will be able to compute the critical distance.

3 37. Given a list of at least four statements, the student will be able to select the statement that best describes what happens to sound pressure level at r_c distance when the walls of the room are made more absorbent.

3 38. Given a list of at least four statements, the student will be able to select the statement that best describes transmission loss of a partition.

3 39. Given a list of materials and methods of construction, the student will be able to select the materials and methods of construction that will reflect little sound and transmit little sound.

3 40. Given a wall constructed of two materials (e.g., glass and brick), surface area of each material, and the transmission loss of each material, the student will be able to calculate the total transmission of the wall.

3 41. Given a list of definitions, the student will be able to select the definition that best describes noise reduction.

3 42. Given the following:

a. sound power level in a room
b. room constant of a large room
c. room constant of the adjoining smaller room
d. transmission loss of the adjoining wall
e. the surface area of the adjoining wall

the student will be able to compute

a. noise reduction
b. the sound pressure level at the wall of the adjoining room at the adjacent wall.

Performance Objectives	
Lesson: Physics of Sound	Module 4 Unit 1

3 43. Given a list of at least four statements, the student will be able to select the statement that best describes under what conditions

a. NR < TL
b. NR > TL

Physics of Sound	Module 4 Unit 1

In order to present the unit material to the students, the instructor will be responsible for the following:

Lesson 1--Physics of Sound

Classroom Presentation

Conduct a lecture related to:

a. Definition of sound
b. Sound waves
c. Velocity of sound in air
d. Definition of

(1) Sound pressure
(2) Sound power
(3) Sound intensity

e. Relationship between sound power, sound pressure, and sound intensity

(1) Inverse square law
(2) Derivation of

$$P = \sqrt{\frac{W}{(1.52)^2\ 4\pi r^2}}$$

This will be a straight lecture but allow the students to ask questions during the lecture time.

Time Allotted

1 Hour

Demonstrations

No skill demonstrations are required; however, the following in-class demonstrations of concepts are encouraged:

a. Visualization of sound wave, using slinky toy
b. Visualization of sound wave, using slinky toy: Part II
c. Concept of sound pressure, using a tuning fork.

Supervised Practice

No supervised practice is required

Lesson 2--Physics of Sound (Continued)

Classroom Presentation

Conduct a lecture to include the following topics:

a. Complex sound
b. Harmonics
c. Frequency bands
d. Decibels

(1) Sound power level
(2) Sound pressure level
(3) Sound intensity level

e. Adding and subtracting decibels
f. Relationship between sound power level and sound pressure level
g. Q, directivity factor

Time Allotted

1 Hour

Demonstrations

No demonstrations are required

Supervised Practice

No supervised practice is required

Lesson 3--Physics of Sound (Continued)

Classroom Presentation

Conduct a lecture to include the following topics:

a. Reverberant
b. Coefficient of absorption
c. Room constant
d. Critical distance
e. Relationship between sound power level and sound pressure when considering

    (1) Q
    (2) r
    (3) R

f. Transmission loss
g. Noise reduction
h. Sound pressure in a secondary room

Time Allotted

1 Hour

Demonstrations

No demonstrations are required

Supervised Practice

No supervised practice is required

Unit Activities--Student	
Physics of Sound	Module 4 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--Physics of Sound

Classroom Activity

Attend a one-hour lecture introducing the topic of the physics of sound including the introduction of sound pressure, sound power, and sound intensity.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 4 Chapter 1
Industrial Noise Control Manual		Chapter 1
PROBLEMS		
Industrial Hygiene Engineering and Control		Section 3 Chapter 3
Industrial Hygiene Engineering and Control		Section 3 Self-Test

Physics of Sound	Module 4 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 2--Physics of Sound (Continued)

Classroom Activity

Attend a one-hour lecture continuing the discussion of the physics of sound.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 4 Chapter 2
the Industrial Environment--its Evaluation and Control		Chapter 23
PROBLEMS		
Industrial Hygiene Engineering and Control		Section 4 Chapter 1

Unit Activities--Student

Physics of Sound	Module 4 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 3--Physics of Sound (Continued)

Classroom Activity

Attend a one-hour lecture continuing the discussion of the physics of sound.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control	Section 4 Chs. 1,2,3	Section 4 Chapter 3
Industrial Hygiene and Toxicology, Volume I		Chapter 18
PROBLEMS		
Industrial Hygiene Engineering and Control		Section 4 Chapter 2

Facilities, Equipment, and Materials	
Physics of Sound	Module 4 Unit 1

Facilities

Lecture/discussion--Normal classroom

Equipment and Materials

Educational

Chalkboard
Chalk
Erasers
35 mm slide projector with remote control
Screen
Charts and lists

1. Adding and subtracting decibels
2. Correction for temperatures and barometric pressure
3. Relative sound pressure, given room constant
4. List of formulas

Health and Safety

None required

Visuals

Slide series--Industrial Hygiene Engineering and Control, Module 4, Unit 1

References Used in Class

Industrial Hygiene Engineering and Control
Industrial Noise Control Manual
the Industrial Environment--its Evaluation and Control
Industrial Hygiene and Toxicology, Volume I

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 1

TOPIC	REMARKS
	This lesson is prepared as a one-hour lecture. It is to acquaint the student with the definitions of sound, sound wave, sound power, sound pressure, and sound intensity. The instructor should proceed slowly. It is important to the remaining lessons in this unit that the students understand completely the concepts in this lesson.
I. Introduction A. What is Sound? 1. An oscillation in pressure (a traveling vibratory movement of molecules) within an elastic medium (material) of any phase (gas, liquid, solid). 2. The auditory sensation evoked by the oscillation discussed above. B. What is Noise? 1. Unwanted sound. a. subjective nature of unwanted sound (1) depends upon individual (2) depends on circumstances	
II. An Example of Sound A. Situation 1. Vibratory machine surface in an air medium. B. Discuss the Following: 1. Movement of surface in one direction (sound source). 2. <u>Compression</u> of adjacent molecules (increased pressure).	Slide 4.1.1.1.--Areas of Compression and Rarefraction Display slide during discussion.

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 1

TOPIC	REMARKS
3. High pressure acts to push immediately surrounding molecules at low pressure.	
4. Movement of surface in opposite direction. a. produces low pressure area, <u>rarefraction</u>	
5. Alternating compression and rarefraction of adjacent air molecules due to vibrating surface-causes fluctuations in atmospheric pressure.	
6. As molecules move, cause other molecules to move away from vibrating surface.	Point out that molecules do not move much distance but oscillate around a central location.
7. This disturbance in the air molecules then travels through air to reach ears. a. mechanical components of ear vibrate, changing to electrical energy	
8. As compression and rarefraction move, a sound wave is produced.	
III. Sound Wave A. What is a <u>Sound Wave?</u> 1. Pattern of fluctuation in air over distance or time.	
2. Can be graphed.	Slide 4.1.1.2.--Pattern of Sound Wave Discuss: 1. Vertical axis air pressure. 2. Horizontal axis distance or time. Show: 1. Correspondence between wave and rarefraction of air molecules.

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 1
TOPIC	**REMARKS**
B. Visualization of Sound Wave	Demonstration conducted by instructor in class. <u>Material</u> Slinky toy (spring) <u>Procedure</u> 1. Hold slinky vertically 2. Quickly lower the top once a. Ask students to note --grouping and spreading of elements --elements oscillate around a central location 3. Repeat so students can see movement and groupings. Slide 4.1.1.3.--Areas of Compression and Rarefraction--A Sound Wave
IV. Velocity of Sound A. Speed through a given medium depends upon 1. Density of medium. 2. Elasticity of medium. B. Expression $C^2 = \frac{\text{Elasticity}}{\text{Density}}$ where C denotes velocity (ft/sec) In Gas $C^2 = \frac{\gamma P_o}{\rho}$ where C denotes velocity, γ denotes specific heat ratio, ρ denotes density, and P denotes atmospheric pressure. 1. Normal temperature in air $\gamma = 1.41$	

TOPIC	REMARKS
2. ∴ $C = \sqrt{\frac{1.41\ P_o}{\rho}}$ C. Velocity of sound in air = 1127 ft/second or 344 meters/sec 1. C will change due to temperature of air. Increase 1 ft/sec for each degree Fahrenheit or about 2 ft/sec for each increase in one degree Celsius. 2. Usually assumed that C remains constant in a given medium. V. Frequency of Sound A. Frequency (f) rate at which complete cycles of high and low pressure regions are produced by the sound source; the number of times maximum sound pressure occurs in one second. 1. Cycles per second (CPS) or Hertz (Hz). 2. Ear can hear frequency 20 to 20,000 CPS, or Hz. B. Period (T) time required for one cycle of pressure change. 1. Reciprocal of frequency $\therefore\ T = \frac{1}{f}$ T denotes period, and f denotes frequency	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 1

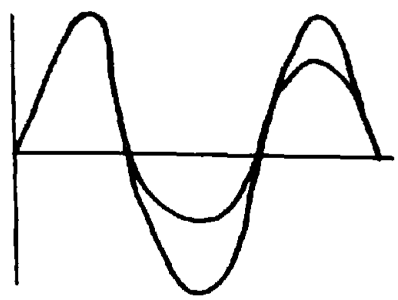
TOPIC	REMARKS
VI. Wavelength A. At a given velocity (C), how far would a wave travel in one period (T)? 1. Recall $\text{Velocity} = \frac{\text{Distance}}{\text{Time}}$ $C = \frac{\lambda}{T}$ where λ denotes wavelength. 2. ∴ $\lambda = CT$ or $\lambda = C \frac{1}{f}$ $= \frac{C}{f}$	Problems: 1. What is the wavelength of a 1000 Hz wave being propogated through air at 68°F? $\lambda = \frac{1127 \text{ ft/sec}}{1000 \text{ cycles/sec}}$ = 1.127 ft/cycle or 1.127 ft 2. What is the wavelength of a 1000 Hz wave in air at 90°F? Answer: 1.149 ft/sec
B. Visualization of Wavelength	Slide 4.1.1.4.--Representation of a Wavelength Demonstration conducted by instructor: Material Slinky toy (spring) Procedure 1. Hold slinky vertically 2. Oscillate the top up and down --ask students to note groupings, space between groupings --point out spacing is λ

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 1

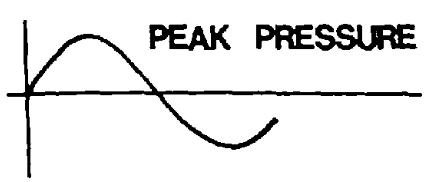
TOPIC	REMARKS
	Demonstration Procedure-Continued 3. Oscillate top faster, then slower (i.e., increase and decrease cycles per second) --ask students what differences they note when CPS changes --assume speed remains constant (rate does not affect speed). Groupings will travel the same speed. --wavelength changes.
VII. Sound Pressure, Power, and Intensity A. Overview 1. Definition of each. 2. Relationship between. B. <u>Sound Pressure</u> 1. Difference between atmospheric pressure and actual pressure during rarefraction and compression. 2. Why is sound pressure needed to describe sound?	Demonstration by instructor: <u>Material</u> Tuning Fork <u>Procedure</u> 1. Tap tuning fork lightly to generate a sound. 2. Tap tuning fork harder to generate a sound. 3. Ask students what the difference is between the two. Determine logically --frequency remains constant (CPS) --speed (velocity) will be equal --thus λ (wavelength) will be equal

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 1

TOPIC	REMARKS
	Demonstration Outline-Continued 4. Repeat steps 1 and 2 above. Now ask what is the difference. --tines move a greater distance when struck hard, thus increased pressure fluctuations. Slide 4.1.1.5.--Waves Having Same Wavelength but Different Sound Pressure  5. Note C, λ, T are not enough to describe sound. Pressure is needed. 6. Note: If loudness is mentioned, discuss it at this time.
3. Sound pressure units. a. pressure by definition is force per unit area (e.g., 14.7 pounds per square inch) b. pressure usually measured in bars 1 bar = 14 lbs/sq inch which is atmospheric pressure.	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 1

TOPIC	REMARKS
c. however, fluctuations in pressure that result in sound are small compared to a bar (1) u bar = 1 millionth of a bar is usually used as the unit u bar = atmospheric pressure x 10^{-6} sound pressure can also be expressed in dynes per square centimeter or newtons per square meter (where one dyne equals 10^{-5} newtons) (2) range of pressures in hearing (a) threshold .00002 N/M^2 (b) discomfort 20 N/M^2 Note: Above are in RMS pressure. 4. Relationship between sound pressure and frequency. a. no relationhsip; a pure tone at any given frequency may have a small or large pressure 5. Sound pressure changes over time and is not constant.  Since it is constantly changing, pressure must be integrated over time.	

TOPIC	REMARKS
a. RMS (Root Mean Square) (1) square sound pressure (2) sum and divide by number of measures (average) (3) take square root of average Note: Above discussion assumes a pure tone, i.e., steady-state sound. The time interval over which a simple periodic sound pressure pattern must be measured is equal to an integral number of periods of that sound pattern, or the interval must be long compared to a period. There must be more than 10 peaks per second for noise to be considered to be steady state for measurement purposes. b. there are instruments to measure sound pressure in RMS c. maximum peak pressure is normally used when peak pressure is repeated no more than 2 per second	
C. Sound Power 1. Total sound energy radiated per unit time by a sound source. a. sound power refers to sound source b. recall $\text{Power} = \frac{\text{Energy}}{\text{Time}}$	The concept of sound power can be attained by using mechanical terms: Energy--One pound lifted one foot off the ground requires one foot pound of energy. Power--One pound lifted one foot off the ground in one second.
2. Sound power units. a. foot pounds per second b. horsepower--550 foot pounds per second	Slide 4.1.1.6.--Sound Power Radiated by Familiar Sound Sources

TOPIC	REMARKS
c. joules per second (1 joule per second equals one watt); (one watt is equal to about 3/4 of a foot pound per second) d. dyne--centimeters per second (1 joule equals 10,000,000 dyne centimeters) e. newton--meters (1 joule equals 1 newton-meter) 3. Sound power vs. sound pressure. a. notice sound pressure is dependent upon the location of the observer--sound power is not b. relationship between sound power and sound pressure will be discussed later 4. Sound power of a machine (source) is not measured directly but must be calculated from measurements made under controlled conditions in a lab. a. anechoic environment b. or highly reflective surface environment Manufacturers usually specify sound power of a machine. D. <u>Sound Intensity</u> 1. Definition--sound power per unit area. a. is the indication of the concentration of sound power	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 1

TOPIC	REMARKS
b. if sound power is distributed over an area in such a way that 1 watt of power falls on each square foot of area, sound intensity is 1 watt per square foot; thus, when a given sound power is distributed over a small area, intensity will be high	
2. Conceptualization of sound intensity.	Slide 4.1.1.7.--Conceptualization of Sound Intensity
a. discuss pebbles in a still pond being dropped at perfect timing (1) width of black circles indicates height of waves (2) width of circles decreases as diameter increases (3) concentration of sound power at specified distances from the sound source intensity decreases as diameter increases (same sound power is covering a larger area)	
3. Relationship between sound intensity and sound power. a. recall definitions of sound power and sound intensity	

TOPIC	REMARKS
b. since intensity is power transmitted through a unit area--the total sound power radiated by a source through a certain area can be found by multiplying the value of intensity by the number of square feet in the certain area	Give a simple example: If a tuning fork produces a sound intensity of 1 u watt per square at a surface area of hypothetical sphere of 10 sq. ft., the total sound power will be 10 u watts.
(1) expression indicating relationship Sound Power $= I(\pi 4r^2)$ where I denotes intensity, r denotes radius, distance from source, $\pi = 3.1416$	
(2) <u>Inverse Square Law</u> If sound power remains constant, intensity must vary inversely with square of r, distance from the source. $I = \frac{\text{Sound power}}{4\pi r^2}$	Illustration of Inverse Square Law: <u>Procedure</u> 1. On chalkboard, work out the following table: Intensity / Distance: .08 / 1; .02 / 2; .005 / 4 Where sound power = 1 u watt 2. Note: That as distance from the source doubles, intensity drops 1/4.
4. Relationship between intensity and sound pressure. a. relationship expression $I = \frac{P^2}{\rho C}$ where P denotes sound pressure, ρ denotes density, and C denotes velocity.	See the textbook for the derivation of this expression

Physics of Sound	Module 4 Unit 1 Lesson 1

TOPIC	REMARKS
b. under normal conditions, it has been determined that $I = (1.52)P^2$ where I denotes sound intensity and P denotes sound pressure	
c. visualization of the relationship (1) display graphically (2) sound intensity like sound pressure is not constant (3) with each rarefaction and compression a pulse of sound energy is carried away from the source (4) average intensity is 1/2 maximum intensity for steady state sound	Slide 4.1.1.8.--Sound Pressure and Sound Intensity
5. Relationship between sound pressure, sound power, and sound intensity. a. given above Sound power = $I 4\pi r^2$ b. or $W = I\ 4\pi r^2$, where W denotes sound power, I denotes sound intensity, and r denotes distance Also recall $I = \frac{P^2}{\rho C}$ thus that $P = \sqrt{\frac{W\rho C}{4\pi r^2}}$ where P denotes sound pressure, ρ denotes density, C denotes velocity	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 1

TOPIC	REMARKS
b. (continued) under normal atmospheric conditions $P = \sqrt{\frac{3.5W \times 10^2}{r^2}}$ where W is given in watts, r in feet, P will be in newtons per square meter	Example Problem Under normal atmospheric conditions, predict the sound pressure that would be produced at a distance of 100 feet from a pneumatic chipping hammer. The manufacturer states that the hammer has an acoustical power of 1.0 watts. Solution $W = 1.00$ watt $r^2 = 100$ feet^2 $P = \sqrt{\frac{3.5(1.0) \times 10^2}{100 \text{ feet}^2}}$ $= 0.187$ N/M^2
6. Free field. a. above equations are only appropriate for a free-field condition (1) explain free field	

Practice Exercises

Physics of Sound	Module 4 Unit 1 Lesson 1

1. How is sound defined?

2. What is the wavelength of a sound traveling in air ($68^{o}F$) that has a frequency of 2 Hz (cycles/second)?

3. What is the wavelength of a sound traveling in air ($68^{o}F$) that has a period of 2 seconds for each complete cycle?

4. If a sound source in a free field generates a sound power of 10 watts, what is the sound intensity at 15 feet?

5. At 10 feet away from a sound source in a free field, the sound intensity is 0.5 watts per square foot. What is the sound power of the sound source?

6. Under normal atmospheric conditions, what is the sound intensity at 5 feet from the sound source if the sound pressure is 1.52 u bars at that distance?

7. What is the sound pressure in newtons per square meter at 5 feet from a sound source that generates a sound power of 0.00025 watts?

8. What is the sound power of a machine (in watts) if the sound pressure is 0.005 newtons/meter^2 at 3.5 feet?

Practice Exercises--Solutions	
Physics of Sound	Module 4 Unit 1 Lesson 1

1. Sound is defined as an oscillation in pressure within an elastic medium of any phase.

2.
$$\lambda = \frac{C}{f}$$
$$= \frac{1127 \text{ ft/sec}}{2 \text{ cycles/sec}}$$
$$= 563.5 \text{ ft/cycle}$$

3.
$$T = \frac{1}{f}$$
$$\therefore \lambda = CT$$
$$= 1127 \text{ ft/sec} \cdot 2 \text{ seconds/cycle}$$
$$= 2254 \text{ ft/cycle}$$

4.
$$I = \frac{W}{4\pi r^2}$$
$$= \frac{10 \text{ watts}}{4(3.1416)(15 \text{ feet})^2}$$
$$= 0.003537 \text{ watts/ft}^2$$

5.
$$I = 4\pi r^2$$
$$= \frac{0.5 \text{ watts} \cdot 4(3.1416)(10 \text{ feet})^2}{\text{ft}^2}$$
$$= 628.32 \text{ watts}$$

6.
$$I = (1.52P)^2$$
$$= (1.52 \cdot 1.52)^2$$
$$= 5.338 \text{ watts/ft}^2$$

7.
$$P = \sqrt{\frac{3.5W \times 10^2}{r^2}}$$
$$= \frac{3.5(0.00025 \text{ watts}) \times 10^2}{(5 \text{ feet})^2}$$
$$= 0.0035 \text{ newtons per square meter}$$

Practice Exercises--Solutions	
Physics of Sound	Module 4 Unit 1 Lesson 1

8.

$$W = \frac{P^2 r^2}{3.5 \times 10^2}$$

$$= \frac{(0.005)^2 (3.5)^2}{3.5 \times 10^2}$$

$$= \frac{(0.005)^2 \cdot 3.5}{100}$$

$$= 0.000000875 \text{ watts}$$

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
	This lesson is presented as a one-hour lecture. Its main emphasis is sound levels and adding and subtracting decibels.
I. Overview A. Complex Sound B. Discussion of 1. Sound power level. 2. Sound pressure level. 3. Sound intensity level. C. Discussion of relationship of different level indices.	
II. Complex Sound A. Pure Tone vs. Complex Sound 1. Industrial sound is complex sound.	Slide 4.1.2.1.--Illustration of Complex Sound
2. <u>Complex sound</u>. a. usually is composed of a number of pure tones that are related by simple numbers b. lowest frequency tone is called "fundamental" c. remaining tones are overtones or harmonics and are related by frequency d. number of harmonics can be determined by dividing the frequency of harmonic by the fundamental frequency e. notice from slide that peak pressure is only slightly above the peak pressure of fundamental; if the same sound as in Slide 4.1.2.2 were plotted by sound intensity over time, Slide 4.1.2.3 would result	Slide 4.1.2.2.--An Analysis of Complex Sound These two slides should be shown together. The quality of a sound is determined by the overtones.

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
f. Slide 4.1.2.3. gives components and complex sound	Slide 4.1.2.3.--Sound Intensity and Complex Sound
(1) easy to determine shape of combination given	Discuss this slide; be sure to point out the following: The top right hand side of the slide shows the average intensity of the complex sound. The bottom right hand of the slide shows the average sound intensities of the components making up the complex sound. Notice that the sum of the average intensities of the components equals the average intensity of the complex sound.
(2) in most cases, start with combination; trying to determine shape of components then becomes difficult	
(3) process called <u>"Fourier Analysis"</u>	
h. rather than being interested in shape of the components, it is usually more important to know frequency and intensity; i.e., to break combination sound into frequency and determine the intensity at each frequency	Slide 4.1.2.4.--Frequency Analysis
(1) most industrial sound is not harmonically related	
(2) industrial sound is random sound	
B. Given that intensity is plotted against frequency, it seems impractical to measure intensity at every frequency. What is more practical is to measure intensity in each of a set of frequency bands.	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
III. Frequency Bands	
A. Three frequency band scales typically used.	
1. Octave band.	Slide 4.1.2.5.--Octave Frequency Band
a. audible frequency band divided into 8 or more segments	
b. each segment (band) has $F_2 = F_1$ F_2 upper limit of band, F_1 denotes lower limit of band	
c. center frequency of band is the geometric mean $F_M = \sqrt{F_1F_2}$ where F_M denotes center frequency	
2. 1/2 octave band.	
a. band width is narrower so that you can be more specific	
b. $F_2 = \sqrt{2F_1}$	
c. F_M = Geometric Mean	
3. 1/3 octave band.	
a. narrower band width	
b. $F_2 = \sqrt[3]{2F_1}$	
c. F_M = Geometric Mean	
B. Frequency Band and Intensity	
1. Intensity measured in frequency band is equal to the intensity of the components with the frequency limits of the band.	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
2. The overall intensity is equal to the sum of the intensities in each frequency band. IV. Decibels A. Can plot frequency with intensity or pressure, but normally this is not done. 1. The human ear responds to a broad range of sound pressure and intensity and power. a. this means small numbers since the human ear is relatively sensitive b. to avoid small numbers, the log of ratios is used 2. Logarithm. a. defined--the power to which one number is raised to equal another number $4^2 = 16$ $\log_4 16 = 2$ $10^2 = 100$ $\log_{10} 100 = 2$ 3. Ratios of concern. a. ratio of measured quantity to a reference quantity (usually reference quantity is threshold of hearing) b. Ref quantities (1) I ref = 10^{-12} watts/meter^2 (2) P ref = 0.0002 bars or 0.00002 N/M^2 (3) W ref = 10^{-12} watts	

Lesson Outline

Physics of Sound — Module 4, Unit 1, Lesson 2

TOPIC	REMARKS
c. ratios (1) $\frac{W}{W\ ref}$ (2) $\left(\frac{P}{P\ ref}\right)^2$ (3) $\frac{I}{I\ ref}$	
d. log of ratios (1) $\log \frac{W}{W\ ref}$ (2) $\log \left(\frac{P}{P\ ref}\right)^2$ (3) $\log \frac{I}{I\ ref}$	
4. Bels and decibels. a. dimensionless unit related to the ratio of 2 quantities b. Decibel = 10 bels c. ratios expressed in decibels (1) power or sound power level (PWL) $PWL = 10 \log_{10} \frac{W}{W\ ref}$ $= 10 \log_{10} \frac{W}{10^{-12}}$ $= 10 \log_{10} W - 10 \log_{10} 10\text{-}12$ $= 10 \log_{10} W + 120$ dB	What is the sound power level of a source radiating 4.0 watts of sound power (ref 10^{-12} watts)? $PWL = 10 \log_{10} 4 + 120$ $= 10\ (0.6) + 120$ $= 126$ (dB)

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS

(2) sound pressure level (SPL)
ref = 0.00002 N/M^2

$$SPL = 10 \log_{10} \left(\frac{P}{P\ ref}\right)^2$$

$$= 20 \log_{10} \frac{P}{P\ ref}$$

$$= 20 \log_{10} P - 20 \log .00002$$

$$= 20 \log_{10} P - 20\ (\log_2 - \log_{10} 5)$$

$$= 20 \log_{10} P + 94 \text{ dB}$$

(ref = 0.00002 N/M^2)

(3) sound intensity level (SIL)

$$SIL = 10 \log_{10} \frac{I}{I\ ref}$$

$$= 10 \log_{10} \frac{I}{10^{-12}}$$

$$= 10 \log_{10} I + 120$$

At this point, remind the students of the inverse square law.

Power = $I 4 \pi r^2$

Where doubling the distance reduced intensity by 1/4 if power remained the same.

Distance	Intensity	Intensity Level (dB)
1	.08	109
2	.02	103
4	.005	97

A change in 6(dB) for every distance doubled

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
	$SIL = 10 \log_{10} I + 120$ $= 10 \log_{10}(.08) + 120$ $= 10 \log_{10}(8 \times 10^{-2}) + 120$ $= 10(\log_8 + \log 10^{-2}) + 120$ $= 10(.9 - 2) + 120$ $= -10(1.1) + 120$ $= -11 + 120$ $= 109$ $SIL = 10(\log 2 + \log 10^{-2}) + 120$ $= 10(.3 - 2) + 120$ $= -10(1.7) + 120$ $= -17 + 120$ $= 103$ $SIL = 10(\log 5 + \log 10^{-5}) + 120$ $= -10(2.3) + 120$ $= 10(-2.3) + 120$ $= 97$
If the sound intensity level at a given distance is known, then the intensity level at some other distance can be computed using $SIL_r = SIL_1 - 20 \log_{10} r/r_1$ where SIL_r denotes the sound intensity level at distance r, SIL_1 denotes the known sound intensity level at a distance r_1, and r and r_1 denote the distances corresponding to the two sound intensity levels.	

TOPIC	REMARKS
For example, if the sound intensity level at r_1 is 109 dB, then the sound intensity level r = 2 can be computed as follows:	Note: This expression can be used to compute the SIL at the distances above.
$SIL_{(r=2)} = SIL_{(r=1)} - 20 \log_{10}\left(\frac{r}{r_1}\right)$	
$= 109\text{ dB} - 20 \log_{10}\frac{2}{1}$	
$= 109\text{ dB} - 20 \log 2$	
$= 109\text{ dB} - 6.0\text{ dB}$	
$= 103\text{ dB}$	
	Slide 4.1.2.6.--Sound Power and Sound Power Level
	Slide 4.1.2.7.--Sound Pressure and Sound Pressure Level
V. Adding and Subtracting Decibels	
A. Previously, intensities were averaged in presentation	
1. Sound intensity levels cannot be added arithmetically because they are logs.	What is the overall sound intensity level of two sounds, one at 50(dB) and one at 55 (dB)?
2. $LC = 10 \log_{10}(10^{L1/10} + 10^{L2/10})$	
where L_C denotes combined level, L_1 denotes Level 1, and L_2 denotes Level 2.	
or	
$L_C = L_1 + 10 \log_{10}(10^{\frac{L_2 - L_1}{10}} + 1)$	
where L_C denotes combined level, L_1 denotes the lowest level, and L_2 denotes the highest level.	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
	Solution to Problem

<u>Solution to Problem</u>

$$L_C = 10 \log_{10}(10^{\frac{50}{10}} + 10^{\frac{55}{10}})$$

$$= 10 \log_{10}(10^5 + 10^{5.5})$$

$$= 10 \log_{10}(10^5(10^5 \times 10^{.5}))$$

$$= 10 \log_{10}(10^5(1 + 10^{.5}))$$

$$= 10 \log_{10}(10^5(1 + 3.16))$$

$$= 10 \log_{10}(10^5(4.16))$$

$$= 10 \log_{10} 10^5 + 10 \log_{10}(4.16)$$

$$= 10(5 + .6191)$$

$$= 10(5.62)$$

$$= 56.2 (dB)$$

$$L_C = 50 + 10 \log_{10}(10^{\frac{55-50}{10}} + 1)$$

$$= 50 + 10 \log_{10}(10^{\frac{-5}{10}} + 1)$$

$$= 50 + 10 \log_{10}(10^{-5} + 1)$$

$$= 50 + 10 \log_{10}(3.16 + 1)$$

$$= 50 + 10 \log_{10}(4.16)$$

$$= 50 + 10(.6191)$$

$$= 50 + 6.19$$

$$= 56.2 (dB)$$

Lesson Outline

Physics of Sound

Module 4
Unit 1
Lesson 2

TOPIC	REMARKS
B. Table for Adding and Subtracting Decibels	See Textbook or Slide 4.1.2.8 Table for Adding and Subtracting Decibels
Example	Work out example on chalkboard.

Octave Band Center Frequency	Intensity Level (dB)
31.5	85
63	88
125	94
250	94
500	95
1000	100
2000	97
4000	90
8000	88

Find overall sound intensity level.

Rearrange lowest to highest or highest to lowest.

85 88 88 90 94 94 95 97 100

89.8

92.0

94.1

97.1

98.8

100.3

102.0

103.1

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
VI. Relationship Between Sound Power Level and Sound Pressure Level	
A. Recall	
1. $SPL = 20 \log_{10} \frac{P}{P\ ref}$	
2. $SWL = 10 \log_{10} \frac{W}{W\ ref}$	
3. $P = \sqrt{\frac{3.5W \times 10^2}{r^2}}$	
B. Relationships of SPL and SWL	
1. $SPL = SWL - 20 \log_r - 0.5$ dB or $SWL = SPL + 20 \log_r - 0.5$ dB where SWL and SPL are in (dB) ref 10^{-12} watts and 0.00002 N/M^2; and r is in feet.	Free field nondirectional sound. Using the expression $P = \sqrt{\frac{3.5W \times 10^2}{r^2}}$ compute sound pressure, if W = 1.0 watt and r = 100 feet. $P = \sqrt{\frac{3.5(1.0) \times 100}{10,000}}$ $= \sqrt{\frac{3.5 \times 10}{10,000}}$ $= 0.187\ N/M^2$ Now using the expression $SPL = 20 \log_p + 94$ dB convert 0.187 N/M^2 into a sound pressure levl SPL = 20 log 0.187 + 94 dB = -14.56 dB + 94 dB = 79.436 dB

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
	Using the expression $SPL = SWL - 20 \log_r - 0.5$ dB compute the SPL if W = 1.0 watts and r = 100 feet. First $SWL = 10 \log W + 120$ dB $= 120$ dB Therefore $SPL = 120$ dB $- 20 \log 100 - 0.5$ $= 120$ dB $- 40$ dB $- 0.5$ dB $= 79.5$ dB This shows that the two expressions $P = \sqrt{\frac{3.5W \times 10^2}{r^2}}$ and $SPL = SWL - 20 \log_r - 0.5$ dB are equivalent when P is converted to a sound pressure level. <u>Problem</u> Predict the sound pressure level (SPL) that will be produced in a free-field at a distance of 100 feet in front of a particular machine. (Assume omni-directional noise source.) Noise has a sound power of 0.1 watts, ref 10^{-12}. <u>Solution</u> $SPL = SWL - 20 \log_r - 0.5$ dB $= 10 \log_{10} \frac{W}{10^{-12}} - 20 \log 100 - 0.5$ dB $= (10 \log_{10} W - \log_{10} 10^{-12}) - 20 \log 10^2 - 0.5$ dB (continued)

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
	$= 10(\log_{10} .1 - \log_{10} 10^{-12}) -$ $20 \log 10^2 - 0.5$ dB $= 10(-1 + 12) - 40$ dB $- 0.5$ dB $= 110$ dB $- 40$ dB $- 0.5$ dB $= 69.5$ (dB) (ref: 0.00002 N/M^2)
2. Correction in relationship for atmospheric condition (temperature and pressure). a. $SPL = SWL - 20 \log_r -$ 0.5 dB $+ T$ dB or $SWL = SPL - 20 \log_r +$ 0.5 dB $- T$ dB where T denotes correction factor in dB units	Slide 4.1.2.9.--Correction Factor for Atmospheric Conditions
3. Correction in relationship for directivity of sound source. a. Directivity factor (Q) (1) definition--measure of the degree to which sound is concentrated in a certain direction rather than radiated evenly in a full spherical pattern	
b. possible patterns (1) non-directional point source (a) related to area of sphere $4\pi r^2$ $Q = 1$	Slide 4.1.2.10.--Omni-Directional Point Source

TOPIC	REMARKS
(2) half-spherical radiation; where source is in a field but on the ground $\frac{4\pi r^2}{2}$ Q = 2	Slide 4.1.2.11.--Half-Spherical Radiation
(3) sound source on floor next to wall Q = 4 Sound radiation area has been reduced by a factor of 4 $\frac{4\pi r^2}{4}$	Slide 4.1.2.12.--Q = 4
(4) two walls and on floor $\frac{4\pi r^2}{8}$	Slide 4.1.2.13.--Q = 8
C. Adjustment in Relationship SPL = SWL - 20 $\log_r$ - 0.5 dB + 10 logQ + T dB SWL = SPL + 20 $\log_r$ + 0.5 dB - 10 logQ - T dB	Problem: Predict the sound pressure level (SPL) that will be produced in a free-field at a distance of 3 feet directly in front of a machine. A directivity factor of 5 is provided by the machine manufacturer for this location. The noise source has a sound power of 0.1 watts. Assume normal atmospheric conditions; i.e., T = 0. Solution: SPL = SWL - 20 $\log_r$ - 0.5 dB + 10 logQ $= 10\log(\frac{0.1}{10^{-12}}) - 20\log 3 - 0.5\text{ dB} + 10\log 5$ $= 10(\log 0.1 - \log 10^{-12}) - 20\log 3 - 0.5\text{ dB} + 10(0.7)$ (continued)

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS
	$= (-1 + 12) - 20(.47) - 0.5\text{ dB} + 7.0\text{ dB}$ $= 10(11) - 9.40 - 0.5 + 7.0$ $= 110 - 9.40 - 0.5 + 7.0$ $= 180 - 9.9$ $= 170.1(\text{dB})$
VII. Summary A. Complex Sound 1. Fourier-Analysis. 2. Harmonics B. Random Noise C. Frequency Bands 1. Octave bands. D. Decibels E. Levels 1. Sound Power Level $PWL = 10 \log_{10}\left[\frac{W}{W\ ref}\right]$ $= 10 \log W + 120\text{ dB}$ $W\ ref = 10^{-12}$ watts 2. Sound Pressure Level $SPL = 20 \log_{10}\left[\frac{P}{P\ ref}\right]$ $= 20 \log P + 94\text{ dB}$ $P\ ref = .00002\ N/M^2$ $= .00002$ u bars 3. Sound Intensity Level $SIL = 10 \log_{10}\left[\frac{I}{I\ ref}\right]$ $= 10 \log I + 120\text{ dB}$ $I\ ref = 10^{-12}\ \text{watts}/M^2$	Be sure to list the equations discussed in this lesson. A great deal of information was given, and the students will need a brief review.

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 2

TOPIC	REMARKS

F. Adding and Subtracting Decibels

1. Use of table, or
2. $L_C = L_1 + 10 \log \left(10^{\frac{L_2 - L_1}{10}} + 1\right)$

   Where L_C = combined level
   L_2 = highest level
   L_1 = lowest level

3. Can add

   SPL
   SWL
   SIL

   using this approach

C. Relationship of SPL and SWL

$SPL = SWL - 20 \log_r - 0.5\ dB + 10 \log Q + T\ dB$

where T is a correction factor in dB.

Practice Exercises	
Physics of Sound	Module 4 Unit 1 Lesson 2

1. What is Fourier Analysis?

2. What is an octave band?

3. What is a decibel?

4. If the sound pressure is given as 0.002 newtons per square meter, what is the sound pressure level? (ref = 0.00002 N/M^2)

5. If the sound power is given as 100,000 watts, what is the sound power level? (ref = 10^{-12} watts)

6. If the sound intensity is given as 10^{-5} watts per square meter, what is the sound intensity level? (ref = 10^{-12} watts/m^2)

7. If the sound intensity level at 4 meters from the sound source is 97 dB, what is the sound intensity level at 8 meters from the sound source?

8. A machine in the center of a room produces the following sound intensity levels at each of the frequencies given:

Frequency (Hz)	Sound Intensity Level (SIL) dB
63	101
125	115
250	110
500	109
1000	108
2000	104
4000	99
8000	85

What is the combined sound intensity level (i.e., the overall average sound intensity)?

9. If a machine has a sound power level of 100 dB, what is the sound pressure level 10 feet from that sound source? (Assume Q = 1 and T = 0.)

10. What is the sound pressure level in Question 9 if the machine has a directivity factor of 8 (i.e., Q = 8)? (Assume T = 0.)

Practice Exercises--Solutions

Physics of Sound	Module 4 Unit 1 Lesson 2

1. Fourier Analysis is a mathematical procedure for breaking complex sound into simple tones; a fundamental plus the component overtones or harmonics.

2. An octave band is the range of audible frequencies divided into 8 or more equal segments where each segment has an upper and lower frequency limit.

   $$F_2 = 2F_1$$

   where F_2 denotes the upper frequency limit and F_1 denotes the lower frequency limit.

   The center of the frequency band is given as

   $$F_n = \sqrt{F_1 F_2}$$

   where F_n denotes the center frequency.

3. A decibel is a dimensionless unit related to the logarithm of the ratio of a measured quantity to a reference quantity.

4. Sound Pressure Level

   $$SPL = 20 \log P + 94$$
   $$= 20 \log 0.002 + 94$$
   $$= 40 \text{ dB}$$

5. Sound Power Level

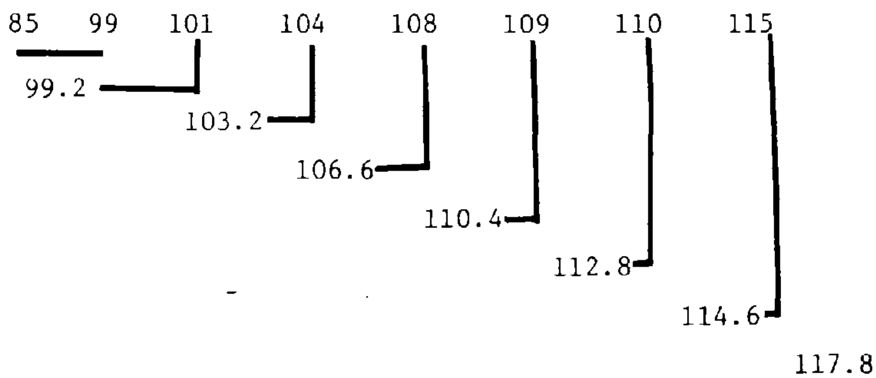
   $$SWL = 10 \log W + 120$$
   $$= 10 \log 100{,}000 + 120$$
   $$= 170 \text{ dB}$$

6. Sound Intensity Level

   $$SIL = 10 \log I + 120$$
   $$= 10 \log 10^{-5} + 120$$
   $$= 70 \text{ dB}$$

7. According to the inverse square law, a change of six decibels occurs for every doubling of the distance. Thus the sound intensity level at 8 meters (double 4 meters) would be approximately 91 dB.

8. Rearrange the SIL (dB) from low to high and use the table on page 4.2.17.



9. Sound Pressure Level

$$\begin{aligned} SPL &= SWL - 20 \log_r - 0.5 + T + 10 \log Q \\ &= 100 \text{ dB} - 20 \log 10 - 0.5 + 0 + 0 \\ &= 80 - .05 \\ &= 79.5 \text{ dB (ref} = 0.00002 \text{ N/M}^2) \end{aligned}$$

10. Sound Pressure Level

$$\begin{aligned} SPL &= SWL - 20 \log_r - 0.5 + T + 10 \text{ Log} Q \\ &= 100 - 20 \log 10 - 0.5 + 0 + 10 \log 8 \\ &= 79.5 + 10 \log 8 \\ &= 88.53 \text{ dB (ref} = 0.00002 \text{ N/M}^2) \end{aligned}$$

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
	This lesson is prepared as a one-hour lecture. Its main emphasis is on the computation of sound pressure level in a secondary room.
I. Introduction	
A. Last lesson discussed sound in a free field.	
1. Directivity factor and relationship between sound power level and sound pressure level.	
$SPL = SWL - 20 \log_r + 10 \log Q + 0.5 \text{ dB} + T$	
Where r denotes distance from source, Q denotes directivity factor, and T denotes the correction factor.	
B. This lesson will discuss:	
1. Sound in a room. a. reverberant sound b. absorption coefficient of the room surface c. room constant	Ask students what factors would influence sound in a room. a. walls b. surface of walls c. sound bouncing off walls
2. Traveling of sound from one room to another. a. transmission loss b. noise reduction	
C. Lesson contains many concepts and formulae that are useful in controlling sound.	
II. Sound in a Room	
A. Sound in a free field. 1. Inverse square law.	Slide 4.1.3.1.--Sound in a Free Field

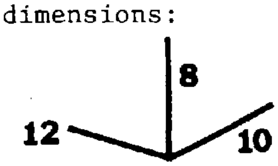
Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
B. Put sound source in room 1. What is going to happen when sound reaches the wall?	Slide 4.1.3.2.--Sound Source in Room
a. generation of a reflected wave  b. incident wave c. reflected wave	Slide 4.1.3.3.--Incident and Reflected Wave
2. Multiple reflections. a. intensity b. fields (1) near field (2) inverse square field -acts like free field; sound of machine predominates and not reflected waves (3) reverberant sound field--where reflected sound predominates	Slide 4.1.3.4.--Sound in a Room
C. Sound in a room and sound pressure level 1. Unable to predict sound pressure level in near field. 2. Inverse square law field. a. sound pressure will drop with square of distance 3. Reverberant field. a. sound pressure will become constant b. method of predicting sound pressure in reverberant field will be given later	Slide 4.1.3.5.--Sound Field in a Room

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
D. Critical Distance	Slide 4.1.3.6.--Sound Field in a Room
1. Distance at which noise level changes from inverse square behavior to reverberant behavior.	
a. expression for computing critical distance will be given later	
b. rough estimate of critical distance by ear	Explain how the critical distance can be determined by the human ear.
E. Factors Affecting Reverberant Field	
1. What will affect amount of reverberant sound against wall?	Ask students this question.
a. absorption ability of the wall	
(1) hard surface will reflect sound	
(2) soft surface will absorb sound	
b. soft, porous material will absorb sound	Slide 4.1.3.7.--Absorption of Sound on a Soft and a Hard Surface
(1) interconnected air spaces	
(2) transfer of energy to heat	
2. A number that expresses absorption ability.	
a. fraction of incident sound intensity that is absorbed is called the absorption coefficient (α)	
(1) α = 1.0--open space (no sound reflected)	
(2) hard surface (marble) where α = 0 (no sound absorbed)	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
3. α is not the same for all frequencies.	Slide 4.1.3.8.--Absorption Curves
4. Published absorption coefficients.	
5. Not all walls in a given room are made of the same material nor is a given wall always of the same material.	
If a wall is glass and brick, what is its absorption coefficient?	
a. $\bar{\alpha} = \dfrac{S_1\alpha_1 + S_2\alpha_2 + \dots S_n\alpha_n}{S_1 + S_2 \dots + S_n}$	Slide 4.1.3.9.--Absorption Coefficient
$= \dfrac{\sum_{i=1}^{n} S_i\alpha_i}{\sum_{i=1}^{n} S_i}$	
where S_i denotes wall surface and α denotes the average absorption coefficient	
b. Problem	
Room has following dimensions:	
	
Ceiling--acoustical tile, $\alpha = 0.95$ Floor--carpeted, $\alpha = 0.37$ Walls--brick, $\alpha = 0.03$	
What is the average α?	

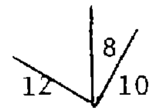
Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
Solution	
$\bar{\alpha} = \dfrac{S_{floor}\,\alpha_{floor} + S_{ceiling}\,\alpha_{ceiling} + S_{walls}\,\alpha_{walls}}{S_{floor} + S_{ceiling} + S_{walls}}$	
$= \dfrac{(12 \times 10).37 + (12 \times 10).95 + 2(12 \times 8).03 + 2(8 \times 10).03}{2(12 \times 10) + 2(8 \times 10) + 2\ (12 \times 8)}$	
$= \dfrac{44.4 + 114.0 + 5.76 + 4.8}{240 + 160 + 192}$	
$= \dfrac{168.96}{592}$	
$= 0.285$	
(1) discuss sabins--units for the absorption coefficient	
6. Room constant.	
a. measure of the ability of room to absorb sound	
b. $R = \dfrac{\bar{\alpha}\Sigma S_i}{1 - \bar{\alpha}}$	Slide 4.1.3.10.--Room Constant
Note:	
if: $\bar{\alpha} = \dfrac{\sum_{i=1}^{n} S_i\alpha_i}{\sum_{i=1}^{n} S_i}$	
then $\alpha\Sigma S_i = \sum_{i=n} S_i\alpha_i$	
and $R = \dfrac{\sum_{i=1}^{n} S_i\alpha_i}{1 - \bar{\alpha}}$	

TOPIC	REMARKS

Problem

What is the room constant of a room with



Ceiling α = 0.95 sabins
Floor α = 0.37 sabins
Brick walls α = 0.03 sabins

$$R = \frac{\bar{\alpha}\Sigma S_i}{1 - \bar{\alpha}}$$

$$= \frac{0.28 \text{ sabins}(592)\text{ft}^2}{1 - 0.28 \text{ sabins}}$$

$$= \frac{165.72 \text{ sabins ft}^2}{0.72 \text{ sabins}}$$

$$= 230.22 \text{ ft}^2$$

7. Room constant will affect the sound pressure level in various parts of the room. If the walls are perfectly absorbent (made of open space), a free field condition prevails, and the sound pressure level in various parts of the room can be computed with

$$SPL_{(r)} = SPL_{(1)} - 20 \log \left(\frac{r}{r_1}\right)$$

where SPL denotes the sound pressure at some distance, $SPL_{(1)}$ denotes the known sound pressure level at distance (1), and r and r_1 denote the distances corresponding to SPL_r and SPL_1 respectively.

This expression hold true only where there is no reverberant buildup.

For example, if sound pressure level at 3 feet is 110 dB, what is the sound pressure level at 15 ft?

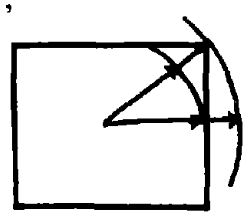
$$SPL_{(15\text{ ft})} = 110 \text{ dB} - 20 \log \frac{15 \text{ ft}}{3 \text{ ft}}$$

$$= 96.02 \text{ dB}$$

Note: This same expression can be used to compute the sound intensity level.

$$SIL_{(r)} = SIL_{(1)} - 20 \log \frac{r}{r_1}$$

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
F. Room constant will affect sound pressure level.	Slide 4.1.3.11.--Chart R and SPL
1. Distance from acoustic center.	Problem: If a sound source were in the center of our room with 8 foot ceilings,  and a room constant of 22.39, what is SPL at the walls? First, what is the average distance to the wall? Average distance = $\sqrt{\frac{\Sigma S_i}{4\pi}}$ $= \sqrt{\frac{592}{12.56}}$ $= 6.87$
2. Relative sound pressure in a room. a. using chart (4.1.3.11.), show how R and $\bar{\alpha}$ affect sound pressure level in various parts of the room b. explain why sound pressure level becomes constant after a certain distance (Note: No expression is given for computing the relative sound pressure level, only the chart or table.)	

TOPIC	REMARKS
G. Room constant also affects relationship between sound power level and sound pressure level.	Slide 4.1.3.12.--Relationship Between SPL and SWL, Considering R
SPL = $SWL + 10 \log \frac{Q}{4\pi r^2} + \frac{4}{R} + 10.5 \text{ dB} - T$	
Where Q denotes directivity factor, r denotes distance in feet, R denotes the room constant, and T denotes the atmospheric condition correction factor. (Ref SPL, 0.00002 N/M^2; and ref SWL, 10^{-12} watts)	
	<u>Problem</u> Chipping hammer that radiates 1 watt of power in the center of our room. Q = 1. Recall, for our room-- Average distance to wall = 6.87 ft R = 230.22 ft^2 $\bar{\alpha}$ = 0.28 sabins What is the SPL at the wall? $SWL = 10 \log W + 120$ $= 10 \log 1 + 120$ $= 10(0) + 120$ $= 120$ dB SPL = $SWL + 10 \log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5$ dB SPL = $120 \text{ dB} + 10 \log\left[\frac{1}{4\pi(6.87 \text{ ft}^2)} + \frac{4}{230.22 \text{ ft}^2}\right] + 10.5 \text{ dB}$ $= 120 \text{ dB} - 17.19 \text{ dB} + 10.5 \text{ dB}$ $= 113.32$ dB

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
1. Discuss table on slide. a. in our room, as you get closer to the wall, there is less drop in pressure	Slide 4.1.3.13.--Curves Problem What is SPL if a worker is 2.14 ft away from the source when Q = 1 R = 230.22 α = 0.28 sabins SWL = 120 dB SPL = $SWL + 10 \log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5$ dB $= 120 \text{ dB} + 10 \log\left[\frac{1}{4\pi(2.14)^2} + \frac{4}{230.22}\right] + 10.5$ dB = 115.9 dB Have students work one more problem at 1.5 feet using the same data as above. SPL at 1.5 feet = 117.72 dB Have students discuss relation of SPL's at the distances of 6.87 ft (at the wall), at 2.14 ft, and at 1.5 feet.
2. From $SPL = SWL = 10 \log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5$ dB it can be shown that the inverse square law field equals the reverberant field when $\frac{Q}{4\pi r_c^2} = 4/R$ where r_c denotes critical distance.	

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS

REMARKS

Solving for r_c and substituting for R results in

$$r_c = \sqrt{\frac{Q\bar{\alpha}\Sigma S_i}{16\pi(1 - \bar{\alpha})}}$$

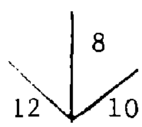
In our example, what is the critical distance if Q = 1, $\bar{\alpha}$ = 0.28 sabins, R = 230.22

$$r_c = \sqrt{\frac{QR}{16\pi}}$$

$$= 2.14 \text{ feet}$$

TOPIC

3. Recall that the room in the examples has the following statistics:



Ceiling--acoustic tile
α = 0.95 sabins
Floor--carpeting
α = 0.37 sabins
Walls--brick, α = 0.03 sabins

What happens if the walls are made more absorbent? Make walls paneling, α = 0.10 sabins

$$\bar{\alpha} = \frac{(12 \text{ ft} \times 10 \text{ ft})0.37 \text{ sabins} + (12 \text{ ft} \times 10 \text{ ft})0.95 \text{ sabins} + 2(12 \text{ ft} \times 8 \text{ ft}) \cdot 0.10 \text{ sabins} + 2(10 \text{ ft} \times 8 \text{ ft})0.10 \text{ sabins}}{592 \text{ ft}^2}$$

$$= \frac{44.4 \text{ ft}^2 \text{ sabins} + 114.0 \text{ ft}^2 \text{ sabins} + 19.2 \text{ ft}^2 \text{ sabins} + 16 \text{ ft}^2 \text{ sabins}}{592 \text{ ft}^2}$$

$$= \frac{193.6 \text{ ft}^2 \text{ sabins}}{592 \text{ ft}^2}$$

$$= 0.32 \text{ sabins}$$

REMARKS

Note: All the problems have been worked with the same room characteristics. Now one of the room characteristics is to be changed (primarily room constant by changing $\bar{\alpha}$), and problems will determine how this affects SPL at various places in the room.

Lesson Outline

Physics of Sound

Module 4
Unit 1
Lesson 3

TOPIC	REMARKS

$$R = \frac{193.6\ ft^2\ sabins}{1\ sabin - .32\ sabins}$$

$$= 284.71\ ft^2$$

Now what is the sound pressure at the walls?
Recall that average distance to wall is 5.87 ft and SWL = 120.

$$SPL = SWL + 10\log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5\ dB$$

$$= 120 + 10\log\left[\frac{1}{4\pi(6.87\ ft)^2} + \frac{4}{284.71\ ft^2}\right] + 10.5\ dB$$

$$= 112.47\ dB$$

Before making the walls more absorbent SPL at walls was 113.32.

Now compute at 1.5 feet and 2.14 feet.

SPL at 1.5 ft = 117.5 (before it was 117.7)

SPL at 2.14 ft = 115.4 (before it was 115.9)

SUMMARY OF COMPARISONS

Slide 4.1.3.14.--SPL's and Absorbing Walls

SPL	Walls Brick	Walls Panel
At wall	113.3	112.4
At worker 1.5 ft away	117.7	117.5
At critical distance	115.9	115.4

Ask students what happened when the walls were made more absorbent.

a. Reduced SPL near walls but not in the work area.
b. For engineering control, then, making the walls more absorbent does not help the worker if he is in the inverse square law region, at the critical distance, or near the near field.

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
II. Sound in an Adjoining Room	
A. Situation	Slide 4.1.3.15.--Our Room and an Adjacent Room What is the SPL in the secondary room?
B. Transmission of Sound Through Walls	Slide 4.1.3.16.--Sound Through an Absorbent Material
1. Sound travels through walls.	Slide 4.1.3.17.--Sound Through a Solid Partition Slide 4.1.3.18.--Sound Through a Combination Partition Slide 4.1.3.19.--(Combination of three slides above)
a. with an absorbing material, a lot of sound goes through the wall b. with a solid partition, less goes through but much less is reflected c. with a combination wall, little goes through and little is reflected	
2. Transmission loss (TL) and the mass law.	
a. theoretically (1) sound pressure on the source side of the partition causes partition to move in and out (2) this motion causes a new sound wave on the opposite side of the partition	

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

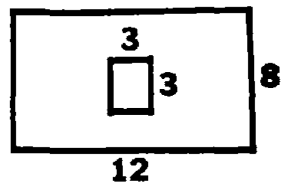
TOPIC	REMARKS
b. movement of partition is dependent upon the mass	
(1) brick wall moves less than wood wall	Slide 4.1.3.20.--Transmission Loss Theoretical Slide 4.1.3.21.--Surface Density of Building Material
(2) discuss use of table and chart. Note: Is dependent upon frequency.	
(3) what is transmission loss	Slide 4.1.3.22.--Published Transmission Loss Tables
(a) difference in SPL on source side and other side (b) the sound pressure level reduction afforded by the wall (c) mathematically	
$TL = 10 \log_{10} \frac{\text{Energy transmitted}}{\text{Energy of incident}}$	
(d) transmission loss difficult to measure; only a few laboratories in US qualified to make standard measures (ASTM E90-61T)	
Note: Make sure the published tables were made using the standard.	

Lesson Outline

Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
(4) most walls are not made of a single material (a) brick and glass (b) to compute the transmission loss of wall constructed of combined material use:	
$TL_{combined} =$ $10 \log \Sigma S_i - 10 \log \Sigma S_i\ 10^{-TL_i/10}$	Slide 4.1.3.23.--Transmission Loss of a Composite Material

Problem



Where

Transmission loss brick = 45 dB
Transmission loss glass = 31 dB

What is the combined transmission loss?

$$\sum_{i=1}^{n} S_i = 8 \times 12$$
$$= 96 \text{ ft}^2$$

$$\sum_{i=1} S_i 10^{-TL_i/10} =$$

$$\left[(8 \times 12) - (3 \times 3)\right] 10^{-45/10} + (3 \times 3)10^{-31/10}$$

$$= (90.439 \text{ ft}^2)10^{-45/10} + (5.56 \text{ ft}^2)10^{-31/10}$$

$$= 0.00286 + 0.00442 = 0.00728$$

$$TL_c = 10 \log 96 - 10 \log 0.0728$$
$$= 19.28 \text{ dB} + 21.38 \text{ dB}$$
$$= 41.20 \text{ dB}$$

TOPIC	REMARKS

C. Transmission loss is the amount of energy lost. If adjoining room is small, this energy will have some reverberant sound which must be considered to compute the sound pressure level in the adjoining room.

1. Noise reduction (NR).

   a. defined as difference in SPL from source side of wall to other side when there is a reverberant buildup in the smaller room

   b. must take into consideration

      (1) transmission loss of wall

      (2) absorbing ability (room constant of adjoining room)

   c. general formula

$$NR = TL - 10 \log_{10} \left[\frac{1}{4} + \frac{S_w}{R} \right]$$

Where

NR = Noise reduction, difference in sound pressure level

TL = transmission loss through a partition or wall

S_w = Surface area of wall between two rooms

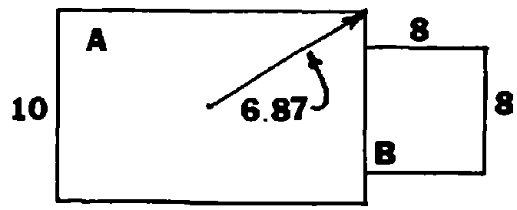
R = Room constant in secondary room

Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS

Problem

Sound power level = 120
Sound source 1.0 watt



Room A	Sabins	Room B	Sabins
Ceiling	α = 0.95	Ceiling	α = 0.95
Floor	α = 0.37	Floor	α = 0.37
Wall	α = 0.03	Adjoining wall	α = 0.03
$\bar{\alpha}$ = 0.28 sabins		Other wall 8' ceiling	α = 0.10
R = 230.22			
Q = 1			

Transmission loss of adjoining wall = 45 dB

What is the noise reduction in the adjoining room, room B?

Compute sound pressure at wall using

$$SPL = SWL + 10 \log\left[\frac{1}{4\pi r^2} + \frac{4}{230.22}\right] + 10.5\,dB$$

$$= 113.3\ dB$$

Then compute R in secondary room

$$R = \frac{\bar{\alpha}\Sigma S_i}{(1 - \bar{\alpha}}$$

$$\bar{\alpha} = \frac{(8' \times 8')(0.95\text{ sabins}) + (8' \times 8') \cdot (0.37\text{ sabins}) + (8' \times 8')(0.03\text{ sabins}) + 3(8' \times 8')(0.10\text{ sabins})}{384\ ft^2}$$

$$= \frac{60.8\ ft^2\text{ sabins} + 23.68\ ft^2\text{ sabins} + 1.92\ ft^2\text{ sabins} + 19.2\ ft^2\text{ sabins}}{384\ ft^2}$$

$$= \frac{105.6\ ft^2\text{ sabins}}{384\ ft^2}$$

$$= 0.275\text{ sabins}$$

Lesson Outline	
Physics of Sound	Module 4 Unit 1 Lesson 3

TOPIC	REMARKS
$R = \frac{105.6\ ft^2\ sabins}{(1 - 0.28\ sabins)}$ $= 146.67$ Now compute the noise reduction. $NR = 45\ dB - 10\ \log_{10}(.25 + \frac{S_w}{R})$ where $S_w = 8\ ft \times 8\ ft = 64\ ft^2$ $NR = 45 - 10\ \log\left(0.25 + \frac{64\ ft^2}{146.67\ ft^2}\right)$ $= 45 -(-1.63)$ $= 43.36\ dB$ SPL in the adjacent room will be $SPL_{room} = SPL_{source} - NR$ $= 113.3\ dB - 43.36\ dB$ $= 70.14\ dB$	
2. Rules concerning NR. a. for a live secondary room ($\bar{\alpha}$ = small) NR will be 5 to 6 dB less than TL b. for a medium dead room ($\bar{\alpha}$ = average) NR will be 1 to 2 dB greater than TL c. for a dead enclosure ($\bar{\alpha}$ = large) NR will be about 6 dB greater than TL	Slide 4.1.3.24.--Rules Concerning Noise Reduction Ask the students how the sound pressure level in the middle of the room (secondary room) might be computed.
III. Summary A. Reverberant Sound 1. Sound bouncing off walls. 2. Sound behavior in a room. a. near field b. inverse square law field c. reverberant sound field	

TOPIC	REMARKS

d. critical distance--where noise changes from inverse square law field to reverberant field.

B. Sound Absorption Coefficient.

1.

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\sum_{i=1}^{n} S_i}$$

C. Room Constant

1.

$$R = \frac{\alpha \Sigma S_i}{1 - \bar{\alpha}}$$

D. Effect of room constant on sound pressure level

1. Levels off near walls
2. Chart to compute difference or drop in sound pressure.

E. Effect of room constant on the relationship between SWL and SPL

$$SWL = SPL - 10 \log F - 10.5$$

$$F = \frac{Q}{4\pi r^2} + \frac{4}{R}$$

F. Transmission Loss

1. Loss of energy through wall.
2. TL_c

$$TL_c = 10 \log S_T - 10 \log \Sigma S_i 10^{TL_i/10}$$

G. Noise Reduction

1. Difference in sound pressure levels between two sides of a structure.

   a. influenced by reverberant sound (room constant in adjoining room and TL of the wall)

$$NR = TL - 10 \log_{10} \left[1/4 + \frac{S_w}{R} \right]$$

2. $SPL_{\text{secondary room}} = SPL_{\text{wall}} - NR$

Practice Exercises	
Physics of Sound	Module 4 Unit 1 Lesson 3

1. If sound is in a free-field condition and the sound pressure level at 10 feet is 100 dB, what is the sound pressure level at 15 feet?

2. What is the average room absorption coefficient at 1000 Hz of a room 16 ft x 16 ft x 8 ft high if the floor is unpainted concrete with an absorption coefficient of 0.02 sabins at 1000 Hz, if the ceiling is composed of plaster (gypsum, with scratch and brown coat on metal lath with wooden joists) with an absorption coefficient of 0.06 sabins at 1000 Hz and the walls are composed of brick with an absorption coefficient of 0.04 sabins at 1000 Hz?

3. What is the room constant (R) of the room described in question #2?

4. If a room 16 ft x 16 ft x 16 ft with an average room absorption coefficient of 0.52 sabins at 1000 Hz has a sound source in the center of the room with a sound power level of 1000 dB and a Q factor of 5, what is the sound pressure level at the walls (i.e., the average distance the walls are away from the sound source)? Assume normal atmospheric conditions.

5. What is the sound pressure level at the critical distance in question #4?

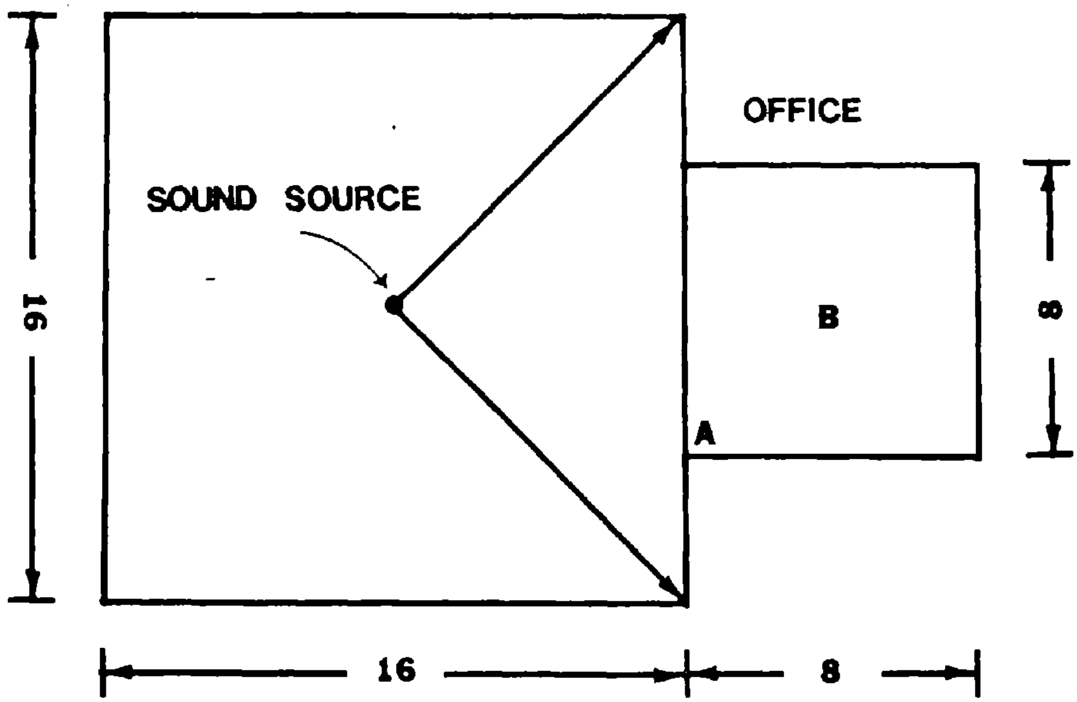
6. If a room 24 ft x 24 ft x 24 ft with an average absorption coefficient of 0.06 sabins, with a sound source in the middle of the room with a Q factor of 1 and a sound power level of 120 dB, was modified by adding more absorbent material so that the average absorption coefficient was 0.48 sabins, what decrease in sound pressure would be achieved at the average distance the wall is from the sound source?

7. What is the sound pressure level at the critical distance (under the old conditions) in question #6? What is the sound pressure level at that distance under the new conditions?

8. What is the combined transmission loss at 500 Hz of a wall 24 ft x 11 ft high that is constructed of concrete block with a transmission loss of 45 dB at 500 Hz? It has a door 3 ft wide by 8 ft high with a transmission loss of 31 dB at 500 Hz and a glass window 21 ft by 5 ft high with a transmission loss of 3 dB at 500 Hz.

9. If the wall described in question #8 was between a room with a sound source and a smaller room 24 ft wide by 8 feet long by 11 ft high with an average absorption coefficient of 0.05 sabins, what would be the noise reduction achieved?

10. If at the source side of a wall with a noise reduction of 27.066 dB the sound pressure level is 98 dB, what is the sound pressure level on the other side of the wall?



11. The diagram above shows a sound source in a large room that is adjacent to a smaller room (an office). Compute the sound pressure level at the adjoining wall in the smaller room. (At location A). (Hint: First compute the SPL at both frequencies then add them together.)

 The following information is provided:

 1. Ceiling in large room and small room is 8 ft.
 2. The sound source has the following sound power levels at 500 Hz and 1000 Hz: 120 dB and 100 dB, respectively (ref 10^{-12} watts); Q = 1.
 3. The floor of the large room is poured, unpainted concrete that has an absorption coefficient of 0.02 sabins at both 500 Hz and 1000 Hz.
 4. The floor in the small room is poured concrete covered with wool pile carpeting with an underpad and has absorption coefficients of 0.35 sabins and 0.40 sabins at 500 Hz and 1000 Hz, respectively.

11. (Continued)

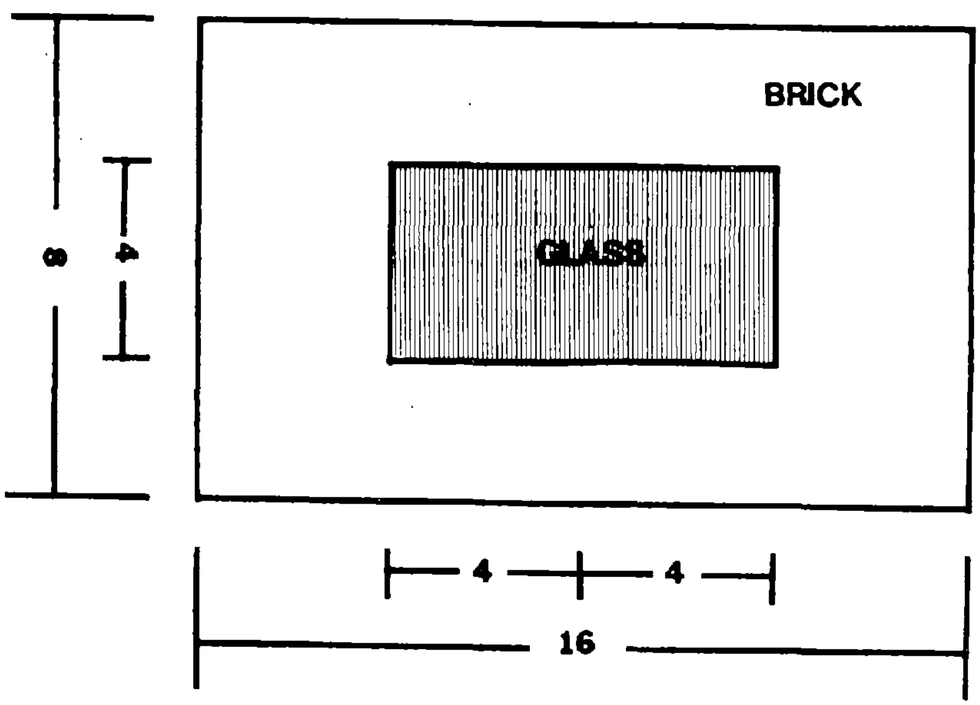
5. The ceiling in both rooms is composed of plaster (gypsum, with scratch and brown coats on metal lath, on wood joists) and has absorption coefficients of 0.04 sabins and 0.06 sabins at 500 Hz and 1000 Hz respectively.
6. All the walls in the large room, except the adjoining wall, are composed of brick and have absorption coefficients of 0.03 sabins and 0.04 sabins at 500 Hz and 1000 Hz, respectively.
7. All the walls of the small room, except the adjoining wall, are plastered (gypsum, scratch and brown coats on metal lath, with wood studs) and have absorption coefficients of 0.04 sabins and 0.06 sabins at 500 Hz and 1000 Hz, respectively.
8. The following diagram represents the adjoining wall.

BRICK

α = 03 at 500 HZ
α = 04 at 1000HZ
TL=45dB at 500 & 1000 HZ

GLASS

α = 03 at 500 & 1000 HZ
TL=31dB at 500& 1000 HZ



Practice Exercises--Solutions	
Physics of Sound	Module 4 Unit 1 Lesson 3

1.

$$SPL_{15\ ft} = SPL_{10\ ft} - 20 \log \left[\frac{15\ ft}{10\ ft}\right]$$
$$= 100\ dB - 20 \log 15$$
$$= 100\ dB - 3.522\ dB$$
$$= 96.478\ dB$$

2.

$$\bar{\alpha}_{1000\ Hz} = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\sum_{i=1}^{n} S_i}$$

$$= \frac{(16' \times 16')0.02\ sabins + (16' \times 16')0.06\ sabins + 4(16' \times 8')0.04\ sabins}{2(16' \times 16') + 4(16' \times 8')}$$

$$= \frac{5.12\ ft^2\ sabins + 15.36\ ft^2\ sabins + 5.12\ ft^2\ sabins}{512\ ft^2 + 512\ ft^2}$$

$$= \frac{25.6\ ft^2\ sabins}{1024\ ft^2}$$

$$= 0.025\ sabins$$

3.

$$R_{1000\ H_z} = \frac{\alpha_i \sum_{i=1}^{n} S_i}{1 - \bar{\alpha}}$$

$$= \frac{0.025\ sabins \cdot 1024\ ft^2}{1\ sabin - 0.025\ sabins}$$

$$= 26.256\ ft^2$$

4. Step 1

(average distance to wall) $= \sqrt{\frac{\sum_{i=1}^{n} S_i}{4\pi}}$

$$= \sqrt{\frac{6(16' \times 16')}{4\pi}}$$

$$= 11.056\ ft$$

4. Step 2

$$R_{1000\ Hz} = \frac{\bar{\alpha}\Sigma S_i}{1 - \bar{\alpha}}$$

$$= \frac{0.52\ \text{sabins}\ (6)(16' \times 16')}{1\ \text{sabin} - 0.52\ \text{sabins}}$$

$$= \frac{798.72\ \text{ft}^2\ \text{sabins}}{0.48\ \text{sabins}}$$

$$= 1664\ \text{ft}^2$$

Step 3

$$SPL = SWL + 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5\ \text{dB} + T$$

$$= 100\ \text{dB} + 10 \log \left[\frac{5}{4\pi(11.056\ \text{ft})^2} + \frac{4}{1664\ \text{ft}^2}\right] + 10.5\ \text{dB}$$

$$= 100\ \text{dB} + (-22.473\ \text{dB}) + 10.5\ \text{dB}$$

$$= 88.027\ \text{dB (ref}\ 0.00002\ \text{N/M}^2$$

5. Step 1

$$r_c = \sqrt{\frac{QR}{16\pi}}$$

$$= \sqrt{\frac{5(1664\ \text{ft}^2)}{16\pi}}$$

$$= 12.865\ \text{ft}$$

Step 2

$$SPL = SWL + 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5\ \text{dB} + T$$

$$= 100\ \text{dB} + 10 \log \left[\frac{5}{4\pi(12.865\ \text{ft})^2} + \frac{4}{1664\ \text{ft}^2}\right] + 10.5\ \text{dB}$$

6. Step 1

$$R = \frac{\alpha\Sigma S_i}{1 - \bar{\alpha}}$$

$$= \frac{0.06\ \text{sabins}(6)(24\ \text{ft}^2)}{1\ \text{sabin} - 0.06\ \text{sabins}}$$

$$= 220.596\ \text{ft}^2$$

6. Step 2

Compute average distance to wall

$$r_{\text{average distance to wall}} = \sqrt{\frac{\Sigma S_i}{4\pi}}$$

$$= \sqrt{\frac{3456\ ft^2}{4\pi}}$$

$$= 16.584\ ft$$

Step 3

Compute SPL at wall under old room conditions

$$SPL = SWL + 10\log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5\ dB + T$$

$$= 120\ dB + 10\log\left[\frac{1}{4\pi(16.584\ ft)^2} + \frac{4}{220.596\ ft^2}\right] + 10.5\ dB + T$$

$$= 120\ dB + (-17.347\ dB) + 10.5\ dB + T$$

$$= 113.153\ dB + T\ (ref = 0.00002\ N/M^2)$$

Step 4

Compute new room constant

$$R = \frac{\alpha\Sigma S_i}{1 - \bar{\alpha}}$$

$$= \frac{0.48\ sabins\ (6)(24\ ft^2)}{1\ sabin - 0.48\ sabins}$$

$$= 3190.154\ ft^2$$

Step 5

Compute sound pressure level at walls under new conditions

$$SPL = SWL + 10\log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5\ dB + T$$

$$= 120\ dB + 10\log\left[\frac{1}{4\pi(16.584\ ft)^2} + \frac{4}{3190.154\ ft^2}\right] + 10.5\ dB + T$$

$$= 120\ dB + (-28.116\ dB) + 10.5\ dB + T$$

$$= 102.3842\ dB + T\ (ref\ 0.0000\ N/M^2)$$

6. Step 6

Compute difference between two SPL

Difference = 113.153 dB + T − (102.3842 dB + T)

= 10.769 dB

7. Step 1

$$r_c = \sqrt{\frac{QR}{16\pi}}$$

$$= \sqrt{\frac{1 \cdot 220.596\ ft^2}{16\pi}}$$

= 2.095 ft

Step 2

$$SPL = SWL + 10 \log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5 + T$$

$$= 120\ dB + 10 \log\left[\frac{1}{4\pi(2.095\ ft)^2} + \frac{4}{3190.154\ ft^2}\right] + 10.5\ dB + T$$

= 120 dB + (−17.125 dB) + 10.5 dB + T

= 113.374 dB + T (ref 0.00002 N/M^2)

Notice: The room was made 8 times more absorbent, and at the critical distance there was a decrease of only 12.721 dB while at the wall (problem #6) there was a decrease of 10.769 dB.

8.

$$TL_{combined} = 10 \log \Sigma S_i - 10 \log \Sigma S_i 10^{-TL_i/10}$$

$$= 10 \log 264\ ft^2 - 10 \log\ (24\ ft^2 \cdot 10^{-31\ dB/10}) + (105\ ft^2 \cdot 10^{-31\ dB/10}) + (135\ ft^2 \cdot 10^{-45\ dB/10})$$

= 24.216 −(−9.717)

= 33.933 dB

9. Step 1

Compute room constant in small room.

$$R = \frac{\bar{\alpha}\Sigma S_i}{1 - \bar{\alpha}}$$

$$= \frac{0.05 \text{ sabins } \left[2(24' \times 8') + 2(8' \times 11') + 2(24' \times 11')\right]}{1 \text{ sabin} - 0.05 \text{ sabins}}$$

$$= \frac{54.4 \text{ ft}^2 \text{ sabins}}{0.95 \text{ sabins}}$$

$$= 57.263 \text{ ft}^2$$

Step 2

Compute the noise reduction

$$NR = TL - 10 \log\left[\frac{1}{4} + \frac{S_w}{R}\right]$$

$$= 33.933 \text{ dB} - 10 \log\left[\frac{1}{4} + \frac{264 \text{ ft}^2}{57.263 \text{ ft}^2}\right]$$

$$= 33.933 \text{ dB} - 6.867 \text{ dB}$$

$$= 27.066 \text{ dB}$$

10.

$$SPL_{\text{other side}} = SPL_{\text{at wall on source side}} - NR$$

$$= 98 \text{ dB} - 27.066 \text{ dB}$$

$$= 70.934 \text{ dB (ref } 0.00002 \text{ N/M}^2)$$

11. Step 1

Compute average distance wall is from sound source in the large room.

$$r_{\text{average distance to wall}} = \sqrt{\frac{\sum_{i=1}^{n} S_i}{4\pi}}$$

$$= \sqrt{\frac{2(16' \times 16') + 4(8' \times 16')}{4\pi}}$$

$$= 9.03 \text{ ft}$$

11. Step 2

Compute average absorption coefficient of large room (at 500 Hz and 1000 Hz) using

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\Sigma S_i}$$

Material	S_i	(Sabins) $\alpha_{i_{500\ Hz}}$	(Sabins) $\alpha_{i_{1000\ Hz}}$	(Sabins) $S_i \alpha_{i_{500}}$	(Sabins) $S_i \alpha_{i_{1000}}$
Floor	16' x 16'	0.02	0.02	5.12 ft^2	5. 12 ft^2
Ceiling	16' x 16'	0.04	0.06	10.24 ft^2	15.36 ft^2
3 Walls	16' x 8'	0.03	0.04	11.52 ft^2	15.36 ft^2
Adjoining wall Brick area	96 ft^2	0.03	0.04	2.88 ft^2	3.84 ft^2
Glass area	32 ft^2	0.03	0.03	0.96 ft^2	0.96 ft^2
Total	1024 ft^2			30.72 ft^2	40.64 ft^2

$$\bar{\alpha}_{500\ Hz} = \frac{30.72\ ft^2\ sabins}{1024\ ft^2}$$

$$= 0.03\ sabins$$

$$\bar{\alpha}_{1000\ Hz} = \frac{40.64\ ft^2\ sabins}{1024\ ft^2}$$

$$= 0.0399\ sabins\ (Use\ 0.04)$$

Step 3

Compute room constant at 500 Hz and 1000 Hz

$$R = \frac{\bar{\alpha}\Sigma S_i}{1 - \bar{\alpha}}$$

$$R_{500\ Hz} = \frac{0.03\ sabins\ (1024\ ft^2)}{1\ sabin - 0.03\ sabins}$$

$$= \frac{30.72\ ft^2\ sabins}{0.97\ sabins} = 31.670\ ft^2$$

$$R_{1000\ Hz} = \frac{40.64\ ft^2\ sabins}{1\ sabin - 0.04\ sabins}$$

$$= 42.333\ ft^2$$

11. Step 4

Compute SPL at wall in large room (Note: Q = 1 is given)

$$SPL_{500\ Hz} = SWL + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right) + 10.5\ dB + T$$

$$= 120\ dB + 10\log\left(\frac{1}{4\pi(9.03\ ft)^2} + \frac{4}{31.670\ ft^2}\right) + 10.5\ dB + T$$

$$= 120\ dB + (-8.952\ dB) - 10.5\ dB + T$$

$$= 121.548\ dB + T\ (\text{ref } 0.00002\ N/M^2)$$

(assume T = 0)

$$SPL_{1000\ Hz} = 120\ dB + 10\log\left(\frac{1}{4\pi(9.03\ ft)^2} + \frac{4}{42.33\ ft^2}\right) + 10.5\ dB + T$$

$$= 120\ dB + (-10.202\ dB) + 10.5\ dB + T$$

$$= 120.298\ dB + T\ \ (\text{ref } 0.00002\ N/M^2)$$

(assume T = 0)

Step 5

Compute transmission loss of adjoining wall

$$TL_{combined} = 10\log \Sigma S_i - 10\log\left(\Sigma S_i 10^{-TL/10}\right)$$

$$= 10\log 64 - 10\log\left((8' \times 4')10^{-31/10} + (2)(2' \times 8')\cdot 10^{-45/10}\right)$$

$$= 18.062 - (-15.779)$$

$$= 33.841\ dB$$

Note: Transmission loss will be the same at both figures, 500 Hz and 1000 Hz.

11. Step 6

Compute the average absorption coefficient in the small room at 500 Hz and 1000 Hz.

Material	S_i	(Sabins) $\alpha_{i_{500\ Hz}}$	(Sabins) $\alpha_{i_{1000\ Hz}}$	(Sabins) $S_i\alpha_{i_{500}}$	(Sabins) $S_i\alpha_{i_{1000}}$
Floor	8' x 8'	0.35	0.40	22.4 ft^2	25.6 ft^2
Ceiling	8' x 8'	0.04	0.06	2.56 ft^2	3.84 ft^2
3 Walls	8' x 8'	0.04	0.06	7.69 ft^2	11.52 ft^2
Adjoining wall Brick area	2(2' x 8')	0.03	0.04	0.96 ft^2	1.28 ft^2
Glass area	8' x 4'	0.03	0.03	0.96 ft^2	0.46 ft^2
Total	384 ft^2			34.56 ft^2	43.2 ft^2

$$\bar{\alpha}_{500\ Hz} = \frac{34.56\ ft^2\ sabins}{384\ ft^2}$$

$$= 0.091\ sabins$$

$$\bar{\alpha}_{1000\ Hz} = \frac{43.2\ ft^2\ sabins}{384\ ft^2}$$

$$= 0.112\ sabins$$

Step 7

Compute room constant (R) in small room (at 500 Hz and 1000 Hz).

$$R = \frac{\bar{\alpha}\Sigma S_i}{1 - \bar{\alpha}}$$

$$R_{500\ Hz} \doteq \frac{34.56\ ft^2\ sabins}{1\ sabin - 0.091\ sabins}$$

$$= 38.02\ ft^2$$

$$R_{1000\ Hz} = \frac{43.2\ ft^2\ sabins}{1\ sabin - 0.112\ sabins}$$

$$= 48.649\ ft^2$$

Step 8

Compute the noise reduction at both frequencies. (For TL, see Step 5; for R, see Step 7.)

$$NR_{500\ Hz} = TL - 10 \log \left[\frac{1}{4} - \frac{S_w}{R_{500_{Hz}}} \right]$$

$$= 33.841\ dB - 10 \log \left[\frac{1}{4} - \frac{64\ ft^2}{38.02\ ft^2} \right]$$

$$= 33.841\ dB - 2.863\ dB$$

$$= 30.978\ dB$$

$$NR_{1000\ Hz} = TL - 10 \log \left[\frac{1}{4} - \frac{S_w}{R_{1000_{Hz}}} \right]$$

$$= 33.841\ dB - 10 \log \left[\frac{1}{4} - \frac{64\ ft^2}{48.649\ ft^2} \right]$$

$$= 33.841\ dB - 1.947\ dB$$

$$= 31.894\ dB$$

Step 9

Compute sound pressure level on other side of wall. (SPL on source side = 121.548 dB at 500 Hz and 120.298 at 1000 Hz--see Step 4.)

$$SPL_{\substack{location\ A \\ 500\ Hz}} = SPL_{\substack{at\ wall \\ or\ source}} - NR_{500_{Hz}}$$

$$= 121.548\ dB - 30.978\ dB$$

$$= 90.570\ dB \quad (ref\ 0.00002\ N/M^2)$$

$$SPL_{\substack{location\ A \\ 1000\ Hz}} = 120.298\ dB - 31.894\ dB$$

$$= 88.404\ dB$$

Step 10

Combine SPL at 500 Hz and 1000 Hz to obtain total SPL on small room side of wall.

$$SPL_{combined} = SPL_{lowest} + 10 \log \left[10^{\frac{SPL_{high} - SPL_{low}}{10}} \right] + 1$$

$$= 88.404\ dB + 4.227\ dB$$

$$= 92.631\ dB$$

UNIT 2

THE EAR AND THE EFFECTS OF SOUND

Lesson	Performance Objectives	
	The Ear and the Effects of Sound	Module 4 Unit 2
1	1. Given a list of statements, the student will be able to select and order the statements that best describe the three stages of hearing; i.e., the changing of wave motion to mechanical vibration to wave motion in a liquid to electrical energy.	
1	2. Given a list of statements, the student will be able to select those statements that describe how sound reaches the ear.	
1	3. Given a series of lists of statements, the student will be able to select the statement that best describes the function(s) of: a. Pinna b. External Auditory Canal c. Ear Drum (Tympanic Membrane) d. Middle Ear e. Oval Window f. Round Window g. Eustachian Tube h. Inner Ear (Cochlea) i. Upper Canal (Scala Vestibuli) j. Lower Canal (Scala Tympani) k. Inner Ear Duct (Cochlear Duct) l. Organ or Hearing (Organ of Corti) m. Basilar Membrane n. Hair Cells	
1	4. Given a list of statements, the student will be able to describe the purpose of wax in the external auditory canal.	
1	5. Given a list of statements (or bones), the student will be able to select those bones that compose the ossicular chain.	
1	6. Given a list of statements, the student will be able to select the statement that best describes how the ossicular chain is protected from sudden explosive sound.	
1	7. Given a diagram containing the following labels: a. Scala Vestibuli b. Scala Tympani c. Cochlear Duct d. Basilar Membrane e. Organ of Corti f. Inner Hail Cells g. Outer Hair Cells h. Ganglion the student will be able to describe in writing the transmission of sound in the inner ear.	

Performance Objectives		
Lesson	The Ear and the Effects of Sound	Module 4 Unit 2

1 | 8. Given a series of lists of locations, the student will be able to select the locations of the inner ear which

a. are sensitive to low frequency sound
b. are sensitive to high frequency sound

1 | 9. Given a list of statements, the student will be able to select the statements that are true about hair cells.

1 | 10. Given a series of lists of statements describing types of hearing loss, the student will be able to select the statements associated with

a. conductive hearing loss
b. sensorineural hearing loss
c. mixed hearing loss
d. central hearing loss
e. psychogenic hearing loss

1 | 11. Given a list of at least four statements, the student will be able to select the statement that best describes or defines hearing loss.

1 | 12. Given a list of at least four statements, the student will be able to select the statement that best describes or defines a negative hearing loss.

1 | 13. Given a list of at least four statements, the student will be able to select the statement that best defines or describes threshold shift.

1 | 14. Given a list of statements, the student will be able to select the statement that best describes the sensitivity of hearing (both frequency and intensity).

1 | 15. Given a list of statements, the student will be able to select the statement that best describes the meaning of a 40 dB hearing loss at 4000 Hz.

1 | 16. Given two lists, each containing at least four statements, the student will be able to select the statements which best define or describe

a. temporary threshold shift
b. permanent threshold shift

1 | 17. Upon request, the student will be able to list the extra-auditory effects of sound.

1 | 18. Given a list of statements, the student will be able to select the statement that best describes the term, "presbycusis."

Performance Objectives		
Lesson	The Ear and the Effects of Sound	Module 4 Unit 2
1	19. Upon request, the student will be able to list the type of noise that is most annoying to people (e.g., high pitch is more annoying than low pitch).	
1	20. Given a list of statements, the student will be able to select the statement that best describes or defines loudness.	
1	21. Given a list of statements, the student will be able to select the statement that best describes the dBA scale.	
1	22. Given a list of statements, the student will be able to select the statements that best describe or define a. sones b. phons	

The Ear and the Effects of Sound	Module 4

In order to present the unit material to the students, the instructor will be responsible for the following:

Lesson 1--The Ear and the Effects of Sound

Classroom Presentation

Conduct a lecture concerning the anatomy and physiology of the human ear and the effects of sound on the ear. Of primary importance is the transmission of sound in the inner ear and the function of the hair cells. When discussing the effects of sound, of primary importance is

a. the factors affecting the ear
b. what is known about sound and its effects
c. the difference between hearing loss and threshold shifts
d. criteria of damaging sound

Time Allotted

1 Hour

Demonstration

No demonstrations are required

Supervised Practice

No supervised practice is required.

Unit Activities--Student	
The Ear and the Effects of Sound	Module 4 Unit 2

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--The Ear and the Effects of Sound

Classroom Activity

Attend a one-hour lecture on the anatomy and physiology of the human ear and the effects of sound on the ear.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 4 Chapter 4
the Industrial Environment--its Evaluation and Control		Ch. 24, 25 pp. 325-331
Optional Industrial Noise Manual		Ch. 8, 9
PROBLEMS		
Industrial Hygiene Engineering and Control	Section 4 Chapter 3	Section 4 Chapter 3

Facilities, Equipment, and Materials	
The Ear and the Effects of Sound	Module 4 Unit 2

Facilities

Lecture--Normal Classroom

Equipment and Materials

Educational

Chalk
Chalkboard
Erasers
Screen
35 mm Slide Projector with Remote Control

Health and Safety

None required

Visuals

Slide Series--Industrial Hygiene Engineering and Control
Module 4, Unit 2

References Used in Class

Industrial Hygiene Engineering and Control
the Industrial Environment--its Evaluation and Control

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
I. Introduction A. The Ear 1. External ear. 2. Middle ear. 3. Inner ear. 4. Discussion of change of energy to electrical impulse and transmission to the brain. B. The Effects of Sound 1. Sensitivity of hearing. 2. Threshold of hearing. 3. Hearing loss. 4. Types of hearing loss. 5. Threshold shifts. 6. Effects of excessive noise on the ear. C. Established Criteria of Noise Level D. Loudness/Concept of II. The Human Ear A. General Function 1. Transmission of sound energy in the environment to the brain where it is perceived and interpreted. 2. To understand the effects of sound energy on the ear, it is important to understand structure of the ear. 3. Process of hearing complex and involves three stages. a. changing wave motion to mechanical vibration	The purpose of the lesson is to acquaint the student with the ear and how it works. From this information, the student will be better able to understand how sound affects the ear.

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
b. changing mechanical vibration to wave motion within a liquid c. changing wave motion in liquid to electrical (or chemical) nerve impulses	
B. How Sound Reaches the Ear	
1. By air conduction--a wave motion traveling through air.	
2. By bone conduction--by vibration of the body.	At this point, have students tap their jaws. The sound perceived is not coming primarily through the ear but is being transmitted through bone (the skull).
3. Conduction through the round window. a. round window is special structure in the ear; will be discussed later	
C. Air Conduction of Sound and the Ear	Slide 4.2.1.1.--The Ear
1. Ear divided into three parts. a. outer ear b. middle ear c. inner ear	
2. Outer ear or external ear. a. called pinna b. consists of (1) auricle (2) external auditory canal (about 1 inch long)	
c. auricle	Locate on slide
(1) purely decorative or ornamental -does not concentrate sound pressure -does not stop foreign bodies from entering the ear	

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
d. external auditory canal	Locate on slide
(1) skin portion of the canal secretes a wax that helps to maintain stability due to differences in temperature and humidity	
(2) main function is to -protect the ear drum -act to amplify sound intensity of the sound pressure wave	
3. Sound wave enters the outer ear, travels down the auditory canal and becomes amplified.	
a. then hits the ear drum	Locate on slide
(1) called tympanic membrane	
(2) separates external ear from middle ear	
(3) shape and size -cone shaped -½ inch diameter -composed of pearl-gray membrane	
b. function of ear drum	
(1) moves (vibrates) in response to sound pressure	
(2) protects middle ear	
(3) produces an acoustical dead space so that vibration in the middle ear will not exert pressure on the round window	Locate round window on slide

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
c. pressure fluctuations traveling down auditory canal hit ear drum and cause it to vibrate (move back and forth)	
(1) first stage--the sound wave in air is converted to mechanical vibration	
4. Middle ear.	Locate on slide
a. composed of	
(1) air space (2) bones	
-hammer (malleus) -anvil (incus) -stirrup (stapes)	Locate bones on slide
b. bones	
(1) extremely small (2) intimately attached and also intimately attached to ear drum and oval window	Locate oval window on slide
c. when ear drum vibrates, small bones move causing stapedial footplate to move in and out of oval window	Locate stapedial footplate on slide
(1) small bones--hammer, anvil, stirrup--are protected by muscles (2) muscles contract only when stimulated by loud noise (3) contraction puts more tension (i.e., causes rigidity) which decreases conduction of sound energy to oval window	

TOPIC	REMARKS
(4) however, muscles do not react fast enough to protect ear when there is a sudden explosive sound	
(5) exposure to steady state sound would cause a weakening of the muscles; i.e., cause them to adapt to the sound stimulus	
d. the eustachian or auditory tube connects the middle ear to the nasopharynx	
(1) function of the tube is to equalize pressure on both sides of the ear drum	
(2) when person swallows, air is forced into the middle ear and pressure is equalized	
5. Inner ear.	Locate on slide
a. called cochlea	
b. contains a liquid	
(1) when stapes are moved it causes a wave motion in the liquid	Optional Discussion (if time allows) One problem of the middle ear is the loss of energy from mechanical to wave motion in the liquid. This loss in energy is great. Only 0.1% of the airborne sound enters the liquid medium--99.9% is reflected away. To handle this decrease, the ear has special arrangements. a. Size differential between the relatively large ear drum and footplate of stapes causes an increase in intensity by about 23 dB.

Lesson Outline

The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
	b. the lever action of bones increases sound intensity by 25 dB. These arrangements cause in increase of 25.5 dB at the air-liquid interface.
c. composed of	
(1) complex system of ducts and sacs that house the end organs for hearing balance	
(2) is snail-shell shaped	Locate on slide
(a) locate the following on slide -cochlear nerves -ganglion -modiolus, bony structure, that the snail-shaped tubes surround	Slide 4.2.1.2.--Cross Section of Cochlea (Inner Ear)
(b) point out on slide -upper canal (scala vestibuli) that comes from oval window -lower canal (scala tympani) that goes to the round window -inner ear duct (cochlear duct)	Slide 4.2.1.3.--Transmission of Sound Through the Inner Ear
(c) cochlear duct contains	
-organ of hearing organ of corti (triangularly shaped)	Locate organ of hearing on slide

TOPIC	REMARKS
-basilar membrane narrow and stiffer, near oval window; widest at apex (top of snail shell) -hair cells-- arranged in definite pattern inner row about 3,500 cells; outer rows (3-5) about 12,000	Go back to Slide 4.2.1.2.
d. transmission of wave in inner ear; third stage of hearing (1) oval window and round window allow sound wave to travel through inner ear; inward movement of stapes in oval window causes round window to move inward into middle ear; if round window did not move, wave would not travel	
(2) oval window movement causes fluid to move in upper canal (scala vestibuli); vibration travels up scala vestibuli but also puts downward pressure on cochlear duct (3) movement causes hair cells to vibrate (bend to and fro) vibration is picked up by nerves and electrical impulse is sent to the brain	Go back to Slide 4.2.1.3.

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
(4) movement causes deflection in basilar membrane, disturbing fluid, causing round window to move outward	
(5) more about movement of hair cells	
-don't know if it is electrical or chemical action that activates nerve endings -hair cells near oval window transmit high frequency sound -hair cells near apex respond to low frequency sound -characteristic is interesting and has something to do with size of basilar membrane	Point out membrane on slide again.
Note: High frequency sound travels a shorter distance in the inner ear, while low frequency sound travels farther.	At this point, review how sound is transmitted through the inner ear. The instructor may want a student to repeat how this is accomplished.
e. final note about the hair cells	
-continuous sound may damage the hair cells -once the hair cells are damaged, they do not regenerate	

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
III. Effects of Sound on the Human Ear	
A. Classification of Hearing Loss	Slide 4.2.1.4.--Types of Hearing Loss
1. Conductive hearing loss. a. any condition that interferes with the transmission of sound to cochlea or inner ear (1) nerve endings are not damaged (2) organ of hearing (organ of corti) is not damaged (3) causes (a) wax build-up (b) perforation of ear drum (c) blockage of eustachian tube (d) diseased bones, trauma to bones (e) fluid in middle ear	
2. Sensorineural hearing loss. a. usually irreversible b. damage to organ of hearing or nerve endings c. causes (1) exposure to excessive noise, causing degeneration of hair cells or damage to nerve endings (2) old age (3) viruses (e.g., mumps) (4) drug toxicity (e.g., streptomycin)	
3. Mixed hearing loss. a. conductive b. sensorineural	

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
4. Central hearing loss. a. inability of person to interpret what he hears b. implies damage to the brain 5. Psychogenic hearing loss. a. nonorganic cause--malingering or hysteria B. Threshold of Hearing and Hearing Loss 1. Recall from first unit that a. frequency and b. intensity or sound pressure were both needed to describe sound.	
2. <u>Sensitivity of Hearing</u> a. frequency (1) 16 Hz to 20,000 Hz for young, healthy ear (2) from 16 Hz to about 1,000 Hz, it takes progressively less pressure or intensity for a tone to be audible (3) from 1,000 Hz to 4,000 Hz the ear's response is fairly constant (4) from 4,000 Hz to higher frequency, trend is reversed and greater intensity or intensity is required to make tone audible	Slide 4.2.1.5.--Auditory Sensitivity Curve

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
b. intensity (1) 120 dB--listener will report a sound to be uncomfortable (2) 130 dB--he will report a tickle (3) 140 dB--actual pain will result (4) these tolerances do not vary with frequencies although higher frequencies are reported to be more uncomfortable than lower frequencies of the same intensity	
3. Threshold of Hearing a. at a given frequency, subjects (young, healthy adults) are asked when the sound becomes audible while intensity or pressure is manipulated	
b. as height and weight, threshold of hearing is not the same for everybody; distributed over a wide range of intensities or pressures (1) almost a normal distribution--most at middle, few at the extremes (2) spread of about 25 dB (3) Threshold is the modal response--not the lowest sound intensity or pressure (4) hearing loss is measured in decibels with the modal response being the reference	Slide 4.1.2.6.--Threshold of Hearing

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
c. "hearing loss" (1) difference between this normal response and an individual's response (2) negative hearing loss --individual may be below the mode of the distribution (3) if a person has a 40 dB hearing loss at 4,000 Hz, it means that for the individual to perceive a tone, the intensity of that tone must be raised 40 dB above the standard	
d. "threshold shift" (1) should be differentiated from hearing loss since hearing loss has a particular meaning (2) refers to the difference in two audiometric readings of the same person	
(3) for example, a person with a 30 dB hearing loss as a result of 20 dB threshold shift means the original 10 dB hearing loss may be quite normal	Slide 4.2.1.7.--Audiogram
e. discuss audiogram and its interpretation	
C. Hearing Loss with Age	Slide 4.2.1.8.--Hearing Loss with Age
1. Auditory sensitivity increasingly diminishes from 1,000 to 6,000 Hz.	

TOPIC	REMARKS
2. Very little loss until late in life at lower frequencies, 1,000-2,000 Hz. 3. At higher frequencies, 4,000-6,000 Hz show relatively early effects of age	
D. Effects of Excessive Noise Exposure 1. Review how sound travels through the ear. 2. Prolonged exposure destroys hair cells that cannot be regenerated. a. typically, destruction starts at the first turn in the cochlea (inner ear) (1) about 4,000 Hz (2) destruction spreads from here to both upper and lower frequencies	
3. Temporary Threshold Shifts (TTS) a. difference in one's hearing sensitivity before and after exposure to noise b. called "temporary" because there is a return to the pre-exposure hearing level after several hours c. usually the first stage of noise-induced hearing loss d. threshold level becomes increased usually at 4,000 Hz	Slide 4.2.1.0.--TTS and PTS and the Theory of Hearing Loss

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
4. Permanent Threshold Shifts (PTS) a. under constant exposure to noise, 4,000 Hz reaches maximum level and then levels out in about 10 years b. below 3,000 Hz there is no leveling off and damage keeps increasing	
5. Extra-auditory effects. a. exposure to high sound levels for prolonged time or periods has been discussed primarily b. but noise has effects on other body systems (amount of permanent damage to other body systems is uncertain)	
c. other body systems affected (1) blood vessels constrict and blood pressure increases (2) pupils dilate (3) voluntary and involuntary muscles become tense (4) adrenal glands stimulated and production of catecholamine increases -possible cause of heart disease or other circulatory disease (5) nausea (6) headaches (7) disturbances in balance Note: Same effects as general stress.	Slide 4.2.1.10.--Effects on Other Parts of the Body

TOPIC	REMARKS
d. noise can also interfere with communication; thus causing accidents e. noise can be annoying and interfere with productivity	
E. Annoyance of Noise	
1. Interferes with speech, but may not cause permanent damage.	Slide 4.2.1.11.--Maximum Permissible Speech Interference Level
a. determined by averaging the sound pressure level at 600-1200, 1200-2400, 2400-4800 on old bands; for preferred bands 500, 1000, and 2000 Hz b. procedure is to rate the ability of noise to interfere with communication between two people in an environment free of nearby reflecting surfaces that might strengthen talkers' voices c. tables available that show when reliable communication between two males at specific distances is possible	
2. Other characteristics.	
a. loudness (subjective judgment)--louder noises are considered more annoying b. pitch--high pitch, 1500 Hz, is more annoying than low pitch at equal loudness c. noise--varying frequency and intensity is more annoying than continuous unchanging sound	

Lesson Outline

The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
d. noise that appears to be moving is more annoying	
IV. Loudness	
A. Loudness Level	Slide 4.2.1.12.--Equal Loudness Contours
1. How determined.	
a. psycho-acoustic judgment b. observers determine when two sounds are equal, one sound is usually a pure tone at 1,000 Hz c. discuss interpretation of the curve d. introduce phons	
2. Loudness number.	
a. arithmetically related to loudness level b. numerical designation that for a given noise is proportional to the subjective magnitude of the loudness of that sound judged by a normal listener c. sones--loudness number of a 1,000 Hz tone with a sound pressure level of 40 dB; loudness level of 40 phons is taken as one sone. Tone that is twice as loud has a loudness number of 2 sones	
3. Changing sound pressure levels into loudness level and loudness number	
a. locate loudness index from table	Slide 4.2.1.13.--Loudness Index Tables

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
b. use following expression to convert into sones Loudness (sones) = $0.3\Sigma S_i + 0.7S_{max}$ where S_i denotes the loudness index and S_{max} denotes the largest loudness index c. convert total loudness in sones into phons using relationship shown on right hand side of slide	

Problem

At the following frequency bands, the following sound pressure levels were recorded:

Band	Sound Pressure Level
31.5	75
63	72
125	69
250	66
500	63
1000	60
2000	56
4000	54
8000	54

From table, the loudness indices are

3.0
3.7
4.7
4.9
4.9
4.9
4.6
4.9
5.8

Lesson Outline

The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
	Loudness in sones is then Loudness (sones) = $0.3\Sigma S_i + 0.7S_{max}$ $= 0.3(41.4) + 0.7(5.9)$ $= 12.42 + 4.13$ $= 16.55$ sones From right hand side of table, 16.55 sones equals about 80.5 phons. From the data above, also compute the speech interference level. Speech Interference Level = $\frac{63 + 60 + 56}{3}$ $= 59.67$ dB
B. Other Indices of Loudness 1. Perceived Noise Level 2. Perceived Level--Steven's Mark VII 3. Noise Curves 4. Noise and Number Index 5. Noise Pollution Level	Each has a special application.
V. Sound (Noise) Level dBA A. dBA	
1. Overall sound pressure level from sound level meter A weighted. 2. Can be calculated from sound pressure readings or measurements.	Slide 4.2.1.14.--Correction for dBA

TOPIC	REMARKS
	<u>Problem</u> Calculate overall dBA from the following data:

Band	SPL	Correction	dBA
31.5	85	-39.2	45.8
63	88	-26.2	61.8
125	94	-16.1	77.9
250	94	- 8.6	85.4
500	95	- 3.2	91.8
1000	100	0	100.0
2000	97	+ 1.2	98.2
4000	90	+ 1.0	91.0
8000	88	- 1.1	86.9

TOPIC	REMARKS
	Add last column using the procedure for adding logs. Overall dBA approximately 103 dBA.
3. A, B, C networks on sound level meter. a. A network approximates ear's response for low level sounds (55 dB) b. B network approximates ear's response for levels between 55 dB to 85 dB c. C network approximates above 85 dB	Slide 4.2.1.15.--Frequency Characteristics of Sound Level Meter
VI. Establishing Criteria	
A. Factors Known to Affect Hearing Loss Due to Noise	Slide 4.2.1.16.--Factors Influencing Noise-Induced Hearing Loss
1. <u>Overall decibel level</u>--If exposure does not cause auditory fatigue, it is considered not harmful. 2. <u>Time distribution</u>. a. intermittent noise is less harmful than constant noise	Ask students to try to think of possible factors.

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
b. as total work duration increases so does the chance of hearing loss 3. <u>Susceptibility of the worker</u>. a. not all workers are affected the same, some are more susceptible than others B. Problems in Establishing a Criteria - 1. Definition of terms that must be considered. a. damage--risk (1) what is damage -damage that speech or pure tone cannot be heard; if speech, what kind of speech -damage so that a pure tone at a high or low frequency or the complete audible spectrum cannot be heard -what is meant by risk? risk to whom? risk to how many? 2. What about susceptibility of certain individuals? 3. What about the effects of age? How are the effects separated? 4. Most of the answers to the above questions are arbitrary. Establishing a criterion is not an easy job.	

Lesson Outline	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

TOPIC	REMARKS
C. Review Current Criteria	Slide 4.2.1.17.--Current Criteria
1. Be sure to explain dBA Scale.	
a. approximation to response of ear and correlation with hearing loss potential	
b. dBB Scale	Slide 4.2.1.18.--Weighted Scales
c. dBC Scale	Slide 4.2.1.19.--Correction for dBA Scale
d. how different from sound pressure dB	
VII. Summary	
A. Physiology of Ear	
1. Outer ear. 2. Middle ear. 3. Inner ear.	
a. hair cells	
B. Effects of Sound	
1. TTS. 2. PTS. 3. Hearing loss. 4. Extra-auditory effects. 5. Annoyance factor.	
C. Loudness	
1. Phon. 2. Sones.	
D. Things Not Discussed in This Unit	The student should be encouraged to read more about these topics.
1. Audiometric techniques. 2. Audiometric programs.	See Industrial Noise Manual, Chapters 8 and 9.

Practice Exercises

The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

1. Given the following information, compute the loudness, loudness level, dBA level, and preferred speech interference level.

Center Frequency Hz	Sound Pressure Level dB
31.5	54
63	58
125	69
250	75
500	77
1000	79
2000	85
4000	86
8000	87

2. Suppose the following sound pressure levels were at the following center frequencies:

Octave Band Center Frequencies Hz	Sound Pressure Levels
63	82
125	85
250	87
500	86
1000	93
2000	88
4000	80
8000	81

Compute the dBA level and compare it to the standard (assume an 8-hour exposure). If the criteria are not met, what noise reduction is required?

3. In problem #2, if reduction in the sound pressure levels at 500, 1000, and 2000 Hz were 5, 7, and 8 dBA respectively, would the criteria of 90 dBA for an 8-hour exposure be reached?

Practice Exercises--Solutions	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

1. Starting at 31.5, the loudness indexes (S) from the table are 0.49, 1.33, 4.7, 8.3, 11.1, 15.3, 28.5, 38.0, and 52.0, such that

$$\text{Loudness}_{(\text{sones})} = 0.3\sum_{i=1}^{9} S_i + 0.7S_{max}$$

$$= 0.3(159.72) + 0.7(52.0)$$

$$= 47.92 + 36.40$$

$$= 84.32 \text{ sones}$$

Using a table to convert sones to phons, it is seen that the loudness level is approximately 104 phons.

The speech interference level (three octave band) is equal to the arithmetic average of the sound pressure level at center frequencies 500, 1000, 2000 Hz, or

$$\text{Speech Interference Level} = \frac{77 + 79 + 85}{3}$$

$$= 80.33 \text{ dB}$$

The level that would be recorded on a sound level meter would be computed as

Center Frequency Hz	Sound Pressure Level dB	Correction	dBA
31.5	54	-39.2	14.8
63	58	-26.2	31.8
125	69	-16.1	52.9
250	75	- 8.6	66.4
500	77	- 3.2	73.8
1000	79	0.0	79.0
2000	85	1.2	86.2
4000	86	1.0	87.0
8000	87	- 1.1	85.9

Combining the dBA levels in the last column results in (31.8 + 0.1 = 31.9), (52.9 + 0 = 52.9), (66.4 + 0.2 = 66.6), (73.8 + 0.8 = 74.6), (79.0 + 1.3 = 80.3), (85.9 + 1.1 = 87.00), (87.0 + 2.6 = 89.6), (89.6 + 1.9 = 91.5), or 91.5 dBA.

Practice Exercises--Solutions	
The Ear and the Effects of Sound	Module 4 Unit 2 Lesson 1

2. The dBA level is computed as follows

Center Frequency	Sound Pressure Level	Correction	dBA
63	82	-26.2	55.8
125	84	-16.1	67.9
250	87	- 8.6	78.4
500	86	- 3.2	82.8
1000	93	0.0	93.0
2000	88	+ 1.2	89.2
4000	80	+ 1.0	81.0
8000	81	- 1.1	79.9

Adding the last column results in a dBA of 95.2, which is 5.2 dBA above the criteria. Thus, a noise reduction of 5.2 dBA would be required.

3.

Center Frequency	Sound Pressure Level	Correction	dBA
63	82	-26.2	55.8
125	84	-16.1	67.9
250	87	- 8.6	78.4
500	85-5	- 3.2	77.8
1000	93-7	0.0	86.0
2000	88-8	+ 1.2	81.2
4000	80	1.0	80.0
8000	81	- 1.1	79.9

The total dBA would be 89.4 which is below the desired criteria of 90 dBA.

Unit 3

Vibration

Performance Objectives		
Lesson	Vibration	Module 4 Unit 3

Lesson	Objective
1	1. Given a list of at least four statements, the student will be able to select the statements that best describe how vibration affects the body.
1	2. Given a series of lists, each containing no less than four definitions, the student will be able to select from the list the best definition of a. Whole body vibration b. Segmental vibration
1	3. Given a list of at least four statements, the student will be able to select the statement that best describes resonance.
1	4. Given a list of at least four statements, the student will be able to select the statement that best describes natural frequency.
1	5. Upon request, the student will be able to list the effects of vibration on the human body.
1	6. Given a list of at least four statements, the student will be able to select the statement that best describes Raynaud's Syndrome.
1	7. Given a list of at least four statements, the student will be able to select the statements that are true about Raynaud's Syndrome.
1	8. Given a list of at least four definitions, the student will be able to select the statement that best describes vibration.
1	9. Upon request, the student will be able to list from recall the three basic characteristics of vibration.
1	10. Given a list of at least four expressions, the student will be able to select the expression that indicates the proper relationship between the three basic characteristics of vibration.
1	11. Given a list of at least four statements, the student will be able to select the statement that best describes the difference between period and random vibration.
1	12. Upon request, the student will be able to list from recall in writing the major causes of vibration of a rotating machine.
1	13. Given a series of lists, each containing at least four statements, the student will be able to select the statements that best describe the purpose of a. vibration pick-up b. preamplifier c. analyzer d. vibration recorders

Performance Objectives		
Lesson	Vibration	Module 4 Unit 3

Lesson	Objective
1	14. Upon request, the student will be able to list in writing from recall the sources of possible errors when taking vibration measurements.
1	15. Given a list of at least four statements, the student will be able to select the statements that describe the six possible modes of vibration.
1	16. Given a list of at least four statements, the student will be able to select the statements that best describe methods of reducing mechanical drive for a. rotational machines b. impact machines c. sliding machines
1	17. Upon request, the student will be able to list in writing from recall the three basic methods of controlling vibration.
1	18. Given a list of at least four statements, the student will be able to select the statements that best describe what one needs to know before beginning to solve a problem using isolators.
1	19. Given a list of at least four statements, the student will be able to select those statements that describe what might affect the natural frequency of a machine.
1	20. Given a list of at least four statements, the student will be able to select the statement that best describes what happens to natural frequency when static deflection either increases or decreases.
1	21. Given a list of at least four statements, the student will be able to select the statement that best describes transmissibility.
1	22. Given the driving force in pounds and the desired driving force in pounds, the student will be able to compute the transmissibility.
1	23. Given a set of transmissibility curves, a desired noise reduction (either in decibels or transmissibility), a forcing frequency, and a damping factor, the student will be able to compute the natural frequency of the isolator and the static deflection required of the isolator.
1	24. Given a set of transmissibility curves, the student will be able to determine, upon request, a. what the ratio of f/fn must be before there is a noise reduction. b. what transmissibility must be before there is an advantage in using an isolation system.

Performance Objectives		
Lesson	Vibration	Module 4 Unit 3
1	25. Given a list of types of isolators and a list of conditions, the student will be able to match the best isolator to use in the given condition.	
1	26. Given a list of at least four statements, the student will be able to select the statement that best describes the methods available for reducing the response of the vibrating surface.	
1	27. Given a list of at least four statements, the student will be able to select the statement that best describes how damping works to control vibration.	

Unit Activities--Instructor	
Vibration	Module 4 Unit 3

In order to present the unit material to the students, the instructor will be responsible for the following:

Lesson 1--Vibration

Classroom Presentation

Conduct a lecture concerning the effects of vibration on man, including whole body and segmental vibration, the characteristics of vibration (displacement, acceleration, velocity), methods for measuring vibration, and methods for controlling vibration. When methods for controlling vibration discussed, included are procedures for selecting vibration isolators.

Time Allotted

1 Hour

Demonstrations

No demonstrations are required

Supervised Practice

No supervised practice is required.

Unit Activities--Student

Vibration	Module 4 Unit 3

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--Vibration

Classroom Activity

Attend a one-hour lecture concerning the effects of vibration on man, the characteristics of vibration, and methods for measuring and controlling vibration.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 4 Chapter 5
the Industrial Environment--its Evaluation and Control		Ch. 26, 27 pp. 538-553
The Industrial Noise Manual		Ch. 5, 11 pp. 77-86
PROBLEMS		
Practice Exercises	Section 4 Chapter 4	Section 4 Chapter 4

Facilities, Equipment, and Material	
Vibration	Module 4 Unit 3

Facilities

Lecture and/or discussion--Normal classroom

Equipment and Material

Educational

Chalkboard
Chalk
Eraser
35 mm Slide projector with remote control
Screen
Tuning forks (at least 2--same pure tone)
Unbalanced motor (small)

Health and Safety

Vibration isolators
Vibration pick-up
Preamplifier
Analyzer
Recorder

Visuals

Slide Series--Industrial Hygiene Engineering and Control, Module 4, Unit 3

References Used in Class

Industrial Hygiene Engineering and Control
the Industrial Environment--its Evaluation and Control
The Industrial Noise Manual

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
	The purpose of this lesson is to have students understand the effects of vibration, to know how to measure vibration, and to understand control methods. A large part of the lesson is devoted to the procedure necessary to select a vibration isolator.
I. Introduction A. Effects of Vibration 1. Whole body vibration. 2. Setmental vibration. a. Raynaud's Syndrome B. Characteristics of Vibration 1. What is vibration. 2. How can vibration be described. 3. Types of vibration. C. How to Measure Vibration 1. Instruments and equipment. 2. Field layout. D. How to Control Vibration 1. Reduce driving force. 2. Isolation (how to select an isolator). 3. Reducing response of radiating surface. II. Effects of Vibration on Man A. Noise B. Different effect, effect of the vibration, or movement itself 1. Not much is known about these effects on man. None has been thoroughly researched (most studies have been done in European countries).	

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
C. Type of Vibration Effect 1. "Whole body" vibration. a. whole body is subjected to mechanical vibration (e.g., tractor seat) 2. Segmental vibration. a. vibration to only one part of the body (e.g., using hand tools); rest of the body firmly supported	Slide 4.3.1.1.--Whole Body and Segmental Vibration
D. The Human Body 1. Can be considered as a mechanical system. 2. The body and its parts have natural frequency. a. the concept of resonance and natural frequency (1) any object when struck will vibrate at its own frequency (2) frequency depends upon the elasticity and shape of object	Slide 4.3.1.2.--Human Body as a Mechanical System
(3) resonance occurs when successive impulses are applied to a vibrating object in time with its natural frequency	Illustration of Resonance 1. Either perform or describe situation to students. 2. Use matching tuning forks; set one in motion--the other will be set in motion by the first. 3. Why? Explain. The areas of compression give the prong of the fork a tiny push. Since these pushes correspond to natural frequency, they will successively increase the amplitude of vibration.

TOPIC	REMARKS
(4) when an elastic object is struck with a sound wave of the same natural frequency, the wave will set the object into resonance; sometimes the amplitude that results can be dangerous.	
-1940, Tacoma Narrows Bridge was destroyed by wind-generated resonance	
3. The body and its parts have a natural frequency and can be sent into resonance.	
a. whole body resonance occurs at 3-6 Hz and 10-19 Hz.	
b. resonance of subsystems as a result of whole body vibration	
(1) head and shoulders--20-30 Hz range	
(2) eyeballs--about 60-90 Hz	
(3) lower jaw and skull--100-200 Hz	
4. Effects of whole body vibration.	Slide 4.3.1.3.--Effects of Whole Body Vibration
a. not much is known	
b. what is known	
(1) physiological changes	
-increased consumption of oxygen, pulmonary ventilation and cardiac output	
-inhibition of tendon reflexes	

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
-impairment of ability to regulate posture -alteration in the electrical activity of the brain -affects visual acuity and ability to perform different types of motor activity	
5. Effects of segmental vibration (using hand tools); kind of disorders. a. Raynaud's Phenomenon (dead finger) (discussed in more detail later) b. neuritis and degenerative alterations, particularly in the ulnar and axillar nerves (1) loss of sense of touch (2) loss of sensitivity to heat (3) even paralysis c. decalcification of bones d. muscle atrophy, tengsynovitis	Slide 4.3.1.4.--Effects of Vibration II
6. Raynaud's Syndrome a. about 1/2 of workers exposed to segmental vibration will experience this b. sometimes called (1) dead finger (2) white finter c. circulation becomes impaired and when exposed to cold, fingers become white and void of sensation	Slide 4.3.1.5.--Raynaud's Syndrome

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
e. syndrome appears to be widespread f. really no standards are available--refer student to the following for more information: -the Industrial Environment--its Evaluation and Control, pp. 336-338	Slide 4.3.1.6.--Frequency of Syndrome
III. Characteristics of Vibration A. Characteristics of Vibration 1. Mechanical vibration is an oscillary motion of a system about an equilibrium position produced by a disturbing force. a. motion can be simple harmonic motion or complex motion b. motion can be (1) flexual (2) torsinal (3) compressional c. system can be (1) gaseous (2) liquid (3) solid Note: When the system or medium is air and the motion involves vibration of air particles in the frequency range of 20 to 20,000 Hz, sound is produced.	
B. Visualization of Vibration Wave 1. Pendulum is an example of motion about an equilibrium position.	Slide 4.3.1.7.--Pendulum Wave

Lesson Outline

Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
a. recall from basic physics that the time of swing is $T = 2\pi L/g$ where T = period L = length of pendulum g = acceleration of a free-falling body	
2. Sine wave (period vibration) a. T = time period b. amplitude (or displacement) (maximum displacement of the pendulum) c. crest (highest point) d. trough (lowest point) e. wavelength--distance between crests f. frequency--number of back and forth swings per second	Slide 4.1.3.8.--Sine Wave
C. The motion of any particle can be characterized at any time by	Ask students to suggest characteristics.
1. Displacement from the equilibrium position 2. Velocity--or rate of change of displacement. 3. Acceleration--rate of change of velocity.	Review the following if necessary: $\text{Speed} = \frac{\text{Distance}}{\text{Time}}$ Velocity--refer to speed and direction; i.e., constant velocity => constant speed and constant direction Acceleration is a change in velocity due to a change in speed and/or direction. $a = \frac{\text{change velocity}}{\text{time}}$ or $a = \frac{\text{force}}{\text{mass}}$ to produce change over time

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1
TOPIC	**REMARKS**
D. Relationship among characteristics of sinusoidal vibration $a = -2\pi fv = -(2\pi f)^2x$ where a = acceleration or rate of change of velocity v = velocity or rate of change of displacement x = displacement from equilibrium position f = frequency 1. These three parameters may also be discribed by the root mean square average of their instantaneous values in the same way as sound pressure. 2. The above formula is only appropriate for periodic sound or pure harmonic periodic vibration. 3. Most vibration motion in industry is not of this type; however, it is periodic. a. in these cases, a Fourier analysis is used b. "Any periodic curve, no matter how complex, may be looked upon as a combination of a number of pure sinusoidal curves with harmonically related frequencies" where one cannot plot acceleration against frequency. c. what might produce a periodic vibration that is complex	Slide 4.3.1.9.--Mathematical Relationship Slide 4.3.1.10.--Periodic Vibration

TOPIC	REMARKS
(1) unbalanced, misaligned, loose, or eccentric parts of rotating machinery (e.g., bad gears, bent shafts) (2) also produced hydrodraulically and aerodynamically In either case, the frequency spectrum that occurs is related to the rotational speed (or some multiple of it)	
4. Random vibration.	Slide 4.3.1.11.--Nonperiodic Vibration
a. defined as motion in which the vibrating particles undergo irregular motion cycles that never repeat themselves exactly (nonperiodic vibration) b. theoretical and mechanical models are available to describe this type of vibration; but they are beyond the scope of this course c. sources of nonperiodic vibration (1) sliding or rolling parts (2) turbulent fluid and jet discharge The resulting frequency spectrum is determined by the interaction of the properties of the system with the disturbing force and is not necessarily related to the rotational speed.	

TOPIC	REMARKS
5. Discuss the components of vibration. a. vibrating force b. vibrating surface	
6. Using vibration data requires considerable judgment and experience.	Stress the need to call in a consultant or an expert for complex vibration problems.
a. relationship between the vibration force and vibrating surface is usually complex (1) with a given disturbing force, the vibration response will be far greater at the resonant frequency than the non-resonant frequency (2) in addition, if the frequency of a periodic disturbing force is close to the resonant frequency, the observed vibration maximum may be shifted to the resonant frequency and mask or confuse the identification of that force	
b. there are certain conditions when acceleration data, displacement data, or velocity are more important that other data	
(1) as a rule, displacement data are usually used (2) but in some cases, velocity data are more important (3) in other cases, acceleration data are more important	Explain when each should be used. Use loud-speaker example given in textbook.

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
IV. Measurement of Vibration	Slide 4.3.1.12.--Measurement of Vibration
A. Variety of Methods Available Usually	
1. Vibration pick-up to transform mechanical motion to an electrical signal. 2. Amplifier--to enlarge signal. 3. Analyzer to measure the specific frequency range. 4. A metering device to display the output of the analyzer.	
B. Vibration Pick-Up	Slide 4.3.1.13.--Accelerometer
1. Can measure	Or actually display the equipment.
a. displacement b. velocity c. acceleration	
2. Accelerometer--vibration pick-up to measure acceleration.	
a. most common type is prezoelectric type b. discuss how it works	Slide 4.3.1.14.--Prezoelectric Accelerometer
-discs produce a wattage on their surfaces due to mechanical strain on asymetric crystals that make up disc -the strain is a result of the mass atop the discs -the voltage output is proportional to the acceleration	
c. upper limit of the accelerometer's frequency range is determined by the resonant frequency of the mass and stiffness of whole acceleration d. lower limit determined by cable length	

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1
TOPIC	**REMARKS**
C. Preamplifier 1. Purpose. a. to amplify weak output signal b. to transfer high output impedence of the accelerometer to lower acceptable level 2. Types. a. wattage b. charge c. discuss the difference (1) difference is performance characteristics	Slide 4.3.1.15.--Preamplifier Or an actual display of the equipment.
D. Analyzers 1. Purpose. a. to determine the signal properties being measured 2. Types. a. simplest is a linear amplifier and a detection measuring device to detect (1) peak (2) RMS, or (3) average value of acceleration, velocity or displacement b. Note: The signal reaching the detecting device may be different from the signal input due to possible distortions during linear attenuation c. frequency analyzers (1) constant band width -used for periodic vibration	Slide 4.3.1.16.--Analyzers Or an actual display of the equipment.

TOPIC	REMARKS
(2) proportional band width -constant percentage band width -usually used if the signal is not quite stable	
E. Vibration Recorders (Metering Devices) 1. Purpose--to display analyzer output. 2. Types. a. strip chart b. vibration meter c. opcilloscope	Slide 4.3.1.17.--Metering Devices Or an actual display of the equipment.
F. Field Measurement 1. Typical arrangement (see slide). 2. Sources of error. a. incorrect mounting b. incorrect calibration c. connecting cable noise d. thermal effects e. electromagnetic effects	Slide 4.3.1.18.--Field Arrangements Slide 4.3.1.19.--Common Sources of Error
3. Mounting. a. location is important to detect disturbing force and identifying surface that might contribute to airborne sound b. try to reduct the loading effects of the transducer or pickup; this invalidates the measurements (1) $AR = AS\left(\frac{MS}{MS + MA}\right)$ where AR = response of structure with accelerometer AS = response of structure without accelerometer	

Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS

MS = weight of structure member to which accelerometer is attached
MA = weight of the accelerometer

c. mounting methods

(1) hand-held--however, this may change the vibration characteristics of the light structure
(2) steel stud mount
(3) permanent magnet
(4) wax
(5) soft glue

4. Connecting cable noise.

a. cable should be shielded
b. noise can be picked up by mechanical motion of cable or by a gound loop-induced electrical hum (should ground system at only one point)

5. Temperature.

a. usually does not, but can affect the measurement, particularly at low frequency and low amplitude

6. Any electrical activity (force) might distort the reading or be confused with mechanical activity. (These can be detected by shutting off power--these forces should disappear instantaneously.)

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
G. General Rules or Techniques for Interpreting Results	Slide 4.3.1.20.--General Techniques
1. Rotating machinery as an example.	
a. usually compare vertical and horizontal radial (perpendicular to shaft) to axial (parallel to shaft) reading	
b. results	
(1) unbalance usually produces radial vibration at the basic rotational speed	
(2) misalignment (does the same) but is also associated with axial vibration at 2 or 3 times the basic speed	
(3) looseness produces radial vibration at 2 times the basic rotational speed	
(4) bad bearings produce a high pitched noise unrelated to basic speed which usually varies in frequency and amplitude	
(5) gears, fans, impellers produce vibration at tooth or blade passing frequencies which equals the rotational speed times the number of passes per rotation	

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
V. Control Techniques A. Basic Techniques Include 1. Reducing the mechanical driving force or energy causing the vibration. 2. Isolating the disturbing force from the radiating surface. 3. Reducing the radiating surface area. Note: Optimum solution depends upon a clear understanding of the source of the disturbance, how the vibration is transmitted to the radiating surface, and how the radiating surface contributes to the problem. Measurement techniques should help to understand this.	Slide 4.3.1.21.--Control Techniques Before showing slide, ask the students to suggest control techniques. Summarize their results. Present a simple vibration problem and ask the students how they might control it; e.g., put an unbalanced machine on a large radiating surface. Ask the students how they might control the noise. When discussing the control methods in detail, refer to this example.
B. Review of the Techniques 1. Reducing mechanical driving force or disturbance (i.e., controlling at the source). a. types of forces (1) rotational (2) impact (3) sliding	
b. techniques to reduce (1) rotational -by balancing -by alignment -by reducing clearances -by replacing worn parts -by proper lubrication -by reducing speed large machine--running at a lower speed	Ask students to suggest techniques. Summarize their comments.

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
(2) impact forces -have smaller force over a larger period of time -use helical instead of spur -put fiber gears between metal gears -impact of parts falling in chutes can be reduced by cushion application	Slide 4.3.1.22.--Reduce Driving Force--Segmented Punch and Shear Cut
2. Isolating driving force from vibrating surface. a. installation of isolators (1) extremely difficult job--must know what you are doing, or you can make noise problem worse	Demonstration--Force Vibration 1. Set a vibratory object on any ordinary wood table (e.g., tuning fork or a rotational machine or a motor that is unbalanced). 2. Sound will become intensified because the table has a large surface area. 3. If the source were isolated from the table, the noise could be reduced. Show how you can make noise problem worse. 1. Have a vibrating machine and several types of isolators with different static deflections. 2. Change isolators so the noise becomes worse. The instructor should compute which would be worse before conducting the demonstration. And thus, point out that if you do not know what you are doing, you can make noise problem worse.

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
(2) designing an isolation system (a) must know system natural frequency First, recall for student that vibration can have six modes. linear modes are -horizontal x axis -vertical y axis -transverse horizontal t axis others are rotational modes -rocking back and forth around the center of gravity	
For linear modes, natural frequency can be computed as follows: $f_n = \frac{1}{2\pi}\sqrt{\frac{Kg}{W}}$ where f_n denotes natural frequency k denotes stiffness of isolator g denotes acceleration in gravity, 386 inches per second per second W denotes weight of system per mount An alternate method would be $f_n = 3.13 \times \sqrt{\frac{1}{St}}$ where f_n denotes natural frequency St denotes static deflection of the mount in inches	Slide 4.3.1.23.--Computing Natural Frequency (Linear Modes)

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1
TOPIC	REMARKS

For rotational modes

$$f_n = \frac{1}{2\pi}\left[\frac{Kr}{i}\right]$$

where

f_n = natural frequency
Kr = rotational stiffness of mount, inches-pounds per radian of angular displacement about a given axis
i = mass moment of inertia of supporting load above the given axis through the center of gravity, pound/square inch

(b) natural frequency can change if any of the following factors change

- -weight of system
- -stiffness of mount
- -moment of inertia
- -rotational motion of the mount

these will change the static deflection and therefore change the natural frequency

(c) second thing you need to know to design a good isolation system is the forcing frequency

-i.e., the frequency of the force that needs to be isolated

if many frequencies, use the lowest frequency

TOPIC	REMARKS
(d) transmissibility	
-definition--term used to express the efficiency of the isolation system--ratio of forces. For example if an unbalanced motor running at 1800 RPM was producing 100 pounds of centrifugal force and it was desired to limit the force to 2 pounds on the foundation, transmissibility would be 0.02 or	
$\frac{2}{100} = 0.02$	
-this can also be expressed in a decibel way	
Noise Reduction = 20 logT	Slide 4.3.1.24.--Transmissibility and Decibel Scale
$= 20 \log \frac{\text{Exciting Force}}{\text{Transmitted Force}}$	
(e) note from slide	
-in order for there to be a reduction in decibels, transmissibility must be less than 1.0	
(f) transmissibility curve	Slide 4.3.1.25.--Transmissibility Curve
$-\frac{\text{forcing frequency}}{\text{natural frequency}}$	
-transmissibility and decibels	
-damping factor, limits resonance of system but also reduces isolation	

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
-damping factors steel (0.005) composition material (0.05) elastomer (0.10) shock absorbers (0.05) -notes from the curves when $\frac{f}{f_n}$ = 1.0 and transmissibility ⇒ 1.0 -no isolation is attained; instead an amplification of the exciting force occurs and resonance happens -it is not until $\frac{f}{f_n}$ ⇒ 1.4 that any isolation is achieved -to achieve transmissibility of 0.1 (which means 90% reduction of isolation efficiency) $\frac{f}{f_n}$ must be 3.3	
(g) selecting isolators -determine lowest forcing frequency in machine to be isolated -establish permissible transmissibility or desired noise reduction	Slide 4.3.1.26.--Steps in Selecting Isolators

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
-determine required natural frequency f_n working backwards from chart -determine static deflection to obtain natural frequency -determine weight of each mounting point on machine -select required isolator from manufacturer's information	<u>Problem</u> 200 pound machine transmitting vibration at 40 Hz into a support structure with force of 100 pounds. It is desired to limit the force to 5 pounds using isolators; thus, transmissibility is 5/100 = 0.05. An isolator made of neoprene is desired which has a damping factor of 0.1. Compute the information necessary to select the isolator. Using transmissibility curve with damping factor of 0.1 and a transmissibility of 0.5, the ratio of forcing frequency to natural frequency is $\frac{f}{f_n} = 5.8$ Since the driving frequency is 40 Hz, then $f_n = \frac{40\ Hz}{5.8}$ $= 6.9\ Hz$ Thus, from the expression $f_n = 3.13 \times \sqrt{\frac{1}{St}}$ it can be seen that static deflection is equal to 0.21. Assuming equal distribution of the load on the foundation support, the stiffness required is $\frac{200}{4}\left(\frac{1}{0.21}\right) = 238$ pounds per inch. The isolator can now be selected from a catalog.

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
	Problem If the vibration of a 200 pound machine is causing the supporting structure to radiate a 60 dB noise and it is desired to reduce the noise to 34 dB (a drop of 26 dB), compute the static deflection and stiffness of the required isolator if it is required that the damping factor be 0.1 Using same curve 0.1 and a noise reduction of 26 dB, the ratio of frequency to rotational frequency is 5.8, and the same solution as above is indicated.
(h) types of vibration isolators -springs (air springs) -elastomers -felt -composition pads (i) general rules -springs (air springs) are used for low frequency, 30 Hz or below -elastomers, composition, and felt more effective at higher frequences (above 30 Hz) -metal springs are not affected by oil or other contaminants	
-in addition to isolating the machine, pipes should have flexible sections	Slide 4.3.1.27.--Vibration Machine and Flexible Pipe

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
3. Reducing response of vibrating surface.	Slide 4.3.1.28.--Reducing Response of Vibrating Surface
a. in case where isolation is impractical, may want to reduce response of vibrating surface; particularly true where vibrating force is equal to natural frequency of vibrating surface and resonance results	
b. methods of reducing (1) stiffening (2) increasing mass (3) damping	Ask the students what method they think might work. Summarize their comments.
Note: Anything that would change its natural frequency.	
c. stiffening (1) usually large, flat surface that will vibrate, adding stiffeners will reduce vibration (2) in addition to stiffening, changing shape may help. e.g., dishing or curving panels (3) change the size of radiating surface; make it smaller	
d. increasing mass (1) makes it resistant to movement; must watch resonant frequency, however	

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
e. damping (1) restrain noise by reducing contact with air--such as an absorbing material. Transfer vibration energy to heat energy (2) types of damping material -damping felt -elastomers -tars -maskit materials, etc. (3) optimizing damping treatment is usually complicated procedure and can be expensive; usually need an expert VI. Summary A. Effects of Vibration 1. Noise. 2. Effect of movement itself. 3. Type of vibration effect. a. whole body b. segmental 4. Not much is known. 5. Raynaud's Syndrome B. Resonance C. Characteristics of Vibration 1. Displacement. 2. Acceleration. 3. Velocity. D. Types of Vibration 1. Periodic. 2. Random.	

Lesson Outline	
Vibration	Module 4 Unit 3 Lesson 1

TOPIC	REMARKS
E. Measurement of Vibration 1. Instruments. 2. Field layout. F. Control Techniques 1. Reducing driving force. 2. Isolation. 3. Reducing response of vibrating surface.	

Practice Exercises	
Vibration	Module 4 Unit 3 Lesson 1

1. A 400-pound machine is transmitting a vibration to the floor at 100 Hz with a force of 200 pounds. It is decided to limit the force to 25 pounds by using isolators with a damping factor of 0.2. What static deflection of the isolator is required? Assuming equal distribution of the machine on 4 points, compute the stiffness required.

2. A 526 pound machine is causing the supporting structure to radiate 60 dB noise. It is desired to reduce the noise to 25 dB (a reduction of 60 dB - 25 dB = 35 dB) using an isolator with a damping factor of 0.05. The vibrating force is at 100 Hz. Compute the static deflection of the isolator as well as the stiffness required if it is assumed 4 points of load equally distributed.

1.

$$\text{Transmissibility} = \frac{25 \text{ pounds}}{200 \text{ pounds}}$$

$$= 0.125$$

From Figure 4.5.2 it can be seen that $f/f_n = 4.8$, thus

$f_n = 100/4.8 = 20.83$ Hz

And the static deflection is computed as

$$S_{st} = \left[\frac{3.13}{f_n}\right]^2$$

$$= \left[\frac{-3.13}{20.83 \text{ Hz}}\right]^2$$

$$= 0.023 \text{ inches}$$

Thus, assuming 4 points of equal load distribution, then the stiffness must be

100 lbs/0.023 inches = 4347.85 ibs/inch

2. From Figure 4.5.2,

$f/f_n = 9.00$

Thus

$$f_n = \frac{100 \text{ Hz}}{9.00}$$

$$= 11.11 \text{ Hz}$$

Thus

$$S_{st} = \left[\frac{3.13}{f_n}\right]^2$$

$$= \left[\frac{3.13}{11.11}\right]^2$$

$$= 0.079 \text{ inches}$$

Thus,

526/4 = 131.5 pounds per point, and the stiffness required is

$$\frac{131.5 \text{ lbs}}{0.079 \text{ in}} = 12.658 \text{ pounds/in}$$

Unit 4

Noise Control

Performance Objectives		
Lesson	Noise Control	Module 4 Unit 4

Lesson	Objective
1	1. Upon request and with no aids, the student will be able to list in writing the initial steps involved in noise control.
1	2. Upon request and with no aids, the student will be able to list where noise may be controlled and explain in writing in which locations noise should be controlled first and last.
1	3. Upon request and with no aids, the student will be able to list in writing what information should be contained in a noise specification sheet for the purchase of new equipment.
1	4. Given a list of choices, the student will be able to select which method of production or machine would be quieter than the other; for example, which of the following would be quieter: (a) mechanical forging or (b) drop forging.
1	5. Upon request and with no aids, the student will be able to list in writing the basic methods of controlling noise at the source.
1	6. Given a list of steps involved in selecting a muffler, the student will be able to properly order the steps.
1	7. Given a list of at least four descriptions, the student will be able to select the best description of a. dissipative mufflers b. nondissipative mufflers
1	8. Upon request and with no aids, the student will be able to explain in writing when a total enclosure should be used. To be considered correct, the response must involve a. when a build-up of heat is possible. (Note: Enclosure can be used if properly ventilated.) b. when access to the machine is constantly required (unless doors or windows are used which provide no noise leaks).
1	9. Given a list of at least four outcomes, the student will be able to select the outcome associated with putting an absorption material on the inside of an enclosure.
1	10. Given a list of at least four statements, the student will be able to select the statement that best describes the rule of thumb on selecting an absorption material for the source side of an enclosure.
1	11. Given a list of at least four statements, the student will be able to select the statement that best describes when NR = TL when dealing with an enclosure.
1	12. Upon request and with no aids, the student will be able to list in writing the methods for controlling noise along its path.
1	13. Given a list of statements, the student will be able to select the statement that best describes either choke or nonchoke valves.

Performance Objectives		
Lesson	Noise Control	Module 4
2	14. Given a list of at least four statements, the student will be able to select the statement that best describes a practical way for estimating the amount of noise reduction achieved by a partial enclosure.	
2	15. Given a list of decibels, the student will be able to select the maximum number of decibels of noise reduction that can be achieved by a partial enclosure.	
2	16. Given a list of statements, the student will be able to select the statement that best describes the frequency range in which partial enclosures are effective.	
2	17. Given a list of at least four statements, the student will be able to select the statement that best describes shields.	
2	18. Given a list of at least four statements, the student will be able to select the statement that best describes when shields would be maximumally effective.	
2	19. Given a list of frequency ranges, the student will be able to select the frequency range in which shields are most effective.	
2	20. Given a list of frequency ranges, the student will be able to select the frequency range in which barriers can be effective.	
2	21. Given a list at least four factors, the student will be able to select those factors which influence the amount of noise reduction achieved by a barrier.	
2	22. Given the velocity of sound, the height of a barrier, the angle of deflection, and a noise reduction table, the student will be able to compute the noise reduction achieved by the barrier.	
2	23. Given a list of at least four statements, the student will be able to select the statement that best describes the relationship between noise reduction achieved and the angle of deflection.	
2	24. Given a list of at least four statements, the student will be able to select the statement that best describes the relationship between H/λ and noise reduction achieved by a barrier.	
2	25. Given a list of at least four outcomes, the student will be able to select the outcome associated with putting absorption material on the source side of a barrier.	
2	26. Given a list of statements, the student will be able to select those statements that are true about the construction of barriers.	
2	27. Upon request and with no aids, the student will be able to list and give examples of methods for controlling noise at the receiver.	

Performance Objectives		
Lesson	Noise Control	Module 4 Unit 4
2	28. Upon request and with no aids, the student will be able to list several administrative techniques for controlling noise at the receiver.	
2	29. Given a list of statements, the student will be able to select those statements that are true concerning the Federal Guidelines for ear protection devices.	
2	30. Upon request and with no aids, the student will be able to list in writing the ways sound can reach the ear even if ear plugs or muffs are worn.	
2	31. Given a list of at least four statements, the student will be able to select the statement that best describes the relationship between communications and wearing ear plugs or muffs.	

Unit Activities--Instructor	
Noise Control	Module 4 Unit 4

In order to present the unit material to the students, the instructor will be responsible for the following:

Lesson 1--Noise Control

Classroom Presentation

Conduct a lecture to present the methods of control of industrial noise. This lesson concerns the basic approach to solving noise problems; selecting equipment for a new environment or plant; controlling noise at its source, along its path, and at the receiver. A major part of the lesson concerns building total enclosures.

Time Allotted

1 Hour

Demonstration

No demonstrations are required

Supervised Practice

No supervised practice is required.

Lesson 2--Noise Control, Continued

Classroom Presentation

A continuation of the lecture started in Lesson 1 of this unit. This lesson concentrates on barriers and shields and personal protective devices (ear plugs and ear muffs). It is suggested that case studies be used as examples.

Time Allotted

1 Hour

Demonstration

No demonstrations are required.

Supervised Practice

No supervised practice is required.

Unit Activities--Student	
Noise Control	Module 4 Unit 4

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--Noise Control

Classroom Activity

Attend a one-hour lecture dealing with the methods of controlling industrial noise.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 4 Chapter 6
Industrial Noise Manual		Chapter 11
PROBLEMS		
Industrial Hygiene Engineering and Control	Section 4 Chapter 5	Section 4 Chapter 5

Unit Activities--Student	
Noise Control	Module 4 Unit 4

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 2--Noise Control Continued

Classroom Activity

Attend a one-hour lecture that continues the discussion of controlling industrial noise. The lesson concentrates on barriers and shields and personal protective equipment.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
PROBLEMS		
Industrial Hygiene Engineering and Control	Section 4 Chapter 6	Section 4 Chapter 6

Facilities, Equipment, and Materials	
Noise Control	Module 4 Unit 4

Facilities

Lecture and/or discussion--Normal classroom

Equipment and Materials

Educational Materials

Chalkboard
Chalk
Eraser
35 mm Slide projector with remote control
Screen

Health and Safety

None required

Visuals

Slide Series--Industrial Hygiene Engineering and Control
Module 4, Unit 4

Other

Case studies from Industrial Noise Control Manual, Chapter 5

References Used in Class

Industrial Hygiene Engineering and Control
Industrial Noise Control Manual

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
	The purpose of this lesson is to familiarize the student with noise control techniques. The student should be made aware that solving noise problems is not easy and that, to a large degree, there are no "canned" solutions.
I. Introduction A. Noise Control Solutions 1. No "canned" solutions; each problem is unique. 2. However, many case studies have been published to assist the industrial hygienist in evaluating certain techniques in certain situations.	
B. Does Noise Control Pay? 1. Noise control can be expensive and complex; thus, time consuming. 2. May involve interruption of production. 3. Must be viewed as a long-term investment in the employees' hearing, improvement in communication, and reduction in speech interference.	Slide 4.4.1.1.--Control of Noise
C. First Steps in Noise Control 1. Procedures. a. measure noise levels in dBA b. measure employee exposure time c. compare results to standards	Slide 4.4.1.2.--Noise Control Approach

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
d. set priorities on solving the problem (1) magnitude of reduction will influence type of noise reduction technique. e. further analysis on the top priority issues (1) octave band analysis (2) compare octave band standards (3) determine noise reduction required f. institute control techniques (1) effects of techniques are usually hard to predict (2) unpredictability due to -complexity of source -varying environmental conditions -limitation due to maintenance and operational requirements g. remeasure to estimate degree of effect attained	Point out the following about priorities: 1. Give the following example: a. Three noise source (1) 90 dB (2) 95 dB (3) 101 dB with overall of 102 dB. b. If 90 dB source completely removed, overall is still 102 dB. c. If 90 and 95 are removed, 101 remains. d. If 101 is removed, overall is 96 dB. 2. Work on noisiest source first.
D. Basics of Noise Control 1. Control noise at the source. 2. Control noise along its path to the ear. 3. Control noise at the receiver, the ear.	Slide 4.4.1.3.--Basic Noise Control
II. Plant Planning A. Designing New Plants 1. Great opportunity for noise control.	Slide 4.4.1.4.--Plant Planning

TOPIC	REMARKS
2. To avoid problems, must a. have knowledge of noise characteristics of each machine and process that will be installed b. know location of machines and operation in the floor plan or layout c. design specifications based upon employee exposure	
3. More about specifications. a. specify requirements for noise data (performance data) b. noise problems can be avoided by building solution into machine itself c. most built-in solutions will not increase costs d. example of specifications--Industrial Noise Manual, p. 71-73	
B. Simple Example of New Plant Noise Reduction	Give students following example and work it out with them. A vendor's machine produces a maximum sound pressure level of 104 dB at 1000 Hz when the worker is 3 ft away, Q = 4 and R = 2000 sq. ft. You are considering the machine under these conditions: a. r = 10 ft b. Q = 2 c. R = 2000 sq. ft (Notice sound power level of machine is not specified; but it will be the same under vendor's conditions as under your conditions.)

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
	Solution to Problem:

First, determine the sound power level generated by the machine using the expression

SWL =

$$SPL - 10 \log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] - 10.5 \text{ dB}$$

under the vendor's conditions. From the vendor's information, $Q = 4$, $r = 3$ ft, $R = 2000$ ft^2, and SPL = 104 dB (ref = 0.0002 N/M^2) such that

$$SWL = 104 \text{ dB} - 10 \log\left[\frac{4}{4\pi(3.0 \text{ ft})^2} + \frac{4}{2000 \text{ ft}^2}\right] - 10.5 \text{ dB}$$

$$= 104 \text{ dB} -(-14.275) - 10.5 \text{ dB}$$

$$= 107.77 \text{ dB}$$

where SWL ref 10^{-12} watts. The sound power level is going to remain the same under your conditions as the vendor's conditions. Thus, the sound pressure level under your conditions can be computed by:

SPL =

$$SWL + 10 \log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5 \text{ dB}$$

where $r = 10$ ft, $Q = 2$, $R = 2000$ ft^2 and SWL = 107.77 dB (ref = 0.00002 N/M^2).

SPL =

$$107.77 \text{ dB} + 10 \log\left[\frac{2}{4\pi(10.0 \text{ ft})^2} + \frac{4}{2000 \text{ ft}^2}\right] + 10.5 \text{ dB}$$

$$= 107.77 \text{ dB} +(-24.44) + 10.5 \text{ dB}$$
$$= 93.82 \text{ dB}$$

Lesson Outline

Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
	This is 3.82 dB higher than your desired level; thus the machine will not meet the standards you set under your conditions.
1. Point out to student these problems can be solved from what was learned in the first unit of this module. Note: If vendor gave SWL and not SPL, the problem still could be worked out.	
C. Once specifications have been determined, equipment can be purchased	
1. Compare prices. 2. Know what noise problems you are buying. a. think about how problem can be controlled if you are purchasing problem	
D. New Plant Planning and Substitution of Equipment--Some General Rules	Slide 4.4.1.5.--General Rules Concerning Substitution
1. Present machine was probably the most economical but not necessarily the quietest; same with process. 2. Techniques. a. use welding instead of riveting b. compression riveting instead of pneumatic riveting c. mechanical forging instead of drop forging d. grinding instead of chipping e. electrical tools instead of pneumatic tools f. conveyor instead of chute g. mechanical stripping from punch press instead of air blast stripping	

TOPIC	REMARKS
h. hot instead of cold working metal i. belt drive instead of gears (screw drives instead of gears) j. squirrel cage fans instead of axial fans k. larger, slower spread fan instead of a small fan at higher speeds l. quieter material if possible	
III. Controlling Noise in an Existing Facility	
A. Review of Control Techniques	
1. At source. 2. At path. 3. At receiver.	
B. Best to Obtain Diagram of Noise Flow	Slide 4.4.1.6.--Diagrams of Noise Flow
1. These should include:	Review what the diagrams show.
a. where there is direct radiation through openings in enclosures b. sound radiation from enclosure due to solid borne vibration from the source c. indirect radiation from enclosure (sound from inside the source radiating outside)	
2. Indirect where it might be best to control sound.	
C. Controlling at the Source	Slide 4.4.1.7.--Control at the Source
1. Best way to control.	
a. usually closer to source, the less expensive	

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
2. Types of source. a. vibration b. fluid flow	Note: Unit 3 of this module was concerned with vibration.
3. Types of control methods at the source. a. substitution of equipment, process, and materials (Note: these are the same general principles discussed under new plant conditions.) b. direct the sound away from the point of interest (1) intake or exhaust noise (usually can accomplish this under these circumstances) (2) most machines are directional; can use this to advantage to change sound field (3) technique usually not possible in reverberant field (no reduction will result) -however, in a room, machine can be directed to highly absorbent material c. remove machine to another room d. vibration control technique (discussed in last unit; reviewed here) (1) reduction of driving force -balancing -lubrication -alignment -bearing maintenance	

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
(2) special problems--impact forces -smaller force over a longer period of time -resilient bumpers at point of impact (3) isolation of driving force from responding surface -discussed in detail in last unit -review procedure for selection of isolator -point out danger if improperly accomplished -possible need for a consultant or expert (4) reducing the response of vibrating surface -damping -improving support -increasing stiffness -decreasing size of vibrating surface -changing shape of vibrating surface Point out: -damping can be complicated and expensive -sandwich approach as a rule of thumb; use an outer plate as same gauge as vibrating plate	

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
C. Air and Gas Flow Noise Reduction at the Source	
1. Fans and blowers.	
a. backward curve blades are the quietest	
2. High velocity fluid.	
a. velocity of fluid or gas is not the usual noise source	
b. problem generally the pressure reducing valve (sonic velocity of valve)	Slide 4.4.1.8.--Pressure Reducing Valve
c. how to handle the problem	
(1) use a muffler downstream--muffler should not reduce the velocity of gas downstream	
(2) velocity of 10,000 ft/min can be used without excessive noise	
(3) do not use velocities higher than necessary to do the job	
(4) where ratio of upstream to downstream pressure is 1.9 or greater, excessive noise produced	
(5) special valve	Slide 4.4.1.9.--Special Valve
-explain how the valve achieves a gradual pressure drop -explain how it works	

TOPIC	REMARKS
d. in some cases the special valve cannot be used--will become clogged with dirt; in this case, use a muffler or external pipe covering	
(1) external pipe covering	
-usually not economical	
-usually have to cover a lot of pipe to achieve the desired noise reduction	
e. selecting a muffler--must determine the frequency cutoff and sound powers at each octave band	
(1) must estimate noise level in dB downstream	
(2) tables available to do this--table or curves show how the approximate sound power level can be obtained; to use the curves, need mass flow rate, and pressure ratios up- and downstream	Slide 4.4.1.10.--Pressure Reducing Noise Valves (Curves)
-explain dimensions on table	
-mass flow lbs/min	
-ratio of pressures	
-sound power level	

Lesson Outline

Noise Control

Module 4
Unit 4
Lesson 1

TOPIC	REMARKS
	<u>Problem</u> How to Use Curves (Work problem with students) Situation: Upstream absolute pressure = 165 psia Downstream absolute pressure = 30 psia Gas temperature = 185°C Mass flow rate = 3000 lbs/hr Pipe downstream = 4 in diameter (inside) Note: Mass flow must be in lbs/min $\frac{3000 \text{ lbs/hr}}{60 \text{ min/hr}} = 50$ lbs/min Pressure ratios are $\frac{165}{30} = 5.5$ From table, sound power level is 141 dB
Note about pressure ratios: Noise is produced when pressure ratios are 1.9 or greater.	
(3) from the information, the cutoff frequency can be determined -explain cutoff frequency; useful in determining requirements of muffler and the frequency spectrum of the valve can be determined	
$f_{co} = \frac{C}{2d}$ where f_{co} denotes cutoff frequency d denotes inside diameter of pipe downstream in feet C denotes velocity of sound	Slide 4.4.1.11.--Cutoff Frequency and Sound Velocity

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
To find cutoff frequency, need to determine velocity of sound $C = 1127\sqrt{\frac{t + 273}{300}\frac{29}{M}}$ where t denotes temperature C° M denotes molecular weight For our problem where M = 18 (steam) $C = 1127\sqrt{\frac{(185 + 273)}{300}\frac{29}{18}}$ $= 1127\sqrt{\frac{13282}{5400}}$ = 1127(2.46) = 1170 ft/sec To find the cutoff frequency D = 4 inches or 4/12 = 0.33 ft C = 1170 ft/sec and therefore, $f_{co} = \frac{1770}{2 \times 0.33}$ = 2682 Hz To find frequency spectrum, a rule of thumb is used -sound power level will drop 6 dB in each octave band below the band containing the cutoff frequency -the bands above and at the cut-off frequency will have same dB as the cutoff band.	

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
For our problem:	Slide 4.4.1.12.--Frequency Spectrum

Hz	SWL
63	105
125	111
250	117
500	123
1000	129
2000	125
4000	141
8000	141

This information is used primarily to select a muffler.

Optional Discussion

If the power ratios are less than 1.9, the correction factor must be used in finding the frequency spectrum. Correction factor is given by

$$K = 20 \log_{10} \left[\frac{0.09 \, P_{downstream}}{P_{upstream} - P_{downstream}} \right]$$

The correction factor would be subtracted from the SWL.

Optional Problem

Upstream pressure	=	30 psig
Downstream pressure	=	20 psig
Mass flow rate	=	2000 lb/hr
Gas temperature	=	185°C
Pipe downstream	=	6 in (I.0)
M	=	18

Mass flow rate $= \frac{2000}{60} = 33.3$ lbs/min

Ratio of pressures $= \frac{30}{20} = 1.5$

From table, SWL = 111 dB

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
	Since 1.5 < 1.9, the correction factor must be used.

$$K = 20 \log \frac{0.9(20)}{30-20}$$

$$= 20 \log \frac{18}{10}$$

$$= 20 \log 1.8$$

$$= 20(0.2553)$$

$$= 5.11 \text{ dB}$$

So, sound power level at valve is

111dB - 5.11 dB or 105.9 dB

To determine the spectrum, need to calculate the cutoff frequency and velocity.

$$C = 1127 \sqrt{\frac{(185 + 273)29}{300 \quad (18)}}$$

$$= 1127 \sqrt{\frac{13282}{5400}}$$

$$= 1767.5$$

And the cutoff frequency is

$$f_{co} = \frac{1767.5}{2 \times \frac{6}{12}}$$

$$= 1767.5 \text{ Hz}$$

And using the rule of thumb

	SWL	SWL-K
63	81	76
125	87	82
250	93	88
500	99	94
1000	105	100
2000	111	106
4000	111	106
8000	111	106

Again, this information is used to select a muffler.

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
(4) types of mufflers	
-basically two types	Slide 4.4.1.13.--Types of Mufflers
--dissipative, and --nondissipative muffler	
(5) dissipative muffler	
-uses absorption material as a lining -types	
--straight through type, results in very litte pressure drop, usually used 6" diameter or less --center body type	
-procedures available for selecting lining and thickness of lining; will not be discussed (most mufflers available commercially)	
(6) nondissipative muffler	
-uses principle of resonance -reflects sound of a particular frequency back toward sound and reflection source -design of this type of muffler complicated; will not be discussed here.	

Lesson Outline

Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
	Instructor Note: Optional Discussion Review appropriate case studies in Industrial Noise Control Manual (NIOSH technical information) or have student read the appropriate case studies in class.
IV. Controlling Noise Along Its Path A. Techniques Include 1. Shields and barriers. 2. Partial enclosures. 3. Total enclosures. 4. Room absorption.	Slide 4.4.1.14.--Noise Control Along Its Path
B. Must understand the physics of sound to understand these control techniques 1. Review of material discussed in Unit 1, Module 4. a. how sound travels b. effects of partitions (1) transmission loss--effects of leaks (2) noise reduction c. absorption coefficient d. room absorption e. reverberant sound f. directivity factor g. relationship between sound pressure level and sound power level, when considering -Q -R -r	The student should be made aware that the principles discussed in Unit 1 of this module apply to enclosures. Transmission of sound from one room to another was discussed in Unit 1. If one room (source room) is looked at as an enclosure of the sound source, then the student might better understand what is happening. Therefore, it is important to review some of the basic concepts in that unit. A good way to conduct the review is to ask the students to explain the concepts that are essential. This review should not last more than 15 minutes. In addition to reviewing basic concepts, it might be advisable to review the basic formulas.

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
C. Review of approach adopted in Unit 1, Module 4 1. Problem was to find the sound pressure level in an adjoining room. a. computed -sound pressure level at wall, given a sound power level -transmission loss of combined material -noise reduction that would result b. this problem impractical or impossible to some extent; rather than predicting sound pressure in a secondary room, more customary to determine the construction material of an enclosure -if want to build an enclosure around a sound source that reduces the sound pressure outside the enclosure, must determine the construction material that would give that desired noise reduction	
D. A Total Enclosure Design 1. Problem Suppose a room has the following characteristics: 1. 30 ft x 30 ft x 10 ft high 2. Floor and ceiling are unpainted concrete with α = 0.02 sabins 3. Walls are unpainted brick, α = 0.09 sabins	Slide 4.4.1.15.--Total Enclosure Design Problem Slide 4.4.1.16--Total Enclosure Design Problem, Continued

TOPIC	REMARKS

4. Machine in center of room with directivity factor of 2 (Q = 2)
5. At 4.0 ft from machine, the SPL at each frequency band is

Band	SPL
63	82
125	84
250	87
500	86
1000	93
2000	88
4000	80
8000	81

Further suppose the criteria in each band is given as

Band	Criteria
63	105
125	98
250	93
500	85
1000	85
2000	85
4000	85
8000	85

such that at frequencies 500, 1000, and 2000, the machine is 1, 8, and 3 dB above desired criteria.

To solve the noise problem, it is decided to build an enclosure around the machine. The enclosure is to be made of steel and be 3 ft x 3 ft x 3 ft. Steel has an absorption coefficient of 0.02 sabins.

What thickness of steel is required to achieve the criteria in each of the three octave bands?

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS

Solution

To be on the safe side, add a 5 dB safety factor to the noise reduction required. Thus, at 500 Hz, noise reduction of 6 dB (5 dB + 1 dB) is required; at 1000 Hz, a noise reduction of 13 dB is required (5 dB + 8 dB); and at 2000 Hz, a noise reduction of 8 dB (5 dB + 3 dB) is required.

To compute the transmission loss of the enclosure material, it is essential to compute the sound pressure level at the wall of the enclosure before and after the enclosure is built. When computing the sound pressure level after the enclosure is built, it is necessary to account for the reverberant buildup; i.e., the enclosure will cause a reverberant buildup; this reverberant buildup must be computed and accounted for.

The first step in solving the problem is to compute the sound power level of the machine using

$$SWL = SPL - 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R} \right] - 10.5 \text{ dB}$$

From the information given, Q = 2, SPL at 4.00 ft = 93 (at 1000 Hz), r = 4.0 ft, and R must be computed as

$$R_{1000 \text{ Hz}} = \frac{\bar{\alpha}\Sigma S_i}{1 - \bar{\alpha}}$$

where

$$\bar{\alpha}_{1000 \text{ Hz}} = \frac{\Sigma S_i \alpha_i}{\Sigma S_i}$$

To compute $\bar{\alpha}_{1000 \text{ Hz}}$

Floor (30' x 30')0.02 sabins = 18 ft^2 sabins

Ceiling (30' x 30')0.02 sabins = 18 ft^2 sabins

Walls 4(30' x 10')0.09 sabins = 108 ft^2 sabins

TOPIC	REMARKS

Such that

$\bar{\alpha}$ =

$$\frac{18\ ft^2\ sabins + 18\ ft^2\ sabins + 108\ ft^2\ sabins}{2(30\ ft \times 30\ ft) + 4(30\ ft \times 10\ ft)}$$

$$= \frac{144\ ft^2\ sabins}{3000\ ft^2}$$

= 0.048 sabins

And

$$R_{1000\ Hz} = \frac{0.048\ sabins(3000\ ft^2)}{1 - 0.048\ sabins}$$

$$= 151.26\ ft^2$$

Thus, the sound power level at 1000 Hz would be

SWL =

$$93\ dB - 10 \log \left[\frac{2}{4\pi(4.0\ ft^2)} + \frac{4}{151.26\ ft^2} \right] - 10.5\ dB$$

= 93 dB -(-14.39) - 10.5 dB

= 93 dB - 14.39 dB - 10.5 dB

= 96.89 dB

Now compute the sound pressure level at the proposed wall of the enclosure, before enclosure is built. To compute, need to calculate the average distance the machine will be from the wall.

$$\text{Average distance} = \sqrt{\frac{\Sigma S_i}{4\pi}}$$

where ΣS_i denotes the total surface area of the total enclosure; (i.e., $\Sigma S_i = 6 \cdot 3\ ft^2$) , such that

$$\text{Average distance} = \sqrt{\frac{6 \cdot (3\ ft)^2}{4\pi}}$$

$$= 2.07\ ft$$

TOPIC	REMARKS

The SPL at 2.07 ft before the enclosure is built can now be calculated by

$$SPL_{1000\ Hz} = SWL + 10\ \log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right) + 10.5\ dB$$

where $SWL_{1000\ Hz}$ = 96.89 dB; Q = 2, r = 2.07 ft, and $R_{1000\ Hz}$ = 151.26 ft^2, so that

$$SPL_{1000\ Hz} = 96.89\ dB + 10\ \log\left(\frac{2}{4\pi(2.07\ ft)^2} + \frac{4}{151.26\ ft^2}\right) + 10.5\ dB$$

$$= 96.89\ dB + (-11.97) + 10.5\ dB$$

$$= 95.42\ dB$$

Now, after the enclosure is built, what will be SPL at the wall of the enclosure? First, need to compute the room constant of the proposed enclosure.

$$R_{1000\ Hz} = \frac{\bar{\alpha}_{1000\ Hz}\ \Sigma S_i}{1 - \bar{\alpha}_{1000\ Hz}}$$

where

$$\bar{\alpha}_{1000\ Hz} = \frac{\Sigma S_i \alpha_i}{\Sigma S_i}$$

To compute $\bar{\alpha}_{1000\ Hz}$ for the enclosure, recall that

Floor (3' x 3')0.02 sabins = 0.18 ft^2 sabins

Ceiling (3' x 3')0.02 sabins = 0.18 ft^2 sabins

Walls 4(3' x 3')0.02 sabins = 0.72 ft^2 sabins

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS

Thus, $\alpha_{1000\ Hz}$ = 0.02 sabins, and

$$R_{1000\ Hz} = \frac{0.02 \text{ sabins } \Sigma S_i}{1 - 0.02 \text{ sabins}}$$

$$= \frac{0.02 \text{ sabins } \quad 6 \cdot (3 \text{ ft})^2}{1 - 0.02 \text{ sabins}}$$

$$= 1.10 \text{ ft}^2$$

Now using the expression

$$SPL_{1000\ Hz} = SWL + 10 \log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right) + 10.5 \text{ dB}$$

the SPL at the wall of the enclosure, when the enclosure is built, can be computed; where SWL = 96.89 dB, Q = 1 (originally Q = 2, but when the sound is put into such a small enclosure, the sound will become unidirectional), r = 2.07 ft, and R = 1.10 ft^2, such that

$$SPL_{1000\ Hz} = SWL + 10 \log\left(\frac{1}{4\pi(2.07 \text{ ft})^2} + \frac{4}{1.10 \text{ ft}^2}\right) + 10.5 \text{ dB}$$

$$= 96.89 \text{ dB} + 5.63 \text{ dB} + 10.5 \text{ dB}$$

$$= 113.02 \text{ dB}$$

Without the enclosure, $SPL_{1000\ Hz}$ at wall was 95.45 dB. After enclosure is built, $SPL_{1000\ Hz}$ at wall will be 113.02 dB. Thus the enclosure will cause a reverberant buildup of 17.75 dB (113.02 dB - 94.45 dB).

Thus to achieve a criteria 85 dB at the enclosure wall, the enclosure material would have to have a transmission loss of 13 dB (5 dB + 8 dB) plus 17.75 dB or a total of 30.75 dB. Given this transmission loss figure, the thickness of the steel can be determined by looking at a table of transmission loss.

Lesson Outline	
Noise Reduction	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
To be on the safe side, the transmission loss required at 500 Hz and 2000 Hz should also be computed (following the same procedures as above).	
2. Additional notes about total enclosures.	
a. did not consider any other noise in the room after the enclosure was built; if the larger room were a live room, there would be reverberant sound	
b. nor was putting an absorbent material inside the enclosure considered	Ask the students what effect this would have. Answer: Reduce the amount of reverberant buildup; therefore, reduce the required transmission loss, and a thinner steel could have been used.
(1) Rule of Thumb: If enclosure is lined so that the average absorption coefficient is 0.7 sabins or greater, for all practical purposes TL would equal NR	
To demonstrate this rule of thumb, show the following:	
The enclosure in the above example was made of steel with an absorption coefficient of 0.02 sabins. If the enclosure were lined on the ceiling and walls with a material having an absorption coefficient of 0.90 sabins, then	
$$\bar{\alpha}_{1000\ Hz} = \frac{(3' \times 3')0.02 + 5(3' \times 3') \times (0.90)}{6(3\ ft)^2}$$	

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
$= \frac{0.18 \text{ ft}^2 \text{ sabins} + 40.5 \text{ ft}^2 \text{ sabins}}{54 \text{ ft}^2}$ $= 0.75$ sabins And the room constant of the enclosure would be $R_{1000 \text{ Hz}} = \frac{0.75 \text{ sabins } (54 \text{ ft}^2)}{1 - 0.75 \text{ sabins}}$ $= 162 \text{ ft}^2$ The SPL at the wall of the enclosure would be $SPL = SWL + 10 \log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right) + 10.5 \text{ dB}$ where SWL = 96.89 dB, Q = 2 (since the absorption material would retain the original sound direction of the machine), r = 2.07 ft, and R = 162 ft^2. $SPL = 96.89 + 10 \log\left(\frac{2}{4\pi(2.07 \text{ ft})^2} + \frac{4}{162 \text{ ft}^2}\right) + 10.5 \text{ dB}$ $= 96.89 \text{ dB} + (-12.09) + 10.5 \text{ dB}$ $= 95.30 \text{ dB}$ Recall that without the enclosure, SPL at 2.07 ft would be 95.42 dB. Thus, for all practical purposes, there would be no reverberant buildup and the transmission loss would equal the desired noise reduction. c. did not consider the potential heat buildup in the enclosure. (1) this can be overcome by ventilating the enclosure; this may change the noise reduction	Note to Instructor: Optional Discussion At this point, review a case study involving the total enclosure method of control. As a source of case studies, use NIOSH technical information, "Industrial Noise Control Manual."

Lesson Outline	
Noise Reduction	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS

d. did not consider access to the machine

(1) for maintenance or operation
(2) may require doors or windows

-in these cases, would have to consider combined TL of the building materials to see if it meets overall TL requirements
-also, if combined material were used, would have to be conscious of controlling leaks

3. Enclosure inside a noisy work area.

a. sometimes it is necessary to build an enclosure to keep the noise out (e.g., an office in the middle of a noisy work area)
b. Problem

Suppose there is a work area with the following characteristics:

1. 100 feet by 100 ft by 15 feet high.
2. Walls, ceiling, and floor made of concrete unpainted (α = 0.02 sabins).
3. The sound pressures in the middle of the room are:

Band	Sound Pressure Level
63	82
125	84
250	87
500	89
1000	88
2000	88
4000	85
8000	81

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS

It is desired to put an office, which is 10 ft x 10 ft x 8 ft high, in the middle of the room; and it is desired to have the following sound pressure levels in the office:

Band	Sound Pressure Level
63	76
125	69
250	64
500	60
1000	59
2000	60
4000	61
8000	62

This means that the reductions desired are 6, 15, 23, 29, 29, 28, 24, and 19 dB, respectively. For convenience, assume we are concerned only at 1000 Hz and that the proposed office is to have the following characteristics:

1. Acoustical tile in the ceiling, $\alpha = 0.65$ sabins.
2. Floors and walls are to be made of a material having an absorption coefficient of 0.01 sabins.

The problem now is to determine the transmission losses of the walls and ceiling. For safety, add a 5 dB factor to the required noise reduction; so that at 1000 Hz, the required noise reduction is 29 dB + 5 dB safety factor, or 31 dB.

To compute the transmission loss (TL) recall that

$$NR = TL = 10 \log \left[\frac{1}{4} + \frac{S_w}{R} \right]$$

where NR is the noise reduction required (31 dB), S_w denotes the surface area of office except the floor, and R is the room constant of the office.

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS

First compute the room constant.

$$R_{1000\ Hz} = \frac{\bar{\alpha}_{1000\ Hz}\ \Sigma S_i}{1 - \bar{\alpha}_{1000\ Hz}}$$

where

$$\alpha_{1000\ Hz} = \frac{\Sigma S_i \alpha_i}{\Sigma S_i}$$

$$= \frac{(10' \times 10')0.65 \text{ sabins} \times (10' \times 10') \times 0.01 + 4(8' \times 10')0.01}{2(10' \times 10') + 4(8' \times 10')}$$

$$= \frac{65 \text{ ft}^2 \text{ sabins} + 1.0 \text{ ft}^2 \text{ sabins}}{520 \text{ ft}^2}$$

$$= 0.127 \text{ sabins}$$

Thus, that

$$R_{1000\ Hz} = \frac{\bar{\alpha}_{1000\ Hz}\ \Sigma S_i}{1 - \bar{\alpha}_{1000\ Hz}}$$

$$= \frac{0.127 \text{ sabins} \cdot 520 \text{ ft}^2}{1 - 0.127 \text{ sabins}}$$

$$= 75.65 \text{ ft}^2$$

Next, compute S_w (S_w should not include the floor).

$$S_w = (10' \times 10') + 4(8' \times 10')$$

$$= 100 \text{ ft}^2 + 320 \text{ ft}^2$$

$$= 420 \text{ ft}^2$$

Given R and S_w, then

$$TL_{1000\ Hz} = NR + 10 \log \left[\frac{1}{4} + \frac{S_w}{R}\right]$$

$$= 31 \text{ dB} + 10 \log\left[\frac{1}{4} + \frac{420 \text{ ft}^2}{75.65 \text{ ft}^2}\right]$$

$$= 31 \text{ dB} + 7.6 \text{ dB}$$

$$= 38.6 \text{ dB}$$

Computing the TL at other frequency bands will give the type of material that will achieve the desired noise reduction.

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
V. Summary A. Noise Control Procedure 1. Measurement a. dBA b. exposure time 2. Compare measures to standard. 3. Set priorities. 4. Do further analysis. a. compare to standards b. determine reduction required 5. Institute control technique. 6. Remeasure. B. Plant Planning 1. Writing specifications. 2. Predicting if a machine will work in the environment. 3. General rules for substitution. C. Controlling Noise at the Source 1. Closer to source, usually less expensive. 2. Techniques. a. substitution b. isolation of noise source c. vibration control (1) reduce driving force (2) isolate force from radiating surface (3) reduce response of radiating surface 3. Air and gas flow noise reduction. a. valves b. mufflers (1) different kinds of mufflers	Briefly discuss what was covered in this unit. Be sure to inform students that the next unit will discuss more control techniques.

Lesson Outline	
Noise Control	Module 4 Unit 4 Lesson 1

TOPIC	REMARKS
D. Controlling Noise Along Its Path 1. Total enclosure. 2. To be discussed in next lesson. a. shields and barriers b. partial enclosures E. Control at the Receiver 1. Methods to be discussed in next lesson.	

Practice Exercises

Noise Control	Module 4 Unit 4 Lesson 1

1. You are considering purchasing a machine that produces a maximum sound pressure level of 110 dB at 1000 Hz when the worker is 10 feet away. The vendor claims the machine has a directivity factor of 4 (Q = 4). The vendor tested the machine in a room that had a room constant of 4000 square feet (R = 4000).

   You are considering putting the machine in the center of a room that is 100' x 50' x 14', where the floor is made of poured concrete and has an absorption coefficient of 0.02, the ceiling is made of plaster with an absorption coefficient of 0.06, the walls are made of brick which has an absorption coefficient of 0.01. One of the walls has a window 3' x 10' with an absorption coefficient of 0.04. Another wall has a door 18' x 10' with an absorption coefficient of 0.10. The machine will be put on the floor so Q = 2, and the worker will be only 5 feet from the machine.

   If the machine is put in your plant, will it meet the criteria level of 90 dB?

2. You are considering purchasing a muffler for a saturated stream exhaust system. In order to purchase the muffler, you are required to compile the sound power level specifications at all octave bands. The data on the system are as follows:

Upstream absolute pressure	= 200 psia
Downstream absolute pressure	= 40 psia
Mass flow rate	= 50 lbs/min
Stream temperature	= 200°C
Pipe downstream	= 6 inches (diameter)
Molecular weight of steam	= 18

   Using this information and the following formulas:

   $$f_{co} = \frac{C}{2D}$$ where f_{co} denotes the cutoff frequency, C denotes velocity, and D denotes inside diameter (in feet)

   $$C = 1127\sqrt{\frac{t + 273}{300}\,\frac{29}{M}}$$ where C denotes velocity, t denotes gas temperature in Centigrade, and M denotes molecular weight

   Complete the following table:

Octave Band	SWL
63	
125	
250	
500	
1000	
2000	
4000	
8000	

3. You are considering building a total enclosure around a machine located in the center of a room 100' x 100' x 15' with a Q = 1. The floor of the room is constructed of poured concrete, the walls are constructed of brick, and the ceiling is plastered. One of the walls has a glass window 10' x 20', and another wall has a solid wood door 10' x 25'.

   The proposed enclosure will be 4' x 4' x 4'. (The average distance from the center of the machine to the proposed enclosure wall will be 2.8'.) The enclosure will have a glass window 2' x 2' on one of its walls. It is anticipated that the walls and ceiling will be made of concrete block.

   On Line 1 of the table below are the sound pressure levels at 2.8 feet at each octave-band without the enclosure; on Line 2 is the criteria to be met; on Line 3 is the desired noise reduction; on Line 4 is a 5 dB allowance for noise variation. You are to compute the reverberant buildup as a result of the enclosure and the total transmission loss required of the enclosure.

Line	63	125	250	500	1000	2000	4000	8000
1 SPL at 2.8 feet from source	100	97	90	95	105	95	80	82
2 Criteria	105	98	93	85	85	85	85	85
3 Required noise reduction	0	0	0	10	20	10	0	0
4 Safety factor				5	5	5		
5 Allowance for reverberant buildup				-	-	-		
6 Total TL required				-	-	-		

4. Usually enclosures are built around a noisy machine, but sometimes enclosures are built to protect a group of workers from a noisy area; e.g., an office in the center of a noisy work area. In this case, the office acts as an enclosure to keep the noise out. The following problem is based on this approach.

The center of a 100' x 100' x 15' manufacturing area has the noise levels shown by Line 1 of the table below. You are going to enclose a small office in the center of the room with the following dimensions: 10' x 10' x 8'. Line 2 of the table below indicates the noise level that is desired in the office. Your problem is to determine the required wall and ceiling transmission losses to meet the criteria, given these provisions:

1. The only frequencies of concern are 250 and 500 Hz.
2. The office ceiling must be acoustical tile with an absorption coefficient of 0.65 at 500 Hz and an absorption coefficient of 0.45 at 250 Hz.
3. The absorption coefficient of the floors and walls is to be 0.02 at 500 Hz and 0.01 at 250 Hz.

Line	63	125	250	500	1000	2000	4000	8000
1 Existing noise level	82	84	87	89	88	88	85	81
2 Criteria	76	69	64	60	59	60	61	62
3 Line 1 - Line 2	6	15	23	29	29	28	24	19
4 Allowance (safety factor)	5	5	5	5	5	5	5	5
5 Require noise reduction	11	20	28	34	34	33	29	24
6 Total TL required			--	--				

1. Compute the sound power level under the vendor's conditions.

$$SWL = SPL - 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] - 10.5 \text{ dB}$$

where Q = 4, r = 10 ft, SPL = 110 dB, and R = 4000 ft^2

$$SWL = 110 \text{ dB} - 10 \log \left[\frac{4}{4\pi(10 \text{ ft})^2} + \frac{4}{4000}\right] - 10.5 \text{ dB}$$

$$= 110 \text{ dB} - (-23.785 \text{ dB}) - 10.5 \text{ dB}$$

$$= 75.715 \text{ dB}$$

Using this sound power level, compute the sound pressure level under the new conditions where r = 5 ft, Q = 2, and R is computed by

$$R = \frac{\alpha \Sigma S_i}{1 - \bar{\alpha}}$$

$$\alpha = \frac{\Sigma S_i \alpha_i}{\Sigma S_i}$$

$$= \frac{(500' \times 100')0.02 \text{ sabins} + (500' \times 100')0.06 \text{ sabins} + (500' \times 14' - 3' \times 10')0.01 \text{ sabins} + (100' \times 14' - 10' \times 18')0.01 \text{ sabins} + 2(500' \times 15')0.0. \text{ sabins} + (3' \times 10')0.04 \text{ sabins} + (10' \times 18')0.10 \text{ sabins}}{2(500' \times 100') + 4(500' \times 14)}$$

$$= \frac{4241.1 \text{ ft}^2 \text{ sabins}}{128000 \text{ ft}^2}$$

$$= 0.33 \text{ sabins}$$

And therefore

$$R = \frac{0.033 \text{ sabins } 128000 \text{ ft}^2}{1 \text{ sabin} - 0.033 \text{ sabins}}$$

$$= 4368.15 \text{ ft}^2$$

And SPL at 5 feet is computed as

$$SPL = SWL + 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5 \text{ dB}$$

$$= 75.715 \text{ dB} + 10 \log \left[\frac{2}{4\pi(5 \text{ ft})^2} + \frac{4}{4368.15}\right] + 10.5 \text{ dB}$$

$$= 75.715 \text{ dB} + (-21.38 \text{ dB}) + 10.5 \text{ dB}$$

$$= 64.83 \text{ dB}$$

2. Compute the velocity of sound.

$$C = 1127 \text{ ft/sec} \sqrt{\frac{200^\circ C + 273}{300} \cdot \frac{29}{18}}$$

$$= 1796.21 \text{ ft/sec}$$

Thus, that

$$f_{co} = \frac{C}{2D}$$

$$= \frac{1796.21 \text{ ft/sec}}{2 \cdot 6/12 \text{ ft}}$$

$$= 1796.21 \text{ Hz}$$

The ratio of pressure is computed as

$$\frac{200 \text{ psia}}{40 \text{ psia}} \text{ or } 5$$

From Figure 4.6.1, the reduction at pressure ratio of 5 and mass flow rate of 50 lb/min is 141 dB. So the octave band spectrum would be

Octave Band	Sound Power Level
63	111
125	117
250	123
500	129
1000	135
2000	141
4000	141
8000	141

Practice Exercises--Solutions	
Noise Control	Module 4 Unit 4 Lesson 1

3. First compute, at each frequency band, $\bar{\alpha}$ in the larger room.

Location	Number	Area	α_i			$S_i\alpha_i$		
			500	1000	2000	500	1000	2000
Floor	1	100 x 100	0.02	0.02	0.02	200	200	200
Ceiling	1	100 x 100	0.04	0.06	0.06	400	600	600
Walls	2	100 x 15	0.03	0.04	0.05	90	120	150
with window	1	1300	0.03	0.04	0.05	39	52	65
with door	1	1250	0.03	0.04	0.05	37.5	50	62.5
Window	1	200	0.03	0.03	0.02	6	6	4
Door	1	250	0.10	0.07	0.06	25	17.5	15
Totals		26000					1045.5	1096.5

$$\bar{\alpha}_{500\ Hz} = \frac{\Sigma S_i\alpha_{500}}{\Sigma S_i}$$

$$= \frac{797.5}{26000}$$

$$= 0.031$$

$$\bar{\alpha}_{1000\ Hz} = \frac{\Sigma S_i\alpha_{1000}}{\Sigma S_i}$$

$$= \frac{1045.4}{26000}$$

$$= 0.040$$

$$\bar{\alpha}_{2000\ Hz} = \frac{1096.5}{26000}$$

$$= 0.042$$

Now compute R at each frequency band.

$$R_{500\ Hz} = \frac{\alpha_{500}\Sigma S_i}{1 - \bar{\alpha}_{500}}$$

$$= \frac{797.5}{1 - 0.031}$$

$$= 824.8$$

$$R_{1000\ Hz} = \frac{1045.5}{1 - 0.04}$$

$$= 1089.1$$

$$R_{2000\ Hz} = \frac{1096.5}{1 - 0.042}$$

$$= 1144.6$$

3. (Continued)

Now compute the sound pressure level relative to the sound power level in each frequency band at 2.8 feet before the enclosure is built.

$$SPL_{500} = SWL + 10\log\left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5\text{ dB}$$

$$= SWL + 10\log\left[\frac{1}{4\pi(2.8\text{ ft})^2} + \frac{4}{824.8}\right] + 10.5\text{ dB}$$

$$= SWL + (-18.24\text{ dB}) + 10.5\text{ dB}$$

$$= SWL - 7.74\text{ dB}$$

$$SPL_{1000} = SWL + 10\log\left[\frac{1}{4\pi(2.8\text{ ft})^2} + \frac{4}{1089.1}\right] + 10.5\text{ dB}$$

$$= SWL - 8.09\text{ dB}$$

$$SPL_{2000} = SWL + 10\log\left[\frac{1}{4\pi(2.8\text{ ft})^2} + \frac{4}{1144.6}\right] + 10.5\text{ dB}$$

$$= SWL - 8.15\text{ dB}$$

Next, compute $\bar{\alpha}$ and R, at each frequency, for the enclosure.

		S_i	α_i			$\Sigma S_i\alpha_i$		
Location	Number	Area	500	1000	2000	500	1000	2000
Floor	1	16	0.02	0.02	0.02	0.32	0.32	0.32
Ceiling	1	16	0.06	0.07	0.09	0.96	1.12	1.44
Walls	3	16	0.06	0.07	0.09	2.88	3.36	4.32
with glass	1	12	0.06	0.07	0.09	0.72	0.84	1.08
Window	1	4	0.03	0.03	0.02	0.12	0.12	0.08
Total		96				5.00	5.76	7.24

$$\bar{\alpha}_{500\text{ Hz}} = \frac{5.00}{96} = 0.052$$

$$\bar{\alpha}_{1000\text{ Hz}} = \frac{5.76}{96} = 0.06$$

$$\bar{\alpha}_{2000\text{ Hz}} = \frac{7.24}{96} = 0.075$$

$$R_{500} = \frac{5.00}{1 - 0.052} = 5.27$$

$$R_{1000} = \frac{5.76}{1 - 0.06} = 6.13$$

$$R_{2000} = \frac{7.24}{1 - 0.075} = 7.83$$

3. (Continued)

Next, compute the sound pressure level relative to the sound power level at 2.8 feet after the enclosure is built.

$$SPL_{500\ Hz} = SWL + 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R}\right] + 10.5\ dB$$

$$= SWL + 10 \log \left[\frac{1}{4\pi(2.8\ ft)^2} + \frac{4}{5.27}\right] + 10.5\ dB$$

$$= SWL + 9.36\ dB$$

$$SPL_{1000\ Hz} = SWL + 10 \log \left[\frac{1}{4\pi(2.8\ ft)^2} + \frac{4}{6.13}\right] + 10.5\ dB$$

$$= SWL + 8.71\ dB$$

$$SPL_{2000\ Hz} = SWL + 10 \log \left(\frac{1}{4\pi(2.8\ ft)^2} + \frac{4}{7.83}\right) + 10.5\ dB$$

$$= SWL + 7.67\ dB$$

The reverberant buildup (RB) at each frequency band is computed as

$$RB_{500\ HZ} = (SWL + 9.36\ dB) - (SWL - 7.74\ dB)$$

$$= 9.36\ dB + 7.74\ dB$$

$$= 17.1\ dB$$

$$RB_{1000\ Hz} = (SWL + 8.71\ dB) - (SWL - 8.09\ dB)$$

$$= 8.71\ dB + 8.09\ dB$$

$$= 16.8\ dB$$

$$RB_{2000\ Hz} = (SWL + 7.67\ dB) - (SWL - 8.15\ dB)$$

$$= 7.57\ dB + 8.15\ dB$$

$$= 15.82\ dB$$

The transmission loss required at each frequency band is computed as

$$NR_{500\ Hz} = 10\ dB + 5\ dB + 17.1\ dB$$

$$= 32.1\ dB$$

$$NR_{1000\ Hz} = 20\ dB + 5\ dB + 16.8\ dB$$

$$= 41.8\ dB$$

$$NR_{2000\ Hz} = 10\ dB + 5\ dB + 15.82\ dB$$

$$= 30.82\ dB$$

4. Determine the wall and ceiling transmission losses to meet the specified criteria. NOTE: Since the office is small, there is going to be reverberant buildup in the office.

The transmission losses can be computed using the following formula:

$$NR = TL - 10 \log \left[\frac{1}{4} + \frac{S_w}{R}\right]$$

where NR is given in Line 5 of the table; S_w, the surface area of the enclosure is computed using

$$S_w = \sum_{i=1}^{n} S_i$$ where i does not include the floor of the office.

$$= (10 \times 10) + 4(8 \times 10)$$
$$= 100 + 4(80)$$
$$= 100 + 320$$
$$= 420$$

and R, room constant of the enclosure, is computed at 500 Hz using

$$R = \frac{\alpha \Sigma S_i}{1 - \bar{\alpha}}$$

To use the above formula, α_{500} and α_{250} must be computed using

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\Sigma S_i}$$

at 500 Hz

$$\bar{\alpha} = \frac{(10 \times 10).01 + 4(8 \times 10).01 + (10 \times 10).45}{520}$$

$$= \frac{1 + 3.2 + 45}{520}$$

$$= \frac{49.2}{520}$$

$$= .095$$

and therefore, the room constant at 500 Hz is

$$R = \frac{73.4}{.86}$$

$$= 85.35$$

and R at 250 Hz is

$$R = \frac{49.2}{.91}$$
$$= 54.07$$

4. (Continued)

Substituting R at 500 Hz in the formula for NR where NR = 34 results in

$$34 = TL - 10\log(.25 + \frac{420}{85.35})$$

$$TL = 34 + 10\log(.25 + 4.92)$$

$$= 34 + 10\log(5.17)$$

$$= 34 + 10(.7135)$$

$$= 34 + 7.135$$

$$= 41.135$$

and at 250 Hz where NR = 34

$$TL = 34 + 10\log(.25 + \frac{420}{54.07})$$

$$= 34 + 10\log(.25 + 7.77)$$

$$= 34 + 10\log(8.02)$$

$$= 34 + 10(.9042)$$

$$= 34 + 9.042$$

$$= 43.042$$

To determine what material is to be used, look at a table of transmission losses and compare them to the required transmission losses.

Lesson Outline	
Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
I. Introduction A. Briefly review what was discussed in the last lesson. 1. Methods of control. a. at source b. along path c. at receiver B. Continuation 1. Along path. a. total enclosure b. partial enclosure c. room absorption 2. Noise controlled at receiver.	This lesson should be presented as a continuation of the last lesson.
II. Controlling Noise Along Its Path A. Total Enclosures 1. Factors to consider. a. transmission loss of material -desired noise reduction -reverberant buildup b. buildup of heat c. access -combined transmission loss -leaks	
B. Partial Enclosures 1. Usually used because total enclosure is not possible; i.e., access to the machine is needed. a. the more complete the partial enclosure, the greater the obtained noise reduction	Slide 4.4.2.1.--Partial Enclosures

Lesson Outline	
Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
b. useful in giving worker in-shadow effect c. usually will reduce only high frequency noise d. shadow effect depends on (1) worker's distance and position of opening (2) absorption in the room and machine surfaces	
2. General rules of thumb.	Slide 4.4.2.2.--Performance of Partial Enclosures
a. practical method of estimating performance of partial enclosures (1) estimate percent of radiation pattern that is intercepted by the partial enclosure -50% of pattern is intercepted noise reduction of about 3 dB -80%--about 7 dB -90%--about 10 dB (2) maximum noise reduction is about 15 dB to 20 dB	Note to Instructor: Optional discussion at this point. It might be beneficial to review the results of a case study or have the students read a case study. As a source for case studies, use NIOSH technical information, Industrial Noise Control Manual.

Lesson Outline	
Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
C. Shields and Barriers	Slide 4.4.2.3.--Shields
1. Shield: A square piece of material, usually safety glass or clear pastic, placed between the worker and the source. a. effective only if its smaller dimension is at least three times the wavelength contributing most of the noise b. effective only against high frequency sound c. examples where shields might be used -air injection system in punch press -plasma guns -air guns -metal spray guns d. maximum possible reduction is about 8 dB e. if shields are used, be careful to -allow appropriate access -isolate from the machine or else vibration might be produced	
2. Barriers: Usually much larger than shields; usually attached to the floor. a. effective for medium and high frequencies b. problem is escape around sides and top of barrier	Slide 4.4.2.4.--Barriers
c. amount of noise reduction depends on -height of barrier -wavelength -angle of deflection; define and show on slide	Slide 4.4.2.5.--Deflection of Barriers

TOPIC	REMARKS
d. in general -barrier should be as high as possible -should have a TL compatible with the expected noise reduction -should have an absorption material on the source side -barrier should be isolated from the floor -be careful of sound bouncing off ceiling (absorption material on appropriate spot on ceiling)	
e. computing noise reduction due to barriers	Problem: Work out problem for students as part of the lecture.
Compute the noise reduction at 1000 Hz of a barrier 4 feet high and an angle of deflection of 30^o.	The same procedure can be followed to compute the noise reduction at other frequencies.
1. Noise reduction of barriers. 2. From table, need to compute H/λ. $H = 4$ ft (given in problem) What is λ? Recall $\lambda = \frac{C}{f}$ where C denotes velocity and f denotes frequency $\lambda = \frac{1127}{1000}$ $= 1.127$ $\therefore H/\lambda = \frac{4}{1.127}$ $= 3.55$	Slide 4.4.2.6.--Noise Reduction of Barriers Be sure to explain dimensions on table. Be sure to point out that from the table the best results are when $\theta > 30^o$.

Lesson Outline

Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
3. From the table at $\theta = 30^{o}$, noise reduction = 17 dB. Note: These calculations do not account for 1. Sound reflected off ceiling. 2. Distance worker is from barrier.	
D. Summarizing Enclosures 1. Total enclosure--most noise reduction but most expensive. 2. Partial enclosure--not as effective as total enclosure. 3. Barriers and shields provide shadows for workers; not totally effective about 3 to 20 dB reduction.	Note to Instructor--Optional Discussion. At this point, it might be beneficial to the student to review a case involving barriers and shields as a method of control. Use Industrial Noise Control Manual.
E. Controlling Noise Along Its Path by Using Room Absorption 1. Adding absorption material to walls cuts down on reverberant buildup. a. usually will not help the worker in the near field or free field.	
2. Computing amount of noise reduction achieved by room absorption. $NR = 10 \log \frac{\bar{\alpha}_2}{\bar{\alpha}_1}$ where NR denotes noise reduction, $\bar{\alpha}_1$ denotes the average absorption coefficient before and $\bar{\alpha}_2$ denotes the average absorption coefficient after.	Slide 4.4.2.7.--Room Absorption and Noise Reduction Note: $\frac{\bar{\alpha}_1}{\bar{\alpha}_2} = \frac{\frac{\Sigma S_i \alpha_i}{\Sigma S_i}}{\frac{\Sigma S_i \alpha_j}{\Sigma S_i}} = \frac{\Sigma S_i \alpha_i}{\Sigma S_i \alpha_j}$ where $i \neq j$

TOPIC	REMARKS

Have students work the following problem:

Given the following:

Room 30' x 60' x 10'
Ceiling: Plaster α_{1000} = 0.02 sabins
Floor: Concrete α_{1000} = 0.02 sabins
Walls: Glazed tile α_{1000} = 0.01 sabins
Steam Pipes: Surface area 180 sq. ft, magnesium covered α_{1000} = 0.50 sabins
Machinery: Surface area 200 sq. ft., α_{1000} = 0.02 sabins

What would be the noise reduction at 1000 Hz if the ceiling were covered with one inch of acoustical tile α_{1000} = 0.80 sabins?

Solution: Before

Ceiling 30' x 60' x 0.02 sabins = 36 ft^2 sabins

Floor 30' x 60' x 0.02 sabins = 36 ft^2 sabins

Walls (2(10' x 60') + 2(10' x 60')) x 0.01 sabins = 18 ft^2 sabins

Pipes 180' x 0.50 sabins = 90 ft^2 sabins

Machinery 200 ft^2 x 0.02 sabins = 4 ft^2 sabins

$\Sigma S_i \alpha_i$ = 36 ft^2 sabins + 36 ft^2 sabins + 18 ft^2 sabins + 90 ft^2 sabins + 4 ft^2 sabins

= 184 ft^2 sabins

Solution: After--With Ceiling Tile Added

30' x 60' x 0.80 sabins = 1440 ft^2 sabins

and

$\Sigma S_i \alpha_j$ = 1440 ft^2 sabins + 36 ft^2 sabins + 90 ft^2 sabins + 4 ft^2 sabins

= 1588 ft^2 sabins

Lesson Outline	
Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
And $$NR = 10 \log \left[\frac{1588}{184}\right]$$ $= 10 \log 8.63$ $= 10(.9360)$ $= 9.360$ dB at 1000 Hz Note: Inform the students that this should be done at all frequencies.	
	Note to Instructor: Optional Discussion At this point, it might be beneficial for the student to review a case study in which absorption is the method of control. Use Industrial Noise Control Manual as source of case studies.
III. Noise Control at the Receiver A. Last Resort of Noise Control B. Basically Two Techniques 1. Administrative controls. 2. Personal protective equipment. C. Discussion of Techniques 1. Administrative.	
a. review basic current criteria	Slide 4.4.2.8.--Current Criteria
(1) discuss level and exposure (2) discuss how to compute total exposure if exposure is at different times and levels	Slide 4.4.2.9.--Combined Levels $\Sigma C_i/T_i < 1.00$ for all where i denotes an exposure. The sum of the ratios C_i/T_i is called the "daily dose."

Lesson Outline	
Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
b. administrative procedures	Slide 4.4.2.10.--Procedures
(1) workers at 90 dBA are not exposed to higher levels (2) workers at higher levels should be removed from noise after indicated limits are reached and spend balance of day at levels lower than 85 dBA (3) split shifts (work time should be divided between two or more operations) (4) when less than full-time operation of a machine is required, time is split into partial day instead of full day operation (5) exposure time is reduced by shift scheduling to reduce number of exposed employees and number requiring protective equipment	
2. Protective equipment.	Slide 4.4.2.11.--Quote
a. discuss inertia measure or procedure	
b. Department of Labor Bulletin 334 Guidelines	Slide 4.4.2.12.--Guidelines of Ear Protection Devices
(1) only approved ear protectors that have been tested in accordance with ANSI standards, 224.22-1957, should be used	

Lesson Outline	
Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
(2) 5 dB less than the stated attenuation of equipment should be allowed because test data were obtained under ideal conditions that are not normal day-to-day operations (3) ear muffs and ear plugs should be fitted and supplied through a properly trained person who can educate the workers in the use and maintenance of muffs and plugs (4) wax impregnated cotton and fine glass wool are acceptable, but cotton stuffed in the ears has very little value and is not acceptable	
c. types of personal protective equipment (1) ear plugs -sized plugs -formable plugs -individually molded plugs (2) ear muffs -helmets	At this point, direct the student to see the Learning Center associated with personal protective equipment.
d. protection obtained (1) varies because of individual; varies by type of material	

TOPIC	REMARKS
(2) how can sound reach the ear of a person needing protection -by passing through the bone and tissue around the protector -by causing vibration of the protector itself which generates sound in the ear -by passing through leaks in the protector itself -by passing through leaks around the protector	Slide 4.4.2.12.--Performance of Ear Protectors Slide 4.4.2.13.--Cotton vs. Plastic Slide 4.4.1.14.--Poorly Fitted and Well Fitted
(3) ways to avoid leaks -make plugs out of imperforated material -make plugs fit well to avoid audio leaks around protector -design plug so that it does not vibrate	
(4) attenuation of ear plugs and muffs is determined by strict standards -discuss mean attenuation -95% confident interval (standard deviation away from mean)	Slides 4.4.2.15., 4.4.2.16.--Attenuation Expected of Good Muffs and Ear Plugs

Lesson Outline	
Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
-how to determine expected noise reduction; use the graph, mean value and minimum value and subtract from the corresponding frequency dBA, add final values to determine attenuation received (5) noise reduction and communication -wearing ear plugs or muffs in a quiet environment interferes with speech communications; however, wearing ear plugs or muffs in noise levels above 90 dB will not interfere with speech communication (in fact, communication might be increased) -due to ear keeping a constant noise to speech ratio and the ear will not distort speech -may be difficult to assure employees that this happens (6) before starting an ear plug or muff program, do the following: -involve worker; may be some resistance; let him choose type he wants; he will be more likely to use it	

Lesson Outline

Noise Control--Continued	Module 4 Unit 4 Lesson 2

TOPIC	REMARKS
-be sure that medically the employee can wear the plugs and muffs; he should be examined to make sure	
IV. Summary	
A. Review Control Methods	Have students recall the techniques. Use
1. At the source.	Slide 4.4.2.17.--Review of Control Techniques
a. substitution b. direct sound away from point of interest c. vibration control (1) reduce driving force (2) isolate driving force from radiating surface (3) reduce response of vibrating surface d. air flow control (1) mufflers; i.e., reduce velocity e. remove machine to another room	
2. Along path. a. shields b. barriers c. partial enclosures d. total enclosures e. room absorption	
3. At receiver. a. administrative controls b. personal protective equipment	
B. There are Many Solutions to a Given Problem	Note to Instructor: It is advisable to construct for the student a list of references in which case studies can be reviewed.
1. Best to read the available research on how others solved the problem before picking a definite solution.	

Self-Test	
Sound	Module 4

1. What is sound?

____

____

2. What is the wavelength of a 1000 Hz wave being propogated through air at $68^{o}F$?

3. Define the following terms:

Sound pressure ____

____

Sound power ____

____

Sound intensity ____

____

4. Why is the relationship between sound intensity and sound power referred to as the "inverse square law"?

5. What is the sound pressure that would be produced at a distance of 100 feet from a pneumatic chipping hammer if the power of the hammer is given as 1.0 watts?

6. Convert the following to sound intensity level, sound power level, and sound pressure level.

   a. A sound intensity of 0.08 watts per square meter has a sound intensity level of __________.

   b. A sound power of 4.0 watts has a sound power level of __________.

   c. A sound pressure of 20 N/m^2 has a sound pressure level of ________.

7. Predict the sound pressure level that will be produced at a distance of 3 feet directly in front of a machine. The machine has a directivity factor of 5 and a sound power of 0.1 watts. Let T = 0.

8. Describe in words the critical distance.

____

____

9. A room has the following characteristics:

   a. Floor; 10 ft by 10 ft with an absorption coefficient of 0.37 at 1000 Hz.
   b. Ceiling; 10 ft by 10 ft with an absorption coefficient of 0.90 at 1000 Hz.
   c. 4 walls; 10 ft by 8 ft with an absorption coefficient of 0.50 at 1000 Hz.

   What is the average absorption coefficient?

   What is the room constant of the room?

10. Assume a chipping hammer in the center of a room radiates a sound power level of 120 dB; the machine has a Q factor of 1; the average distance the machine is from the wall is 6.87 feet; and the room constant equals 229.37 square feet. What is the sound pressure level at the walls?

11. The sound pressure level in a room is 113.566 dB at the wall. The noise reduction of the wall between room A and B is 41.642 dB. What is the sound pressure level at the wall between A and B on the B side?

12. Define threshold of hearing.

____

____

13. List at least five causes of hearing loss.

a.

b.

c.

d.

e.

14. If on a sound level meter the measured level with the C weighting network is greater than the measured level on the A weighting network, approximately what is the frequency of the sound?

15. How is hearing loss defined?

____

____

16. What systems in the body can be affected by noise exposure?

a.

b.

c.

Self-Test	
Sound	Module 4

17. List four characteristics of noise that people find annoying.

____

____

____

____

____

____

18. What are two types of effects of vibration on the human body?

    a.

    b.

19. What is Raynaud's Syndrome?

____

____

____

20. List three general ways vibration can be controlled.

    a.

    b.

    c.

21. List the three locations where noise can be controlled.

    a.

    b.

    c.

22. List at least three techniques used to control noise along its path.

    a.

    b.

    c.

Self-Test Answers	
Sound	Module 4

1. What is sound?

   Sound is an oscillation in atmospheric pressure within an elastic medium of any phase.

2. What is the wavelength of a 1000 Hz wave being propogated through air at $68^{o}F$?

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

   In normal conditions, C = 1127 ft/sec and f is given as 1000 Hz; thus

   $$\lambda = \frac{1127 \text{ ft/sec}}{1000 \text{ cycles/sec}}$$

   $$= 1.127 \text{ ft/cycles}$$

3. Define the following terms:

   Sound pressure *The difference between atmospheric pressure and the actual pressure during rarefraction and compression.*

   Sound power *The total energy radiated by a sound source per unit time.*

   Sound intensity *Sound power per unit area.*

4. Why is the relationship between sound intensity and sound power referred to as the "inverse square law"?

   Because sound intensity varies inversely with the square of r.

   $$\text{Sound intensity} = \frac{\text{Sound pressure}}{4\pi r^2}$$

5. What is the sound pressure that would be produced at a distance of 100 feet from a pneumatic chipping hammer if the power of the hammer is given as 1.0 watts?

   $$P = \sqrt{\frac{3.5 \times 1.0 \text{ watts} \times 10^2}{(100 \text{ ft})^2}}$$

   $$= 0.187 \text{ N/m}^2$$

6. Convert the following to sound intensity level, sound power level, and sound pressure level.

   a. A sound intensity of 0.08 watts per square meter has a sound intensity level of __________.

   $$SIL = 10 \text{ Log } I + 120$$
   $$= 10 \text{ Log } 0.08 + 120$$
   $$= 109 \text{ dB}$$

   b. A sound power of 4.0 watts has a sound power level of __________.

   $$SWL = 10 \text{ Log } W + 120$$
   $$= 10 \text{ Log } 4 + 120$$
   $$= 126 \text{ dB}$$

   c. A sound pressure of 20 N/m^2 has a sound pressure level of ________.

   $$SPL = 20 \text{ Log } P + 94$$
   $$= 20 \text{ Log } 20 + 94$$
   $$= 120 \text{ dB}$$

7. Predict the sound pressure level that will be produced at a distance of 3 feet directly in front of a machine. The machine has a directivity factor of 5 and a sound power of 0.1 watts. Let T = 0.

   $$SPL = SWL - 20 \text{ Log } r - 0.5 \text{ dB} + 10 \text{ Log } Q + T$$
   $$= 10 \text{ Log } \left(\frac{0.1 \text{ watt}}{10^{-12} \text{ watts}}\right) - 20 \text{ Log } 3 \text{ ft} - 0.5 \text{ dB} + 10 \text{ Log } 5$$
   $$= 106.95 \text{ dB}$$

8. Describe in words the critical distance.

   The critical distance is the point ending the inverse square field and beginning the reverberant field.

9. A room has the following characteristics:

   a. Floor; 10 ft by 10 ft with an absorption coefficient of 0.37 at 1000 Hz.
   b. Ceiling; 10 ft by 10 ft with an absorption coefficient of 0.90 at 1000 Hz.
   c. 4 walls; 10 ft by 8 ft with an absorption coefficient of 0.50 at 1000 Hz.

   What is the average absorption coefficient?

$$\bar{\alpha} = \frac{\sum_{i=1}^{6} S_i \alpha_i}{\sum_{i=1}^{6} S_i}$$

$S_{floor} = 100\ ft^2;\ \alpha_{floor} = 0.37;\ S\alpha_{floor} = 37$

$S_{ceiling} = 100\ ft^2;\ \alpha_{ceiling} = 0.90;\ S\alpha_{ceiling} = 90$

$S_{wall} = 320\ ft^2;\ \alpha_{wall} = 0.50;\ S\alpha_{wall} = 160$

$$\bar{\alpha} = \frac{37 + 90 + 160}{100 + 100 + 320} = \frac{287}{520} = 0.55 \text{ sabins}$$

   What is the room constant of the room?

$$R = \frac{\sum_{i=1}^{6} S_i \alpha_i}{1 - \bar{\alpha}} = \frac{287 \text{ sabins sq. ft}}{(1 - 0.55) \text{ sabins}} = 637.7 \text{ sq. ft.}$$

10. Assume a chipping hammer in the center of a room radiates a sound power level of 120 dB; the machine has a Q factor of 1, the average distance the machine is from the wall is 6.87 feet; and the room constant equals 229.37 square feet. What is the sound pressure level at the walls?

$$SPL = SWL + 10 \text{ Log} \left[\frac{Q}{4\pi r^2} + \frac{4}{R} \right] + 10.5 + T$$

$$= 120 \text{ dB} + 10 \text{ Log} \left[\frac{1}{4(3.14)(6.87\ ft)^2} + \frac{4}{229.37\ ft^2} \right] + 10.5 + T$$

$$= 113.316 \text{ dB} + T$$

11. The sound pressure level in a room is 113.566 dB at the wall. The noise reduction of the wall between room A and B is 41.642 dB. What is the sound pressure level at the wall between A and B on the B side?

$$SPL_B = SPL_A - NR$$
$$= 113.566\ dB - 41.642\ dB$$
$$= 71.924\ dB$$

12. Define threshold of hearing.

A sound is at the threshold of hearing when it is just intense enough to evoke a response from the listener.

13. List at least five causes of hearing loss.

a. age

b. exposure to loud noise

c. congenital defects

d. anatomical injuries

e. disease

14. If on a sound level meter the measured level with the C weighting netword is greater than the measured level on the A weighting network, approximately hwat is the frequency of the sound?

$$L_C - L_A > 0$$

Then the sound is at a low frequency.

15. How is hearing loss defined?

The difference between an individual's hearing and the average threshold for young, healthy adults.

16. What systems in the body can be affected by noise exposure?

a. cardiovascular

b. endocrine

c. neurological

Self-Test Answers	
Sound	Module 4

17. List four characteristics of noise that people find annoying.
    a. *Loud noise is more annoying than a less loud noise.*
    b. *Noise varying in intensity and frequency is more annoying than a continuous, steady-state noise.*
    c. *Nondirectional noise is more annoying than directional noise.*
    d. *Noise that appears to be moving is more annoying that noise that appears to be stationary.*
18. What are two types of effects of vibration on the human body?
    a. *whole-body vibration*
    b. *segmental vibration*
19. What is Raynaud's Syndrome?
    It is often called "dead fingers" or "white fingers." It is the condition where the circulation of the hands becomes impaired and when exposed to the cold the fingers become white and void of sensation.
20. List three general ways vibration can be controlled.
    a. *By reducing the driving force.*
    b. *By isolating the driving force from the radiating surface.*
    c. *By reducing the response of the radiating surface.*
21. List the three locations where noise can be controlled.
    a. *At the source.*
    b. *Along its path.*
    c. *At the receiver (ear).*
22. List at least three techniques used to control noise along its path.
    a. *Shields and barriers*
    b. *Partial and total enclosures*
    c. *Room absorption*

References	
Sound	Module 4

American Industrial Hygiene Association. Industrial Noise Manual. Akron: American Industrial Hygiene Association, 1975.

Baumeister, Theodore, ed. Mark's Standard Handbook for Electrical Engineers. New York: McGraw-Hill Book Company, 1967.

Beranek, Leo L., ed. Noise and Vibration Control. New York: McGraw-Hill Book Company, 1971.

Hewitt, Paul G. Conceptual Physics . . . A New Introduction to Your Environment. Boston: Little, Brown and Company, 1974.

Patty, Frank A. Industrial Hygiene and Toxicology, 2d ed. New York: Interscience Publishers, Inc., 1958.

Peterson, Arnold P. G. and Ervin G. Gross, Jr. Handbook of Noise Measurement, 7th ed. Concord, Massachusetts: General Radio, 1974.

Salmon, Vincent, James S. Mills, and Andrew C. Peterson. Industrial Noise Control Manual. HEW Publication No. (NIOSH) 75-183. Washington: U. S. Government Printing Office, 1975.

United States Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. the Industrial Environment--its Evaluation and Control. Washington: U. S. Government Printing Office, 1973.

☆ U. S. GOVERNMENT PRINTING OFFICE