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Experiment 1

PENDULUM EXPERIMENT

INTRODUCTION

In this experiment we determine the period of a *simple pendulum* – a mass suspended on a string. By the period we mean the time it takes for one complete swing (or oscillation), back and forth. (A *rapidly* swinging pendulum has a *short* period.) The idea is to make careful observations, so that we may test hypotheses about the effect of various factors on the period. The factors we will investigate are:

1. the mass
2. the length of the string
3. the *amplitude* of the swing

Before making any observations, use your imagination. Try to figure out -or guess- what effect the mass, string length, and amplitude are going to have on the period, and record your hypotheses below, by checking the appropriate box.

Pendulum: Hypothesis Table

Change	influence on period		
	longer	shorter	no change
more mass			
longer string			
larger swing			

Now you are ready to make observations. It is best to work in teams, with one person counting the number of swings while the other measures the time using a stop-watch or a smartphone. Determine the time required for 25 *complete swings* (or any comparable number of swings, it is up to you). Do this *three times* for each particular set of variables, and record your measurements on the data sheets.

VARYING MASS

Set the length at some convenient value (say 50 cm), and measure the time for 25 swings, for four different masses starting with 20 g or less, and increasing to 500 g or more. Try to start the pendulum with the same amplitude in each case say 10^o.

Length:– – – – – – – –cm.

	time for 25 swings				mean / 25
mass (g)	trial 1 (s)	trial 2 (s)	trial 3 (s)	mean* (s)	period (s)

* The mean is just the average of your three time measurements, *for a given mass.*

VARYING LENGTH

Keep the mass fixed (at 100 or 200 g), and measure the time for 25 swings, for four different lengths, starting at about 10 cm, and increasing to the largest length the setup allows.Try to start the pendulum with same amplitude in each case, say 10^o.

Mass:– – – – – – – –g.

	time for 25 swings				mean / 25
length (cm)	trial 1 (s)	trial 2 (s)	trial 3 (s)	mean (s)	period (s)

VARYING THE AMPLITUDE

Keep the mass fixed (at 100 or 200 g), and set the length at 50 cm or so. Measure the time for 25 swings, for four different amplitudes, starting at about 10^o, and increasing to 90^o.

Mass:− − − − − − − −g; Length:− − − − − − − −cm.

	time for 25 swings				mean / 25
amplitude	trial 1 (s)	trial 2 (s)	trial 3 (s)	mean (s)	period (s)

ANALYSIS

1. Compute the mean times and record in the table. If one of your three time measurements is very different from the other two, notify the instructor - there may be an error, and it may be advisable to repeat that measurement.

2. Based on your measurements, state the effect of varying *mass* on the period. Do your measurements support or refute your original hypothesis?

3. Based on your measurements, state the effect of varying *length* on the period. Do your measurements support or refute your original hypothesis?

4. Make a plot of the period versus the amplitude. Based on your measurements, state the effect of varying *amplitude* on the period. Do your measurements support or refute your original hypothesis?

Experiment 2

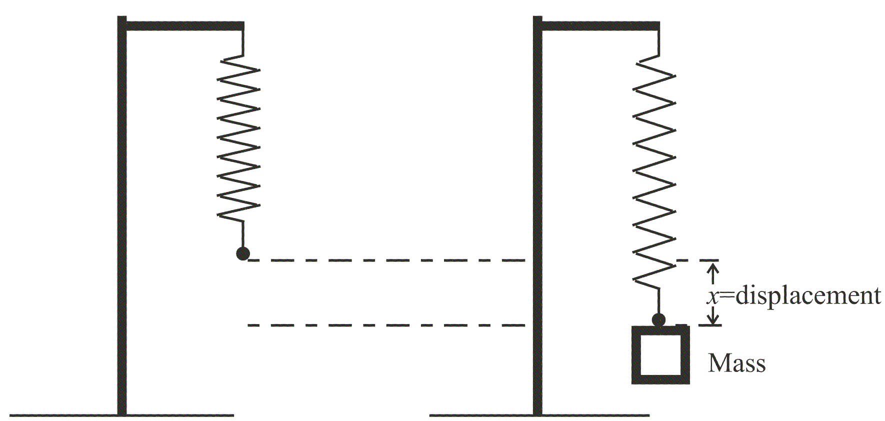
SIMPLE HARMONIC MOTION

PURPOSE

The purpose of this experiment is to understand the concept of simple harmonic motion using the example of a mass suspended by a spring and verify the theoretical prediction for the period of oscillation of a mass-spring system.

APPARATUS

Spring, weightholder and weights, stop-watch, half-meter stick, balance.



THEORY

When a body of mass m is suspended from a spring, its weight (weight=$F = mg$) causes the spring to elongate. The elongation x, is directly proportional to the force exerted

$$F = kx,$$

where k is the spring constant (or force constant). k measures the stiffness of the spring. The above relationship is known as Hooke's law and applies to all elastic materials within the elasticity limit. According to Newton's third law, the force with which the spring is acting on the suspended mass, is the opposite of the above,

$$F = -kx.$$

The sign minus in this formula reflects the fact that the force from the spring on the mass is a *restoring* force. Restoring force is the main prerequisite for oscillations.

If the body is pulled down and then released, it will oscillate about the equilibrium position (the position of the body when the spring was stationary). This motion is called simple harmonic motion. In this experiment we will measure the period of oscillation and see how amplitude and mass affect the period.

The theoretical value for the period, T, of the motion is given by

$$T = 2\pi\sqrt{\frac{M}{k}}, \qquad (1)$$

where M is the effective mass of the vibrating system, which is made up of the mass of the suspended body plus a part of the mass of the spring, since the spring itself is also vibrating. From mechanics follows

$$M = m + \frac{m_{\text{spring}}}{3} \qquad (2)$$

EXPERIMENT

Part A. To determine how the period of oscillations depends on the amplitude.

A1. Suspend a 100 g mass from the spring.

A2. Make careful measurements of T (period) versus A (amplitude) for various amplitudes such as 1.5 cm, 3 cm and 4.5 cm. (To get an amplitude of 3 cm, displace the mass 3 cm from its rest position and then let it go.) For each amplitude, measure the time for 50 complete cycles. Fill Table A with data. (The values above are just for your orientation. You may choose modified values.)

TABLE A

Suspended mass, $m =$__________

Amplitude A (cm)	Time for 50 cycles t (s)	Period $T = t/50$ (s)	Frequency $f = 1/T$ (Hz)

Part B. To find the mass of the spring and the spring constant k.

B1. Use the balance to determine the mass of the spring and of the weight holder.

B2. Suspend the holder and move the scale vertically so the pointer is on zero. Add 50 g and allow the system to come to equilibrium. Record the added mass and the new position of the pointer in Table B. Continue in this manner, adding 50 g at a time until the final load is 250 g.

TABLE B

Suspended mass m (g)	Displacement x (cm)	Force on the spring $F = mg$ (N)

Part C. To determine how the period of oscillation changes for different masses and to verify the theoretical formula for the period.

C1. Suspend a 150 g mass from the spring. Set the mass into vertical oscillation of a small amplitude. Using a stop-watch, measure the time for 50 complete cycles. Write data in Table C. If the holder is suspended, add its mass to m.

C2. Repeat the procedure C1 for a 200 g and 250 g masses.

TABLE C

$m_{\text{spring}} =$________________

Suspended mass m (g)	Time for 50 cycles t (s)	Period $T = t/50$ (s)	Frequency $f = 1/T$ (Hz)

ANALYSIS

Part A.

1) Using your data from A2 calculate the period and frequency of vibration for each observation and fill in Table A.

2) Does the period of vibration depend on the amplitude for the cases you studied?

Part B.

3) From the data in Table B, plot a graph of $F = mg$ versus displacement x, where $g = 9.8\ \mathrm{m/s^2}$. Make sure that the mass is expressed in kg ($1000\,\mathrm{g} = 1\,\mathrm{kg}$) and the displacement x is measured in meters ($100\,\mathrm{cm} = 1\,\mathrm{m}$).

4) Determine the spring constant k (in N/m) from the slope of this graph, as explained in Lab 1.

Part C.

5) Calculate the theoretical value for the period, T, for the masses used in measurement of the period, using the formulas (1) and (2), k being the value determined from your graph above.

6) Compare your experimental values for T in Table C with the theoretical values for T by calculating the percentage discrepancy. Fill in the Table below.

Effective mass, M M (g)	Period (experiment) T_{exp} (s)	Period (theory) T_{theor} (s)	% discrepancy

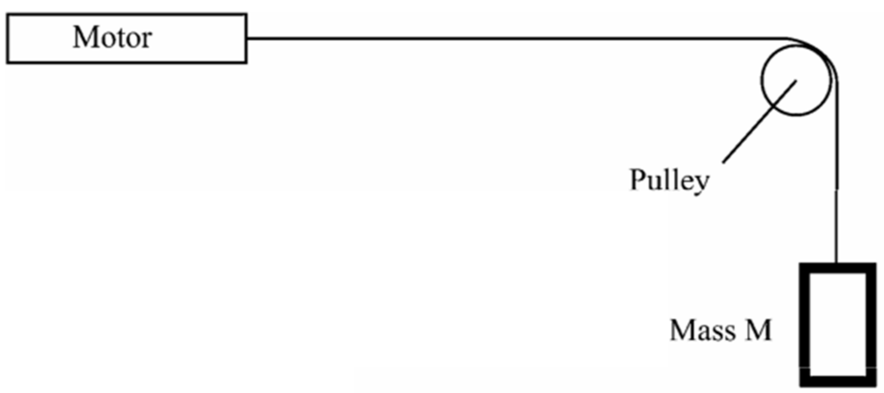
7) Discuss your results and discrepancies. Did the lab produce the expected outcome?

Experiment 3

STANDING WAVES ON STRINGS

PURPOSE:

To observe standing waves on a stretched string and to verify the formula relating the wave speed to the tension and mass per length of the string.



APPARATUS:

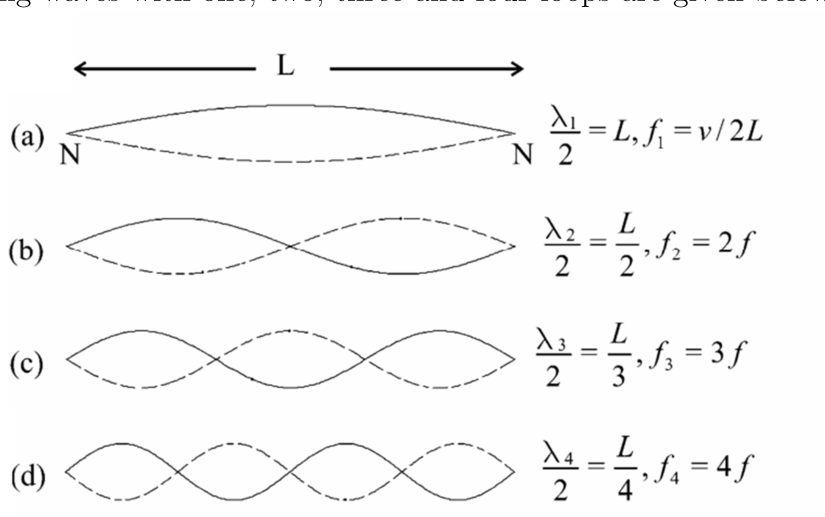
String vibrator, string, set of slotted weights, weight holder, pulley and clamp, meter stick, analytical balance.

THEORY

Standing waves are produced by the interference of two waves of the same wavelength, speed of propagation and amplitude, travelling in opposite directions through the same medium.

If one end of a light, flexible string is attached to a vibrator and the other end passes over a fixed pulley to a weight holder, the waves travel down the string to the pulley and are then reflected, producing a reflected wave moving in the opposite direction. The vibration of the string is then a composite motion resulting from the combined effect of the two oppositely directed waves. If the proper relationship exists between the frequency, the length and the tension, a *standing wave* is produced and when the conditions are such as to make the amplitude of the standing wave a maximum, the system is said to be in *resonance*. A standing wave has points of zero displacement (due to destructive interference) and points of maximum displacement (due to constructive interference). The positions of no vibration are called nodes (N) and the positions of maximum vibration are called antinodes (A). The segment between two nodes is called a loop.

Standing waves with one, two, three and four loops are given below.



The solid line represents the form of the string at an instant of maximum displacement and the dotted line represents the configuration one half-period later when the displacements are reversed. In each case $\lambda = 2l$, where λ is the wavelength and l is the distance between two nearby nodes. For a string with both ends fixed the allowed wavelengths for standing waves can only take fixed values related to the length L of the string, as can be seen in the figure above.

If one changes the tension in a vibrating string, the number of loops between the ends of the string change. As a result the distance between neighboring nodes changes, thus producing a change in wavelength.

The speed of the wave can be obtained if the frequency f is known and the wave length λ has been measured:

$$v = \lambda f. \tag{3.1}$$

The frequency is fixed by the string vibrator; the wavelength can only take on fixed values related to the length of the string, as shown in the figure above. Thus, standing waves can only exist for particular values of v that is controlled in this experiment by the tension of the string.

The velocity of the wave is given by the Mercenne's law:

$$v = \sqrt{\frac{T}{m}}, \tag{3.2}$$

where m is the mass per length of the string and T is the tension. The tension of the string (in newtons) equals the total hanging mass M times the gravitational acceleration $g = 9.8\ m/s^2$, that is, $T = Mg$.

The main objective of the work is to compare the experimental value of the wave speed given by Eq. (1) and its theoretical value of Eq. (2).

EXPERIMENTAL SETUP

A string is attached to a vibrator made of steel and then passed over a small pulley as shown in Fig.1. The coil producing the alternating magnetic field acting on the vibrator is being fed by the standard ac current with a fixed frequency of 60 Hz. The attraction force exerted on the vibrator is proportional to the square of the magnetic field and thus of the electric current in the cirquit. As the result, the vibrator is vibrating at the double frequency, 120 Hz.

The weight on the hanger has to be adjusted to achieve the tension T and thus the wave speed v at which a standing wave is clearly visible. As the range of the tension is limited, not all kinds of standing waves can be observed without changing the string length L. For instance, to observe lower overtones, the tension T can be increased or L can be decreased.

The best way to measure the wave length λ is to measure the distance d between the end of the string at the pulley (where there is a node) and the node closest to the vibrator and count the number n of loops within this region. Then

$$\lambda = \frac{2d}{n}.$$

Keep in mind that there is no node directly at the vibrator, thus using L to obtain λas shown in the figure above will result in errors.

PROCEDURE

1. Measure the length of the loose string (not the one attached to the vibrator) and then measure its mass using the analytical balance to the nearest milligram. Calculate the mass per unit lengh m for the string.

2. Suspend a light weight holder from the string and adjust the load until the string vibrates with maximum amplitude. Record the load in kilograms, including the weight of the holder. Measure λ as explained above and record it in the table together with the number of loops you observe.

3. Repeat the observations with load (and maybe the string length) adjusted to give other numbers of loops. Take measurements for at least three different numbers of loops.

DATA

f=

(frequency)

Length= m	Mass= kg	m=mass/length= kg/m
(length of loose string)	(mass of loose string)	(mass per length of string)

Number of loops	λ (m)	$v_{\text{exp}} = f\lambda$ (m/s)	M (kg)	$T = Mg$ (N)	$v_{\text{theor}} = \sqrt{T/m}$ (m/s)	% discr
1 loops						
2 loops						
3 loops						
4 loops						

ANALYSIS

1) Calculate the mass per unit length and express it in kg/m.

2) Calculate the velocity of the wave on the string using equations (1) and (2) and compare the results. Calculate the percent discrepancy. Fill all of this in the data table.

3) In your conclusion discuss your results.

4) If the frequency of the vibrator were 240 Hz, calculate theoretically how much tension is necessary to produce a standing wave of two loops. Consider that the string is fixed at its two ends, has a length of 1 meter and has the same mass per length as determined before.

Experiment 4

STANDING WAVES IN AIR COLUMNS

PURPOSE

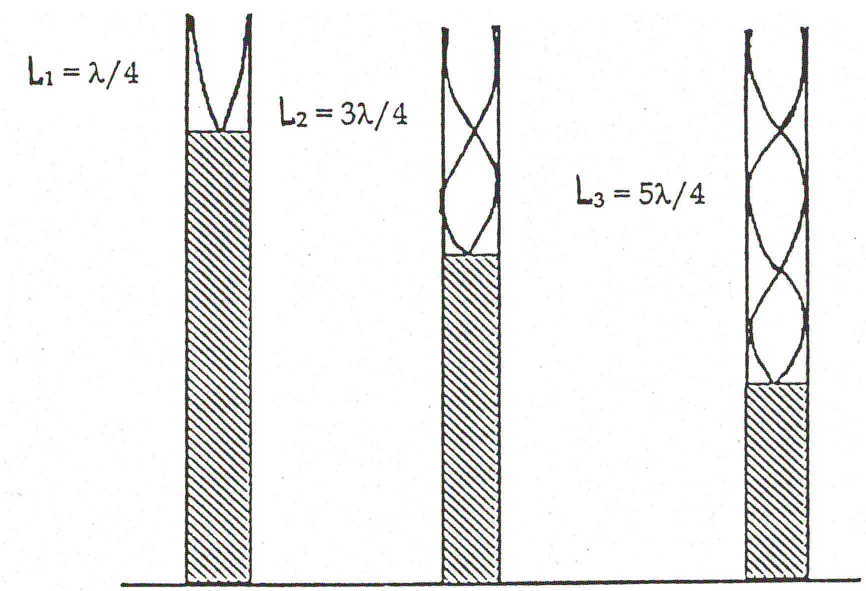
To understand standing waves in closed pipes and to calculate the velocity of sound in air.

APPARATUS

Resonance tube apparatus, three tuning forks, meter stick, thermometer.

THEORY

If a tuning fork is set in vibration and held over a tube open at the top and closed at the bottom, it will send a sound wave, down the tube. This wave will be reflected at the tube's closed end, thus creating the possibility of a standing wave being set up in the air column in the tube. The figure below shows three such standing waves.



The relationship between the (variable) lengths of the air column in the tube L and the wavelengths of the standing waves λ are:

$$\lambda_1 = 4L_1, \qquad \lambda_3 = 4L_3/3, \qquad \lambda_5 = 4L_5/5, \tag{4.1}$$

etc. Note that in the case of a pipe with one end open and the other end closed there are no even overtones. Whenever the tube has one of the lengths satisfying these relations, the tube and the sound source are in resonance, or in other words, the tube resonates at the source's frequency. The condition of resonance is indicated by an increase in the loudness of the sound heard when the air column has the resonant length. The wave length λ depends in this experiment on the frequency f of the tuning fork used as

$$\lambda = v/f, \tag{4.2}$$

where v is the speed of sound.

Practically, in this experiment λ is measured and then the speed of sound is found from

$$v = f\lambda. \tag{4.3}$$

A closed tube has a displacement node at the closed end and a displacement antinode at the open end. This antinode is not located exactly at the open end but a little beyond it. A short distance is required for the equalization of pressure to take place. This distance of the antinode above the end of the tube is called the *end correction* and it is given by $l_{\mathrm{corr}} = 0.3d$, where d is the diameter of the pipe. Therefore, to be exact, one has to add this correction factor to the length of the tube at resonance in order to derive the wavelength from equation (1).

The velocity of sound in air is 331.5 m/s at 0°C. At higher temperatures the velocity is slightly greater than this and is given by

$$v = (331.5 + 0.6T)\,\mathrm{m/s} \tag{4.4}$$

where T is the room temperature in degrees Celsius.

This formula can be used to calculate the theoretical value for the speed of sound which should be compared to your experimental value calculated using equations (1) and (3).

In this experiment, a closed tube of variable length is obtained by changing the level of the water contained in a glass tube. The length of the tube above the water level is the length of the air column in use. The apparatus consists of a glass tube 1.2 m long, closed at the bottom. The height of the water column in the tube can be easily adjusted via moving up and down a supply tank, which is connected to the tube by a rubber hose.

To feed the water into the system, hold the supply tank higher then the glass pipe and slowly add water into the tank, so that the water flows from the tank into the pipe. End filling water when the level in the pipe reaches its top or somewhat less. After that, one can decrease the water level in the pipe by lowering the tank. Do not overfill the system.

PROCEDURE

Use only the rubber mallet to strike the tuning fork. Striking it on the lab bench or any other hard object will damage the tuning fork.

Do not at any time let the vibrating fork strike the top of the glass tube.

1. Record the frequency of each tuning fork, the temperature of the room and the inside diameter of the tube.

2. Raise the water level in the tube until it is close to the top. Strike one of the tuning forks and hold it over the open end of the tube. Determine the shortest tube length for which resonance is heard by slowly lowering the water level until you hear a resonance (loudening of the sound). When the approximate length for resonance has been found, run the water level up and down near this point to determine the position for which the sound is maximum. Measure and record the length of the resonating air column in Table 1 under the L_1 column.

3. Lower the water level until the next position at which resonance occurs is found and repeat Procedure 3 to determine the length of the tube for this case. Record your result under the L_3 column.

4. Repeat Procedures 3 and 4 using the other two tuning forks.

DATA

Table 1

tube diameter $d =$ m, $l_{\text{corr}} = 0.3d =$ m

frequency (Hz)	L_1 (m)	L_3 (m)	$L_1 + l_{\text{corr}}$ (m)	$L_3 + l_{\text{corr}}$ (m)	λ_1 (m)	λ_3 (m)	v_1 (m/s)	v_3 (m/s)

Table 2

frequency	$v_{\text{exp}} = (v_1 + v_3)/2$	v_{theor}	% discr

ANALYSIS

1. Calculate the correction factor, $l_{\text{corr}} = 0.3d$, where d is the inner diameter of the tube and add it to the tube lengths at resonance to find the corrected lengths. Enter your results in Table 1 in the appropriate columns.

2. Calculate the wavelength λ_1 and λ_3 using the corrected tube lengths and equation (1). Then calculate the corresponding speed of sound v_1 and v_3 using equation (2).

3. Calculate the theoretical value for the speed of sound using equation (3) and compare with your experimental value. To get the experimental value, average the two values from the Table 1. Determine the percent error in measuring the speed of sound in each case.

QUESTIONS

1) Suppose that in this experiment the temperature of the room had been lower. What effect would this have on the length of the resonating air column for each reading?

2) An observer measured an interval of 10 seconds between seeing a lightning flash and hearing the thunder. If the temperature of the air was 20^oC, how far away was the source of sound?

Experiment 5

SOUND INTENSITY - THE DECIBEL SCALE

PURPOSE

To understand the decibel scale in measuring sound intensities.

APPARATUS:

Sound source, two loudspeakers, sound level meter.

THEORY

The human ear on average can detect sounds with an intensity as low as $10^{-12}\ W/m^2$ and as high as $1\ W/m^2$ (and even higher, although above this it is painful). This is an incredibly wide range of intensity, spanning a factor of a trillion (10^{12}) from lowest to highest. Presumably because of this wide range, what we perceive as loudness is not directly proportional to the intensity. The human ear responds *logarithmically* to sound, which means that the intensity scale is compressed so that distances between the endpoints are not so large. To produce a sound that sounds twice as loud requires a sound wave that has about 10 times the intensity; a sound that sounds three times as loud requires a sound wave that has 100 times the intensity and so on. This is roughly valid at any sound level for frequencies near the middle of the audible range.

Because of this relationship between the subjective sensation of loudness and the physically measurable intensity, it is usual to specify sound-intensity levels using a logarithmic scale called *decibel* scale. The *sound intensity level* in dB (decibels) of any sound is defined as follows:

$$SIL = 10\log(\frac{I}{I_0}) \tag{5.1}$$

where $I_0 = 10^{-12}\ W/m^2$ is the threshold of hearing and I is the intensity of the sound in W/m^2.

Using this scale the SIL of a sound with intensity I_0 (threshold of hearing) is 0 dB. Similarly the SIL of a sound with intensity at the threshold of pain, 1 W/m^2, is 120 dB.

The decibel scale has to be used carefully if one deals with more than one sound source. If there are two sound sources, each with SIL of 50 dB for example, the combined sound intensity level is *not* 100 dB. Instead one has to convert the SIL to W/m^2, add the intensities from the two sources and then convert back to decibels.

To convert from SIL in dB to intensity in W/m^2 one can use the formula:

$$I = I_0\ 10^{\frac{SIL}{10}} \tag{5.2}$$

PROCEDURE

In this lab, two speakers will be used to produce sound. You will measure the sound intensity level in dB with a sound level meter for each speaker separately and then for both speakers together at different points in the room.

1. Take a station in the room. Be very quiet. When the first speaker is turned on, record the intensity in dB. Do the same when the other speaker is turned on. Next record the combined intesity when both speakers are turned on. Fill in the Table 1 below.

2. Move to the next station and repeat the experiment until your table is complete.

DATA

Table 1

Station	SIL 1 (dB)	SIL 2 (dB)	Combined SIL (dB)

ANALYSIS

1) Convert the decibel readings in Table 1 into W/m^2 using the formula given in the theory section. Fill in the table 2 below.

2) The combined intensity in W/m^2 should be the sum of the two individual intensities. Do your measurements agree with this? Compare the last two columns in table 2. Comment.

Table 2

Station	intensity 1 (W/m^2)	intensity 2 (W/m^2)	Combined intensity (W/m^2)	intensity 1 + intensity 2 (W/m^2)

Experiment 6

REVERBERATION TIME

PURPOSE

To understand how to calculate the reverberation time for a room.

THEORY

Reverberation is the combined effect of multiple sound reflections in a room which result to a gradual decay of the sound heard by the listener after the source of sound stops.

In order to deal with this effect in a quantitative way, the concept of *reverberation time* T_R is used. T_R is defined to be the time it takes for the sound to drop by 60dB from its steady state value after the sound is turned off. The reverberation time depends on the size and shape of the room as well as its contents.

A rather simple, approximate formula for the reverberation time in seconds is

$$T_R = 0.05\,\frac{V}{A} \tag{6.1}$$

where V is the volume of the enclosure in ft^3 (V=length $\times$ width $\times$ height) and A is the total absorption of the surface of the room in ft^2 (or sabin).

The total absorption A is

$$A = a_1 A_1 + a_2 A_2 + a_3 A_3 + \ldots \tag{6.2}$$

where the $A_1,\ A_2,\ A_3,\ldots$ are the areas of the various types of absorbing surfaces and the $a_1, a_2, a_3\ldots.$ are the absorption coefficients of the respective surfaces.

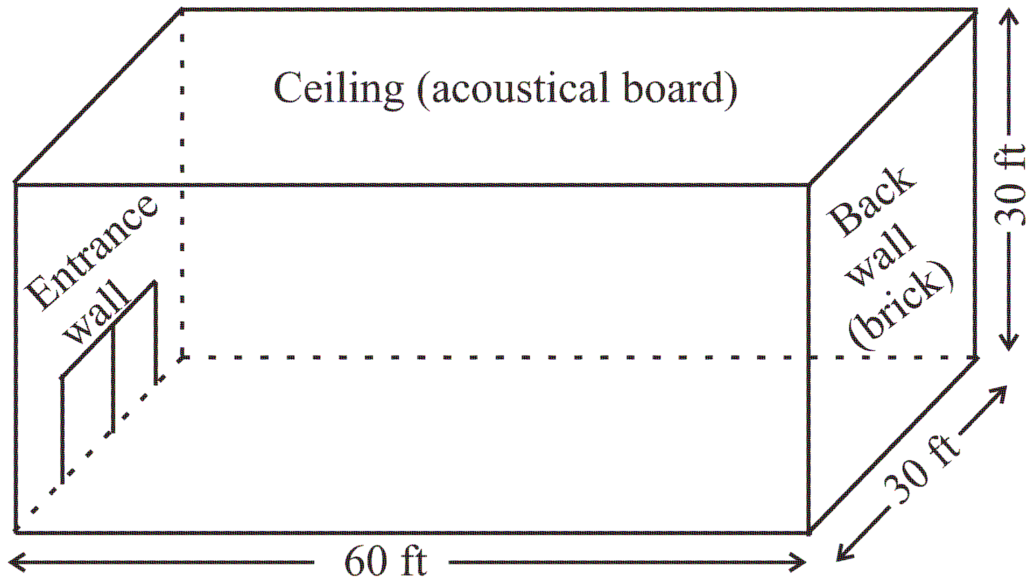
(If the areas and volumes are measured in meters rather than feet, the coefficient 0.05 is replaced by 0.161 in the formula for T_R.)

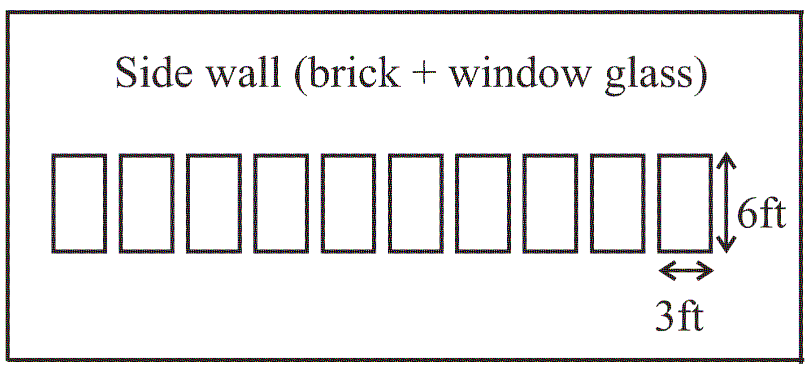
Attached is a table of sound absorption coefficients for some common materials found in studios or concert halls. Note that the absorption coefficients are frequency dependent.

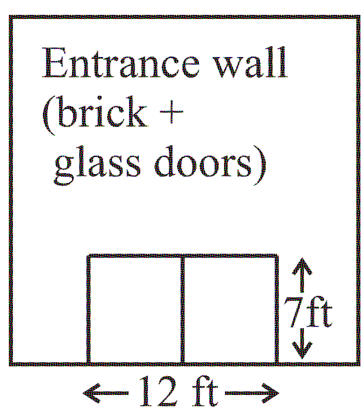
PROCEDURE

Calculate the reverberation time for the room shown below. The ceiling is made of acoustical boards. The long side walls are made of brick and there are 20 windows overall, each of size 3ft $\times$ 6ft. The entrance wall has a glass door of size 12ft $\times$ 7ft. The rest of the entrance wall as well as the back wall are also made of brick. The room also contains 400 upholstered seats.

Calculate the reverberation time for this hall for f=1000 Hz, when *all the seats are occupied*.


Ceiling (acoustical board)
Entrance wall
Back wall (brick)
30 ft
30 ft
60 ft


Side wall (brick + window glass)
6ft
3ft


Entrance wall
(brick +
glass doors)
7ft
12 ft

DATA-ANALYSIS

f=1000 Hz

Material	a_i	A_i	a_iA_i
ceiling			
floor			
brick			
glass			
seats			

Sum of column 3 = A =

Volume= V =

reverberation time = $T_R = 0.05\ \frac{V}{A} =$

QUESTIONS

1) For which purposes might this room be suited? (Check Fig. 1)

2) If you wanted to redesign the hall to have a longer T_R, what might you do?

3) What is the reverberation time if the seats in the hall are unoccupied?

4) A room with a volume of 10,000 ft^2 has T_R = 1.8 sec. What is the total absorption of the room surface in sabins (or ft^2) ?

TABLE 8–3 AVERAGE ABSORPTION COEFFICIENTS FOR SEVERAL TYPES OF BUILDING MATERIALS AT OCTAVE FREQUENCY INTERVALS

	Frequency (Hz)					
Material	125	250	500	1000	2000	4000
Concrete, bricks	0.01	0.01	0.02	0.02	0.02	0.03
Glass	0.19	0.08	0.06	0.04	0.03	0.02
Plasterboard	0.20	0.15	0.10	0.08	0.04	0.02
Plywood	0.45	0.25	0.13	0.11	0.10	0.09
Carpet	0.10	0.20	0.30	0.35	0.50	0.60
Curtains	0.05	0.12	0.25	0.35	0.40	0.45
Acoustical board	0.25	0.45	0.80	0.90	0.90	0.90
Wood Floor	0.15	0.11	0.10	0.07	0.06	0.07

TABLE 8–4 AVERAGE ABSORPTION IN SABINS AT OCTAVE FREQUENCY INTERVALS OF TWO TYPES OF AUDITORIUM SEATS, OF THE AVERAGE ADULT PERSON, AND OF AN AVERAGE ADULT PERSON SITTING IN AN UPHOLSTERED SEAT

	Frequency (Hz)				
	125	250	500	1000	2000
Unupholstered seat	0.15	0.22	0.25	0.28	0.50
Upholstered seat	3.0	3.1	3.1	3.2	3.4
Adult person	2.5	3.5	4.2	4.6	5.0
Adult in upholstered seat	3.0	3.8	4.5	5.0	5.2

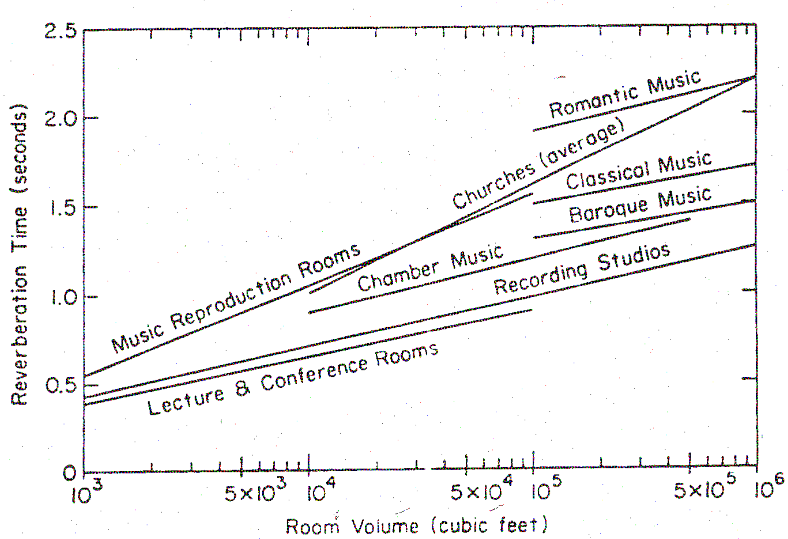


Figure 8–4 "Ideal" average reverberation time versus room volume for several basic types of rooms. Also shown are the optimum average reverberation times for several important types of music.