The objectives of this experiment are:

- To understand the concept of sound intensity and how it is measured.
- To learn how to operate a Sound Level Meter

**APPARATUS:** Radio Shack Sound Level Meter, meterstick, function generator in FFTSCOPE, headphones.

**INTRODUCTION**

Sound energy is conveyed to our ears (or instruments) by means of a wave motion through some medium (gas, liquid, or solid). At any given point in the medium the energy content of the wave disturbance varies as the square of the amplitude of the wave motion. That is, if the amplitude of the oscillation is doubled the energy of the wave motion is quadrupled.

The common method in gauging this energy transport is to measure the rate at which energy is passing a certain point. This concept involves sound intensity. Consider an area that is normal to the direction of the sound waves. If the area is a unit, namely one square meter, the quantity of sound energy expressed in Joules that passes through the unit area in one second defines the sound intensity. Recall the time rate of energy transfer is called "power". Thus, sound intensity is the power per square meter. The common unit of power is the watt (1 W = 1 Joules/s).

Normally, sound intensity is measured as a relative ratio to some standard intensity, $I_0$. The response of the human ear to sound waves closely follows a logarithmic function of the form $R = k \log I$, where $R$ is the response to a sound that has an intensity of $I$, and $k$ is a constant of proportionality. Thus, we define the relative sound intensity level as

$$SL(dB) = 10 \log \frac{I}{I_0}$$

The unit of $SL$ is called the decibel (abbreviated dB). $I$ is the intensity of the sound expressed in watts per meter and $I_0$ is the reference intensity defined to be $10^{-12}$ W/m². This value of $I_0$ is the threshold (minimum sound intensity) of hearing at 1 kHz for a young person under the best circumstances. Notice that $I/I_0$ is a unitless ratio; the intensities need only to be expressed in the same units, not necessarily W/m².

Another logarithmic measure of loudness is the sound pressure level defined as
\[ L_p = 20 \log \frac{p}{p_0} \]

Where \( p \) is the pressure amplitude and \( p_0 = 2 \times 10^{-5} \frac{N}{m^2} = 20 \mu Pa \) is the reference pressure variation. The units of the sound pressure level are also decibels (dB). Though typically indistinguishable from the sound intensity level, it is the sound pressure level which is measured on most common devices for determining loudness (e.g. the sound level meter discussed below). The sound pressure level is also written “SPL” for short.

**Examples:**

1. If we measured a sound intensity to be 560 greater than the threshold reference, what would be the sound intensity level expressed in dB?

\[
SL(dB) = 10 \log \left( \frac{560 \times 10^{-12}}{10^{-12}} \right) = 10 \log (560) = 27.5 dB
\]

2. The threshold of pain is about 120 dB. How many times greater in intensity (in \( W/m^2 \)) is this?

\[
SL(dB) = 10 \log \left( \frac{I}{I_o} \right)
\]

\[
\frac{120}{10} = 12 = \log \left( \frac{I}{10^{-12}} \right)
\]

\[
10^{12} = \frac{I}{I_o}
\]

\[
I = 1 watt / m^2
\]

Notice that the approximate threshold of pain is a factor of \( 10^{12} \) (that's a trillion!) greater than the threshold of hearing.

**The Sound Level Meter**

The instrument we will use for measuring sound levels is a Sound Level Meter (SLM) shown in Figure 1.* It consists of a microphone to detect the sound and convert it to a voltage, an amplifier to increase this

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* Adapted from the owner's manual of the Radio Shack Sound Level Meter, ©1985 Tandy Corporation.
voltage, weighting circuitry which is explained below, and a meter to display the sound level in dB.

The SLM has three switches to control its operation:

**Range Selector:** The rotary switch is used to select one of seven sound level ranges, each spanning 16 dB. Numbers of RANGE switch refer to the center-points of the seven ranges. The needle indicator shows the actual sound level as a displacement from the center-point.

Examples: Suppose RANGE is set to 80, and meter scale reads -3. Actual sound level is 80 - 3 = 77 dB. If the meter scale reads 0 (same RANGE setting), the actual sound level is 80 + 0 = 80 dB.

**Response Selector:** In FAST position, the meter will react quickly to the change in the sound level, giving you an indication of peak sound levels present in the environment. On SLOW position, the meter is damped and indicates an averaged valued for the sound level. The effect of bursts of sounds (intensity peaks) is minimized in the SLOW response.

**Weighting Selector:** The frequency response of the Sound Level Meter for each weighting characteristic is shown below. The C-weighting curve is nearly uniform over the frequency range from 32-10,000 Hz, thus giving an indication of overall sound level. The A-weighting characteristic responds primarily to frequency ranges in the 500-10,000 Hz range, which is the area of the greatest sensitivity of the human ear.

![Graph showing C and A weighting curves](image)

**Taking Accurate Measurements:** Select the RESPONSE and WEIGHTING. If the sound source consists of short bursts, or if you are interested in peak values only, set the RESPONSE to FAST. To measure average sound levels, use the SLOW setting. Select A-weighting for noise level determinations, and C-level for measuring sound levels which stay at 90 dB or above, or for which you wish to eliminate the ear's weighting.
factor. The A-weighting gives a better indication of apparent loudness at low frequencies because its frequency response is similar to that of the human ear. The C-weighting may be slightly more accurate in this respect at frequencies above 1 kHz.

Start with the HIGHEST RANGE setting (120 dB) and work downward until there is significant deflection of the needle. For GREATEST ACCURACY, always use the lower of any two possible settings.

Example: If the RANGE is set to 80 dB and the meter reads around -5, reset the RANGE to 70 dB and the meter will read +5, for an actual sound level of 75 dB.

In addition to the older model SLMs described above, your lab may also use newer devices with digital display of the sound pressure level. Their operations are analogous.

**The Sone**

The decibel is a measure of the sound level which does not include the human perception of loudness. The SONE is a unit that measures the perceived loudness of a sound. It is defined in terms of decibels and frequency:

\[
1 \text{ Sone} = 40 \text{ dB} @ 1 \text{ kHz}
\]

\[
= \text{ the loudness of a 1 kHz sound with an SPL of 40 dB.}
\]

At 1 kHz, the loudness in Sones can be related to the SPL in decibels by the following formula:

\[
\text{Loudness (Sones)} = 2^{(\text{SPL} \text{ in dB} - 40)/10}
\]

In general though, the apparent loudness of a sound depends on its frequency. As mentioned, the ear is less sensitive to low frequency sounds. Therefore a unit called the phon is defined so that it will have the same value at low or high frequencies if the sound at these different frequencies produces the same subjective impression of loudness. The curves of equal loudness level \((L_e)\) pictured left correspond to a certain loudness in phons. The results of two different studies are pictured in red and blue.
The general equation for loudness in Sones is therefore

\[ S = 2^{\frac{L - \text{in phons} - 40}{10}} \]

Since the loudness level in phons can be estimated for a given frequency and SPL with the Fletcher-Munson curves or the more modern ISO convention (both pictured above), the loudness in Sones can be readily determined. Notice that it takes a sound of greater intensity and pressure to achieve the same loudness at lower frequencies.

Example: What is the loudness in Sones of a 50 dB sound at 1 kHz?

\[
\text{Loudness (Sones)} = 2^{\frac{50 - 40}{10}} = 2^1 = 2
\]

Sones are useful units in that 2 Sones are supposed to be twice as loud as 1 Sone and 4 Sones are 4 times as loud as 1 Sone. However, the ear has no meterstick to judge loudness very accurately. The interpretation of the data from the ear is done by the brain, not by a more exact electronic meter. In fact the convention above that a ten-fold increase in SPL is required for a doubling of apparent loudness at 1 kHz has been called into question. Some researchers believe that a doubling in loudness is effected by a 6 dB increase in SPL. Thus, the seemingly universal perception of a similarity in sound upon doubling the frequency of a tone (i.e. the octave in music) doesn't necessarily have an exact counterpart where loudness is concerned. In part 2.A of this experiment, we will try to find out how accurate the Sone scale is.
INTENSITY OF SOUND

LAB REPORT FORM

NAME: _____________________________________ DATE: _____________
PARTNER(S): _______________________________________________________

Procedure Part One:

A. Familiarize yourself with the operation of the Sound Level Meter by measuring the background sound level of the lab room. Turn on the meter by setting the range dial to 120 dB. Set the response of the meter to SLOW. First measure the background sound level of the room by choosing C weighting. Rotate the range knob down through the ranges until the meter moves. Then measure the background sound level using the A weighting of the meter. If the value is too low for the sound level meter to read, assume that it is 60 dB.

Background Sound Level with C weighting = ________________________
Background Sound Level with A weighting = ________________________

Calculate the difference between the SPL measured with the C and A weighting and use the graph (Figure 2) to estimate the average frequency of the background sound.

B. Measure the sound level of a person talking from various distances. You will want to use FAST response to get peak sound levels. This does not have to be quantitatively accurate. Use the meter stick to measure the distances.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Sound Level</th>
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<td>(dB)</td>
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|              |              |
**Question One:** What role does distance play in the sound intensity? Explain your conclusions in terms of the qualitative trend of the data and the theoretical expectation (hint: consider the power radiated from a point source into a hemispheric area; then consider the corresponding intensity’s proportionality to a function of distance).

**Procedure Part Two:**

A. Connect the headphones to the PC speaker headphone jack. Set the function generator option of FFTSCOPE to a 1 kHz sine wave. Put the Sound Level Meter microphone next to one earpiece of the headphones and adjust the speaker volume so that the meter reads 60 dB. Use the “A” weighting.

**Question Two:** Approximately how many Sones is this? Show your calculation.

For the following procedure be careful not to hurt your hearing. If the sound is too loud for your ear, STOP! Put on the headphones. Now adjust the PC speaker volume until the sound is twice as loud. Your calculation should have shown that the original sound is 4 Sones. Now you have a sound level twice that or 8 Sones. Take off the headphones and measure the sound level in dB using the Sound Level Meter. Repeat your adjustment several times to see how reproducible it is. (Lab partners can try it too.) Now double the loudness again (16 Sones) and measure the sound level in dB. Repeat again for 32 Sones.

Compare your data to the theoretical model which claims that the doubling of loudness in Sones is the equivalent at 1 kHz to an increase in $L_p$ by 10 dB. Calculate the percent deviation between the two.

\[
\text{Deviation (\%)} = 100\% \times \left( \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} \right)
\]
<table>
<thead>
<tr>
<th>Loudness (Sones)</th>
<th>Theoretical Sound Level (dB)</th>
<th>Measured Sound Level (dB)</th>
<th>Deviation (%)</th>
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B. Now set the function generator to 100 Hz sine wave. Set the Sound Level Meter to "A" weighting. Now adjust the loudness from the headphones to 60 dB. Listen to the sound. Keeping the speaker volume the same, measure the sound level for 1 kHz. Listen again. Which signal sounds louder? Why? If your sound level meter will not register 60 dB (i.e. it is sub-threshold), you may use 70 or 80 dB instead. Enter your measured values in the table on the following page.

Try repeating this for "C" weighting. Is there any difference between the sounds at the two frequencies? Any difference from the “A” weighting? Explain.
Tabulate your results. Determine the loudness in phons by using the chart on pg.4 (red lines) with the “C” weighted values. Remembering that the “A” weighting already provides a good estimate of apparent loudness, compare the values for loudness level in phons as read from the chart and as measured with the “A” weighting. Comment below. From the “A” weighted value, compute the loudness in sones. Enter it in the final column.

<table>
<thead>
<tr>
<th>Signal (Hz)</th>
<th>Sound Level &quot;A&quot; Weighting dB(A)</th>
<th>Sound Level &quot;C&quot; Weighting dB(C)</th>
<th>Approximate Loudness (Phons)</th>
<th>Sones - &quot;A&quot; Weighting (Sones)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
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