2. Theory

Sound intensity level, loudness level and equal loudness curve (including hearing threshold curve and pain threshold curve):

The waves that cause sound perception in the hearing organs are called sound waves. The frequency range is usually 20 - 20000 Hz. The size of sound wave energy is described commonly by two physical quantities, sound intensity and sound intensity level. Sound intensity is the energy of a sound wave passing through a unit area perpendicular to the direction of sound wave propagation per unit time. It is represented by the symbol I and its unit is W/m^2. The sound intensity level is a logarithmic scale of sound intensity, which is defined according to the ability of the human ear to distinguish the change in sound intensity, expressed by the symbol L, and its unit is decibel (dB). The relationship between L and I is:

$$L = 10 \times \lg (I/I_0), \tag{1}$$

where $I_0 = 10^{-12} W/cm^2$. The frequency is 1000 Hz.

The subjective perception of the human ear about the strength of the sound is called loudness. Generally speaking, it increases with the increase of sound intensity, but the two are not a simple linear relationship, because it is also related to frequency. Sound waves of different frequencies cause equal loudness in the human ear, their sound intensity (or Sound intensity level) are not equal. In medical physics, the physical quantity of loudness level is used to describe the human ear's subjective perception of the strength of the sound. Its unit is *Phon*. It selects pure sound with a frequency of 1000 Hz as the reference sound and specifies its loudness level equal to the value of its sound intensity level (Note: their units are different). And then compare the sound of a certain frequency measured with this reference sound, if the sound of the measured sound sounds the same as the sound intensity level of the reference sound, the loudness level of the reference sound (numerically equal to the sound intensity level) is the loudness level of the sound. For example: A 1000 Hz and 40 dB sound, its loudness is 40 *Phon*. While a sound with a frequency of 100 Hz and a sound intensity level of 72 dB is equal to a reference sound with a sound intensity level of 1000 Hz of 60 dB, then a sound with a frequency of 100 Hz and a sound intensity of 72 dB has a loudness level of 60 *Phon*. Taking the common logarithm of frequency as the abscissa and the sound intensity level as the ordinate, plot the relationship curve between the sound intensity level and frequency when sounds of different frequencies and 1000Hz standard sounds are equal, the resulting curve is called equal loudness curve.

The sound that causes hearing not only has a range in frequency, but also a certain range in sound intensity. For any frequency within the range of human ear hearing, such as 20 Hz to 20,000 Hz, the sound intensity must also reach a certain value to cause human ear hearing. The minimum sound intensity that can cause hearing is called the hearing threshold. For different frequencies of sound waves, the threshold is different. The relationship between the threshold and the frequency is called the hearing threshold curve. As the sound intensity increases, the

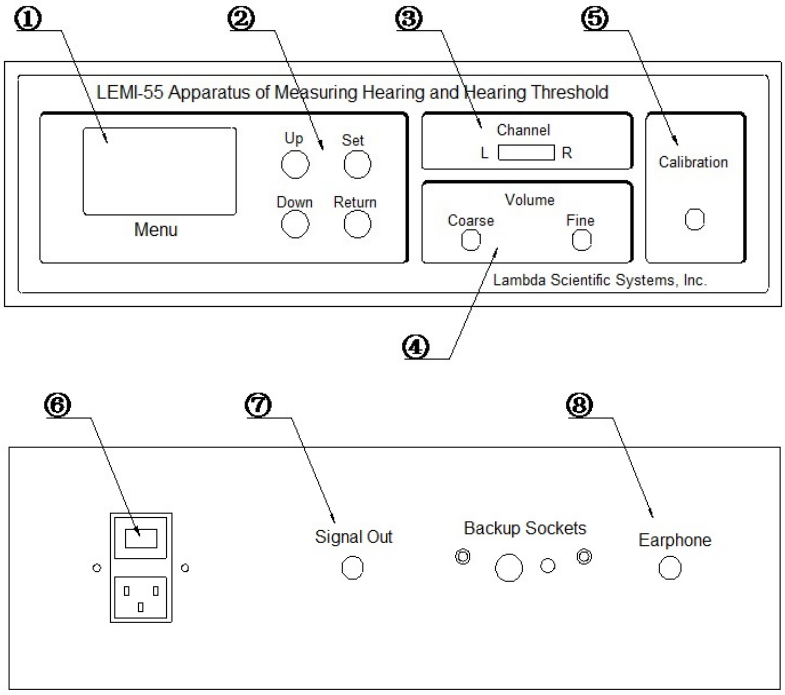
human ear feels that the loudness of the sound also increases. When the sound intensity exceeds a certain maximum value, the sound will cause pain in the human ear. This maximum sound intensity is called the pain threshold. For sound waves of different frequencies, the pain threshold is also different, and the relationship curve between the pain threshold and the frequency is called the pain threshold curve. The hearing threshold curve is an equal loudness curve with a loudness level of 0 *Phon*, and the pain threshold curve is an equal loudness curve with a loudness level of 120 *Phon*.

In clinical practice, audiometers are commonly used to measure the hearing thresholds of patients for sounds of various frequencies, and compare them with the hearing thresholds of normal people to diagnose whether the hearing of the patients is normal.

3. Apparatus Structure and Specifications

1) LEMI-55 human ear auditory test apparatus is composed of a standard sine wave generator in the audio frequency range, a frequency meter, a power amplifier circuit, a digital sound intensity indicator (dB meter), a fully sealed headset (monitor grade), and so on. The signal generator can generate a sine signal of any frequency from 20 Hz to 20,000 Hz through keying with a resolution of 1 Hz. Volume can be adjusted by adjusting the knobs of the amplifier (including coarse adjustment and fine adjustment) and send it to the headset to get different decibel sound levels. This instrument can measure the hearing of the human ear (left or right) for sounds with different frequencies and different sound intensities.

   The front and back panels of the apparatus are shown in Figure 1.



1. Menu display, 2. Setting keys, 3. Channel selection, 4. Volume adjustment
5. 0 dB calibration, 6. Power switch, 7. Signal output to oscilloscope, 8. Headset socket

Figure 1 Schematic of front and back panels of the apparatus

This apparatus uses a group of keys to set various parameters for the testing operations and a LED screen to display these parameters. The interfaces of menu, measurement and setting are shown in Figure 2. The keyboard consists of 4 keys.

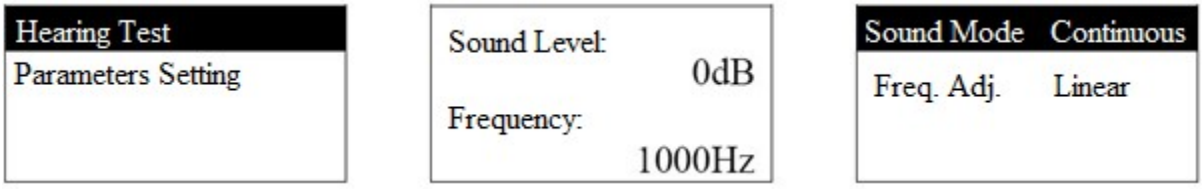


Figure 2 Interfaces of menu, measurement and setting

a) "Up" key

In the menu interface, the cursor moves up. In the measurement interface, when the Frequency mode is "Continuous", the frequency is increased by 1. Press for a long time to enter the key lock mode. The frequency is continuously increased, and the frequency adjustment range is 20 to 20,000 Hz. When the Frequency mode is "Logarithmic", the frequency is switched among a fixed number of characteristic frequencies. When the Frequency mode is "Number", it is used to increase the number value at the cursor position.

2. "Down" key

In the menu interface, the cursor moves down. In the measurement interface, when the Frequency mode is "Continuous", the frequency is reduced by 1. Press for a long time to enter the key lock mode, the frequency is continuously reduced, and the frequency adjustment range is 20 ~ 20,000 Hz. When the Frequency mode is "Logarithmic", the frequency is switched between a fixed number of characteristic frequencies, and when the Frequency mode is "Number", it is used to decrease the number value at the cursor position.

3. "Set" button

In the menu interface, access the menu item. In the measurement interface of Frequency mode, switch the cursor position. In the parameter setting interface, switch the function: continuous intermittent switching or frequency mode switching.

4. "Return" key

Return to the menu interface.

2) Key specifications

Description	**Specifications**
Signal source	Frequency range: 20 ~ 20 kHz; standard sine wave (smart key controlled)
Digital frequency meter	20 ~ 20 kHz, resolution 1 Hz
Digital sound strength meter (dB meter)	relative -35 dB to 30 dB
Headset	monitoring grade
Power consumption	< 50 W
Instruction manual	electronic version