Acoustics Kit U8440012

Instruction sheet

05/09 ELWE/ALF

1. Description

This set of apparatus makes it possible to impart an extensive and well-rounded overview on the topic of acoustics. The set can be used for conducting numerous experiments.

Sample experiments:

1. String tones
2. Pure acoustic tones
3. Vibrating air columns
4. Open air column
5. Whistle
6. Vibrating rods
7. Infrasound
8. Ultrasound
9. Tuning fork with plotter pen
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20. Stringed instruments and the laws they obey
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24. Wind instruments and the laws they obey
25. C major scale and its intervals
26. Harmony and dissonance
27. G major triad
28. Four-part G major chord
29. Major scales in an arbitrary key
30. Introduction of semitones

The set is supplied in a plastic tray with a foam insert that facilitates safe storage of the individual components.

2. Contents

1 Trays with foam inserts for acoustics kit
2 Monochord
3 Bridge for monochord
4 Metallophone
5 Chladni plate
6 Tuning fork, 1700 Hz
7 Tuning fork, 440 Hz
8 Tuning fork with plotter pen, 21 Hz
9 Spring balance
10 Retaining clip
11 Table clamp
12 Helmholtz resonators
70 mm dia.
52 mm dia.v
40 mm dia.
34 mm dia.
13 Glass tube for open air column
14 Kundt’s tube
15 Glass tube for closed air column
16 Rod for Chladni plate/bell dome
17 Galton whistle
18 Plotter pen with holder
19 Lycopodium powder
20 Plastic block for clamp
21 Rubber top
22 Bell dome
23 Reed pipe
24 Whistle
25 Steel string
26 Nylon string
27 Resonance rope
28 Plunger

3. Technical data

Dimensions: 530 x 375 x 155 mm^3 approx.
Weight: 4.5 kg approx.

4. Sample experiments

1. String tones

- Pluck the monochord string hard when it is moderately taut.
- Subsequently increase the tension on the string by turning the peg to the right. Pluck the string again.

At first, a low tone is heard. As the string is tightened the tone gets higher.

Reasons: vibrating strings generate acoustic tones by inducing alternating compression and rarefaction of the surrounding air. The greater the tension in the string, the faster the vibrations are and the higher the tone.

2. Pure acoustic tones

- Hit the 440 Hz tuning fork hard with the metallophone beater.

A pure acoustic tone of a very specific, unchanging pitch can be heard. This tone dies away very slowly.

Reasons: a tuning fork consists of a U-shaped steel piece which merges into the stem at its vertex. As the tuning fork only vibrates in one oscillation mode (with both prongs either both moving apart or both moving towards one another), it produces a pure tone of an unchanging pitch. Owing to its property of producing a constant pitch, tuning forks are used for tuning musical instruments.

3. Vibrating air columns

- Attach the glass tube for demonstrating a closed air column by means of the table clamp, plastic block and retaining clip.
- Insert the tuning plunger into the glass tube.
- Hit the 440 Hz tuning fork hard with the metallophone beater. By pulling out the plunger to a greater or lesser degree it is possible to alter the length of the closed air column.

There is only one plunger position at which the air column resonates strongly. At any other position there is no sound. Resonance can be detected by the increase in sound volume.

Reasons: a closed air column starts resonating when its length corresponds to one quarter of the excitation wavelength. The tuning fork vibrates with a frequency of 440 vibrations per second. Applying the following equation:

$$Wavekength = \frac{Speedofpropagation}{Frequency}$$

$$\frac{34000 \cdot cm/s}{440 \cdot Exciting \quad freq/s} = 77.2 \cdot cm$$

the wavelength of the tone produced is 77.2 cm. One quarter of this wavelength is therefore 19.3 cm.

The distance between the plunger and the opening at the end of the tube is 19.3 cm when resonance occurs.

4. Open air column

- Conduct the same experiment with an open air column (14).

The open air column, which is exactly double the length of the closed air column, starts resonating when the tuning fork is brought into its vicinity, as can be heard by means of the increased volume.

Reasons: an open air column starts resonating when its length is half that of the wavelength or multiples of that length. Antinodes are formed at the ends of the open air column and a node at the middle.

5. Whistle

- Blow the whistle and change its length by gradually drawing out the plunger.

Depending on the length of the whistle, its note gets higher or lower but the character or timbre of the note remains the same.

Reasons: blowing a uniform air stream into the opening of a whistle causes the air trapped in the pipe to vibrate and eddies then occur at regular intervals air the air passes over the blade. The resulting tone depends on the length of the air column. In the case of a closed air column, the length of the whistle (measured from the edge of the blade to the base of the whistle) corresponds to a quarter wavelength of the base tone. A node is formed at the blade of the whistle and an antinode is formed at the end of the pipe

6. Vibrating bars

- Use the striking hammer supplied to strike several bars of the metallophone. When the metal bars are struck, they produce a distinct, melodious note, each of which has a similar timbre. The shorter the length of the bar, the higher the tone.

Reasons: elastic rods form systems capable of oscillating if they are resting upon a point where a node is formed (about 22% of the total length between the two ends).

7. Infrasound

- Without the plotter pen attached, make the tuning fork (21 Hz) vibrate by pressing its prongs together and suddenly releasing them.

The tuning fork produces slow vibrations that can be perceived by the naked eye. When held close to the ear, a very deep (barely audible) tone can be heard.

Reasons: the prongs of the tuning fork vibrate in opposite directions and give rise to compressions and rarefactions in the surrounding air. When this reaches the ear, it makes the eardrum vibrate. A tone is thus perceived.

The tuning fork vibrates at approximately 20 vibrations per second. The lowest note that can be perceived by human hearing has a frequency of approximately 16 vibrations per second. Vibrations below 16 Hz are not audible to the human ear. The sound produced by these vibrations is called infrasound. (Latin: *infra* = below).

8. Ultrasound

- Blow the Galton whistle.

No sound can be heard, simply a hiss.

Reasons: owing to its short length, the Galton whistle produces very high tones which are not audible to the human ear. This phenomenon is called ultrasound. (Latin: *ultra* = above).

9. Tuning fork with plotter pen

- Attach the pen (8) to the prongs of the tuning fork (21 Hz).
- Make the tuning fork vibrate by pressing the prongs together and move a sheet of paper as uniformly as possible under the pen so that the motion is plotted onto it. Make sure that the surface on which the paper rests is not too soft.

The pen traces a wavy line of a constant wavelength but decreasing amplitude on the paper.

Reasons: sound is produced by harmonic oscillations of solids, liquids or gases. The locus of the oscillating particles of the body in relation to the time traces a sine curve. When struck once, vibrating bodies exhibit a “damped” oscillation (continuous decrease in amplitude). If the supply of energy is uninterrupted (constant sound of a car horn, constant blowing of an organ pipe), the result is an undamped oscillation of constant amplitude (loudness or volume).

10. Progressive waves

- Make a simple knot in the resonance rope and attach it by the loop to the handle of a door.
- Make the wire moderately taut and jerk it suddenly to the side.

From the centre of motion (the hand), a wave is produced which runs along the wire with an increasing velocity, gets reflected at the fixed end and returns to the point of origin.

Reasons: every solid, liquid and gas produces vibrations when disturbed suddenly. These vibrations spread through a medium with a definite propagation velocity.

11. Doppler effect

- Strike the light-metal tuning fork (1700 Hz) hard with the metallophone beater. Hold it still for a short while and then rapidly move it to and fro through the air.

In a state of rest, the tuning fork produces a clear tone of uniform pitch. In a state of motion, the pitch constantly changes. If the tuning fork is moved towards the ear, the pitch rises, and if it is moved away from the ear, the pitch decreases.

Reasons: when the distance between the source of sound and the ear is decreasing, the time interval between two compressions also decreases as a second compression has to travel a shorter distance to reach the ear compared to the first. The ear registers a higher frequency. The tone thus gets higher. When the source of sound is moved away from the ear, the intervals between compressions and rarefactions get longer. The tone thus becomes deeper.

12. Chladni figures

- Use the table clamp and plastic block to attach the Chladni plate to the workbench. Scatter some bird sand or a similar material onto the plate. Allow it to spread in a thin layer so as to cover a third of the plate.
- With one hand, bow the plate exactly half way between two corners with a good violin bow, simultaneously touching one other corner lightly with the finger of your other hand.
- Bow several strokes across the plate, preferably quite forcefully so that the vibrations of the plate are vigorous and well audible.

When the plate is being bowed, a very distinct acoustic tone can be heard. At certain points, the grains of sand experience lively resonance and begin to bounce up and down on the surface of the plate, accumulating in unusual figures on the surface.

Reasons: “standing waves” are formed on the plate. When bowed, the plate does not vibrate uniformly across its surface. At certain points (antinodes), the plate begins to vibrate, whereas it is in a state of complete rest at other points (nodes). By touching the plate at one corner, the point is forced into being a node.

13. Chimes

- Secure the bell dome to the bench with its open end facing upwards using the table clamp and plastic block.
- Strike the edge of the bell at different points with a hammer. (Alternatively, the edges can also be bowed with a violin bow.)

The pitch depends on the point at which the bell has been struck. It is easily possible to obtain differences of a whole tone. If the bell is struck at definite points, both tones are excited and the result is a familiar “beating” (periodic increase and decrease in volume at varying speeds).

Reasons: bells are curved vibrating plates. The overtones are mostly not in harmony with the fundamental tone. Bells too exhibit specific vibrating regions while they are chiming

14. Standing waves

- Make a simple knot in the resonance wire and attach it by the loop to the handle of a door.
- Make the wire moderately taut and gently move it round in circles.
- Now make the wire tighter and spin it faster.

When moved gently, nodes arise at both ends of the wire and an antinode is created in the middle of the wire. When moved faster, three nodes and two antinodes are formed, and when moved even faster, four nodes and three antinodes are formed.

Reasons: owing to the reflection at the door handle, standing waves are formed. Due to persistence of vision, the original and reflected waves appear to be simultaneous. In its fundamental mode, the whole of the wire vibrates in one length, thus describing one half-wave. One antinode is observed in the middle of the wire with nodes at both ends. In the case of a first harmonic (octave), the wire vibrates describes the form of a complete wave (two antinodes and three nodes); for the second harmonic, there are three antinodes and 4 nodes; and so on.

15. Overtones

- First blow the whistle gently, then blow it very hard.

Initially, a fundamental tone is heard. When the whistle is blown hard, a much higher tone can be heard.

Reasons: since the whistle is closed at one end standing waves are always formed with a node at the base and an antinode at the blade opening. This is the case when the length of the whistle is exactly 1/4 of the wavelength. It is also the case if the distance of the opening from the base is 3/4, 5/4, 7/4, etc. of the wavelength.

Apart from the fundamental tone, all the possible odd overtones or harmonics from the harmonic series are produced at varying degrees of intensity.

The fact that every musical instrument has a very characteristic timbre can be attributed solely to the presence of individual harmonics of this kind appearing to a greater or lesser degree.

16. Measurement of wavelength

- Seal off the end of the 45-cm glass tube (21) with the rubber cap and, holding the tube at an angle, put a small quantity of lycopodium powder into the tube using a teaspoon. Carefully spread a moderate quantity of the powder uniformly to form a fine yellow strip in the tube.
- Attach the glass tube by means of the retaining clip, table clamp and plastic block.
- Strike the tuning fork (1700 Hz) hard on the handle of the hammer and hold one prong directly alongside the opening of the tube. If necessary, repeat this acoustic excitation several times.

At the antinodes, the lycopodium powder begins to resonate strongly, whereas it is absolutely static at the nodes. The powder particles fall to the base of the tube and form periodic clusters that repeat 4½ times along the axis of the tube.

Reasons: the light-metal tuning fork has a frequency of 1700 vibrations per second. According to the following equation:

$$Wavelength = \frac{Speed}{Frequennc y}$$

$$\frac{340 \cdot m/s}{1700 \cdot Hz} = 0.2 \cdot m$$

The corresponding wavelength is 20 cm. Thus, 4½ half-waves or 2 full waves and one quarter wave can “fit” in a 45-cm-long tube, as demonstrated in the experiment. At the opening of the tube, there is always an antinode and there is always a node at the base of the tube.

17. Soundboard

- Hit the tuning fork that produces the note a’ = 440 Hertz hard using the metallophone beater and push the stem down onto the table top.

Simply by holding it on the table, the barely audible tone produced by the tuning fork is amplified to such an extent that it is now clearly heard throughout the room.

Reasons: owing to the rising and falling vibrations in the shaft of the tuning fork, the surface of the table begins to resonate. Since the effective table surface is much larger than the tuning fork, the loudness of the tone is considerably intensified.

18. Resonator box

- Strike the A tuning fork (440 Hz) nice and hard and place its stem on the resonator box of the monochord.

There is a significant amplification of the tone.
Reasons: as explained in experiment 17.

19. Spherical cavity resonator

- One by one, bring the narrow tip of each of the Helmholtz resonators close to your ear.

You hear a tone which gets deeper as the diameter of the resonator becomes greater.

Reasons: every hollow space, regardless of its shape, e.g. pipes, hollow spheres, has a very specific resonant frequency which is almost lacking overtones. This harmonic can be produced by blowing air across the opening of the hollow space or simply by tapping the hollow space with your knuckles. However, natural resonance is also created if the surrounding noise possesses tones which match the harmonic of the resonator. In this way, the spherical cavity resonator can be used to identify individual components of a mixed sound. If the room is absolutely quiet, the resonator remains silent.

20. String instruments and the laws they obey

- Insert the bridge vertically below the string of the monochord so that its right edge exactly coincides with the number 20 on the scale and the 40-cm string is divided into two equal sections of 20 cm each.
- By tightening the peg, tune half the length of the string to match the A tuning fork (440 Hz) (standard pitch).
- By plucking, or preferably by bowing the string, compare the pitch for string lengths of 40 cm, 20 cm, 10 cm and 5 cm.

For a string length of 20 cm, the note matches the standard concert pitch A' = 440 Hz. For a string length of 40 cm, the pitch is one octave lower at A = 220 Hz. For length 10 cm, the pitch is one octave higher A” = 880 Hz. Finally, when the length of the string is 5 cm, the pitch is two octaves higher A”' = 1760 Hz.

Reasons: when the string is twice as long, the pitch is lowered by one octave. When string length is half the length it is one octave higher and when the length of the string is reduced to a quarter, the note rises to the second octave. The frequency of a string vibration is inversely proportional to the string's length.

21. Scales on stringed instruments

- By moving the bridge, play the musical scale that is tuneful to the human ear. In each case, calculate the ratio of the vibrating section of the string to the total length of the string (40 cm).

Tone	String length	Ratio of the string length to the total length of the string
C	40 cm	1
D	35.55 cm	8/9
E	32 cm	4/5
F	30 cm	3/4
G	26.66 cm	2/3
A	24 cm	3/5
B	21.33 cm	8/15
C’	20 cm	1/2

Reasons: under consistent conditions (e.g. string length, string thickness, etc.), the sound is an octave higher when the string length is halved. In the case of the other tones on the musical scale, the relation between the vibrating section of the string’s length and its total length also forms simple ratios. The smaller the ratio, the more pleasing the harmony (octave 1:2, fifth C/G 2:3, etc.).

22. Measurement of string tension

- Attach the spring balance onto the monochord and insert the end of the nylon string into the eye of the spring balance.
- Pull the peg and, using the A' tuning fork (440 Hz), tune the string to standard pitch.
- Use the spring balance to determine the tension of the string.

The string tension in the case of a nylon string is 5.5 kg.

23. Relation between pitch and string tension

One of the results of experiment 22 was that in order to obtain a standard pitch, the tension on the nylon string needs to be 5.5 kg. How much tension should be applied in order to obtain a pitch that is one octave lower (A = 200 Hz)?

- Loosen the peg till you hear the pitch of A.
- To make sure this is right, place the bridge under the string at 20 cm on the scale (i.e. half the total length of the string) and tune this half-of the string to standard pitch. Removing the bridge, the whole string will vibrate at half the frequency.

The string tension has been reduced to 1.4 kg.

Reasons: the frequency of the string is proportional to the square root of the tension. If the tensile force on the string is higher by a multiple of 4, 9, 16, etc., the frequency is increased two-fold, threefold, four-fold, etc. As measured earlier, 1/4 of 5.5 is 1.4 (rounded up).

24. Wind instruments and the laws they obey

- Blow the whistle. You can change the effective length of the whistle by moving the plunger.

When the length is short, the whistle produces a high tone and when it is longer, it produces a lower tone.

Reasons: when a weak air current passes through the whistle, standing waves are produced. In this case, the length of the whistle corresponds to a quarter wave length. When a strong air current passes through the whistle, overtones are produced whose frequency is an odd multiple of the fundamental tone.

In the case of an open whistle, the first harmonic is twice the frequency of that for a closed whistle.

25. C major scale and its intervals

- To determine the intervals, the higher frequency is divided by the lower frequency.

For the interval D/C = 1188/1056, the common divisor is 132. We thus get ratios of 9/8, 10/9, 16/15, 9/8, 10/9, 9/8 and 16/15.

Reasons: the intervals between the individual tones of a musical scale are not equal. Intervals can be distinguished into the major tone (9/8), minor tone (10/9) and half-tone (16/15).

26. Harmony and dissonance

- Play all possible combinations on the reed pipe.

Pleasing harmonies (consonances) are produced at the octave, the fifth note, the fourth, the major third and minor third. Discordant notes (dissonances) emerge between the second and seventh notes. The combination of tones produced by two neighbouring tones is also called dissonance.

27. G major triad

- Simultaneously blow notes G, B and D on the reed pipe.

A highly melodious combination is heard. This combination of notes is termed the G major triad.

Reasons: consonance is produced if several notes produce a melodious combination of pairs. The G major triad is formed as a combination of the major third and the minor third. The frequencies of the notes G, Band D have a very simple ratio to one another, viz. 4:5:6.

In order to derive this ratio, the fundamental frequencies specified on the reed pipe should each be divided by 6.

(To obtain a physically correct frequency, the fundamental frequencies printed on the pipe need to be multiplied by 33).

It is also possible for the tuning of the reed pipe and metallophone to differ audibly due to manufacturing processes.

28. Four-part G major chord

- Add to the G major triad the G’ octave as well. To achieve this, simultaneously play G, B, D and G’.

The result is a full and melodious “four-part G major chord”.

Reasons: a four-part major chord features the following consonances:

Octave	1:2
Fifth	2:3
Major third	4:5
Minor third	5:6

29. Major scales in an arbitrary key

- First play the C major scale on the metallophone. Begin with C. Subsequently play a similar scale starting from G.

A C major scale from C’ to C” sounds pleasantly consonant. If you try to play a similar scale starting at G’, though, there is a definite dissonance at F”. The note is a semitone too low.

Reasons: according to experiment 25, the following intervals must be exhibited in every scale:

9/8, 10/9 16/15, 9/8, 10/9, 9/8, 16/15

For the sequence of notes G’…G”, however, the following intervals are specified on the base plate of the metallophone:

10/9, 9/8, <u>16/15</u>, <u>9/8</u>, <u>10/9</u>, 16/15, 9/8

The underlined intervals are correct, the others are incorrect in this sense.

The intervals 9/8 and 10/9 are so close to one another that it is extremely difficult to distinguish between them. Hence, the divergence from the ideal between G’ and B’ is irrelevant. However, the “imperfection’ between E” and F” is easily noticeable. In this case, an interval of 16/15 occurs instead of 9/8. The F’ note is therefore a semitone too deep.

30. Producing half-tones

- On the reed pipe, play the scale from G’ to G” making sure that the A’ note of the reed pipe is genuinely tuned to standard pitch. Use the tuning fork to compare the pitch.

A G major scale on the reed pipe is pleasantly consonant.

Reasons: instead of the F’ note, a completely new note, F#, is introduced. The interval between F’ and F#’ is 9/8 and the interval between F#” and G’ is 16/15. This is achieved by taking the frequency of the F note and increasing it by multiplying it by 25/24.

The new notes produced by sharpening the tones are called C#, D#, F#, G# and A#. (E# and B# are equivalent to F and C respectively).

This sharpening is denoted in musical notation by a sharp sign appearing on the clave before the note.

Flat notes, which are a semitone lower than the conventional notes are produced by multiplying the latter by 24/25. These notes are denoted in musical notation by a flat sign preceding the note on the clave. The new flat notes are called Db, Eb, Gb, Ab and Bb.

In the tempered scale used on a piano, the notes C# and Db, D# and Eb, F# and Gb etc. respectively are played using the same key, since in each case they are close enough to being identical.