What are the Sounds of Music?

Contents: Reading and questions about sound and music, together with suggested teacher demonstrations and class investigations.

Time: 2 to 4 periods for demonstrations and discussion followed by reading and questions for homework. Parts 1 to 3 of the unit can be used as a reading and comprehension exercise. Part 4 can be omitted if time is short.

Intended use: GCSE Physics and Science. Links with work on sound, wave motion and music.

Aims:

- To consolidate work on wave motion and sound. To exemplify the concepts of waveform, amplitude, frequency and displacement. To provide simple waveforms for interpretation
- To provide a simple understanding of the factors affecting the pitch, loudness and quality of musical notes from wind and stringed instruments
- To provide an elementary explanation of electronic sound synthesisers (pitch, harmonics, vibrato, waveform and envelope)
- To provide opportunities to apply physics concepts to interpret information
- To provide opportunities for planning and carrying out investigations.

Requirements: Students' worksheets No.903.

Apparatus for demonstrations: see the diagrams below.

Apparatus for investigations in Part 4: microphone, oscilloscope, a selection of musical instruments and tuning forks (if these are not available, different waveforms can be produced by singing and whistling), 3.5m length of hose-pipe, brass instrument mouthpiece, funnel, 2 or more signal generators and loudspeakers. Leads for connecting together the electrical equipment.

A VELA (program 010) and a synthesizer can be used for extension work.

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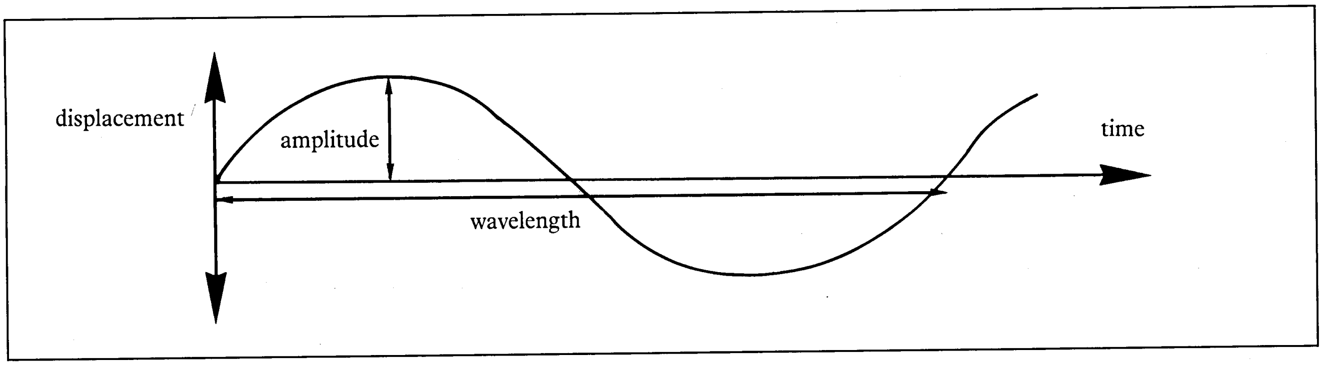
This unit is in four parts:

Part 1 Music or noise ?
Part 2 Strings and wind
Part 3 Synthesizers
Part 4 Investigations.

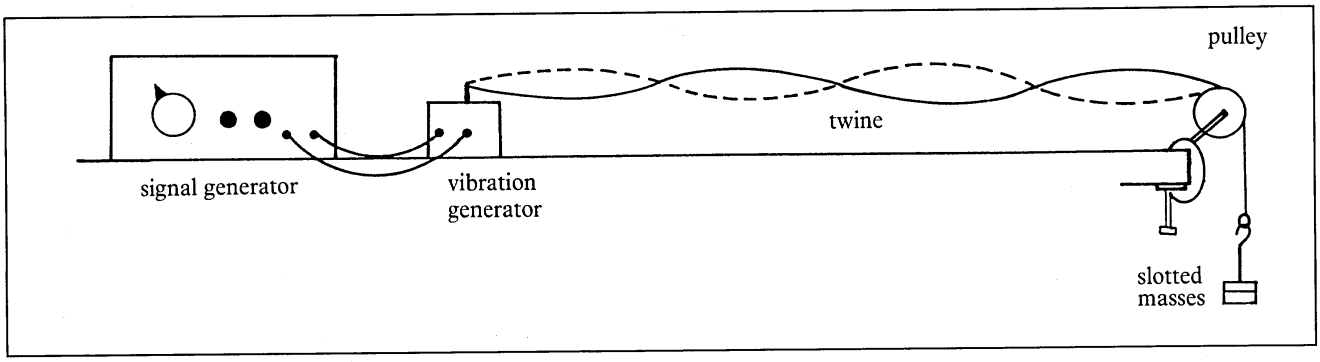
Part 1 Music or Noise?

The unit hints at the distinction between subjective noise, which is anything someone does not want to hear, and objective noise, such as the hissing of steam, which gives a trace like the noise trace in Figure 2 of the students' worksheets.

Students should be familiar with the representation of a wave motion as a displacement–time graph.



A prior demonstration of the modes of vibration of a string is helpful. Students may be interested to watch the vibrations when illuminated with a strobe lamp.



The effect of waveform on quality can be shown by listening to square, triangle and sine waves from a loudspeaker while watching them on a CRO screen.

Tone is used to describe quality or timbre. It can also be used to describe a musical interval, for example, a semitone, or the sound you hear when somebody plays a note.

The unit does not emphasize the distinction between the objective, measurable quantities of frequency and intensity, and the subjective, perceived quantities of pitch and loudness. This might be discussed with some students.

Part 2 Strings and wind

There are three terms used to describe the components of a vibration: harmonic, partial and overtone.

A **harmonic** must have a frequency that is an integral number of times the frequency of the fundamental. That number is the number of the harmonic.

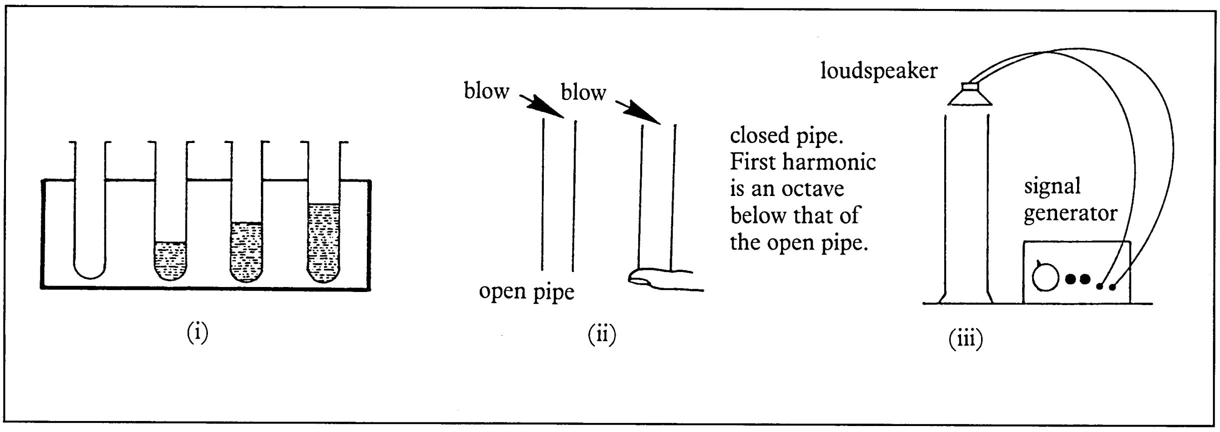
Partial is the name given to each component of a wave. Partials may, or may not, be harmonics and they are numbered in sequence from the lowest frequency. Some of the partials for bells are not harmonics.

An **overtone** is a component higher than the fundamental and is numbered in sequence from the lowest frequency. Overtones are not necessarily harmonics.

If a clarinet is overblown to produce a note an octave plus a fifth above its fundamental, this is the *first* overtone (that is the first component above the fundamental), the *second* partial (the fundamental being the first) but it is the *third* harmonic (because its frequency is three times that of the fundamental).

In the unit the only term used is 'harmonic' but students may meet the other words in physics or music textbooks.

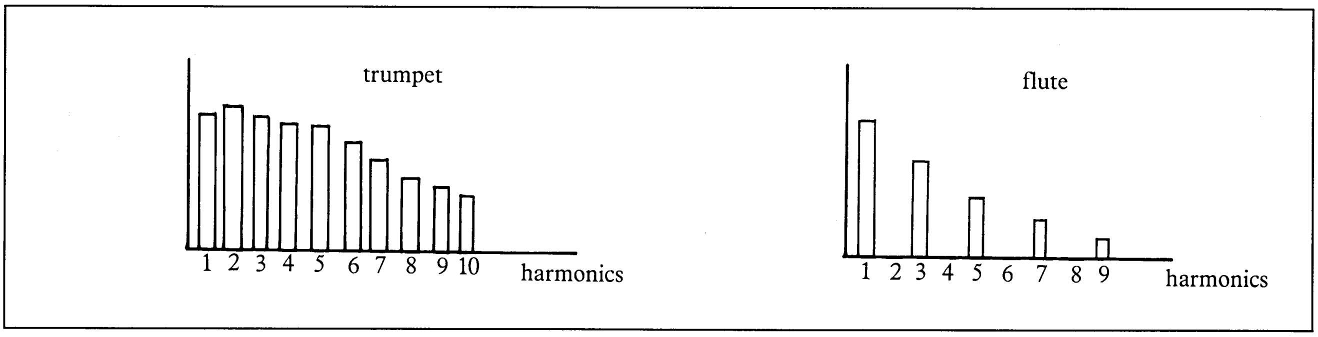
Students who have not encountered simple experiments on 'music' may enjoy (i) making a test-tube organ (and playing it by blowing across the top of the test tubes), (ii) investigating closed and open pipes by blowing a thermometer case, (iii) investigating the resonant frequencies of a measuring cylinder.



Part 3 Synthesizers

The advent of microchip technology has produced a surge of interest in the synthesis of speech and musical sounds. Early attempts based on textbook physics were very disappointing. It was soon discovered that synthesizing a sound was not merely a matter of specifying pitch, duration and a number of harmonics.

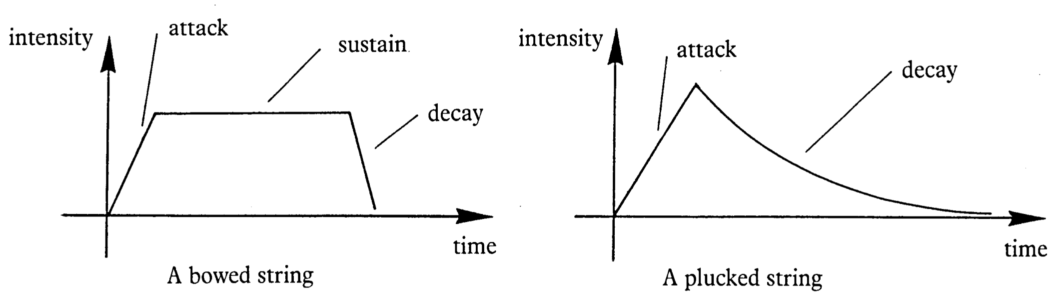
The study of musical notes with a spectrum analyser has revealed that tone depends on both the number and the intensity of the harmonics which sound. Low notes from open pipes (like brass instruments) are rich in harmonics in the audible range, while higher ones have fewer which can be heard. Harmonics may interact with each other so that some build up while others decay, causing the timbres to change as the note sounds. This is easily heard when a note on a piano is played.



Musical notes have beginnings, middles and ends characteristic of each instrument. They can be compared by studying the intensity envelope of the sound.

The science of musical sound is now well understood. Any sound can be synthesized and new ones invented. The BBC radiophonic workshop and composers like Jean Michel Jarre have used this technology to create new kinds of musical sounds.

The loudness of a musical note is not uniform for its duration. The way it builds up and decays is a characteristic of each instrument. The sound envelopes produced by most musical instruments have three parts, attack, sustain and decay. If a string is plucked, its envelope has attack and decay phases only.



Synthesizers such as the Yamaha DX7 have an envelope divided into four parts, attack, decay, sustain and release.

It is possible to record musical sounds using a VELA or a Philip Harris Data Memory and play back through an oscilloscope. The 'attack' phase will be missed with automatic triggering of the recording. Manual triggering is a rather hit-and-miss affair, but with practice can produce worthwhile results. Musical students could investigate the effects of different techniques (for example, tonguing, embouchure, bowing) on the envelope of the waveform.

The attack phenomenon results from the inertia of the vibrating system. A tuning fork struck and then placed on a table cannot make the table jump instantly into vibration. Similarly a reed cannot start a vibration in a column of air immediately. The inertia of the system leads to the relatively slow build up during the attack phase.

Answers to selected questions

Q. 9 (a) recorder, (b) flute, (c) clarinet, oboe, etc. (d) trumpet, trombone, etc.
Q.10 The player has to set his/her lip tension in advance.
Q.11 If $f_1 = 110$, $f_2 = 220$, $f_3 = 330$, $f_4 = 440$, $f_5 = 550$

on the piano: A, A, E, A, C$^{\#*}$

* C$^{\#}$ on the piano is sharp because of equal tempering. C$^{\#}$ is 554 Hz while the fifth harmonic is 550 Hz. Brass players have to 'lip up' the fifth harmonic to sharpen it.

References

Freeman, Ira, M., *All about Sound and Ultrasonics.* W.H. Allen, 1967.

Mathews, Max V. and Pierce, Hon R., 'The computer as a musical instrument', *Scientific American,* February 1987.

The Physics of Music. Readings from *Scientific American* with introduction by Carleen Maley Hutchins. W.H. Freeman, Oxford, 1978.

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Acknowlegements Figure 1 supplied by the Photographic Unit, ILEA Television and Publishing Centre; Figure 8 supplied by Dr. B.E. Richardson, Department of Physics, University College, Cardiff.

WHAT ARE THE SOUNDS OF MUSIC?

Why may one person's music be another person's noise? Why do musical instruments sound different even when they are playing the same note? How can an electronic keyboard play notes which are similar to those made by other musical instruments? These are some of the questions for you to think about as you study this unit.

Figure 1

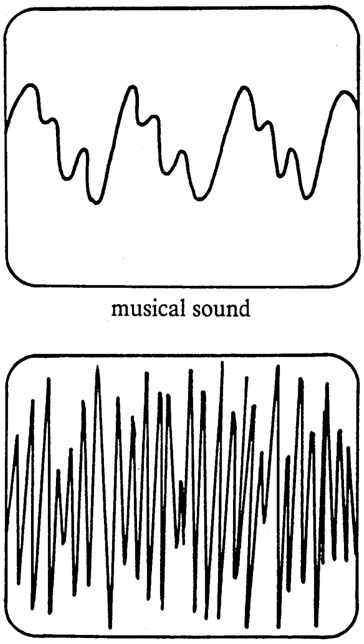


Figure 2

Part 1 Music or noise?

A jet engine and a clarinet both produce sounds. You would probably call the sound from the jet engine 'noise' and the sound from the clarinet 'music'. Noises are sounds which we find unpleasant.

Sometimes an oscilloscope shows a clear difference between music and noise. Figure 2 gives examples of what you see on the screen with a musical sound and with noise. You can see that the musical sound has a regular *waveform*. (You can do this for yourself if you try Investigation 1 in Part 4.)

The difference between noise and music is not always so clear. Someone who cannot play the violin makes a 'noise', while a trained musician produces the regular waveforms of 'music'. It also depends on personal taste. The sound of a rock band may be 'music' to teenagers but 'noise' to their parents.

Your own taste depends on what waveforms you have learned to understand. Many teenagers listen to rock bands regularly and recognise the waveforms. Their parents are often less familiar with these sounds.

Chinese pop tunes do not reach the charts in England. They sound strange to our ears. The reason is the same, most of us cannot recognise the regular patterns of the sounds. The waveforms are unfamiliar.

Now answer questions 1 to 3.

Questions

1 *Which of these sounds are 'noise' and which are 'music':*
(a) a jet aircraft taking off
(b) a symphony orchestra playing Mozart
(c) heavy lorries on the motorway
(d) the signature tune to 'Coronation Street'?
Does everyone in your class agree on the answers?

2 *In what ways is the waveform for music different from that for noise in Figure 2?*
Why do people find noise unpleasant?

3 *How would you classify these sounds? What do you need to know about the performers before you can be sure?*
(a) somebody playing a violin
(b) a rock band.
How might your grandparents classify them?

Waveforms

You are probably not aware of the amazing way that your ear and brain can sort out different sounds.

Every time you enjoy music you are responding to many complex waveforms at the same time. Even one note on a piano has a waveform made from many waves combined together. The waveform actually changes as the note sounds. Imagine what your brain has to cope with when you listen to several instruments together.

A French mathematician called Jean Baptiste Fourier (1768-1830) made the discovery that a complicated wave can be produced by adding together simple waves. The simple waves are called harmonics. Figure 3 shows the four harmonics which are combined in the note from a piano.

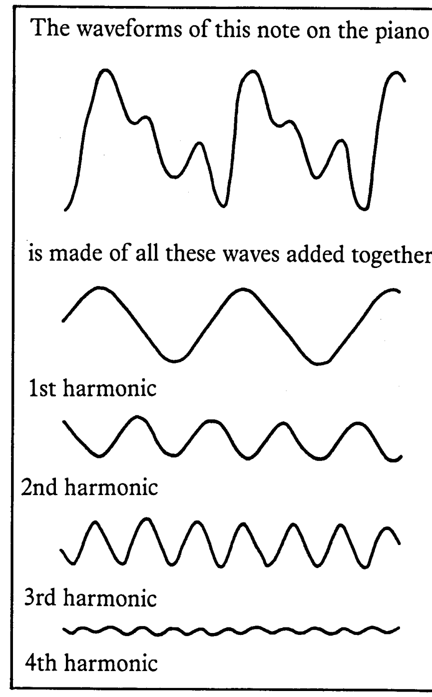


Figure 3

Properties of musical notes

Pitch is the term musicians use to describe how high or low a sound seems to be. Scientists measure the pitch of a note by the frequency of its sound wave.

Loudness is related to the amount of power per square metre reaching the ear. This depends on the amplitude of the sound wave. The greater the amplitude, the louder the sound.

Tone or **timbre** is the quality of the note. Notes from different musical instruments may have the same pitch and loudness but still sound different. This is because they are made up of a different mixture of waveforms. Musicians use words like *rich, thin, harsh, clear* and *warm* to describe different timbres.

Now answer questions 4 and 5.

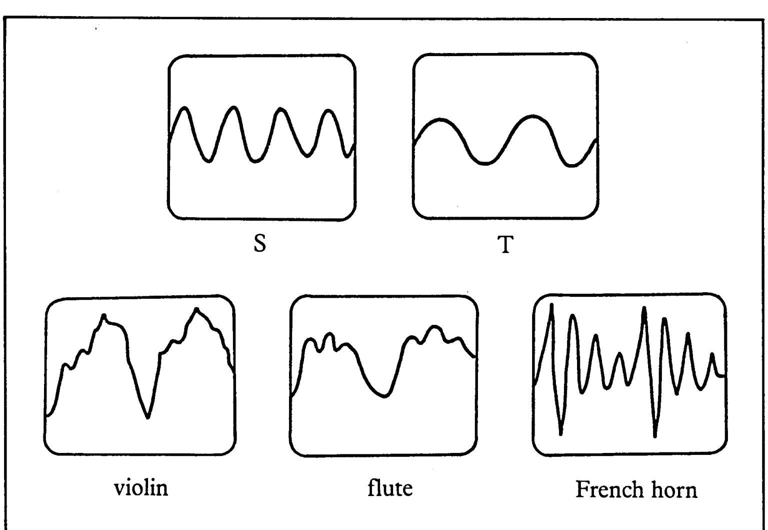


Figure 4 The time base of the oscilloscope was kept constant so that it was always scanning at the same rate

Questions

4 *Look at the waveforms produced by tuning forks S and T in Figure 4.*
   (a) Which note has the shorter wavelength?
   (b) Which note would sound higher in pitch?
   (c) Which tuning fork is vibrating with the higher frequency?
   (d) Which is the smaller tuning fork?

5 *Look at the kinds of waveforms produced by a violin, flute and French horn in Figure 4.*
   (a) Do they have the same wavelength?
   (b) Are they playing a note of the same pitch or frequency?
   (c) Suppose all three instruments play the same note. You can hear the difference because their sounds differ in tone. How could you deduce this from the trace on the oscilloscope screen?

Part 2 Strings and wind

Stringed instruments

Stringed instruments (such as the guitar, harp, piano and violin) produce a sound when you make the strings vibrate by plucking, hitting or bowing them.

The **pitch** of the note you hear depends on the *length* of the string, its *tension* and the *mass per unit length.*

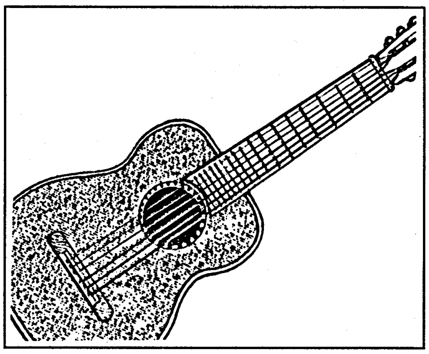


Figure 5 A guitar

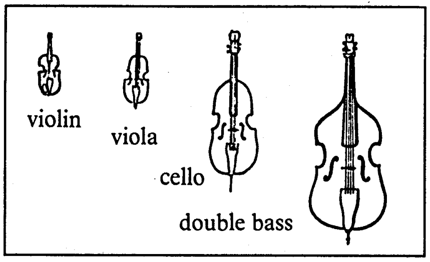


Figure 6 A family of string instruments

Figure 7 shows how the string of an instrument can move when a note sounds. Each harmonic is a different mode of vibration. In Figure 7 you see a family of harmonics called a **harmonic series.**

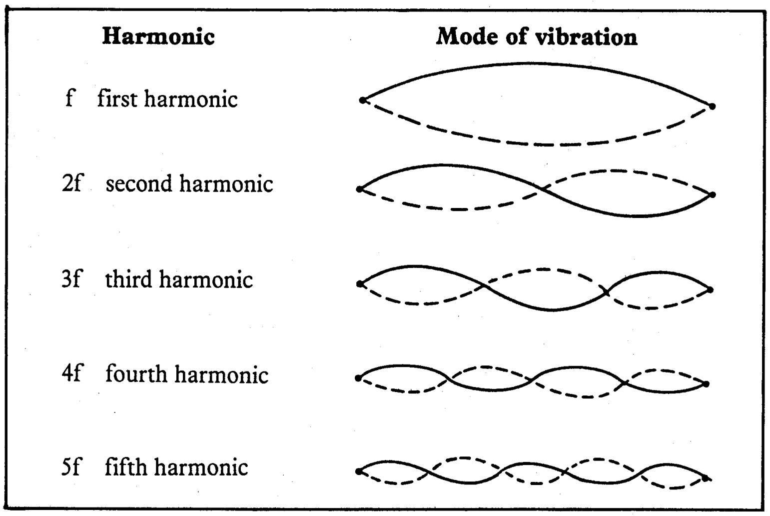


Figure 7 The modes of vibration of a string

The wave on a string does not move along the wire like a wave on water. The wave stays in one place as each part of the string vibrates.

If you watch a vibrating string you can see that its movement is complex. It is a combination of harmonics. Strings can vibrate only at frequencies which are two, three, or more times the frequency of the simplest vibration. The combination of all these modes of vibration gives the sound its tone.

Amplifying the sound

A single vibrating string gives little sound because it moves a very small volume of air. The vibrations of strings on electric guitars are amplified electronically. The signal from the amplifier has the power to allow the loudspeakers to make more air vibrate.

On most stringed instruments, sound is amplified 'acoustically' by a sound box. The string forces the sound box to vibrate. This sets a much larger volume of air into vibration. The shape and structure of the sound box affects the way it vibrates and helps to produce the characteristic tone of the instrument.

Now answer questions 6 to 8.

Questions

6 *Name* one *instrument in which the strings are set vibrating by:*
(a) plucking
(b) bowing
(c) hitting.

7 *Cello, double bass, viola and violin are members of a family of instruments with the same shape.*
(a) Which gives the highest notes and has the shortest strings?
(b) Which gives the lowest notes. Why?
(c) How can a player change the pitch of a note?
(d) These instruments all produce a similar tone. Why?

8 *(a) How does a guitarist change*
(i) the length,
(ii) the tension of a string?
(b) How can guitar strings be made with different values for the mass per unit length*?*

Wind instruments

Wind instruments include the clarinet, flute, recorder and trumpet. They produce a sound when the air inside them is made to vibrate. A woodwind player blows over a reed, a hole or a sharp edge. Brass players set up a vibration by making their lips vibrate.

If you have tried to play a flute or a trumpet you will know that you need to practise to produce a sound at all. Even reeds are difficult to coax into vibration and need sucking to soften them.

The air in a pipe has modes of vibration giving a set of notes called the harmonic series. This is very similar to the vibrations of strings.

Simple trumpets are just brass tubes with no holes or valves. They can sound only the notes produced by the harmonic series. The modern trumpet can play all the notes of the scale by using valves to divert the air through three extra lengths of tubing. This increases the length of the instrument so as to lower the pitch by a definite amount.

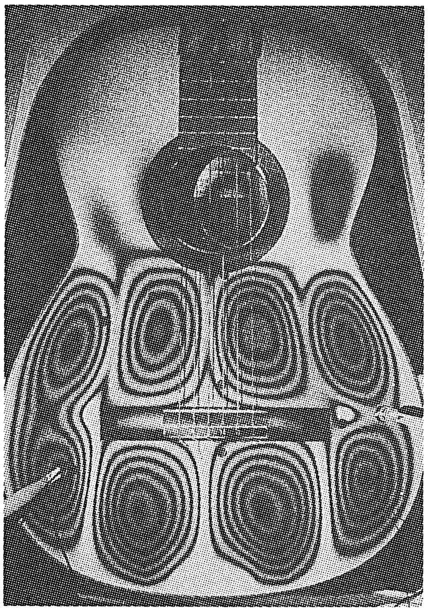


Figure 8 The mode of vibration of a guitar at 1010Hz. The vibrations were made visible by holographic interferometry

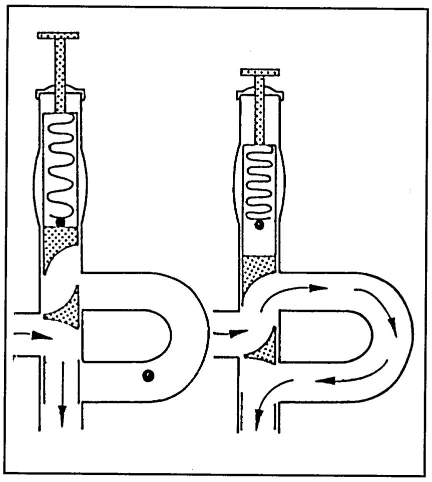


Figure 9 A trumpet valve — closed and open

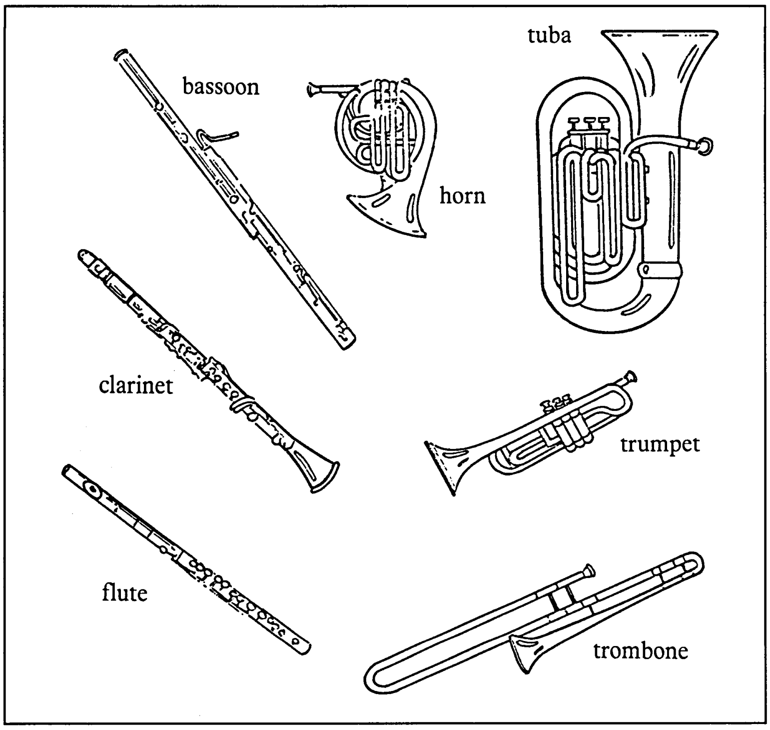


Figure 10 Wind and brass instruments

The longer the column of air, the lower the frequency at which it vibrates. So the longest wind instruments produce the lowest notes. There are whole families of instruments which show this pattern.

On a woodwind instrument you open or close some of the holes to play different notes. This has the effect of changing the length of the air column inside. Modern woodwind instruments, like the clarinet, have keys which open and close holes that are too far away to reach easily.

Now answer questions 9 and 10.

Questions

9 *Give examples of wind instruments where the air is set into vibration by blowing:*
(a) over a sharp edge
(b) across a hole
(c) over a reed
(d) through tightened lips.

10 *Why do you think brass players find it so difficult to 'pitch in' and play the first note at the correct pitch?*

Part 3 Synthesizers

Almost all pop groups use a synthesizer. It can generate notes of any pitch, tone and loudness by controlling a system of oscillators which produce electrical vibrations.

One oscillator is tuned to the first harmonic and this gives the note its pitch. The other oscillators are set to give higher harmonics to make the tone richer. Sometimes an oscillator is set slightly out of tune to give a vibrato effect.

The loudness of a note is more complicated. It always takes a little time for the sound of a note to build up. It may then be sustained or gradually die away. When a violin is played with a bow the sound is sustained. When the string is plucked the sound gradually dies away. A typical 'envelope' for the loudness of a note on a synthesizer consists of four parts, attack, decay, sustain and release (Figure 12).

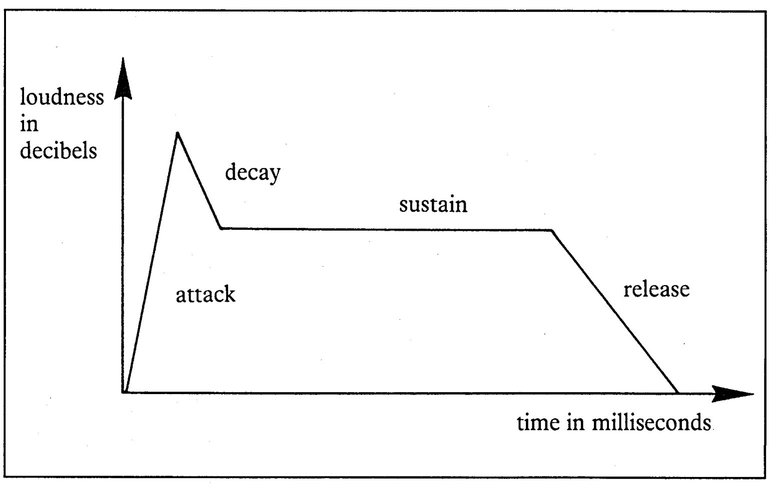


Figure 12 A typical envelope for a synthesizer note

Rich sounds can be synthesized by adding waveforms but many oscillators and complex circuits are needed to control them all. In practice, synthesizers use frequency modulation (FM) to produce a similar result with fewer oscillators.

Now answer questions 11 to 13.

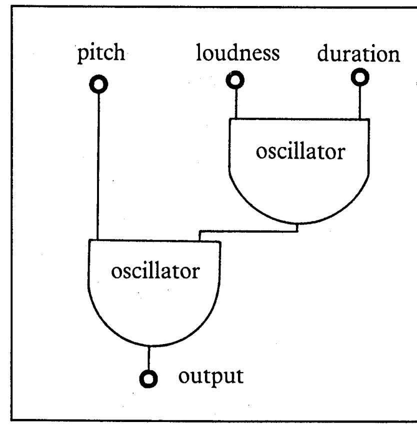
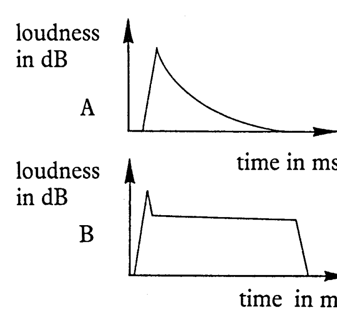


Figure 11 A simple synthesizer

Questions

11 Calculate the first five harmonics of a note of frequency 110Hz. What are these notes on the piano? (See Figure 13.)

12 Which envelope (A or B) could be the sound of a bowed string and which a plucked string?



13 Do you think that synthesizers could eventually replace ordinary musical instruments? Give reasons for your opinion.

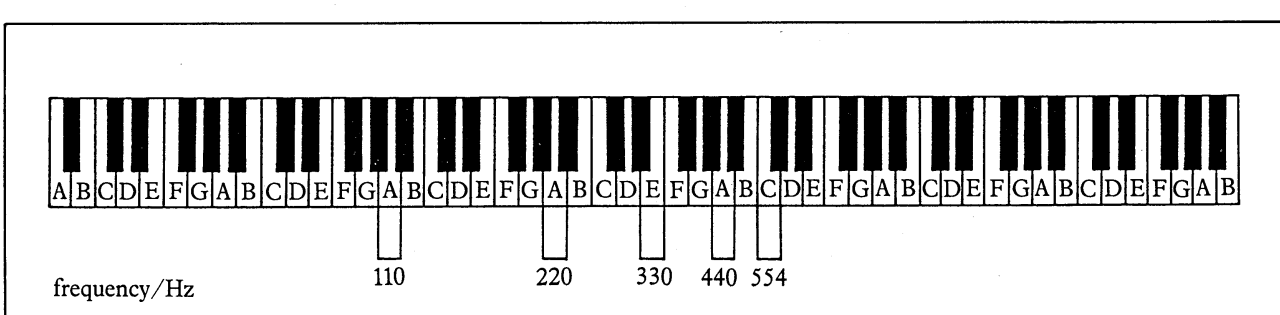


Figure 13 A keyboard showing the frequencies of some notes

Part 4 Investigations

A Looking at waveforms

Use a microphone and oscilloscope to study the pitch, loudness and tone of musical notes from various instruments. Compare the notes from a single musical instrument with the same note from the loudspeaker of an electronic keyboard.

(Remember that sound waves are longitudinal. They make the diaphragm in the microphone vibrate backwards and forwards. The movement of the diaphragm produces an electrical signal which is displayed on the oscilloscope. You are looking at a displacement–time graph on the screen.)

B Sounding the harmonics

If you have a stringed instrument such as a guitar available, you can try to sound the harmonics. Just plucking the string gives mostly the first harmonic. To sound the second harmonic, touch the string at its mid point and pluck it (Figure 14). The string will vibrate in two halves. The second harmonic is an octave above the first. The third harmonic is quieter but you can sound it by touching the string at one third of its length and plucking it on either side.

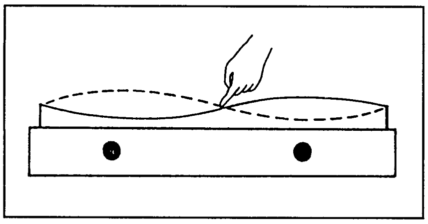


Figure 14

C Playing a hose-pipe trumpet

You can make a hose-pipe trumpet from 3.5m of garden hose, a plastic funnel and a mouthpiece from a brass instrument (Figure 15). The length of this instrument is about the same as a French horn.

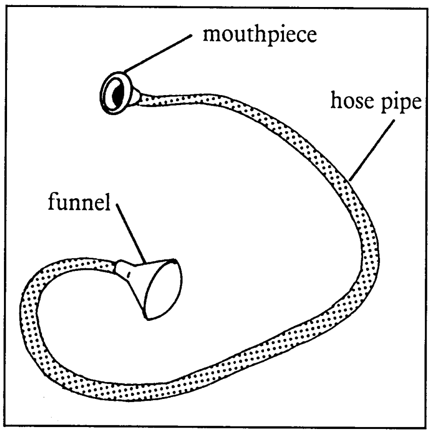


Figure 15

To play a brass instrument you need to pucker your lips (do not put your tongue between them) and blow a 'raspberry' to make them vibrate.

Find the lowest note you can play and then by tightening your lips you can increase their frequency of vibration to play higher notes. The notes you get will be those in the harmonic series, not every note in the scale. Try playing with and without the funnel to find out why most instruments have bell-shaped ends.

D Synthesizing a musical sound

Set a signal generator to 110 Hz and connect it to a loudspeaker. The note you hear is boring because there are no harmonics sounding at the same time and it has no definite beginning or end. Try tuning a second signal generator and loudspeaker to the second, third, fourth and fifth harmonics. The tone of combined sounds will be better. (With a third signal generator and speaker the sound of three harmonics together is richer still.)

To produce a vibrato effect, tune two signal generators to the same frequency, say 110 Hz, and then alter one of them slightly. The two sounds will seem to vibrate or 'beat' together.