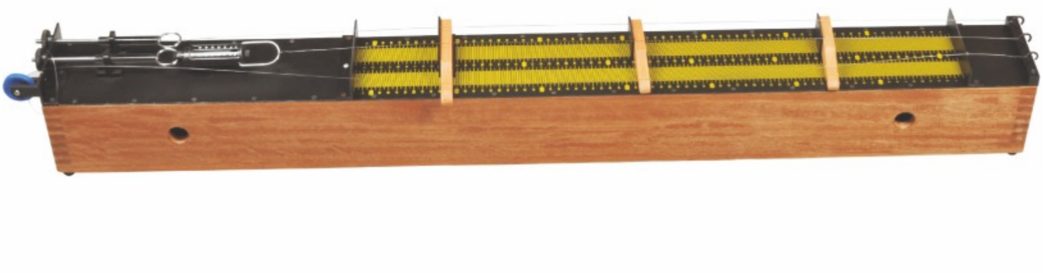
SONOMETER 3-WIRE

PH0730



Experiment Guide

Purpose

The purpose of the apparatus is to demonstrate the effects of wire gauge, tension and length on the natural frequency of strings, and to demonstrate harmonics. Students will develop some skills in tuning, resonance and matching frequencies.

Contents

Sonometer - overall size including the guitar tuning machines and fixed bridges 720 x 120 x 103mm
50N spring balance with hook and ring
2 x small & 1 x big movable bridges
3 x steel wires (one of 0.45mm diameter, two of 0.55mm)

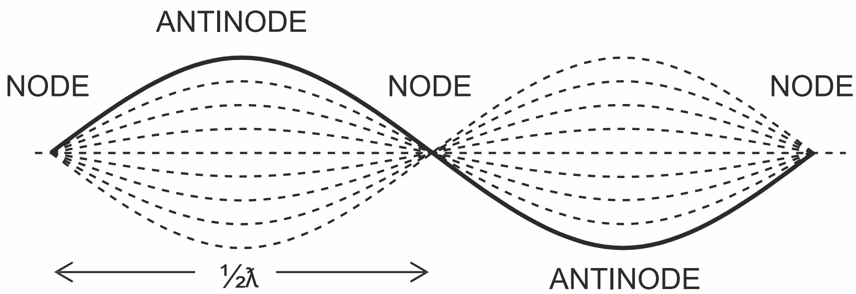
Safety advice

This advice is not a replacement for a formal risk assessment, which should be done according to your school or LEA policy.

There is a small risk of breaking wires through over-tensioning. The sharp ends of the wires may "whip" as the wire breaks. This is no different from the risks with a guitar or violin. The recommended tensions in the text below are within the safe limits of the Sonometer.

Theory

When a wire or string is plucked, a transverse wave is set up along it at a frequency determined by the gauge of the wire, its length and tension. The wave consists of stationary nodes and antinodes, which are separated by half-wavelengths.



By adjusting the tension and/or vibrating length of a string, notes of higher and lower pitch can be produced. The fixed 500mm (50cm) scales allow for accurate positioning of the movable bridges supplied.

Nodes can be created artificially, by plucking the string while at the same time lightly touching the string at certain positions. These positions include: a half, a third and a quarter of the string's full length.

Frequency = number of vibrations per second, now called hertz, Hz
Wavelength = the length of one complete wave of a vibration, the solid line in the diagram above, measured in metres or millimetres.

Initial tuning
There are two thick strings (0.55mm diameter) and one thin string (0.45mm diameter). Pluck the strings. Until they are tensioned, they will rattle and give a poor sound.

Increase the tension in the string attached to the newtonmeter, until it reads 40 newtons. Pluck the string and listen to the note produced.

Leave it at this tension and we'll call it string A.

Now adjust the tuning machine attached to the other thick string. We'll call this string B.
Pluck string A and B to compare the notes produced.

Increase the tension in string B, by turning the tuning machine, until the note matches the note produced by string A.

The strings are the same length and thickness and are now giving the same note – we say they vibrate at the same frequency.
Q1 What can we assume about the tensions in string A and string B?

Using a rider
Cut a piece of paper, about 2 x 1cm, fold it in half and rest it on string A, near the centre of the length. Pluck string B. The paper "rider" should dance on the string, or possibly jump off completely, if you had closely matched the notes before.

Using a paper rider is a good way to check whether two strings are in tune.

A note about resonance
The use of the paper rider depends on resonance.
When two strings are set to the same note or frequency, and one string is plucked, it sends sound energy through the bridges and the sonometer box, and makes the other string vibrate, shaking the paper rider. We say the two strings resonate.

Reduce the tension in string A to 35 newtons, but leave string B unchanged. Pluck the strings in turn, you should hear the different notes, string A is lower.

Put the paper rider at the centre of string B and pluck string A. Does the rider jump off now?

Resonance only happens when two strings are able to vibrate at the same frequency. If the tensions are different, then the natural frequencies will be different – no resonance.

Using the thinner string
First set string A's tension at 40 newton, and tune string B to match string A.

Adjust string C (the thinner string) using the tuning machine to give the same note as A and B.

Use a paper rider to help you match the notes.

Feel the tension in the three strings by pressing down lightly at the centre of each string.
Q2 What do you notice?
Q3 Can you think of a way to measure the difference you detected?
Q4 What would happen to the note given by string C, if its tension was the same as A and B?

Using the movable bridges
Have the pulley at left hand end, put one of the small bridges under string A, near the middle. If you pluck the string now, you may find that both sections vibrate, possibly giving different notes!

To avoid confusion, it is a good idea to damp the unused part of the string. Drape a soft, light cloth or paper tissue over the left hand section of string A. Make sure the cloth does not touch string B.

Pluck string A again, you should hear a clear note.

Move the bridge to the right and left, plucking the string after each adjustment.
Q5 What is the effect of shortening the string?

Put a paper rider on string B, then pluck string A.
Q6 Did the rider move or jump off? Why?

Now put a small bridge under string B and set it to the same position as the bridge under string A. This time damp the unused parts of both strings using the cloth or tissue.

Pluck either string. Use a rider to check your observation.
Q7 Same tension, same thickness of wire, . . . Complete the statement.

Increasing the tension
Remove the bridges and damping.

Check string A's tension is 40 newtons, and make sure the note given by string B is the same as string A. Check by using a rider.

Now increase the tension in string A to 50 newtons.

Pluck string A and B. Musicians might recognise the relationship between the notes. String A is giving a higher note, higher by one octave (one full scale of eight notes).

Put a bridge under string B, exactly at the centre and damp the left hand section with a cloth or tissue.

Pluck string A and B again.
Q8 Do the notes match now?
Q9 How was the note from string A changed? Hint: tension.
Q10 How was the note from string B changed? Hint: length.

When a note changes by one octave, its frequency is doubled.
You can test this using a signal generator. Start at 200Hz – listen to the note. Increase the frequency to 400Hz – listen again.
Try 800Hz. Musicians recognise these changes as octaves.

When you put the bridge at the centre of string B, the note changed by one octave: the string length was halved. In fact, the wavelength was halved.

Q11 Try to put together a rule connecting: tension, string length, frequency and wavelength. It should help you to predict the behaviour of plucked strings.

Using the thinner string again
First set string A's tension at 40 newtons, then tune string B to match string A.

Now increase the tension in string A to 50 newtons. The note should be one octave higher than string B.

Adjust string C (the thinner string) using the tuning machine to give the same note as string A. Use a paper rider to help you match the notes.

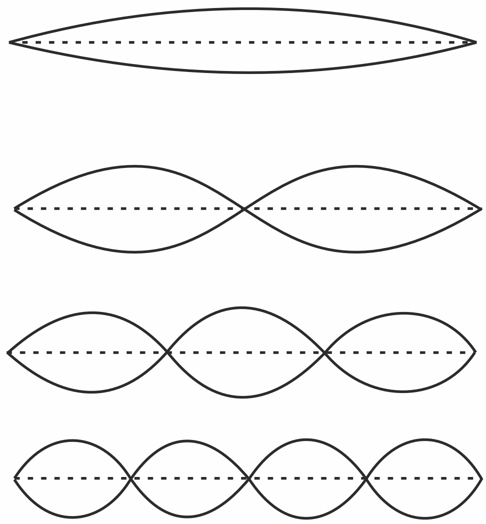
String B is giving the low note. Strings A and C are giving the higher note, one octave higher.

You already know that doubling the tension in a string doubles its frequency, so the relationship between tension and frequency is fairly simple – for strings of the same diameter (A and B).

You know that the tension in string A is 50 newtons.
String C is the same length as string A, and giving the same note or frequency.

Feel the tension in strings A and C by pressing down lightly at the centre of each string.
Q12 Which has the higher tension?
Q13 Write a simple statement about tension and thickness (diameter) for strings A and C.

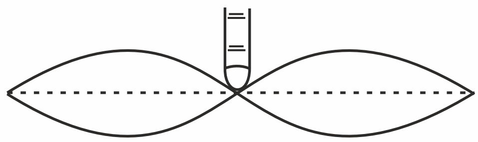
Harmonics
When a string is vibrating, it will do so at the fundamental (lowest) frequency. The vibration will contain higher frequencies, typically double and quadruple the fundamental – one octave and two octaves above the fundamental.



The diagrams show the fundamental, and second, third and fourth harmonics.

The third harmonic is one and half octaves above the fundamental, 3 times the frequency.

The last diagram shows how to produce the second harmonic artificially, by lightly touching the exact centre of the string's length, while plucking the string with the other hand.



The second harmonic (one octave higher than the fundamental) should be clearly heard.

Set string A's tension at 50 newtons. Tune string B to the same note.

Now put a small bridge at the centre of string B, and place a paper rider half way along one half of the string. Pluck string A.

The rider should dance due to the harmonics present in the vibration of the longer string, A.

Now place the paper rider at the centre of string A and pluck the shorter string, B. The rider should stay still because the vibration in the shorter string lacks the low frequency harmonic to make the longer string oscillate.

Comparison with a guitar or other stringed instrument
On all stringed instruments, the strings are tuned to give certain notes (frequencies) when the strings are "open" – plucked with no fingers on the fingerboard. Pressing down on any string ("fretting" on a guitar) shortens the string giving a higher note. In this way, a thicker string can give the same note as a thinner, open string. Guitarists tune their guitars in this way.

Use a paper rider to check the tuning of a guitar. It should jump off, whenever the frequencies of two strings are accurately matched.

Students may wish to extend their investigations by testing and comparing steel guitar strings. To avoid any risk of damage to the Sonometer, the maximum gauge of strings used must be limited to 0.55mm - the thickness of strings A and B in the experiments above.

Guitar strings are typically measured in fractions of an inch. 12 gauge strings are 0.012 of an inch and are equivalent to the thinner wire (0.45mm) supplied with the Sonometer.
The 0.55mm Sonometer wire is 22 gauge or 0.022 inch, in guitar terms.
Note that guitar strings may be made from special alloys rather than plain steel. These alloys are likely to have a different density from steel. This provides further scope for investigations.

Storage and maintenance
Return the product to its box for storage. There is no need to remove the strings, but they should be slackened to relieve strain on the box and newtonmeter. Store the Sonometer in a dry place and ensure nothing heavy is placed on top of it.

Related investigations
To capture the sound waveforms from the Sonometer, an electric guitar pickup can be used. Placed under the wires and connected to an oscilloscope, this should give a clear display of the waveform and enable students to measure the frequencies produced.

Alternatively, a sound sensor and datalogger could be used to capture and measure the waveforms produced.

Either method can help to show that doubling the frequency and halving the wavelength go hand in hand.

Further reinforcement is provide by examination of waveforms captured from a signal generator, as the output frequency is doubled.

Answers to questions

Q1 The tensions are equal.
Q2 The tension in string C is less than in strings A and B.
Q3 Use a newtonmeter to pull the strings sideways at their centres, deflecting them by the same distance. Knowing the tension in string A, you can estimate the tension in string C
Q4 The note would be higher. You might guess that doubling the tension will double the frequency.
Q5 Shortening the string gives a higher note, a higher frequency.
Q6 The rider should not move, because string A is set at a different, higher frequency than string B.
Q7 Same tension, same thickness of wire, same length – same note/pitch/frequency.
Q8 Yes, they should.
Q9 We have doubled the tension in A.
Q10 We halved the vibrating length of string B.
Q11 The frequency of a vibrating string depends on the length, the tension and the thickness (actually mass per unit length) of the string. A higher frequency has a shorter wavelength. Longer and/or slacker gives lower frequency. Shorter and/or tighter gives higher frequency. A thinner (lighter) string gives a higher frequency at the same length and tension as a thicker string.
Q12 String C is thinner, and the tension in it is less, when its frequency is the same as A.
Q13 Tension and diameter of string have opposite effects on the frequency. At the same length and tension, thicker strings give lower frequencies.
For any string, increasing the tension increases the frequency.

Safety advice

This advice is not a replacement for a formal risk assessment, which should be carried out according to your school or LEA policy.

Disclaimer

If the equipment is used in a way not specified by Philip Harris, then the protection provided may be impaired.

Warranty, repairs and spare parts

The Sonometer is guaranteed for a period of one year from the date of delivery to the customer. This warranty does not apply to defects resulting from the action of a user such as misuse, improper wiring, any operations outside of its specification, improper maintenance or repair, or unauthorized modification.

Our liability is limited to repair or replacement of the product. Any failure during the warranty period should be referred to Customer Services.

Edulab
Karoo Close
Bexwell Business pArk
Bexwell, Noroflk
PE398 9GA
United Kingdom

+44 (0)1366 685777 | sales@edulab.com