Lecture 1-1: Sounds and Vibrations

Overview

1. **Physical characteristics of sound**. Physically, sounds are fluctuations in air pressure which travel through the air in the form of longitudinal pressure waves. Longitudinal refers to the fact that the waves of compression and rarefaction lie along the direction of travel. When an object vibrates in air, it compresses the gas in the direction of its motion and rarefies the gas behind it. Air then moves to equalize these pressure changes, but because air itself has mass, these movements overshoot and simply cause other fluctuations in pressure at a distance from the object. A repetition of this equalization and overshoot leads to a pressure wave propagating away from the source of sound at high speed (about $330ms^{-1}$), see Fig 1-1.1. Note that sound propagation does not involve the physical movement of air – only of small changes in pressure between adjacent regions. Similar longitudinal pressure waves can travel through liquid or solid media.
2. **Sounds we hear**. The air pressure changes that we perceive with our hearing mechanism are limited to small, rapid fluctuations. Our hearing is "centered" around pressure changes of about 0.0001% of atmospheric pressure which repeat about 1000 times per second.
3. **Vibrations**. Many everyday sounds originate from regularly vibrating objects or surfaces. If an object is vibrating cyclically, then we can measure the length of time taken to complete one cycle, this is called the **period** of vibration and is measured in seconds. Alternatively, we could measure how many cycles of vibration occur in one second, this is called the **frequency** of vibration and is measured in **hertz** (abbreviation Hz). The two are obviously related since frequency = 1/period.
4. **Simple vibrating systems**. It is easiest to study vibrations when they are generated by simple physical systems: for example a pendulum, a mass on a spring, or a tuning fork, see Fig 1-1.2. These systems have a characteristic frequency of vibration which they demonstrate once pushed or struck. This is called their **natural frequency**. The value of the natural frequency can be affected by the physical size, structure and composition of the systems: a long pendulum vibrates at a lower frequency (longer period) than a short one, a compliant spring vibrates at a lower frequency than a stiff spring, and a more massive tuning fork vibrates at a lower frequency than a light one.
5. **Amplitude and Damping**. When an object is vibrating periodically, we can measure the physical size of the movement with respect to some centre or equilibrium position of the object, this is called the **amplitude** of vibration. It is easy to see that the harder we push a pendulum the larger the amplitude of the vibrations that result. The amplitude of the vibrations is an indicator of the amount of energy we imparted to the object to make it vibrate. Commonly as an object vibrates it will lose some of its energy to its surroundings, for example as frictional losses to the air that is moved by the vibration. Thus the energy and hence the amplitude of vibration will gradually diminish over time. The rate at which vibrational amplitude diminishes with time is called the **damping** of the system. Note that damping and amplitude are different and independent – a system can be highly damped and yet vibrate with a large amplitude (which will reduce rapidly over time).
6. **Laboratory Experiment**. We'll measure the natural frequency of a pendulum of different sizes and see how the addition of a paper cone affects its natural frequency and damping, see Fig 1-1.3. The lab is a good practice of essential laboratory skills.

Readings

There are many good teaching and learning resources about sound on the web. This one is recommended:

http://www.physicsclassroom.com/Class/sound/

Look under Web Resources on the course web site for this and other links.

Learning Activities

You can help yourself understand and remember this week's teaching by doing the following activities before next week:

1. Write a description of the Speech Chain as a way of understanding spoken language communication.
2. Write down your own definitions for the new terms we have met this week, for example: sound, period, frequency, amplitude, natural frequency, damping.
3. Write a description of the scientific aims of the Damped Pendulum experiment.
4. Write a description in your own words of the method we used to measure the natural frequency and damping of a pendulum.
5. Tabulate and graph the results of the Damped Pendulum experiment.

If you are unsure about any of these, make sure you ask questions in the lab or in tutorial.

Reflections

You can improve your learning by reflecting on your understanding. Here are some suggestions for questions related to this week's teaching.

1. What units would you use for measuring the amplitude of (a) a pendulum vibration, (b) a sound wave, (c) the output of a microphone?
2. Does a pendulum have a frequency when it is not vibrating? Does it have a natural frequency when it is not vibrating?
3. How might you increase the damping of (a) a pendulum, (b) a mass on a spring, (c) a car?
4. If the period of a sound vibration is 1ms, and the speed of sound is $330ms^{-1}$, how big in space is one wave cycle? (This is called the wavelength of the sound)

Fig 1-1.1 Longitudinal wave propagation

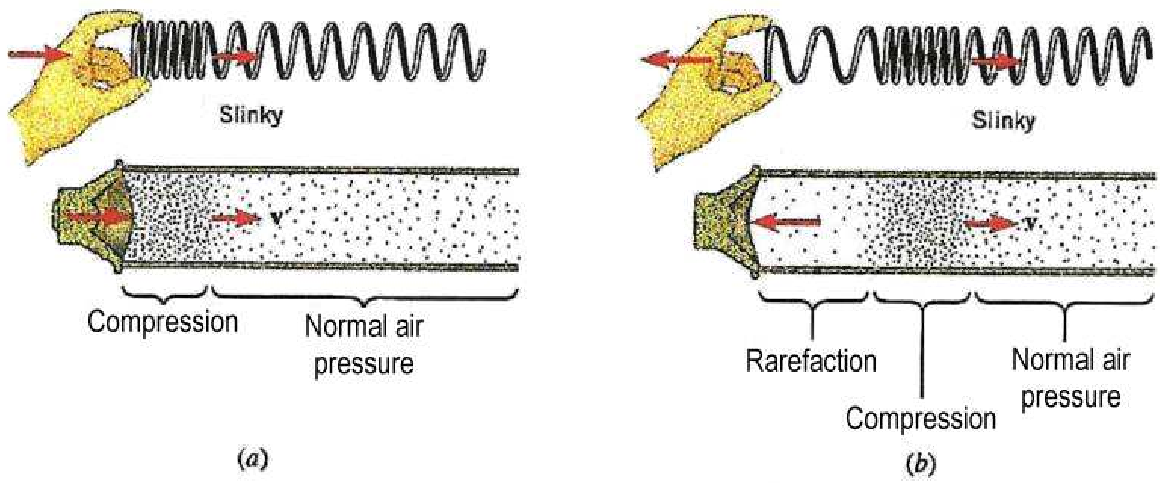


Fig 1-1.2 Simple Vibrating Systems: (a) pendulum, (b) mass on a spring, (c) tuning fork

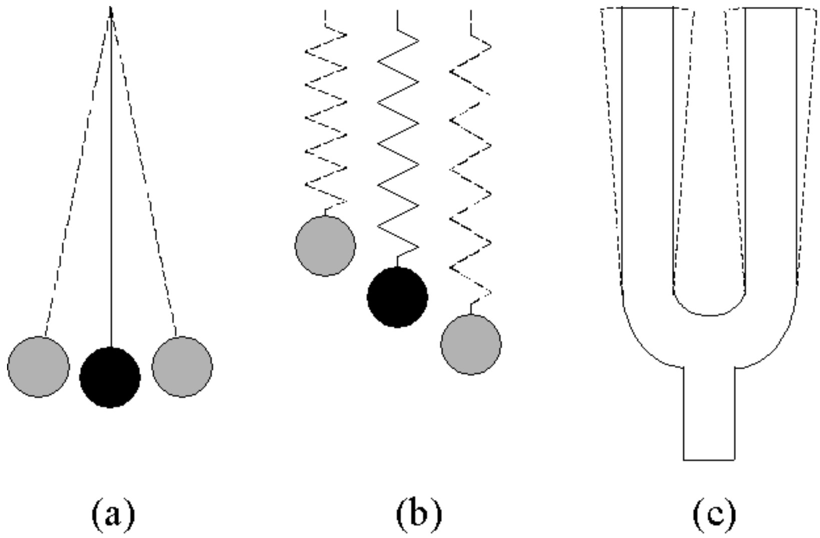
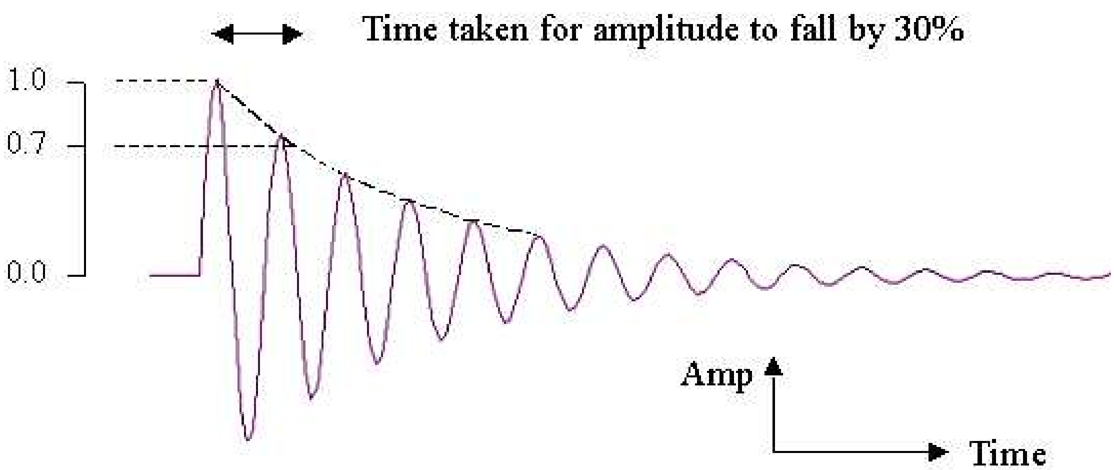


Fig 1-1.3 How to measure degree of damping



Lab1-1: The Damped Pendulum

Introduction

To understand how systems as complex as the vocal tract change the properties of sounds, we first need to consider much simpler systems. The pendulum is an example of a simple vibrating system, we call it a *simple resonator*. The signal we put in to this system is a 'push', and the signal we get out is the observed swinging of the pendulum bob.

Scientific Objectives

- To investigate how the resonant period of a pendulum is affected by its length and its damping.

Learning Objectives

- To draw parallels between the pendulum as a system and other simple resonating systems.
- To practise key laboratory skills.

Apparatus

You have a pendulum bob on a thin thread, a pendulum stand with a sharp edge, a measuring tape, a stopwatch, paper, scissors and sticky tape. You can use the lab PCs to plot your graphs if you know how.

Method

To measure the period of a pendulum, time between 10 and 20 cycles at each length. Only use small swings, plot the shortest and longest lengths first to find the limits of your graph, and **plot your graph as you go along**. Measure the length of the pendulum from the sharp edge on the stand to the centre of the bob.

To damp the pendulum, cut a paper circle of about 20cm in diameter, make a cut from edge to centre, fold and tape into a cone. Slip the paper cone over the pendulum bob.

Observations

1. Measure the period of a pendulum varying from 10cm to 100cm in steps of 10cm. Set the results out in a table with headings: Length (cm), No. of swings, Time (s), Period (s), Period^2 (s^2). Comment on the accuracy of your measurements.

2. Plot a graph of period against pendulum length as you go along.

3. Plot a graph of period^2 against pendulum length.

4. With a pendulum of 100cm, estimate how long it takes for the amplitude of its swing to diminish by 30% (e.g. from a swing of amplitude ± 20cm to a swing of ± 14cm). This time is a measure of the *damping* of the pendulum (see Fig. 1-1.3).

5. Measure the period of a 100cm pendulum damped with the paper cone. Repeat for two or three other lengths.

6. With a damped pendulum of 100cm, estimate how long it takes for the amplitude of its swing to diminish by 30%.

Concluding Remarks

1. Interpret your graphs to come to some conclusion about the relationship between the resonant period of a pendulum and its physical size.
2. Explain how you can estimate the period of pendulums of other lengths (e.g. 0.86m) from your graphs. Which is the best graph to use and why?
3. What effect does the paper cone have on the way the pendulum swings (i.e. its period and its damping)? Why do you think the cone has these effects?
4. Other simple resonators include a tuning fork and a mass on a spring. Think of a physical property of each system that would affect its resonant period. Think of a different physical property that would affect its damping.