Episode 301: Recognising SHM

This episode allows you to familiarize your students with the main features of SHM, before going on to a more mathematical description.

Summary

Demonstration: Observing SHM in the lab. (20 minutes)

Discussion: The importance of SHM. (10 minutes)

Demonstration: SHM is isochronous. (10 minutes)

Student activity: Identifying SHM. (20 minutes)

**Demonstration: Sinusoidal graphs on a CRO. (10 minutes)**

Demonstration:

Observing SHM in the lab

Start by talking about oscillations. Oscillatory motion is a type of motion that repeats itself in a cyclic fashion.

Set up some visual aids: a pendulum and a mass on a spring. Set them oscillating.

It is easier to see what is going on with a slower oscillation. Tether a dynamics trolley by springs between two retort stands. Add weights to the trolley, so that its period of oscillation is a couple of seconds. Set it oscillating; you will be able to hear the trolley as it speeds up and slows down. If you use a motion sensor connected to a computer it is easy to see the displacement time graph and velocity time graph. You could do the same for a long pendulum.

(resourcefulphysics.org)
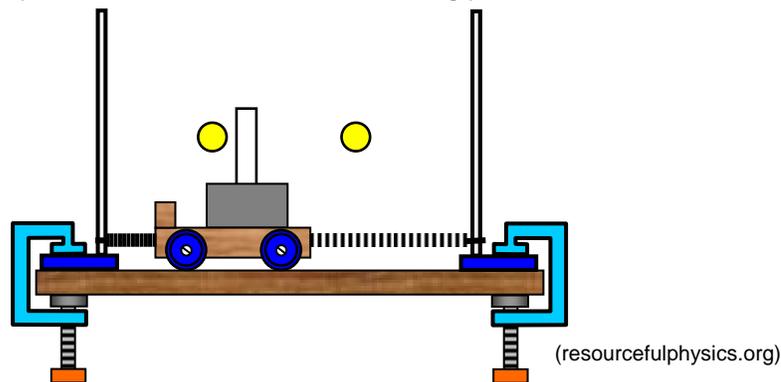
Set up an oscilloscope with its timebase switched off, so that the spot is central on the screen. Connect to a very slow signal generator, set at a frequency of less than 1 Hz. Watch the up-and-down motion of the spot on the screen. Ask about the shared characteristics of these different oscillations. Points to bring out:

The oscillatory motion repeats itself and thus has similarities with circular motion which also repeatedly returns to its starting point. (This fact will be fruitfully exploited later.)

- Displacement is the greatest at the extremes of the oscillation.
- Velocity is the greatest at the midpoint.

- The oscillating mass is in equilibrium at the midpoint of its oscillation; show this by stopping the mass at this point – it remains stationary.

- When the mass is oscillating, its inertia carries it through the midpoint.

So we have the following pattern of motion:

The mass speeds up as it heads towards the midpoint, has its greatest speed as it passes through the midpoint, and slows down as it continues towards the other extreme of the oscillation. Here, it reverses and starts to accelerate again towards the midpoint.

Of course, not all oscillations are as simple as this, but this is a particularly simple kind, known as
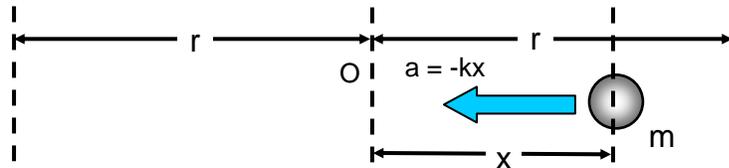
simple harmonic motion (SHM). It is relatively easy to analyse mathematically, and many other types of oscillatory motion can be broken down into a combination of SHMs.

Discussion:

SHM is isochronous

At this point, it is worth saying a few words about the importance of SHM.

All clocks (starting with the pendulum in a grandfather clock) are essentially simple harmonic oscillators; all transmitters and receivers of waves are essentially simple harmonic oscillators; many aspects of engineering design from the massive to the microscopic require a detailed knowledge of SHM (e.g. bridges, earthquake protection of buildings, atomic force microscopes for imaging single atoms). Detailed theories of the behaviour of atoms and molecules (in solids and gases) are applications of SHM. Other aspects of SHM are at the heart of unsolved questions in physics today. Thus although the model oscillators that students meet appear rather basic, they mirror pretty well applications and problems far beyond the school laboratory.

The key aim is to get across how to recognise SHM experimentally as well as the features that are built into the theoretical model of SHM.

Demonstration:

Identifying SHM

Using the apparatus of the earlier demonstration, set one oscillator in motion. Now change the amplitude. What do you notice about the time period of the oscillation? (It doesn't change.) This is obvious if a motion sensor is used.

Try with the others.

This is a characteristic of SHM; the period is independent of the amplitude, and we say that the motion is *isochronic*.

Student activity:

Identifying SHM

Your students can try out some other oscillating systems; are they isochronic? Do they appear to be SHM?

Set up a circus of experiments (see below). Students in pairs try out a selection and report back to a plenary session.

TAP 301-1: Oscillation circus

1.   mass on a spring (vertical)

2.   mass (large cube of polystyrene) on the end of a slinky spring suspended from the ceiling

3.   mass between two springs (vertical, both springs in tension when the mass is at rest)

4.   mass between two springs (horizontal, both springs in tension when the mass is at rest – use an air track slider for the mass to have a low friction system)

5.   air track slider moving between two 'buffer' springs, or rebounding due to magnetic repulsion
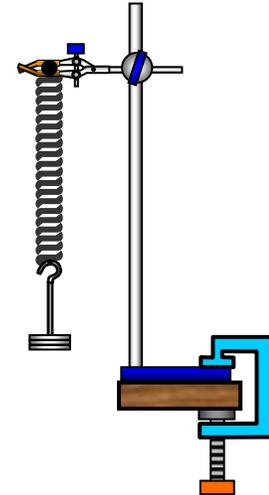
   TAP 301-2: Mass oscillating between elastic barriers

(resourcefulphysics.org)
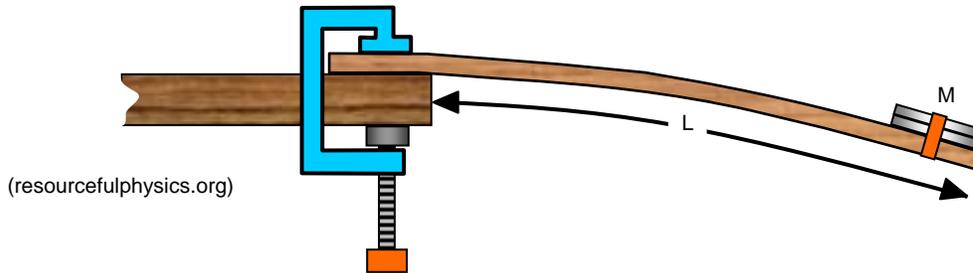
(resourcefulphysics.org)

6.   vibrating cantilever

7.   simple pendulum

8.   simple 'half' pendulum (one that bounces off a hard surface when its string is vertical)

   TAP 301-3: Oscillating ball

9.   simple pendulum whose string intercepts a peg when vertical, so the length of the pendulum gets shorter for one half of its cycle

10.   a torsion pendulum

   TAP 301-4: Swinging bar or torsion pendulum

11.   a ball bouncing off a hard surface

12.   ball moving in a semi-circular shaped track (curtain rail)

13.   ball moving in a vertical V shaped track (rounded enough at the point of the V to let the ball pass easily)

14.   ball moving in a vertical parabolic shaped track (draw out the parabola on a large piece of paper to aid the bending of the track into the parabolic shape)

15.   a right circular cone on an inclined plane

16.   a rectangular or square section bar balanced on top of a cylinder – the length of the bar at right angles to the axis of the cylinder

17.   water in a U tube

18.   hydrometer in water

Demonstration:

Sinusoidal graphs on a CRO

Set one or more of the masses oscillating. Ask: what would a displacement-time graph for this look like? You can show the graph using the oscilloscope. Switch on the time base to see the sinusoidal graph as it is traced out. Emphasise that the graph produced is 'a sine wave' or 'a sinusoidal variation'. Alternatively show the motion with a computer and a motion sensor. A pendulum with about a 2 m string and a suitably large bob, (large coffee can with some sand) works well. The Trolley and spring system works well for slow oscillations. A card may be needed on the trolley so it is picked up correctly by the sensor. Be safe: when fixing a string to a high point, two persons are needed – one to hold the ladder or steps and one to do the job.

(If your signal generator will also generate triangular and square waves, show the oscillations these produce with the timebase off. Ask for predictions of the displacement-time graphs.)

A more challenging question, which you may wish to leave until later: What would a velocity-time graph look like? (Also sinusoidal, but maximum value when displacement = 0.) And acceleration? (Sinusoidal, but 180° out of phase with displacement.)
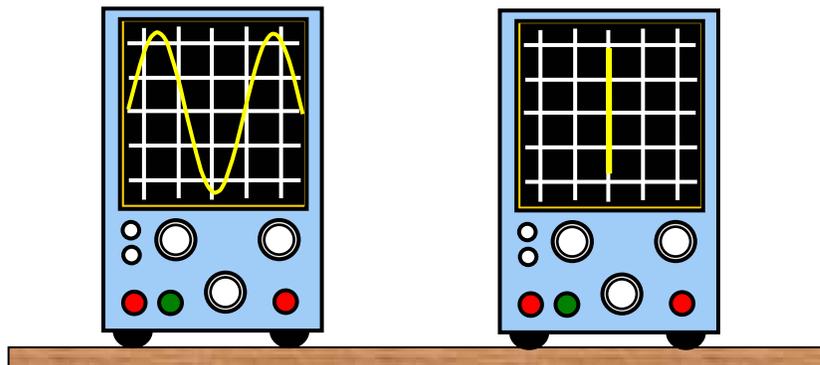
TAP 301- 1: Oscillation circus

Observe a variety of oscillating systems and decide whether each exhibits simple harmonic motion. Try to identify what provides the inertia and what provides the stiffness of the system. Some systems lend themselves to detailed measurements, while others simply require observation.

Much of the data-gathering activity for oscillations will be made easier using the Motion Sensor and associated software from Data Harvest or other suitable sensor.

Apparatus

- ✓ 'simple' pendulum (small mass on a string)
- ✓ 'compound' pendulum (a rigid pendulum like a metre rule, with or without a mass on the end)
- ✓ 'torsion' pendulum (a mass hanging from a single wire, executing twisting oscillations)
- ✓ flexible strip of wood or plastic, clamped horizontally to a vertical support, oscillating in a horizontal plane
- ✓ inertia balance (a version of the previous oscillator)
- ✓ rolling ball on curved plastic tracking
- ✓ mass oscillating on a vertical spring
- ✓ large amplitude 'pendulum' (vertically rotating disc, pivoted at the centre with an off-centre mass clamped to it)
- ✓ test tube ballasted and floating vertically in water
- ✓ liquid in a large U-tube
- ✓ vehicle on an airtrack between elastic barriers
- ✓ 'catapulting' type oscillator (on an airtrack, or a trolley on a runway)

Optional

Access to a computer running the CD-ROM *Multimedia Motion*.

Sensing equipment and data-gathering software will be needed for recording the motion of some of the oscillators.

Study some, or all, of the following oscillating systems:

- 'simple' pendulum (small mass on a string)
- 'compound' pendulum (a rigid pendulum such as a metre rule, with or without a mass on the end)
- 'torsion' pendulum (a mass hanging from a single wire, executing twisting oscillations)
- flexible strip of wood or plastic, clamped horizontally to a vertical support, oscillating in a horizontal plane
- inertia balance (a version of the previous oscillator)

- rolling ball on curved plastic tracking

- mass oscillating on a vertical spring

- large amplitude 'pendulum' (rotating disc, pivoted at the centre with an off-centre mass clamped to it)

- test tube ballasted and floating vertically in water

- liquid in a large U-tube

- vehicle on an air track between elastic barriers

- 'catapulting' type oscillator (on an air track, or a trolley on a runway).

Observations

While you experiment on a particular oscillator consider the following questions:

Is the period constant (i.e. is it affected by the amplitude)? If the motion dies away quickly, you will need to think carefully how you will answer this point.

Can you identify separate stiffness (k) and inertia (m) components? If you cannot easily do this, can you pick out features of the system that behave like k and m (and try and say in a sentence or two why you found it difficult)?

What adjustments do you think you would need to make to the system to reduce its period (increase its frequency)?

Graphs of motion

Where feasible, obtain a trace showing how displacement varies with time. (You might find this the easiest way to answer the first question above.)

How would you find how the velocity and acceleration vary with time from such a trace?

Without doing any detailed measurement or calculation, sketch on the same (horizontal) axes graphs showing how the velocity and acceleration vary during the course of the motion.

Exactly how you take measurements and record displacement– time traces will depend on the data-gathering equipment you have available.

For example, if you are using a motion sensor you might

- use the associated software to produce velocity and acceleration traces for you as well – but don't rely on a computer to do all the work.

- Think how velocity and acceleration graphs relate to a displacement graph.

Extension

Use the *Multimedia Motion* CD-ROM to investigate the motion of a pendulum and obtain graphs of horizontal displacement, velocity and acceleration. Print out and keep a table of the numerical values of these quantities as well.

Practical advice

It is not possible to be very specific for apparatus, as what is provided will depend on local circumstances. A range of oscillators is suggested and it is recommended that as far as possible once the apparatus is assembled it is useful to keep it together and dedicate it to this activity.

Students explore a range of different types of oscillator. It is not envisaged that all the examples suggested are available, nor that students will attempt all that are put out – the range is not exhaustive and you will have your own preferences.

One suggested oscillator in the circus is a torsional oscillator (a twisting mass hanging from a single wire).This is worth including as it is one of the few examples of oscillations that remain simple harmonic for very large amplitudes (several complete revolutions).

Ideally some of the apparatus should be accompanied with sensing and data-logging equipment to enable displacement–time graphs to be displayed. For example, a motion sensor can easily detect the movement of a mass on a spring, and a potentiometer or other angle sensor can be used with a compound (rod-type) pendulum. More ambitiously, strain gauge sensors can be used with flexural oscillations.

Students should be encouraged to derive (or at least make rough sketches of) velocity and acceleration graphs before using any software that might generate them directly.

The oscillations will fall into three categories:

(a) SHM (i.e. constant period) (within the accuracy of observations)

(b) Approximately SHM, but departing at high amplitudes

(c) Definitely not SHM.

It will probably emerge that (b) is the largest category. You might like to know the result that for pendulum-type oscillations, the period is

$$T = T_0 + (1 + \frac{\theta^2}{16})$$

where T_0 is the period for very small amplitudes and θ is the angular amplitude in radians. For an amplitude of 1 radian (nearly 60°), $T = 1.063T_0$, and for very lightly damped oscillations it ought to be possible to detect the 6% increase in period.

The main point of the activity, though, is to demonstrate that many different oscillators behave in a way that is simple harmonic or nearly so.

A note on teaching SHM

SHM is sometimes considered to be a difficult area, probably because students can get overwhelmed by the maths and cannot see any direct use for their efforts. A context-setting discussion will largely avoid the second concern. As far as the first is concerned, we recommend that you use whatever approach to SHM you feel most comfortable with and which best suits your students

External reference

This activity is based on Salters Horners Advanced Physics, section BLD, activity 15

TAP 301- 2: Mass oscillating between elastic barriers

This oscillator is an air-track vehicle or low-friction dynamics trolley bouncing between elastic bands mounted at either end of the track.

You will need

- ✓ two trolley catapults
- ✓ dynamics trolley, low friction
- ✓ trolley board
- ✓ stopwatch
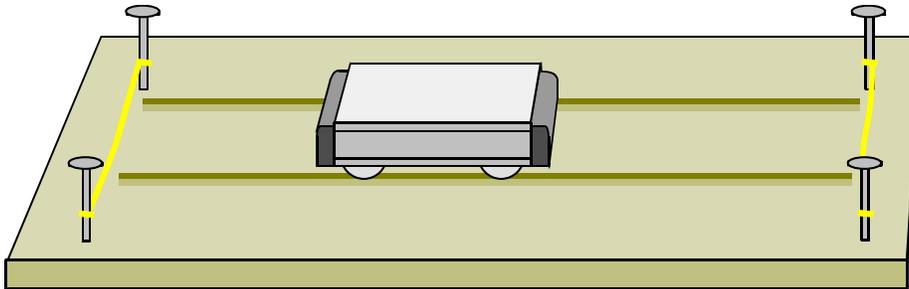
What to do

Set the oscillation going by gently pushing the vehicle towards one of the catapults.

1. Measure the time it takes for the vehicle to move along the track for a number of consecutive runs and enter the results into the table.

Run along track	Time taken / s
1	
2	
3	
4	
5	
6	

Is the oscillation isochronous?

2. Draw a displacement–time graph and a velocity–time graph of two full oscillations. Take zero displacement to be in the middle of the track and consider displacements to the right of the middle point as positive.

You have seen

1.   This oscillation is not isochronous.

2.   The velocity does not substantially change during a single run of the trolley, but does fall each consecutive run.

Practical advice

This gives an example of a rather different 'oscillator'. The major point to stress here is that the velocity does not change except at the ends of the oscillation, because that is the only place a force acts on the trolley (other than friction, which we are doing our best to reduce to zero).

Alternative approaches

Students may suggest other interesting oscillators.

External reference

This activity is taken from Advancing Physics chapter 10, 230P

TAP 301- 3: Oscillating ball

The simple pendulum is a very well known oscillator. In this case you are looking at what appears to be a simple pendulum with half its swing removed.

You will need

- ✓ table-tennis ball mounted on thread
- ✓ retort stand, boss and clamp
- ✓ glass block
- ✓ hand-held stopwatch

table tennis ball
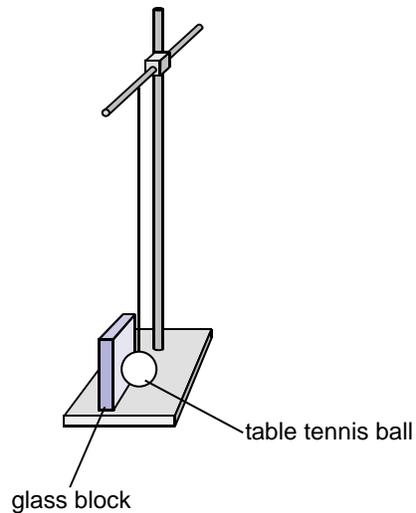
glass block

1. Check to see whether the table-tennis ball is isochronous when swinging freely.

2. Now place the glass block at the centre of the swing, pull the ball back about 8 cm and release. Is the oscillation isochronous? How do you know?

3. Sketch a displacement–time graph for the oscillation. Include some measurement of time interval so that someone else looking at the graph could tell the time period of the oscillator.

What you have done

1. You have drawn a displacement–time graph for the motion.

2. You have found that the oscillation is not isochronous.

Practical advice

This very quick activity is designed to encourage the students to move from what they are familiar with, in this case the simple pendulum, to something with which they are less familiar. They should apply their knowledge of the displacement–time graph of a pendulum to make a sketch of this interrupted pendulum motion. Encourage your students to include some numerical detail on the sketch graph.

Alternative approaches

Students may suggest other interesting oscillators.

External reference

This activity is taken from Advancing Physics chapter 10, 220P

TAP 301- 4: Swinging bar or torsion pendulum

Twisting motions can set up oscillations. In this activity you observe the oscillation of a torsion pendulum, to decide if it is isochronous or not.

You will need

- ✓ two each of retort stands, bosses and clamps with pairs of wood or metal strips to clamp strings
- ✓ retort stand rod
- ✓ two extra bosses
- ✓ two 0.5 m lengths of string
- ✓ hand-held stopwatch
- ✓ pen torch
- ✓ graph paper

retort stand

pen torch

bosses to balance rod and
increase the time period
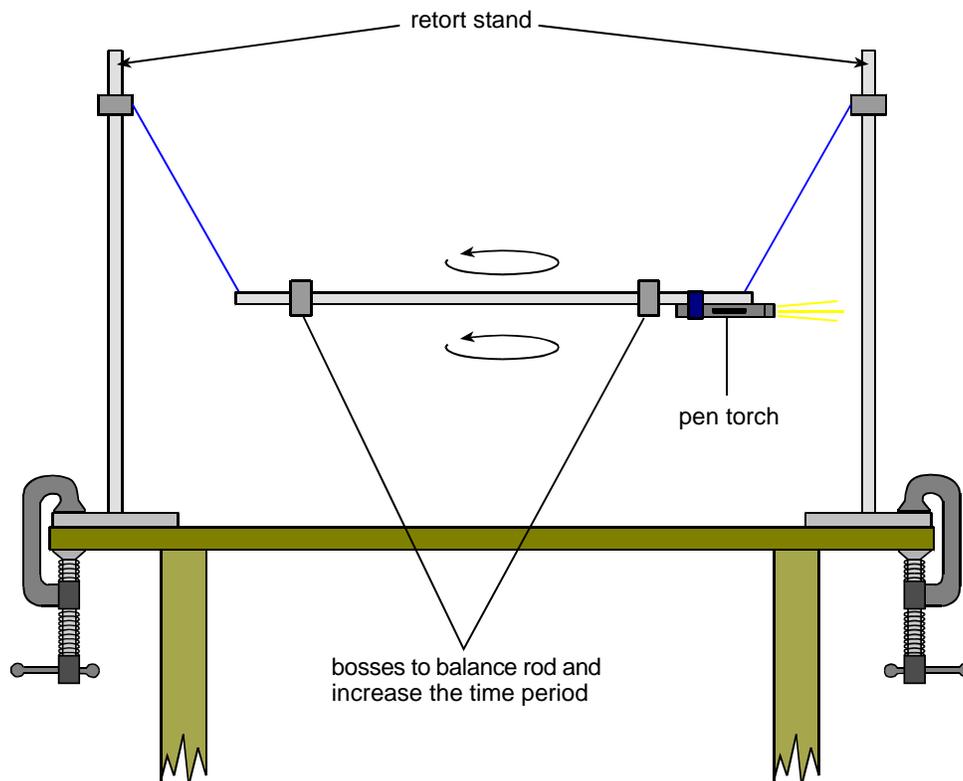
What to do

The pen torch, suitably focused, will allow you to see a magnified representation of the motion on either graph paper or a distant wall.

1.   Time how long each five oscillations take and enter the results in the table. Is the oscillation isochronous?

Oscillations	Time / s
1–5	
6–10	
11–15	
16–20	
21–25	

2.   Can you think of a way to produce a displacement–time record of the motion, or take results that will lead to such a record?

3.   As an extension, you might like to investigate how the distance between the strings affects the periodic time.

You have seen

1.   The oscillation is approximately isochronous.

Practical advice

This activity shows that torsional forces can lead to oscillation. It may also give imaginative students an interesting practical problem, recording displacement–time results.

Alternative approaches

Students may suggest other interesting oscillators.

External reference

This activity is taken from Advancing Physics chapter 10, 210P