Episode 205: Describing motion

This episode introduces (or revises) basic kinematics. The equations of motion are met in separate science (triple award) pre-16 level but are not discussed in detail in double award. This is an area which many moderate-to-weak students find difficult and they may well remember their

pre-16 experience with some unease. It is worthwhile including a direct measurement activity to ensure that students spend sufficient time on the basic physics of velocity, distance and time. This is a busy episode that focuses on one activity that all students should perform individually.

Summary

Discussion: Scalars and vectors, velocity and displacement. (5 minutes)

Student experiment: Balls down ramps. (25 minutes)

Discussion: Average velocity, time and displacement. (10 minutes)

Discussion: Chalk in the air. (5 minutes)

Student questions: Using these ideas. (30 minutes)

Discussion:

## Scalars and vectors, velocity and displacement

If necessary, briefly remind students of the difference between vectors and scalars. Taking a marble and rolling it along the bench in one direction then back along the bench in the other direction at the same speed clearly demonstrates the difference between velocity and speed. Defining acceleration as the rate of change of velocity allows a discussion of an orbiting body (or a conker on a string) moving with constant speed whilst also experiencing constant acceleration.

Before proceeding with the student experiment it is worthwhile explaining why the final velocity of a body is twice its average velocity if (and only if) it has uniformly accelerated from rest.

Student experiment:

Balls down ramps

Rolling balls down ramps: This is a version of the experiment that Galileo performed towards the end of the sixteenth century.
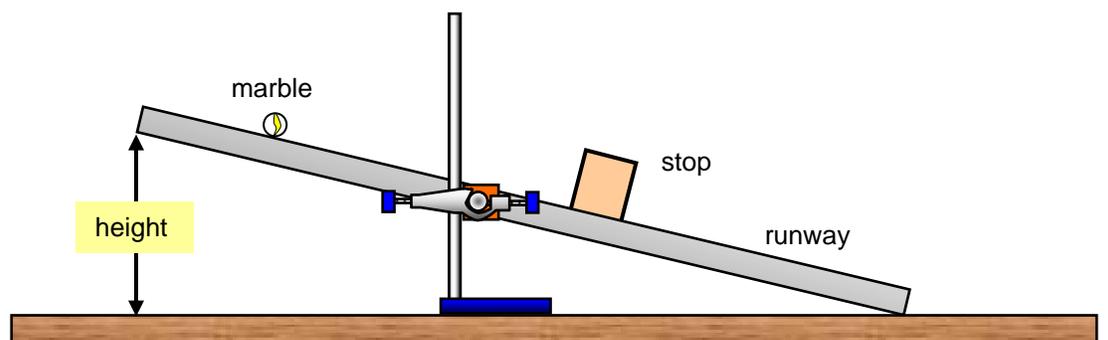
(resourcefulphysics.org)

Students time a marble rolling a fixed distance down the slope. From this, they can produce graphs of final velocity against distance and final velocity against time. The first graph will show a square relationship whereas the velocity-time graph will show a linear relationship. However, there is much scatter in the points and it is a useful exercise to consider whether the velocities are more 'accurate' for readings over small distances than those over larger distances.

TAP 205-1: Rolling balls down ramps

Discussion:

Average velocity, time and displacement

Using the graphs drawn from the experiment you can show two things:

$a = \Delta v/\Delta t$, that is, that the gradient of a velocity-time graph yields acceleration.

The area under the velocity time graph gives the distance travelled by the marble.

Ask your students to read off a time (say 1.5 s) from the distance-time graph and find the corresponding distance value. The area under the velocity-time graph up to 1.5 s will come to the same value as the distance. Bright students will see the circularity in this method, but this, in itself, is of value.

Discussion:

Chalk in the air

Throw a piece of chalk (or a board marker) in the air vertically and catch it when it returns to its original position. Ask students to sketch a velocity-time graph of the motion, assuming no air resistance.

Very few will produce a graph like this:

velocity (v)

time (t)
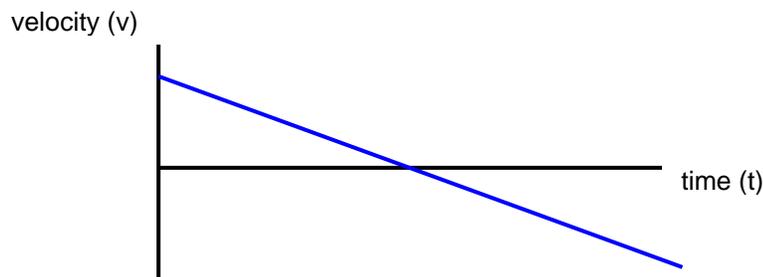
The errors made by the students will allow you to highlight many points of physics. For instance, a graph may suggest that the acceleration due to gravity is different when a body is travelling upwards from the value for a descending body. Particularly revealing is to ask what is the acceleration when the object reaches its maximum height. You will find this a fruitful discussion from which even the bright and confident students can learn a lot.

Student questions:

Using these ideas

Select from the questions those most suitable to the level of your students. You might choose to give different questions to different students – for example, those not taking AS mathematics might need to work through more examples than those studying mathematics.

TAP 205-2: Distance, time and speed calculations

TAP 205- 1: Rolling balls down ramps

This is a version of the experiment that Galileo performed towards the end of the sixteenth century.
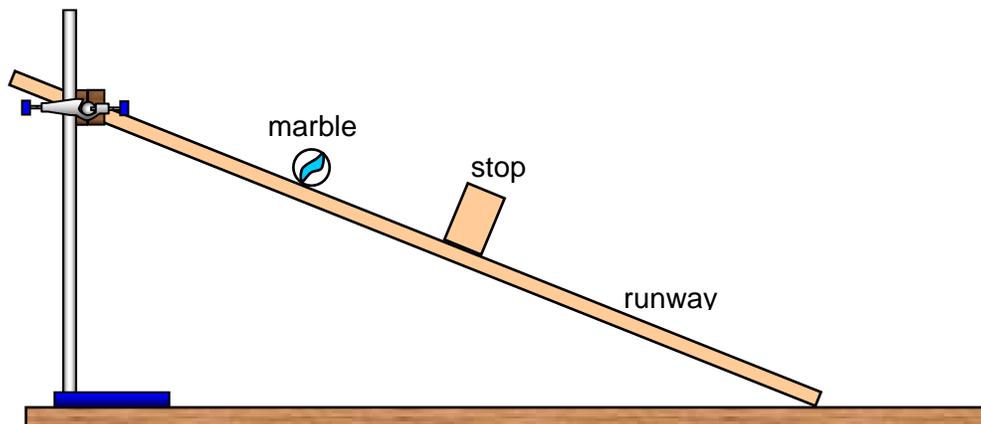
Apparatus required

- ✓ wooden runway
- ✓ digital stop clock
- ✓ metre rule to measure lengths along runway
- ✓ metre rule to act as a 'stop'.
- ✓ retort stand and clamp
- ✓ marble

Procedure

- Set the ramp at about 20° slope.

- Measure the time taken for the marble to run from the top of the slope to a rule ('stop') 10 cm along the slope. Repeat this measurement a sensible number of times to establish a mean value.

- Move the stop point to 15 cm from the top of the slope and repeat the process.

- Continue the process, at 5 cm intervals until the marble runs the length of the ramp.

- Results can be recorded in a table with the following headings:

distance along ramp / m	mean time/ s	average velocity / m s^{-1}	final velocity = 2 × average velocity / m s^{-1}

Analysis

Draw graphs of final velocity against distance and final velocity against time. From the second graph deduce the marble's acceleration.

Repeat the experiment using a different angle of slope, and find the new value of acceleration.

If you have time repeat with a marble of different mass.

TAP 205- 2: Distance, time and speed calculations

Try these calculations

Graph paper is needed for some. These questions are all based on the connection between speed, distance and time. Answer in the spaces provided:

## Hints

In these questions it is useful to remember that:

– if an object is accelerating steadily from rest its average speed is half the maximum speed

– and that distance travelled = average speed time

1. You are watching a batsman hit a cricket ball. If 0.375 s passes between the time you see him strike the ball and the time you hear the sound of this, how far from the batsman are you sitting? The speed of sound in air is 340 m s^{-1}. (The speed of light is nearly a million times bigger than this, so you see the bat hit the ball more or less at the instant it occurs.)

2. A girl diving from a 15 m platform wishes to know how fast she enters the water. She is in the air for 1.75 s and dives from rest (with an initial speed of zero). What can you tell her about her entry speed?

3. An experiment performed on the Moon finds that a feather falls 20.75 m from rest in 5 s. What is its speed as it hits the Moon's surface?

4.   The sketch graph shown represents the variation in vertical height with time for a ball thrown upwards and returning to the thrower.
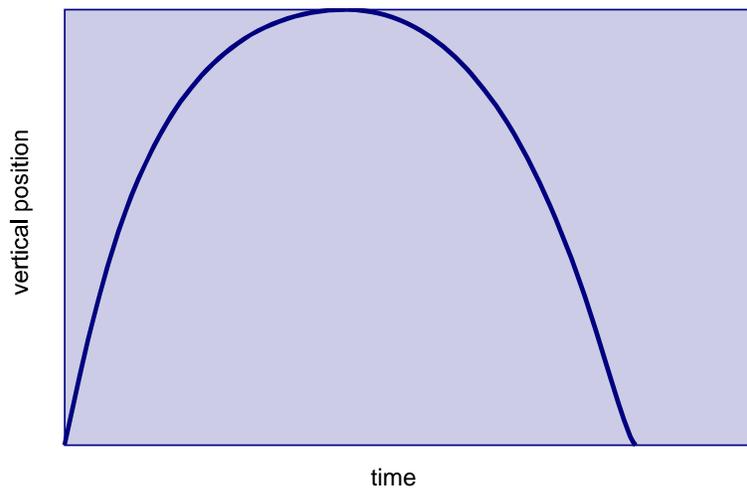
time

      From this graph sketch a velocity–time graph.

5.   In a Tour de France time trial a cyclist is able to reach a top speed of 100 km h^{-1} by starting from rest and pedalling flat out for a distance of 3 km. If the rate at which the cyclist's speed changes is uniform, how long will this take?

6.   You are travelling in a car moving at 50 km h^{-1} (just over the 30 mph speed limit). What is this speed in m s^{-1}? You have to brake so the car comes to rest uniformly in 1.4 s, how far will you travel? A cat runs out in front of your car and your reaction time is 0.6 s. What is the total distance the car will travel before stopping?

7.   A steam traction engine speeds up uniformly from rest to 4 m s^{-1} in 20 s. It then travels at a steady speed for 440 m and finally comes to rest uniformly in 10 s having travelled 500 m in total. Draw a speed–time graph for its motion showing key values of speed and time. What is the total time for the journey? What is the average speed for the whole journey?

8.   A tennis ball is dropped from a height of 2 m above a hard level floor, and falls to the floor in 0.63 s. It rebounds to a height of 1.5 m, rising to a maximum height 1.18 s after it was released. Draw a speed–time graph indicating speed and time at key points of the motion.

Practical advice

These questions are mostly revision from pre-16 level. They do address application of distance, time and speed measurements in a variety of contexts, and force students to think carefully about interpreting and using graphs of motion.

Social and human context

Sports provide many examples of coordinated and relative motion.

Answers and worked solutions

1.

$$\text{Speed} = \frac{\text{distance}}{\text{time}} \Rightarrow \text{distance} = \text{speed} \times \text{time} = 340 \text{ m s}^{-1} \times 0.375 \text{ s} = 127.5 \text{ m}$$

= 128 m to 3sf

2. When you have read chapter 9 you will be able to do this calculation using ideas about acceleration. There is a simpler way: the girl's average speed is

$$\text{average speed} = \frac{\text{distance}}{\text{time}} = \frac{15 \text{ m}}{1.75 \text{ s}} = 8.57 \text{ m s}^{-1}$$
.

As she dives from rest, her final speed must be twice this average (if we assume that she accelerates uniformly). So, her speed on entry is

$$\text{maximum speed} = 2 \times 8.57 \text{ m s}^{-1} = 17.14 \text{ m s}^{-1} \approx 17.1 \text{ m s}^{-1}$$
.

=17 ms^{-1} to 2sf

3. The solution to this problem is similar to that for question 2. Find the average speed and then double it. The average speed is

$$\text{average speed} = \frac{\text{distance}}{\text{time}} = \frac{20.75 \text{ m}}{5 \text{ s}} = 4.15 \text{ m s}^{-1}$$
.

Hence:

$$\text{maximum speed} = 2 \times 4.15 \text{ m s}^{-1} = 8.30 \text{ m s}^{-1}.$$

4. The velocity is calculated from the gradient of the distance–time graph. At first the graph rises, implying a positive gradient, which gradually decreases to zero, implying a speed of zero. The gradient then becomes negative and gradually steeper, showing an increasing negative velocity.
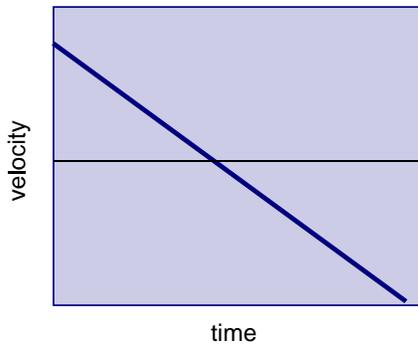
5. The top speed of the cyclist is 100 km h^{-1}. If the cyclist accelerates uniformly from rest, the average speed must be half this, i.e. 50 km h^{-1}. To find the time taken to travel 3 km at this speed:

$$\text{speed} = \frac{\text{distance}}{\text{time}} \Rightarrow \text{time} = \frac{\text{distance}}{\text{speed}} = \frac{3\text{ km}}{50\text{ km h}^{-1}} = 0.06\text{ h} = 216\text{ s}$$
.

6. To convert 50 km h^{-1} to m s^{-1}:

    50 km h^{-1} = 50 km h^{-1} x 1000 m km^{-1} / 3600 s h^{-1} = 13.8 m s^{-1}.

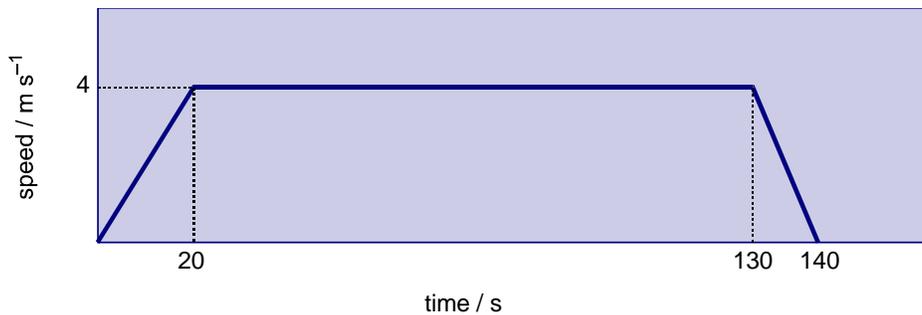   The average speed of the car is half the maximum, or 6.9 m s^{-1}. Then:

    distance = speed x time = 6.9 m s^{-1} x 1.4 s = 9.7 m

    When the cat runs out, you first move for 0.6 s at the maximum speed of 13.8 m s^{-1}. Hence, the additional 'thinking distance' travelled is

    distance = speed   time = 13.8 m s^{-1} x 0.6 s = 8.3 m

    Thus, the total distance travelled is 8.3 m + 9.7 m = 18 m.

7.

    The engine travels 440 m at 4 m s^{-1}.

    time = distance / speed = 440 m / 4 m s^{-1} = 110 s

    Distance travelled = area under the speed-time graph.

    total distance = (1/2 x 20 x 4) + (110 x 4) + (1/2 x 10 x 4) = 500 m

    The total time for the journey is then 20 s + 110 s + 10 s = 140 s. The average speed is then

$$\text{Average speed} = \frac{\text{distance}}{\text{time}} = \frac{500\text{ m}}{140\text{ s}} = 3.57\text{ m s}^{-1}$$

8. The ball falls to the floor in 0.63 s. Its average speed during the fall is

$$\text{average speed} = \frac{\text{distance}}{\text{time}} = \frac{2 \text{ m}}{0.63 \text{ s}} = 3.17 \text{ m s}^{-1}.$$

Its maximum speed (the speed with which it hits the floor) is then 2 x 3.17 m s^{-1} = 6.35 m s^{-1}. On the rebound, the average speed is

$$\text{average speed} = \frac{\text{distance}}{\text{time}} = \frac{1.5 \text{ m}}{0.55 \text{ s}} = 2.73 \text{ m s}^{-1}.$$

The time in this equation is calculated from 1.18 s – 0.63 s = 0.55 s. The maximum speed on the rebound must then be 2 x 2.73 m s^{-1} = 5.45 m s^{-1}.
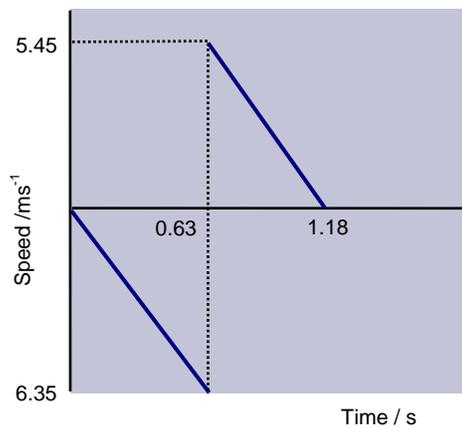
External references

This activity is taken from Advancing Physics Chapter 8, 20S