Graphing Motion Investigation – Teacher Notes

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Figure 1 – Motion

Aim

Why waste your time writing a whole essay on a real-life event when you can convey the whole story in a compact form! This is what graphs are all about, however not everyone can read a graph or analyse it appropriately.

Motion is one of our daily life routines and it can efficiently be represented by graphs; for example, a journey of a car travelling from home to the supermarket and back can be fully represented graphically, showing how fast the car was travelling and how many miles it took for the whole journey and the total time taken. Furthermore, we will be able to find the instantaneous velocity at any time from the graph. This is how powerful graphing is. In this study, students will analyse the motion of a ball and will learn how to extract information by investigating a motion graph.

Plan

Students are required to learn two main things in order to be able to conduct this experiment and analyse the results:

a. What forces are acting on a particle in motion and how will these forces affect the velocity and acceleration.
b. How to plot and read a motion graph and how to analyse it to get information that is not directly shown in the graph.

The teacher needs to check the students' background knowledge to be able to clear any misconceptions when explaining these concepts. One of the very popular misconceptions is thinking that in a displacement/time graph if the lines are going up, this means that the object is moving upwards, as seen in figure 2.

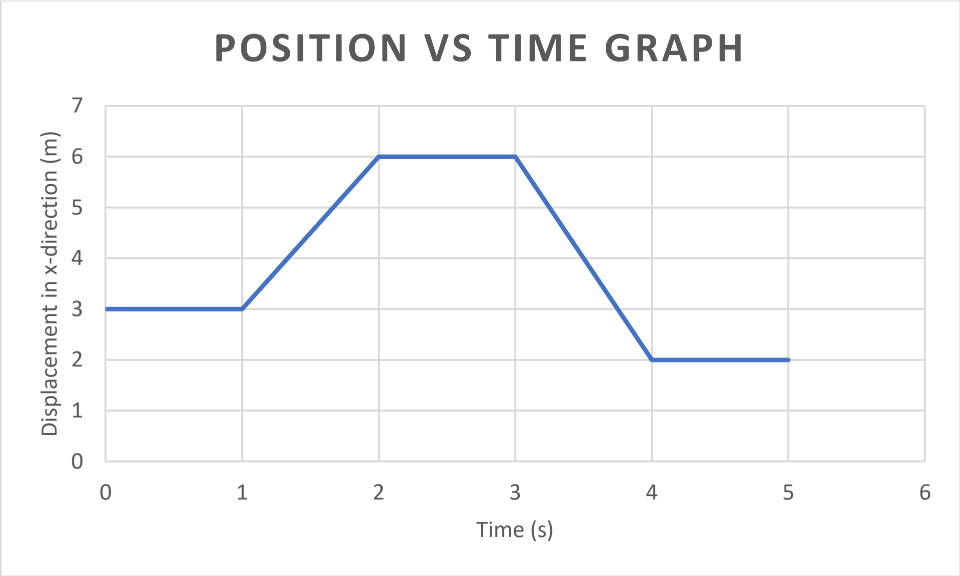

Figure 2 – Displacement/time graph in a horizontal motion (across the x-axis)

The graph simply means that an object is moving in a horizontal direction. The lines going up and down are showing whether the object is going forward or backwards. So, this graph tells us that the object started moving forward at (1s) and then backwards at time (3s).

A good video clip to watch is at https://www.youtube.com/watch?v=7GJ_SYM8cyU and https://www.youtube.com/watch?v=bqf8m7xNvLg

Discuss with your students the safety issues associated with the experiment, this includes clearing the area around where the experiment is being conducted and being cautious not to hit their classmates.

Conduct

The experiment is a mix of prescribed inquiry where students are given the question, the procedure and instructions on how to record their results; and open inquiry where they will choose how to analyse their data, formulate conclusions and justify their findings.

Students will use LoggerPro, a laptop with webcam, a tennis ball and a 1 metre ruler to conduct the experiment. It is important for students to familiarise themselves with the LoggerPro application and with how to record a video before they start.

The experiment includes two parts:

Part 1 – Dropping a ball with an initial velocity of zero

In this part of the experiment, students will hold a metre ruler and drop the ball from a specified height (best if they drop it from 1 metre). The motion of the falling ball will be captured with the webcam. Students need to ensure that the quality of the video is good enough for analysis, if not they can repeat this process.

Part 2- Throwing a ball upwards with an initial vertical velocity

Students will repeat the whole experiment, but with throwing the ball upwards instead of dropping it. This will give the ball an initial velocity. More practice will be needed to catch a good video for this part.

Extension experiment

For senior classes, students can throw the ball at an angle using iFetch by placing iFetch at different angles and measuring the launch angle. Another method is to use a launcher and a steel ball, the launch angle can be adjusted and measured.

Students will video capture the projectile path to analyse it.

Analyse

Part 1 - Dropping a ball with an initial velocity of zero

Students will analyse the path of the ball and will plot a graph of displacement vs time and another graph for velocity vs time. They are required to describe the shape of both graphs. Graphs should look similar to the figures below.

Students should be able to extract as much information as they can from the shape of the graphs. Encourage them to spend time together analysing the shape of the graphs. The teacher may like to go around the classroom and listen to students' reasoning. This is a good time to discover any misconceptions students might have before they write their discussions.

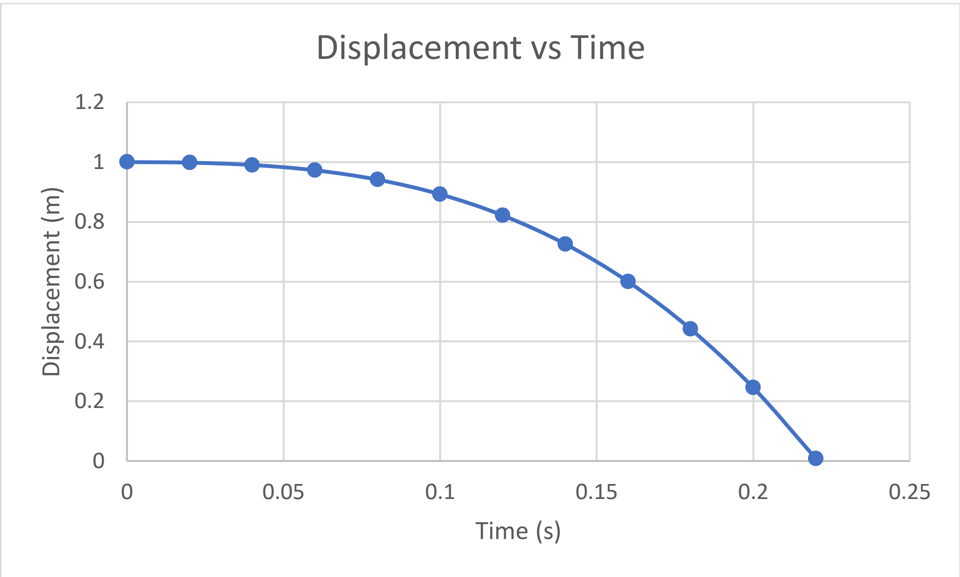

Figure 3- The displacement vs time graph for the free fall of the ball

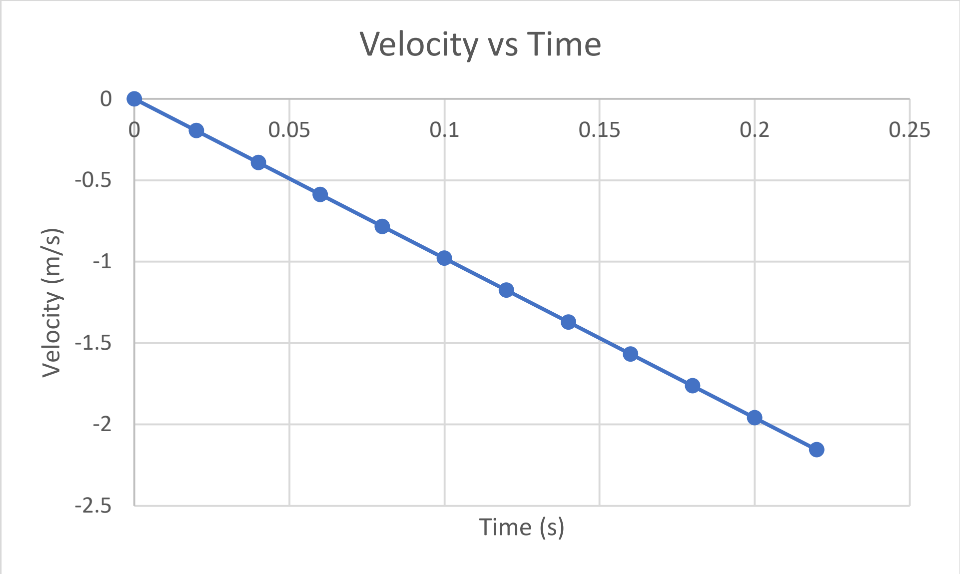

Figure 4 – The velocity vs time graph for the free fall

Part 2- Throwing a ball upwards with an initial vertical velocity

Here, students will analyse the course of motion and how velocity changes for a ball thrown upwards with an initial vertical velocity. The graphs for this section should look similar to the graphs below.

Again, students may have some difficulties analysing the shape of the curves and the teacher may help them by giving them hints to figure out what the graphs mean.

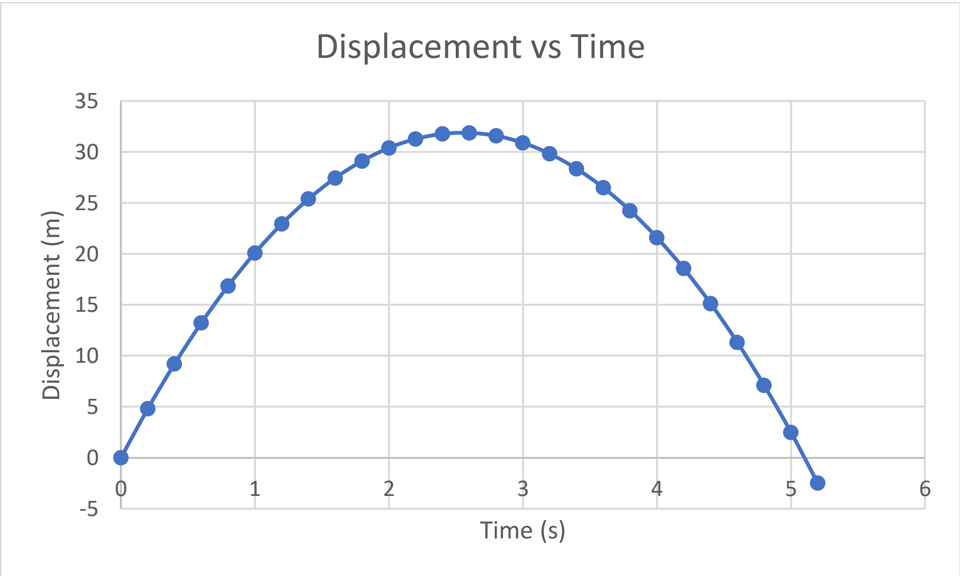

Figure 5- Displacement vs time graph for a ball thrown upwards with an initial vertical velocity

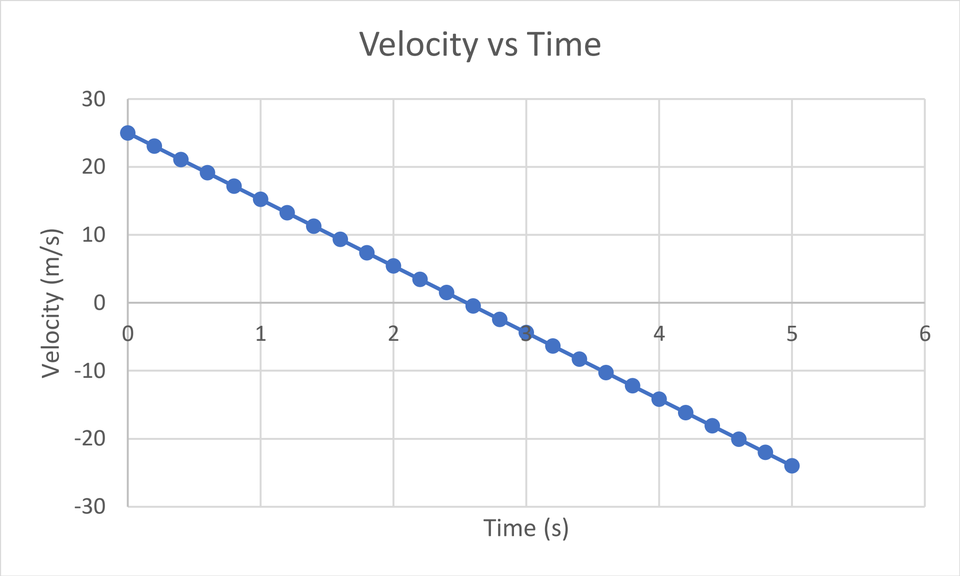

Figure 6 – Velocity vs time graph for a ball thrown upwards with an initial vertical velocity

Part 3 – Throwing a ball at an angle

In this experiment students will analyse the graphs in the x- and y- directions, the graph in the y-direction should look similar to figures 5 and 6 for the displacement vs time and velocity vs time respectively. For the displacement and velocity in the x-direction, they should obtain graphs similar to figure 7 and figure 8 respectively.

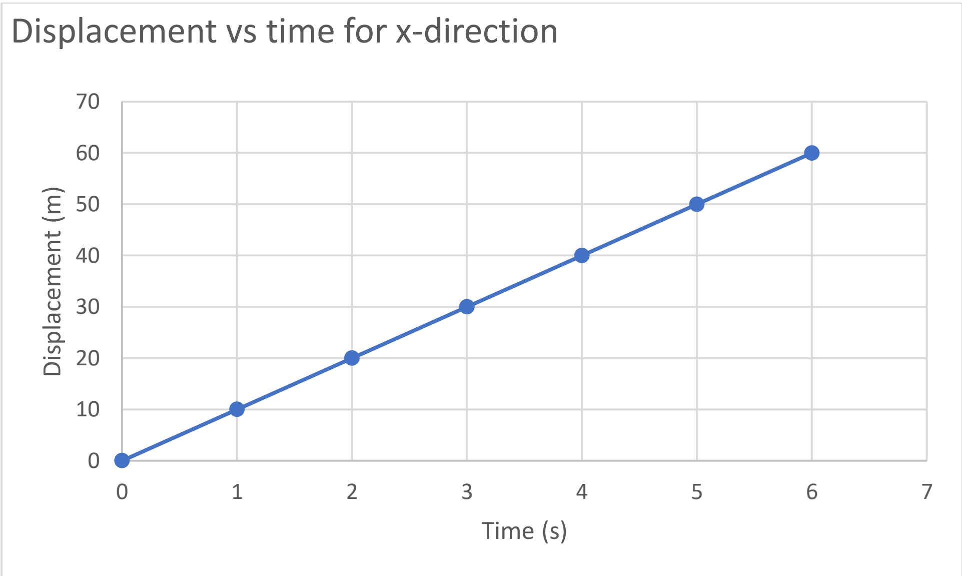

Figure 7- Displacement vs time graph for the ball in the x-direction

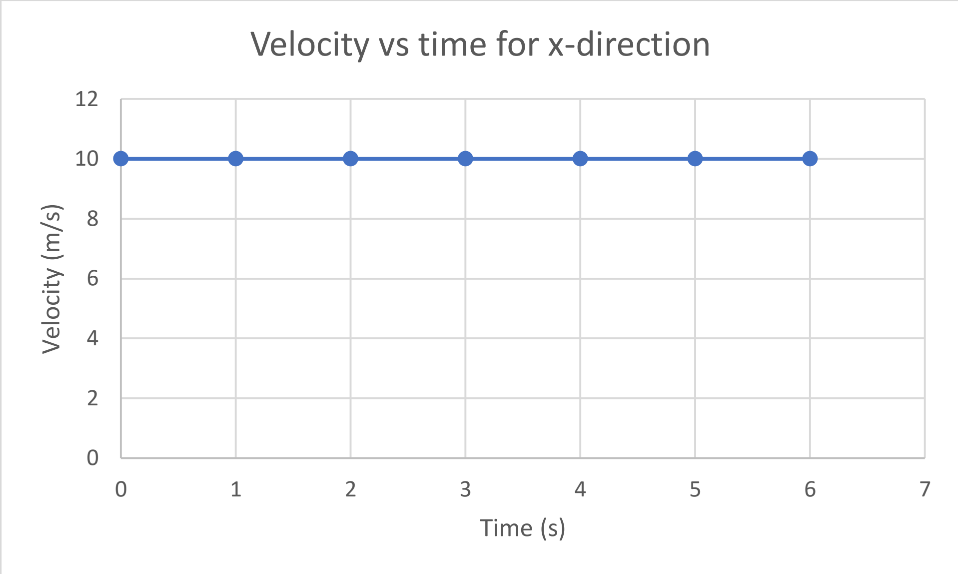

Figure 8- Velocity vs time graph for the ball in the x-direction

Problem solving and discussion

Part 1 - Dropping a ball with an initial velocity of zero

Students will explain the shape of the graphs obtained. In figure 3, the displacement vs time graph for a free-falling ball shows a curved line. This curve means that the motion is accelerating. All falling bodies are accelerating at the rate of 9.8 m/s^2 (m/s/s), which we call gravitational acceleration. In other words, the velocity is increasing by 9.8 m/s every second, so the ball starts with a small velocity and finishes its trip with a large velocity. Students can obtain the velocity at any time during the fall by taking the slope of the position vs time graph at this particular time. The negative slope of the line means that the velocity is negative, which simply means that the velocity is in the negative direction (i.e. in the downward direction).

Figure 4 shows the velocity vs time graph. The line is straight and diagonal, which means that the ball is accelerating with a constant acceleration. The slope of the velocity vs time graph yields the acceleration, and since the line is a straight line, this means that the slope is the same at any point along the line which signifies a constant acceleration. The graph shows that the ball starts with a velocity of zero and increases along the path, The negative velocity means that the ball is speeding in the negative direction (downwards).

The acceleration can be obtained by taking the gradient of the velocity vs time graph. Students should get a value close to -9.8 ms^{-2}. The negative acceleration is due to the fact that acceleration is a vector quantity, i.e. it is defined by its magnitude and its direction. The direction of the acceleration depends on two factors:

1. Whether the object is speeding up or slowing down, the rule is (if an object is slowing down, in our case when it is moving upwards, the acceleration is in the opposite direction of motion).
2. Whether the object is moving in a positive or a negative direction (this applies when the object is on its way downwards).

Part 2- Throwing a ball upwards with an initial vertical velocity

After analysing the graphs for this section, students will write their understanding of what is happening in terms of the displacement of the ball and how its velocity is changing over time.

Figure 5 shows the displacement-time graph thrown vertically upwards from a player's hand. The ball starts rising until it reaches a maximum height and then falls downwards towards the ground. The curve starts at the origin (point 0,0); this point is the height from which the ball is thrown. The ball then moves upwards (in the positive direction) as shown by the curved line with the positive slope (first half of the curve from zero up to 32.5 m). The fact that the line is curved signifies that the velocity is not constant, but is changing with time, i.e. the ball is experiencing acceleration (at this stage it is a deceleration or decrease in speed). The ball then stops momentarily at this height where the slope is zero (meaning that the velocity is zero) and then starts falling down. If the students analyse the second part of the graph from where it is starting to fall down, they will find that it resembles the free fall curve in figure 3. The same explanation for figure 3 applies to this section. The fact that the curve goes below the origin means that the ball has fallen to the ground below the initial point of release of the ball.

Analysing figure 6, we can tell that the ball was thrown with an initial velocity of 25 m/s. Its velocity reaches zero at 2.55 s. Students can even superimpose the two graphs to see how velocity and displacement are related as shown in figure 7. Again, starting from the time 2.55 s, the graph resembles the one shown in figure 4 for the free-fall and can be explained in a similar way to how figure 4 was explained.

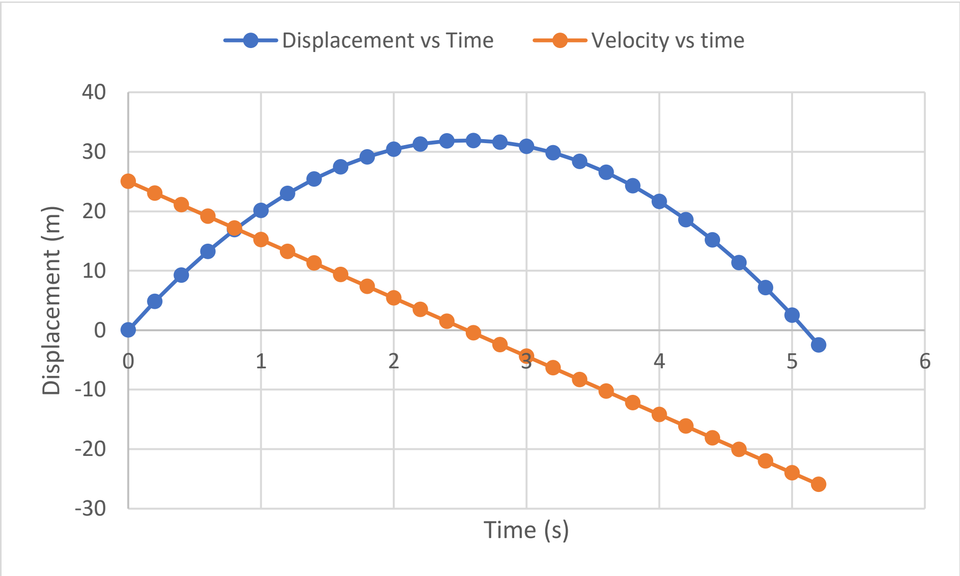

Figure 7 – A graph showing how displacement and velocity change with time

Again, students can obtain the acceleration by finding the gradient for the velocity vs time curve. The value they get should be equal to -9.8 ms^{-2} for the same reasons discussed above.

Part 3 – Throwing a ball at an angle

This section targets students in year 12 as a hands-on experiment for their study of projectile motion.

Students should be able to explain how an object thrown at an angle to the horizontal will move in two independent directions, the x- and the y- directions. In doing so, the velocity in the y-direction is equal to u sin ϴ while that in the x-direction is equal to u cos ϴ. They also should understand that because there is no acceleration in the x-direction, it is expected to have a constant velocity in this direction as shown in figure 8. Accordingly, because of the constant velocity, the ball will cut equal distances in equal intervals of time as shown in figure 7, and the slope of this curve gives the value of the velocity. By taking the slope of the horizontal line in figure 8, we obtain the acceleration in the x-direction which is zero.

In the y-direction, acceleration due to gravity applies and the curves are similar to part 2.

In general, students should discuss any difficulties they have faced during the experiment and if so, how they were able to overcome them.

Conclusion

Students should state whether their results have agreed with their previous understanding or not and acknowledge if the experiment has helped clear any misunderstandings. They can suggest any modifications to the experiment that would make it easier to record and take measurements.

The experiment could be presented to the whole school as a video clip or can be uploaded on www.prezi.com or a similar software.

References

Link to figure 1 https://www.flickr.com/photos/keso/421184932/in/photolist-DdFBb-Dpzu8-6ms6i7-Bd2Zjs-y7LZHh-jYM7Yp-4AyfBL-5fJn7-7UWD6K-DdFmg-BbY8Ed-9oLza-2Ut4tm-D9Li5G-LMVC4E-jYM81D-Gv9B4-acJ46B-betFXB-u7fX5G-bCRPys-fSzmjK-54F3Af-7NVuBk-4czd4Q-9fP3DA-sh9sqY-p8m8sS-51TxZb-bkNZNt-zuewSL-grC1PM-qJsEd6-jnBvLE-6JeH1h-RJMABm-grApTZ-bkNZXr-4NQKcf-grzz3S-5RzuX3-nisTL7-fUY4Eq-7imjG2-grFaYT-grzL49-grD6Gc-cZHDs-9nCi9g-grEnEm Author keso s Licence https://creativecommons.org/licenses/by-nc-nd/2.0/