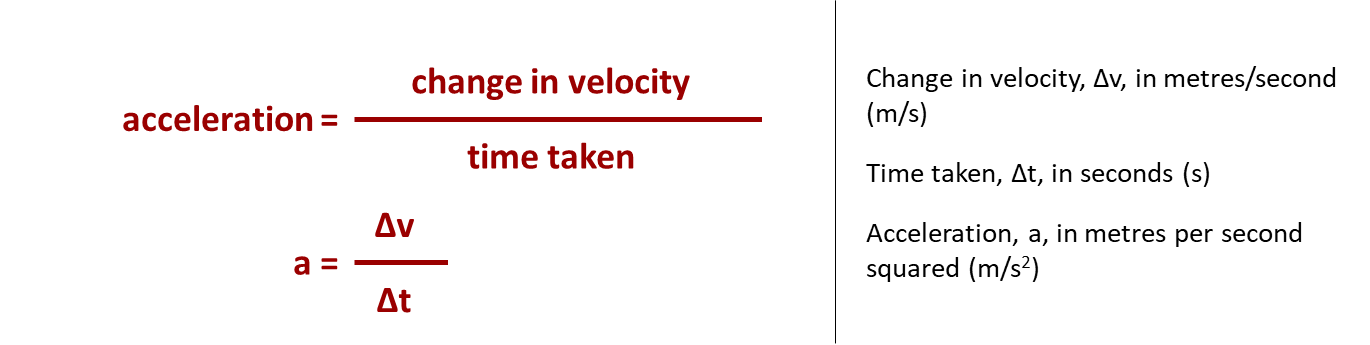
**Using the gradient**

Acceleration is calculated as the change in velocity divided by the time taken for the change:

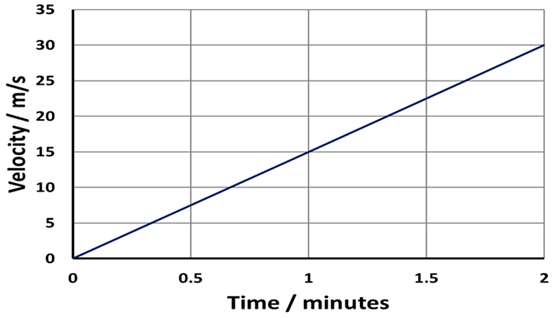
****

**From a graph:**

**Two** values of velocity need to be used to find the **change in velocity**.

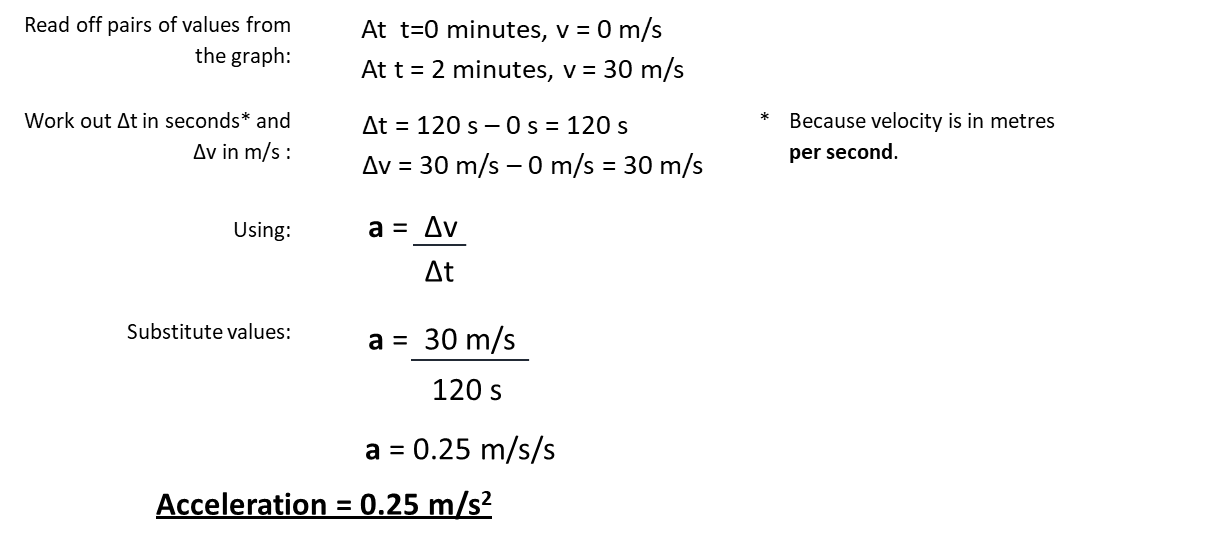
**Two** corresponding values of time are needed to work out time taken.

**Example:**

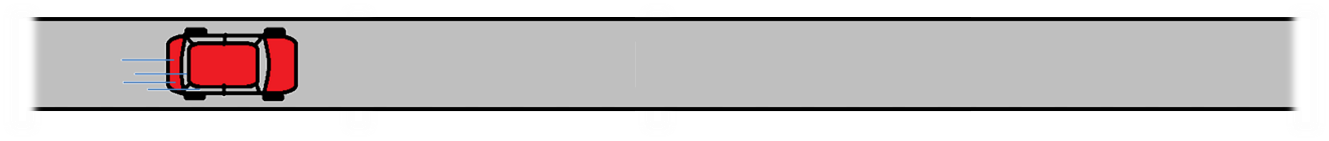
The velocity-time graph shows a steady acceleration.

Use the graph to work out that acceleration.

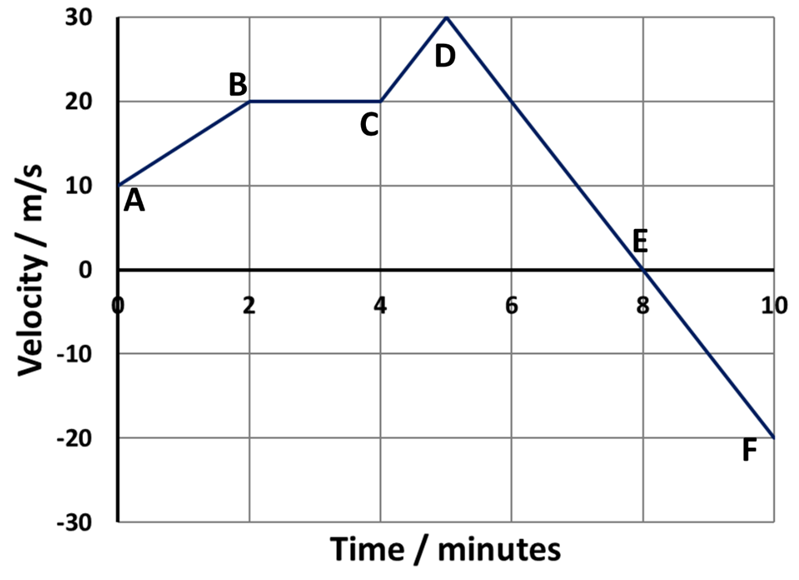
**Model answer:**



A red car is moving to the right along a straight road.



The graph shows how its velocity changes over the next ten minutes.



**To answer**

**1.** Use the graph to calculate the acceleration between:

**a.** A and B.

**b.** B and C.

**c.** C and D.

**d.** D and E.

**e.** E and F.

**2a.** How is the motion between D and E similar to the motion between E and F?

**2b.** How does the motion between D and E differ from that between E and F?

*Physics > Big idea PFM: Forces and Motion > Topic PFM4: Measuring and calculating motion > Key concept PFM4.3: Velocity-time graphs*

|  |
| --- |
| **Response activity** |
| **Using the gradient** |

**Overview**

|  |  |
| --- | --- |
| Learning focus: | A velocity-time graph of an object moving in one dimension can be read to find the object’s velocity at any moment of time. The gradient of the graph at a given time gives the object’s acceleration; and the area under the graph between any two times gives the change in the object’s displacement, or the distance it has travelled. |
| Observable learning outcome: | Calculate, and explain how to work out, the acceleration of an object from the gradient of a velocity-time graph. |
| Activity type: | Application and practice - calculations |
| Key words: | Velocity, acceleration, time, graph, gradient |

This activity can help develop students’ understanding by addressing the sticking-points revealed by the following diagnostic question:

* Diagnostic question: Speeding up

**What does the research say?**

In a study of 700 undergraduates in Ireland, Belgium and Spain (Bollen *et al.*, 2016), students demonstrated two misunderstandings associated with the gradient of a graph: ‘interval-point’ confusion, when students focus on a single point when they should be using a range of values (for example when calculating the gradient of a graph that does not pass through the origin); and ‘slope-height’ confusion, where students confuse the height of a graph with its slope when, for example, calculating acceleration from a velocity-time graph. In a study of several hundred undergraduates and high school students in the USA, McDermott and colleagues found the same misunderstandings (McDermott, Rosenquist and van Zee, 1987). These researchers found these misunderstandings even amongst students who demonstrated a good command of kinematical concepts, and who had a good grasp of how to plot and to read graphs and of how to calculate gradients from their study of mathematics, often misinterpret what the gradient of a velocity-time graph represents.

Units in equations should be treated explicitly and with care. It is good practice always to include units in calculations, not least because this may help students to appreciate that symbols refer to physical quantities. Keeping track of units can also help in checking that calculations make sense physically (Boohan, 2016). The units of acceleration may be particularly problematic as acceleration is a rate of change of a rate of change, and is measured in metres per second squared (m/s2), which is a unit often unfamiliar to students.

Whilst carrying out calculations is an important part of students’ learning, success in using equations is not the same thing as developing conceptual understanding in mechanics (Kim and Pak, 2002), and misunderstandings may remain. To expert physicists, symbols stand for physical quantities, and the results of the mathematical manipulations must be interpreted in terms of their meaning for a given physical system. Experts draw on their experience and (often tacit) knowledge of physical systems in order to make meaning from the mathematics (Carson, 1999; Redish and Kuo, 2015). To novices, the manipulation of the symbols, and the substitution of numbers into formulae may be ends in themselves, devoid of physical meaning. This is why asking students to think qualitatively, as well as quantitatively, about kinematical quantities is important.

**Ways to use this activity**

This activity gives students the opportunity to practise applying their understanding and to clarify their thinking through discussion. To support this, students should answer the questions in pairs or small groups. Listening to individual groups as they work often highlights any difficulties they might have. These can often be overcome, through a whole class clarification or redirection part way through the activity.

Allowing only one student in each pair or small group to write down the answer on behalf of the group encourages discussion of both the science and of the presentation of the answer. Mini-white boards allow groups to show you their answers for immediate feedback.

*Question 1*

Part (a) tests that students use the difference in velocity between , and minutes rather than simply the values of and after 2 minutes, which would result in an answer of 0.17 m/s2.

Part (b) tests that students understand the significance of a horizontal line: the gradient, and therefore the acceleration, is zero, consistent with a constant velocity.

Part (c) tests that students read from the graph both the *difference* in the velocity between C and D, *and* the *difference* in the times.

Parts (c) and (d) test whether students pay attention to the need for a minus sign.

*Question 2*

The second question checks that students understand how to interpret the meaning of a negative acceleration. This depends on the sign of velocity. Both acceleration and velocity are vectors, and their direction, in one dimension, is determined by the sign.

When discussing answers with students, it is important to discuss the numerical answers in conjunction with a qualitative assessment of the steepness of the graph in order to reinforce the relationship between the gradient of the graph and the acceleration of the car.

*Differentiation*

If some students are working with a teaching assistant, then a list of prompt questions for the TA could help to make this activity more purposeful.

**Expected answers**

**1a.** 0.08 m/s2 **b.** 0m/s2 **c.** 0.17 m/s2 **d.** -0.17 m/s2 **e.** -0.17 m/s2

Note that a positive acceleration indicates an acceleration to the right, and a negative acceleration indicates an acceleration to the left.

**2a.** The car is accelerating (changing velocity) at the same rate.

**2b.** Between D and E the car is slowing down, and then between E and F it is speeding up in the opposite direction (towards the left).

**Acknowledgments**

Developed by Simon Carson (UYSEG).

Images: Simon Carson (UYSEG)

**References**

Bollen, L. *et al.* (2016) ‘Generalizing a categorization of students’ interpretations of linear kinematics graphs’, *Physical Review Physics Education Research*, 12(1), p. 010108. doi:10.1103/PhysRevPhysEducRes.12.010108.

Boohan, R. (2016) *The language of mathematics in science: a guide for teachers of 11-16 science*. Hatfield: Association for Science Education.

Carson, S. (1999) *Physics in mathematical mood*. Bristol: Institute of Physics Pub.

Kim, E. and Pak, S.-J. (2002) ‘Students do not overcome conceptual difficulties after solving 1000 traditional problems’, *American Journal of Physics*, 70(7), pp. 759–765. doi:10.1119/1.1484151.

McDermott, L.C., Rosenquist, M.L. and van Zee, E.H. (1987) ‘Student difficulties in connecting graphs and physics: Examples from kinematics’, *American Journal of Physics*, 55(6), pp. 503–513. doi:10.1119/1.15104.

Redish, E.F. and Kuo, E. (2015) ‘Language of Physics, Language of Math: Disciplinary Culture and Dynamic Epistemology’, *Science & Education*, 24(5–6), pp. 561–590. doi:10.1007/s11191-015-9749-7.