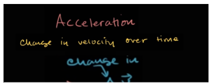
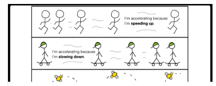


Video

1. Acceleration

Calculating the acceleration of a Porsche



Article

2. What is acceleration?

Velocity describes how position changes; accelerati...

Vi

‹ PHYSICS | ONE-DIMENSIONAL MOTION | ACCELERATION

What is acceleration?

Velocity describes how position changes. Acceleration describes how velocity changes. Two layers of change!

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Introduction

In everyday conversation, to accelerate means to speed up. The accelerator in a car can in fact cause it to speed up. The greater the **acceleration**, the greater the change in velocity over a given time. The formal definition of acceleration is consistent with these notions, but more comprehensive.

Definition of acceleration

Average acceleration is the rate at which velocity changes:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

where $\bar{a}$ is average acceleration, v is velocity, and t is time. The Δ symbol represents the change in a variable. The change in velocity, Δv, is calculated from the difference between final velocity v_f and initial velocity v_0.

Because acceleration is velocity in $\dfrac{\text{m}}{\text{s}}$ divided by time in s, the SI units for acceleration are $\dfrac{\text{m}}{\text{s}^2}$, meters per second squared or meters per second per second, which literally means by how many meters per second the velocity changes every second.

Recall that velocity is a vector that has both magnitude and direction. This means that a change in velocity can be a change in magnitude (or speed), but it can also be a change in direction. For example, if a car turns a corner at constant speed, it is accelerating because its direction is changing. The quicker you turn, the greater the acceleration. So there is an acceleration when velocity changes either in magnitude (an increase or decrease in speed) or in direction, or both.

Keep in mind that although acceleration is in the direction of the change in velocity, it is not always in the direction of motion. When an object's acceleration is in the same direction of its motion, the object will speed up. However, when an object's acceleration is opposite to the direction of its motion, the object will slow down.

Note that speeding up and slowing down should not be confused with a positive and negative acceleration! The next two examples should help to make this distinction more clear.

Example 1: Average acceleration of a racehorse

A racehorse coming out of the gate accelerates from rest to a velocity of $15.0\,\dfrac{\mathrm{m}}{\mathrm{s}}$ due west in $1.80\,\mathrm{s}$. What is its average acceleration?

We can calculate the average acceleration of the racehorse by using the equation for average acceleration from the previous section.

Image of racehorses from OpenStax Physics, CC BY 4.0

Step 1. Draw a diagram and assign coordinate system

First we draw a diagram and assign a coordinate system to the problem. Notice that we assign east as positive (to the right) and west as negative (to the left). We have a purple acceleration vector arrow pointing west (to the left) in the negative x direction, and a green velocity vector arrow also pointing toward the left. The initial velocity is a point labeled as $0\,\dfrac{\mathrm{m}}{\mathrm{s}}$ and final velocity is an arrow labeled as $-15.0\,\dfrac{\mathrm{m}}{\mathrm{s}}$.

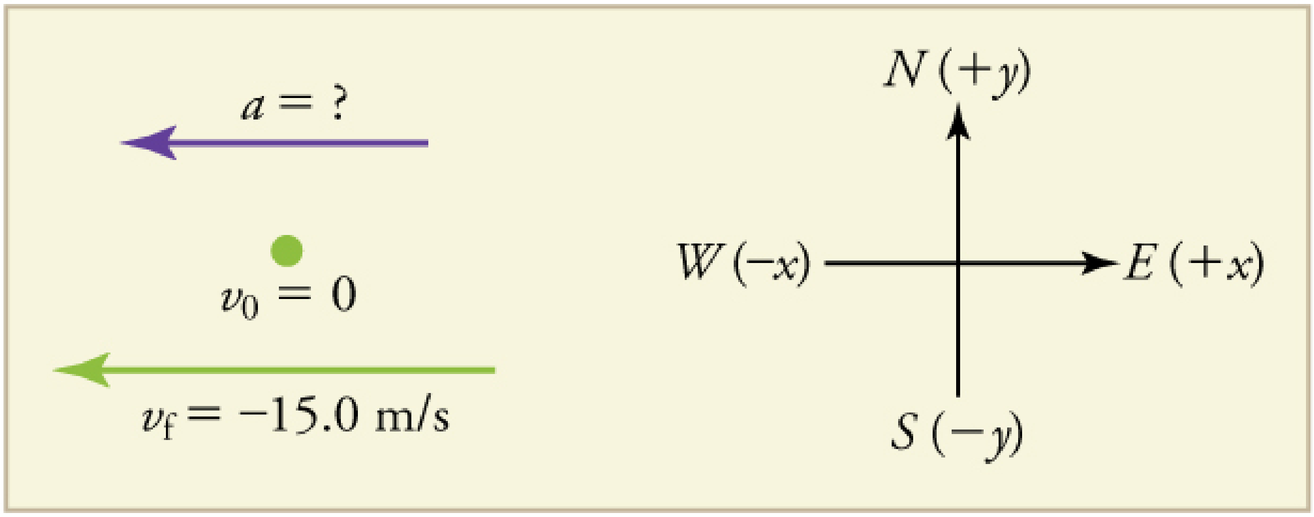


Diagram of accelerating racehorse and the coordinate system. Image from OpenStax Physics, CC BY 4.0

We can see from our diagram that both final velocity and acceleration are negative.

Step 2. Find Δv and Δt

We know that $v_0 = 0$ and $v_f = -15.0\ \frac{\text{m}}{\text{s}}$, where the minus sign for v_f indicates direction toward the west. Also, we know that $\Delta t = 1.80\,\text{s}$. We can use this information to find the change in velocity. Since the horse is going from 0 to $-15.0\ \frac{\text{m}}{\text{s}}$, its change in velocity equals its final velocity:

$$\Delta v = v_f = -15.0\ \frac{\text{m}}{\text{s}}$$

Step 3. Solve for $\bar{a}$

We can plug in the known values of Δv and Δt and solve for the unknown $\bar{a}$ using our equation for average acceleration:

$$\begin{aligned}\bar{a} &= \frac{\Delta v}{\Delta t} \\ &= \frac{-15.0\ \frac{\text{m}}{\text{s}}}{1.80\,\text{s}} \\ &= -8.33\ \frac{\text{m}}{\text{s}^2}\end{aligned}$$

The minus sign for acceleration indicates that acceleration is toward the west. This means that the horse increases its velocity by $8.33\ \frac{\text{m}}{\text{s}}$ due west each second, that is, 8.33 meters per second per second. Keep in mind that this is truly an average acceleration, because the increase in velocity does not necessarily happen smoothly for the rider!

Example 2: Deceleration of a subway train

Suppose a subway train slows to a stop from a velocity of $20.0\ \frac{\text{km}}{\text{h}}$ in $1.00\,\text{s}$. The coordinates for x and the velocity vectors are shown in the diagram below. What is the average acceleration of the train while stopping?

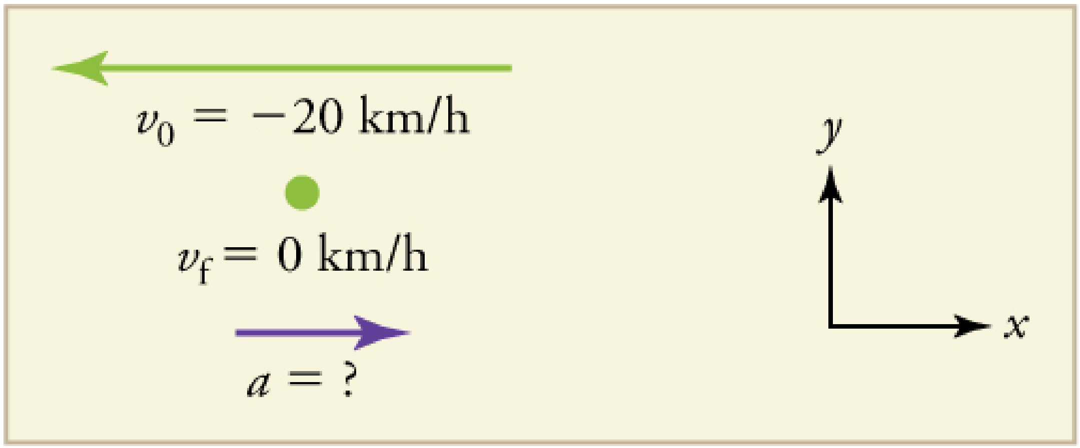


Diagram of the decelerating train and the coordinate system. Image from OpenStax Physics, CC BY 4.0

We can calculate average acceleration by finding the change in velocity and the change in time for the subway train. This is similar to our strategy for **Example 1**.

Step 1. Find Δv and Δt

First we can identify the known quantities, taking care to keep the signs consistent:

$$v_0 = -20.0\,\frac{\text{km}}{\text{h}}$$

$$v_f = 0\,\frac{\text{km}}{\text{h}}$$

$$\Delta t = 10.0\,\text{s}$$

We can use this information to solve for the change in velocity, Δv.

$$\begin{aligned}\Delta v &= v_f - v_0\\ &= 0 - (-20.0\ \frac{\text{km}}{\text{h}})\\ &= +20.0\ \frac{\text{km}}{\text{h}}\end{aligned}$$

Step 3. Convert to SI units and solve for $\bar{a}$

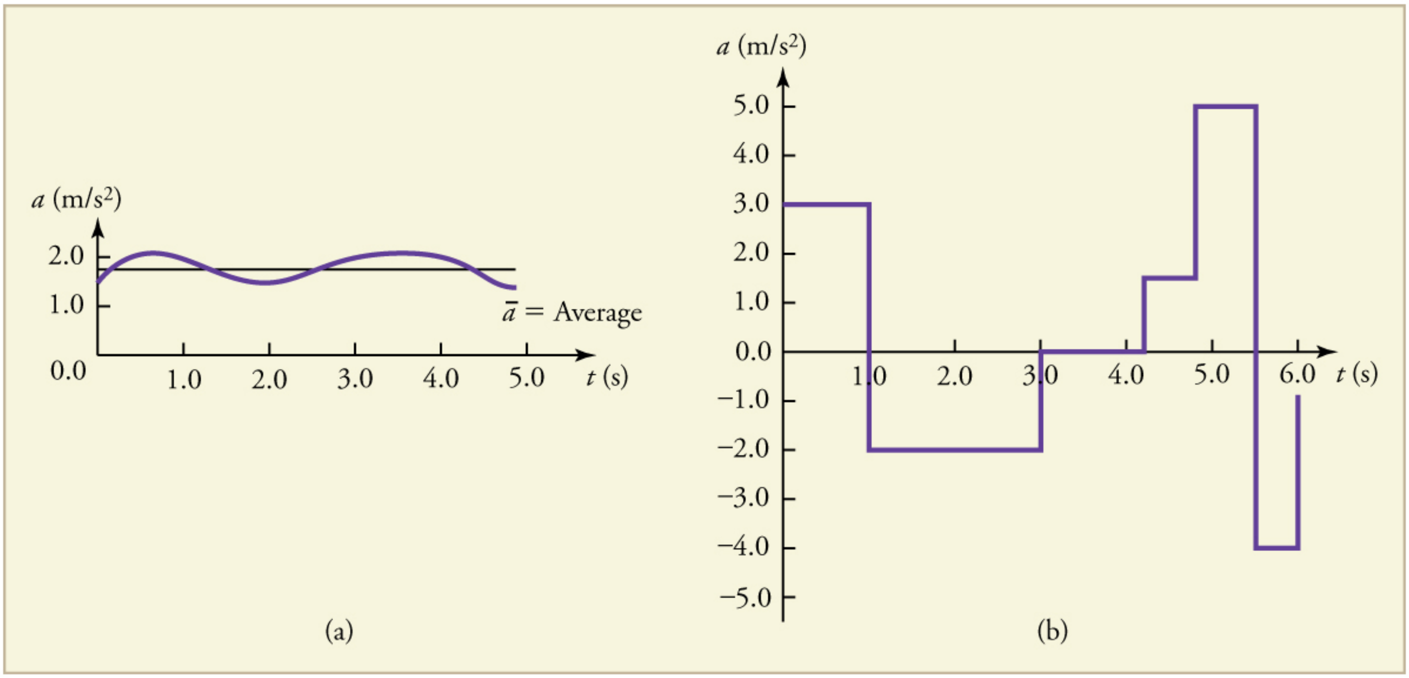
Since the units are mixed (we have both hours and seconds for time), we need to convert everything into SI units of meters and seconds when we solve for $\bar{a}$.

$$\begin{aligned}\bar{a} &= \frac{\Delta v}{\Delta t}\\ &= \frac{+20.0\ \frac{\cancel{\text{km}}}{\cancel{\text{h}}}}{10.00\,\text{s}} \times \frac{10^3\ \text{m}}{1\ \cancel{\text{km}}} \times \frac{1\ \cancel{\text{h}}}{3600\,\text{s}}\\ &= +0.556\ \frac{\text{m}}{\text{s}^2}\end{aligned}$$

The plus sign means that acceleration is to the right. This is reasonable because the train initially has a negative velocity (to the left) in this problem and a positive acceleration opposes the motion (and so it is to the right). Again, acceleration is in the same direction as the change in velocity, which is positive here. This acceleration can be called a **deceleration** since it is in the direction opposite to the velocity.

Instantaneous acceleration

Instantaneous acceleration a, or the acceleration at a specific instant in time, is obtained by considering an infinitesimally small interval of time. How do we find instantaneous acceleration using only algebra? The answer is that we choose an average acceleration that is representative of the motion. Let's look at two examples.



Graphs of instantaneous acceleration versus time for two different motions. In graph a, acceleration varies only slightly and is always in the same direction. In graph b, the acceleration varies widely depending on the time interval. [Image](#) from OpenStax Physics, [CC BY 4.0](#)

The graphs above show instantaneous acceleration versus time for two very different motions. In **graph a**, the instantaneous acceleration varies only slightly over time. Thus, the average acceleration over the entire interval is nearly the same as the instantaneous acceleration at any time. In this case, we could treat this motion as if it had a constant acceleration equal to the average (in this case about $1.8\,\frac{\text{m}}{\text{s}^2}$).

In **graph b**, the acceleration varies drastically over time. In such situations it is best to consider smaller time intervals and choose an average acceleration for each. For example, we could consider motion over the time intervals from 0 to $1.0\,\text{s}$ and from 1.0 to $3.0\,\text{s}$ as separate motions with accelerations of $+3.0\,\dfrac{\text{m}}{\text{s}^2}$ and $-2.0\,\dfrac{\text{m}}{\text{s}^2}$, respectively.

Sign and direction of acceleration

Perhaps the most important thing to note about these examples is the signs of the answers. Most people interpret negative acceleration as the slowing of an object. However, this is not always the case! As we see in **Example 2**, when the acceleration is in the opposite direction from the velocity, a positive acceleration will also result in the slowing of an object.

The relative signs for velocity and acceleration tell us whether the object is slowing down or speeding up.

- If acceleration has the same sign as the velocity, the object is speeding up.
- If acceleration has the opposite sign from the velocity, the object is slowing down.

Summary

- Acceleration is the rate at which velocity changes. In symbols, average acceleration $\bar{a}$ is

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

- The SI units for acceleration are $\frac{\text{m}}{\text{s}^2}$.
- Acceleration is a vector, and thus has both a magnitude and direction.
- Acceleration can be caused by either a change in the magnitude or the direction of the velocity.
- Instantaneous acceleration a is the acceleration at a specific instant in time.
- Deceleration is an acceleration with a direction opposite to that of the velocity.

[Attributions and references]

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In the description of example 2, is it supposed to be 10 s instead of 1.00 seconds?

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