Linear Acceleration

Unit: Kinematics (Motion) in One Dimension

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS2-10(MA)

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 1.2.B.1, 1.2.B.3, 1.2.B.4

Mastery Objective(s): (Students will be able to…)

- Calculate acceleration given initial & final velocity and time.
- Describe the motion of an object that is accelerating.

Success Criteria:

- Calculations for acceleration have the correct value, correct direction (sign), and correct units.
- Descriptions of motion account for the starting and final velocity and any changes of direction.

Language Objectives:

- Correctly use the term “acceleration” the way it is used in physics. Translate the vernacular term “deceleration” into a physics-appropriate description.

Tier 2 Vocabulary: velocity, acceleration, direction

Lab Activities & Demonstrations:

- Walk with different combinations of positive/negative velocity and positive/negative acceleration.
- Fan cart, especially to show the cart moving in one direction but accelerating in the opposite direction.
- Have students make two strings of beads, one spaced at equal distances and the other spaced so they land at equal time intervals.

Notes:

<u>acceleration</u> *($\vec{a}$)* : [vector] a change in velocity; the rate of change of velocity.

$$\vec{\boldsymbol{a}} = \frac{\Delta\vec{\boldsymbol{v}}}{t} = \frac{\vec{\boldsymbol{v}} - \vec{\boldsymbol{v}}_o}{t}$$

The MKS unit for acceleration is $\frac{\text{m}}{\text{s}^2}$. This is because $\Delta\vec{\boldsymbol{v}}$ has units $\frac{\text{m}}{\text{s}}$, which means $\vec{\boldsymbol{a}} = \frac{\Delta\vec{\boldsymbol{v}}}{t}$ has units $\frac{\text{m}/\text{s}}{\text{s}} = \frac{\text{m}}{\text{s}} \cdot \frac{1}{\text{s}} = \frac{\text{m}}{\text{s}^2}$ *.

<u>uniform acceleration</u>: constant acceleration; a constant rate of change of velocity.

* The unit for acceleration is sometimes described as “meters per second per second”.

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Because this is an algebra-based course, acceleration will be assumed to be uniform in all of the problems in this course that involve acceleration.

In the vernacular, we use the term "acceleration" to mean "speeding up," and "deceleration" to mean "slowing down." In physics, we always use the term "acceleration". If an object is moving (in one dimension) in the positive direction, then ***positive acceleration*** means "speeding up" and ***negative acceleration*** means "slowing down".

Note that acceleration is a vector quantity, which means it has a direction. This means that acceleration is *any* change in velocity, including a change in speed or a change in direction. There is a popular joke in which a physics student is taking a driving lesson. The instructor says, "Apply the accelerator." The physics student replies, "Which one? I've got three!"

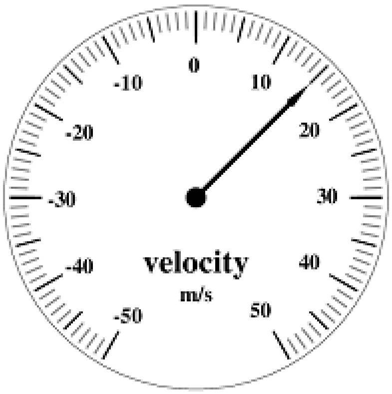
Note that if an object is moving in the negative direction, then the sign of acceleration is reversed. Positive acceleration for an object moving in the negative direction would mean that the object is actually slowing down, and negative acceleration for an object moving in the negative direction would mean that the object is actually speeding up.

Use this space for summary and/or additional notes:

Calculating Acceleration

Suppose that instead of a speedometer, your car has a velocity meter, which displays a positive velocity when the car is going in the positive direction (forward) and a negative velocity when it is going in the negative direction (backward).

The following velocity meters show a car that starts out with a velocity of $+15\,\frac{\text{m}}{\text{s}}$ and accelerates to $+40\,\frac{\text{m}}{\text{s}}$. Suppose this acceleration happened over a time interval of 5 s.



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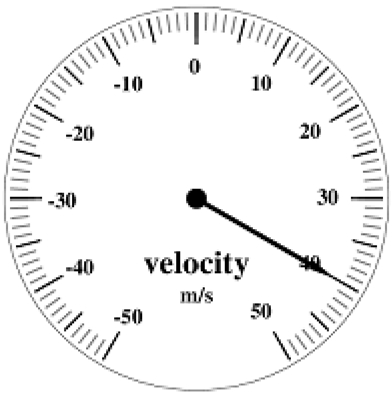
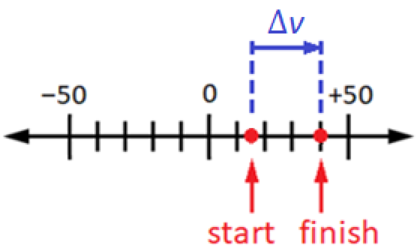


The car's speed is faster at the end ($40\,\frac{\text{m}}{\text{s}}$ *vs.* $15\,\frac{\text{m}}{\text{s}}$), and it is traveling in the positive direction the entire time. The change in velocity ($\Delta\vec{v}$) is $+40-(+15)=+25\,\frac{\text{m}}{\text{s}}$.



The acceleration is therefore $\vec{a}=\frac{\Delta\vec{v}}{t}=\frac{+40-(+15)}{5}=\frac{+25}{5}=+5\,\frac{\text{m}}{\text{s}^2}$.*

If the acceleration (rate of change of velocity) is 5 meters per second per second, then the velocity after each second would be:

time (s)	0	1	2	3	4	5
velocity $\left(\frac{\text{m}}{\text{s}}\right)$	+15	+20	+25	+30	+35	+40

* Note that $5\,\frac{\text{m}}{\text{s}^2}$ is approximately the acceleration of a commercial jet during takeoff.

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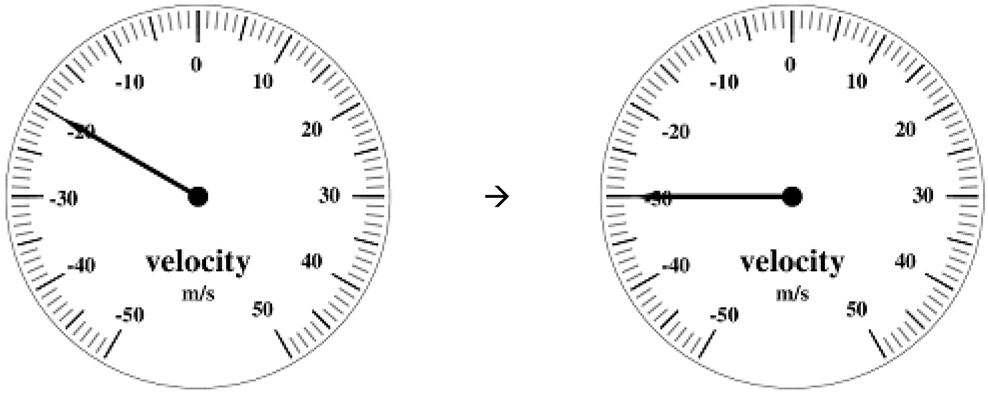
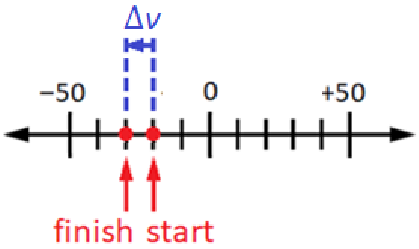
The following velocity meters show a car that starts out with a velocity of $-20\,\frac{\text{m}}{\text{s}}$ and accelerates to $-30\,\frac{\text{m}}{\text{s}}$. Suppose this acceleration also happened over a time interval of 5 s.



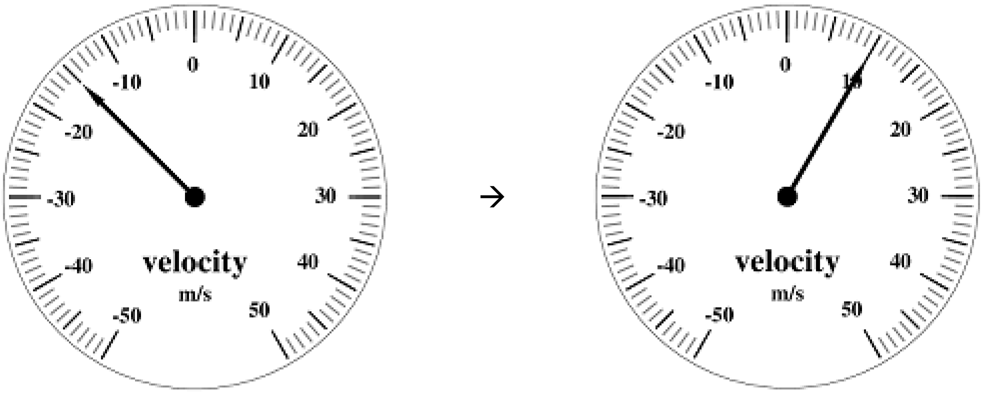
In this case, the car's speed is faster at the end ($30\,\frac{\text{m}}{\text{s}}$ *vs.* $20\,\frac{\text{m}}{\text{s}}$), but it is traveling in the negative direction the entire time. The change in velocity ($\Delta\vec{v}$) is $-30-(-20)=-10\,\frac{\text{m}}{\text{s}}$. This means that although the car is speeding up, because it is speeding up in the negative direction, the *trend* is toward a more negative velocity.



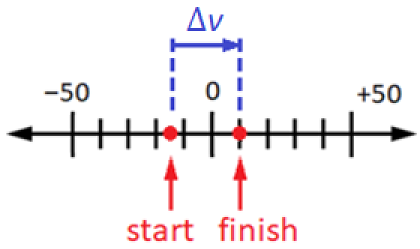
The acceleration is therefore $\vec{a}=\dfrac{\Delta\vec{v}}{t}=\dfrac{-30-(-20)}{5}=\dfrac{-10}{5}=-2\,\frac{\text{m}}{\text{s}^2}$

Use this space for summary and/or additional notes:

Finally, the following velocity meters show a car that starts out with a velocity of $-15\frac{\text{m}}{\text{s}}$ and accelerates to $+10\frac{\text{m}}{\text{s}}$. Suppose this acceleration also happened over a time interval of 5 s.



We calculate the change in velocity and the acceleration as before.



The acceleration is $\vec{a} = \frac{\Delta\vec{v}}{t} = \frac{+10-(-15)}{5} = \frac{+25}{5} = +5\frac{\text{m}}{\text{s}^2}$. This makes sense, because the velocity is continuously *trending* toward the positive direction.

However, a description of the car's motion is more complicated. The car starts out going $15\frac{\text{m}}{\text{s}}$ in the negative direction. During the first 3 s, the car slows down from $15\frac{\text{m}}{\text{s}}$ until it stops ($\vec{v}=0$). Then, during the final 2 s it speeds up in the positive direction from rest ($\vec{v}=0$) to a speed of $10\frac{\text{m}}{\text{s}}$.

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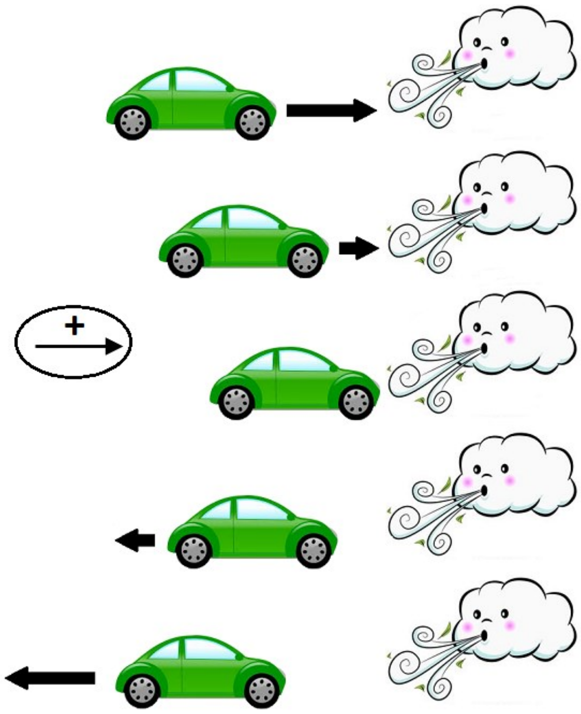
Another Way to Visualize Acceleration

As we will study in detail later in this course, acceleration is caused by a (net) force on an object. A helpful visualization is to imagine that acceleration is caused by a strong wind exerting a force on an object.



In the above picture, the car starts out moving in the positive direction (to the right). Acceleration (represented by the wind) is in the negative direction (to the left). The negative acceleration causes the car to slow down and stop, and then to start moving and speed up in the negative direction (to the left).

Check for Understanding

A car starts out with a velocity of $+30\,\frac{\text{m}}{\text{s}}$. After 10 s, its velocity is $-10\,\frac{\text{m}}{\text{s}}$.

1. Calculate the car's acceleration.

2. Describe the motion of the car.

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Free Fall (Acceleration Caused by Gravity)

The gravitational force is an attraction between objects that have mass.

<u>free fall</u>: when an object is freely accelerating toward the center of the Earth (or some other object with a very large mass) because of the effects of gravity, and the effects of other forces are negligible.

Objects in free fall on Earth accelerate downward at a rate of approximately $10\,\frac{\text{m}}{\text{s}^2} \approx 32\,\frac{\text{ft.}}{\text{s}^2}$. (The actual number is approximately $9.807\,\frac{\text{m}}{\text{s}^2}$ at sea level near the surface of the Earth. In this course we will usually round it to $10\,\frac{\text{m}}{\text{s}^2}$ so the calculations don't get in the way of understanding the physics.)

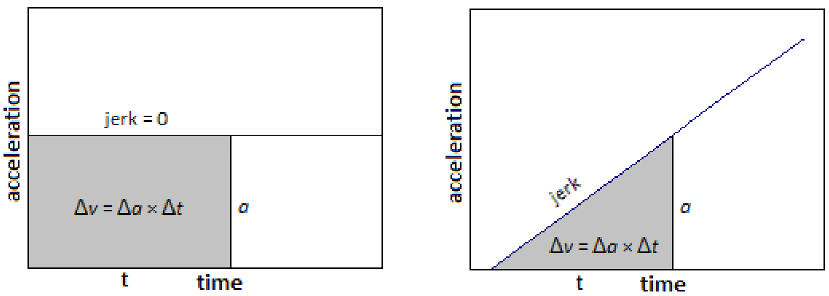
Note that an object going down a ramp is not in free fall even though gravity is the force that caused the object to accelerate. The object's motion is constrained by the ramp and it is not free to fall straight down.

Acceleration Notes

- Whether acceleration is positive or negative is based on the <u>*trend*</u> of the velocity (changing <u>*toward*</u> positive *vs.* changing <u>*toward*</u> negative).
- An object can have a positive velocity and a negative acceleration at the same time, or *vice versa*.
- The sign (positive or negative) of an object's velocity is the direction the object is moving. If the sign of the velocity changes (from positive to negative or negative to positive), the change indicates that the object's motion has changed directions.
- ***An object can be accelerating even when it has a velocity of zero.*** For example, if you throw a ball upward, it goes up to its maximum height and then falls back to the ground. At the instant when the ball is at its maximum height, its velocity is zero, but gravity is still causing it to accelerate toward the Earth at a rate of $10\,\frac{\text{m}}{\text{s}^2}$.

Extension

Just as a change in velocity is called acceleration, a change in acceleration with respect to time is called "jerk": $\vec{j} = \dfrac{\Delta\vec{a}}{\Delta t}$.



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