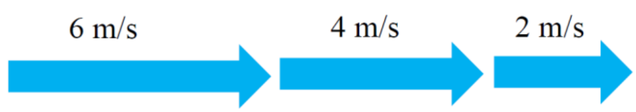
Name: ____ Date: _______

PHYSICS
UNIT 2: FORCES & ACCELERATION

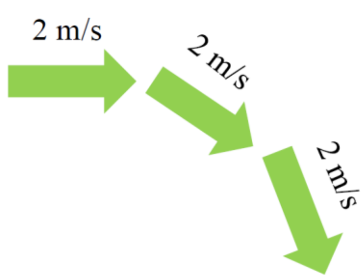
ACCELERATION

Acceleration is a change in velocity per unit time. Acceleration describes how fast velocity changes. Just like velocity, acceleration is a **vector**—it must have a magnitude (how big, the number) and a direction. Remember that **velocity** is defined as the straight-line rate of motion with direction. Any time velocity changes, an acceleration has occurred. If the magnitude of the velocity changes, acceleration has happened. If the direction of the velocity changes, acceleration has happened.

Case 1: Acceleration happens when velocity increases (magnitude gets bigger, object gets faster).

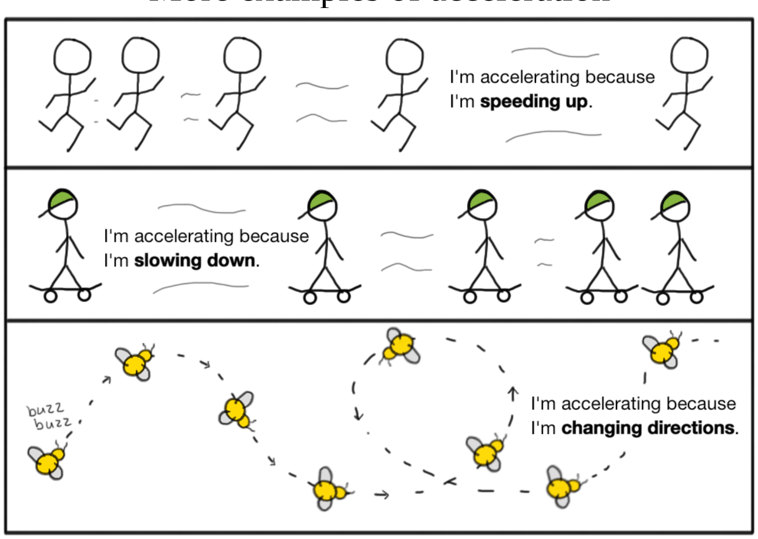


Case 2: Acceleration happens when velocity decreases (magnitude gets smaller, object gets slower).

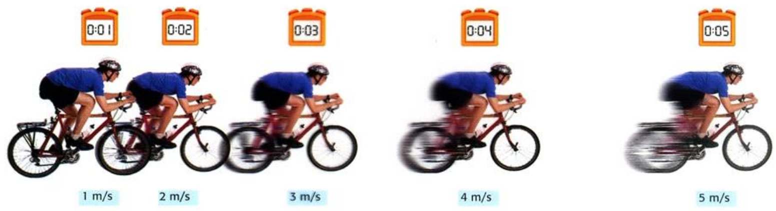


Case 3: Acceleration happens when direction changes. The change in direction makes a new vector, thus a new velocity even if the magnitude remains constant.

More examples of acceleration



- An object's rate of motion may increase with time—get faster.
- An object's rate of motion may decrease with time—get slower.
- An object's direction may change with time—move in a curved path or in a circle.
- An object may experience both a change in rate (faster or slower) and a change in direction.

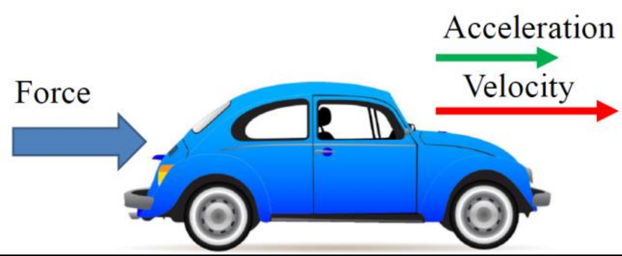


The cyclist is accelerating because his velocity is changing with time. Note that his velocity is progressively increasing by 1 m/s every second he rides.

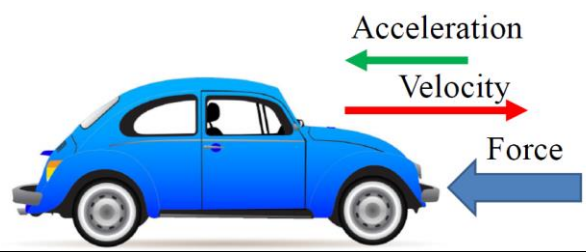
Forces and Acceleration

Forces are push or pull interactions between objects. **Forces cause acceleration**. **Forces cause the motion of objects to change**. When forces act upon objects, **the acceleration of the object is always in the direction of the force.** If the force pushes the object to the right, the acceleration is the right. If the force pushes the object to the south, the direction of the acceleration is to the south.

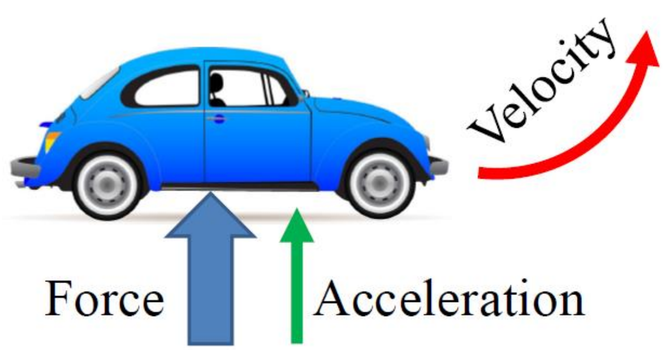
Getting faster: The force acts on the moving car in the same direction that the car is already moving. Acceleration will be in the same direction as the motion of the car. The car will get faster with time.



Getting slower: The force acts on the moving car in the opposite direction to which the car is moving. Acceleration will be in the direction opposite of the moving car. The car will get slower with time.



Changing direction: The force acts on the moving car at an angle (not straight on) relative to the car's motion. The car will accelerate by changing direction. The car will turn. The acceleration is in the same direction as the force acting on the car.



Direction of Force and Acceleration

Acceleration is a **vector**—it must have a magnitude and a direction. If a change in rate (how fast) is observed, identify (1) which direction object is already moving, and (2) identify if the object is getting faster with time or getting slower with time.

- If the object is getting faster with time, then a force is causing acceleration in the same direction that the object is moving—the force is speeding up the object. Thus, the acceleration is in the same direction as motion.
- If the object is getting slower with time, then a force is causing acceleration in the direction opposite that the object is moving. Thus, the acceleration is in the opposite direction as motion—the force is slowing down the object.

Examples of acceleration direction based on changes in velocity.

- Car moves **north**, the car's velocity *increases*
  The acceleration is **north** (same direction)
  The force acting on the car is to the **north**.

- Car moves **west**, velocity *decreases*
  The acceleration is **east** (opposite direction)
  The force actin on the car is to the **east**.

- Rocket moves **up**, velocity *increases*
  The acceleration is **up** (same direction)
  The force acting on the rocket is **up**.

- Rocket moves **right**, velocity *decreases*
  The acceleration is **left** (opposite direction)
  The force acting on the rocket is **left**.

Practical Meaning of Acceleration

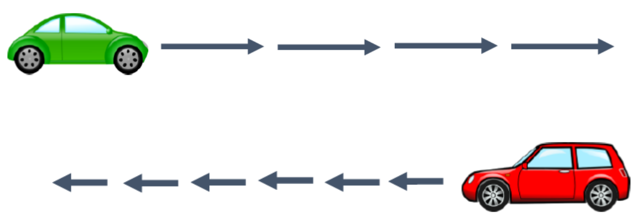
All accelerations are in units of **m/s^2** (meters per square seconds). Acceleration numbers and units should be interpreted as "the amount of increase or decrease in velocity per second of acceleration."

- Suppose a car is speeding up with an acceleration of 1.2 m/s^2. This means that for every second that the car is speeding up, its velocity changes by 1.2 m/s.
- Suppose a car is slowing down with an acceleration of -0.80 m/s^2. This means that for every second that the car is slowing, its velocity changes by -0.80 m/s.

Visual Representations of Velocity and Acceleration

If an object moves at **constant velocity**, velocity is not changing. The object moves at the same rate at all times. Additionally, the object moves **equal distances in equal times.** The spacing between the positions of the moving object at regular time intervals also remains constant. If an object moves at constant velocity, it is not accelerating; acceleration is zero.

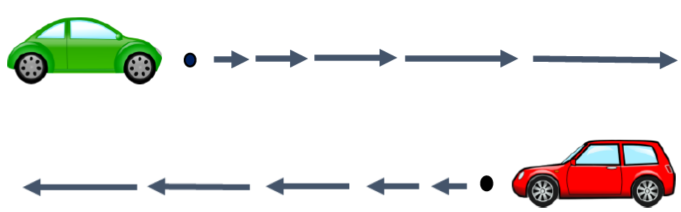
Illustrative Example 1



The green car and the red car are both moving at constant velocity—neither car is accelerating. The vector arrows for velocity are equal in length. The spacing between arrows is also equal in length. The green car is moving faster than the red car—the green car's velocity vector arrows are longer (bigger magnitude). The green car moves in a positive direction (N, E or R). The red car moves in a negative direction (S, W, or L).

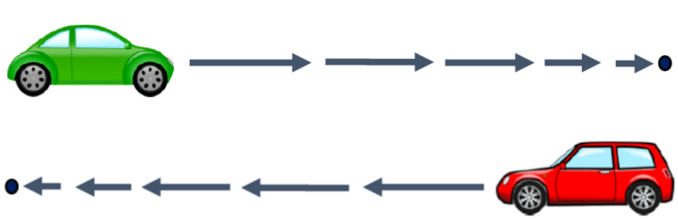
When objects **accelerate**, the magnitude of the velocity will change. The velocity will increase (get faster) or decrease (get slower) with time. The **spacing between the positions of the moving object at regular time intervals will get increasingly greater** (as velocity increases) **or get shorter** (as velocity decreases) **for every second the object moves.**

Illustrative Example 2



The green car and the red car are accelerating by getting faster. The vector arrows are getting progressively longer and longer, indicating that velocity is getting faster and faster with time. Because both cars are getting faster with time, the force making them get faster and the acceleration are in the same direction that they initially move.

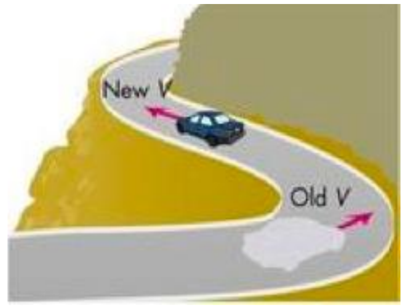
Illustrative Example 3

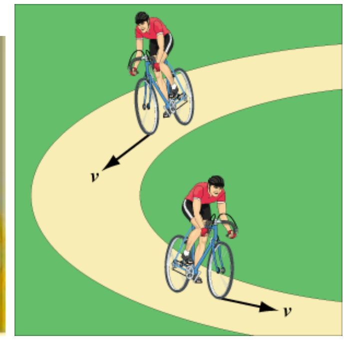


The green car and the red car are accelerating by getting slower. The vector arrows are getting progressively shorter and shorter, indicating that velocity is getting slower and slower with time. Because both cars are getting slower with time, the force making them get slower and the acceleration are in the direction opposite that they initially move.

Centripetal Acceleration

Centripetal acceleration is the acceleration experienced by an object when it changes direction, moves in a curved path, or moves with circular motion. Centripetal acceleration describes how fast velocity changes (accelerates) as the object changes direction.





Moving around a curve or in a circle is form of acceleration even if the object's magnitude of "how fast" remains constant. The acceleration occurs because the direction changes as the object turns.

Calculating Acceleration

Solving for **acceleration**. Use this equation if the problem states the change in velocity: the initial and the final velocities.

$$a = \frac{\vec{v}_f - \vec{v}_0}{t}$$

a = acceleration (m/s^2)
v_f = final velocity, (m/s)
v_o = initial velocity (m/s)
t = time (s)

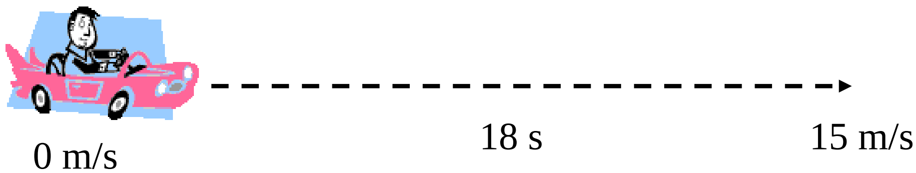
Solving for **acceleration**. Use this equation if the problem states the distance over which the object is speeding up or slowing down, and the initial velocity of the object.

$$a = \frac{2 \cdot (\Delta x - \vec{v}_0 \cdot t)}{t^2}$$

a = acceleration (m/s^2)
v_o = initial velocity (m/s)
Δx = change in position, or distance (m)
t = time (s)

Calculation Example 1

From a stop (0 m/s), a car accelerates to 15 m/s in 18 seconds. Calculate the acceleration of the car.



The problem states the initial and final velocity of the car. Use the first acceleration equation.

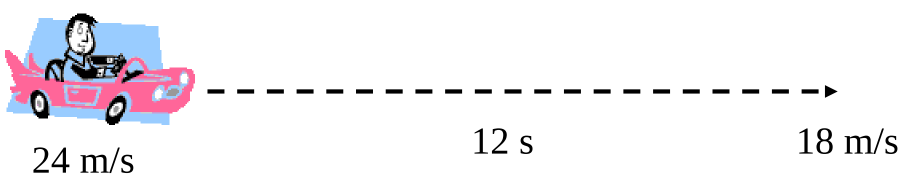
v_0 = 0 m/s
v_f = 15 m/s
t = 18 s

$$a = \frac{v_f - v_0}{t} = \frac{15\,\mathrm{m/s} - 0\,\mathrm{m/s}}{18\,\mathrm{s}} = \frac{15\,\mathrm{m/s}}{18\,\mathrm{s}} = 0.833\,\mathrm{m/s^2}$$

The acceleration is 0.833 m/s^2. The car's velocity got faster by 0.833 m/s every second it accelerated.

Calculation Example 2

A car on the freeway changes velocity from 24 m/s to 18 m/s in 12 seconds. Calculate the acceleration of the car.



The problem gives the initial and final velocity of the car. Use the first acceleration equation.

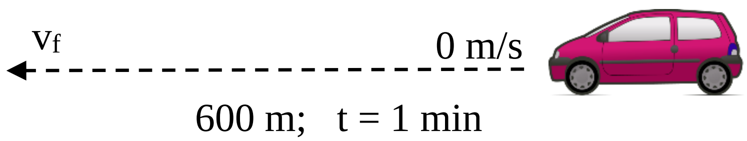
v_0 = 24 m/s
v_f = 18 m/s
t = 12 s

$$a = \frac{v_f - v_0}{t} = \frac{18\,\mathrm{m/s} - 24\,\mathrm{m/s}}{12\,\mathrm{s}} = \frac{-6\,\mathrm{m/s}}{12\,\mathrm{s}} = -0.50\,\mathrm{m/s^2}$$

The acceleration was -0.50 m/s^2. The car's velocity changed by -0.50 m/s every second it accelerated.

Calculation Example 3

Starting from stop at a traffic signal, a car accelerates uniformly for 1 minute over a distance of 600 meters. Calculate the uniform acceleration of the car. Calculate the car's final velocity after acceleration is complete.



The problem gives the initial velocity, the time of acceleration, and the distance over which the car accelerates. Use the second equation.

v_0 = 0 m/s
Δx = 600 m/s
t = 60 s

$$a = \frac{2 \cdot (\Delta x - \vec{v}_0 \cdot t)}{t^2} = \frac{2 \cdot \left(600\,\text{m} - \left(0\,{}^{\text{m}}\!/_{\text{s}} \cdot 60s\right)\right)}{(60\,\text{s})^2} = \frac{1200\,\text{m} - 0\text{m}}{3600\,\text{s}^2} = 0.333\frac{m}{s^2}$$

The car's acceleration was 0.333 m/s^2. The car's velocity changed by 0.333 m/s for every 1 second it accelerated.

Calculating Final Velocity & How Far

Solving for **final velocity** after acceleration is complete. Use this equation if the problem states the initial velocity, acceleration, and time over which acceleration occurred.

$$\vec{v}_f = \vec{v}_0 + a \cdot t$$

a = acceleration (m/s^2)
v_f = final velocity, (m/s)
v_o = initial velocity (m/s)
t = time (s)

Solving for change in position, or **distance**, over which an object accelerates.

$$\Delta x = \vec{v}_0 \cdot t + \frac{1}{2} a \cdot t^2$$

a = acceleration (m/s^2)
Δx = distance(m)
v_o = initial velocity (m/s)
t = time (s)

Calculation Example 4

A car was moving at a velocity of 10.0 m/s. The car accelerated by getting faster for 12 seconds with an acceleration of 1.667 m/s^2. • Calculate how fast the car was moving after it accelerated. • Calculate how far the car moved as it was accelerating.	v_0 = 10.0 m/s t = 12 s a = 1.667 m/s^2

How fast

$$\vec{v}_f = \vec{v}_0 + a \cdot t$$

$$\vec{v}_f = 10.0\frac{m}{s} + \left(1.667\frac{m}{s^2} \cdot 12s\right) = 10.0\frac{m}{s} + 20.0\frac{m}{s} = 30.0\frac{m}{s}$$

After acceleration was complete, the car was moving at 30.0 m/s.

How far

$$\Delta x = \vec{v}_0 \cdot t + \frac{1}{2}a \cdot t^2$$

$$\Delta x = \left(10.0\frac{m}{s} \cdot 12s\right) + \left(0.5 \cdot 1.667\frac{m}{s^2} \cdot (12s)^2\right) = 120m + 120m = 240m$$

As the car accelerated, it moved a distance of 240 meters.

Calculation Example 5

A car was moving at a velocity of 32.0 m/s. The car accelerated by getting slower for 8.0 seconds with an acceleration of -2.40 m/s^2. • Calculate how fast the car was moving after it accelerated. • Calculate how far the car moved as it was accelerating.	v_0 = 32.0 m/s t = 8.0 s a = -2.40 m/s^2

How fast

$$\vec{v}_f = \vec{v}_0 + a \cdot t$$

$$\vec{v}_f = 32.0\frac{m}{s} + \left(-2.40\frac{m}{s^2} \cdot 8s\right) = 32.0\frac{m}{s} + -19.2\frac{m}{s} = 12.8\frac{m}{s}$$

After acceleration was complete, the car was moving at 12.8 m/s.

How far

$$\Delta x = \vec{v}_0 \cdot t + \frac{1}{2} a \cdot t^2$$

$$\Delta x = \left(32.0\frac{m}{s} \cdot 8s\right) + \left(0.5 \cdot -2.40\frac{m}{s^2} \cdot (8s)^2\right) = 256m + -76.8m = 179.2m$$

As the car accelerated, it moved a distance of 179.2 meters.