Newton's second law

Objectives

- Explain the effect of a net force on motion using the concept of acceleration.
- Calculate acceleration in units of m/s² when given mass and force.
- Use the second law to control motion models and graphs to meet predetermined goals.

Assessment

1. A net force of 10 N acts on a cart on a straight track. Label each statement below as true, possibly true, or false.
   a. The cart moves with constant velocity.
   b. The cart moves with constant acceleration.
   c. The cart speeds up.
   d. The cart slows down.

2. A 10 kg object is subject to a net force of 25 N. What is the acceleration of the object in m/s²?
   If the object starts at rest, then how long will it be before its velocity is 25 m/s?

3. What is the minimum force required to increase the speed of a 1,000 kg vehicle by 10 m/s in 3 seconds?

Physics terms

- acceleration
- force
- Newton's second law

Equations

\[ a = \frac{F}{m} \]

\[ F = ma \]
Newton’s second law:

\[ a = \frac{F}{m} \]

The acceleration of an object equals the net force divided by the mass.

The meaning of the second law:

\[ a = \frac{F}{m} \]

Velocity must change if a net force acts on an object.

The net force is zero on an object with constant velocity.

Direction of force and acceleration:

\[ \vec{a} = \frac{\vec{F}}{m} \]

The acceleration is always in the direction of the net force.

Acceleration and force are vectors.
A student drags a 10 kg box across a rough level floor with a constant velocity of 1.5 m/s. What is the net force on the box? 

Test your knowledge

A student drags a 10 kg box across a rough level floor with a constant velocity of 1.5 m/s. What is the net force on the box? The net force on the box is zero!

Test your knowledge

A student drags a 10 kg box across a rough level floor with a constant velocity of 10,000 m/s. What is the net force on the box? The net force on the box is still zero!

Test your knowledge

A student drags a 10 kg box across a rough level floor with a constant acceleration of 1.5 m/s. Now what is the net force on the box? 

Test your knowledge

A student drags a 10 kg box across a rough level floor with a constant acceleration of 1.5 m/s. Now what is the net force on the box? 

Easy! $F_{net} = ma = 15\text{~N}$
The second law can help you remember the definition of a newton.

\[ F_{net} = ma \]

Always use mass in kilograms and acceleration in m/s\(^2\) when applying Newton's second law.

Units

Exploring the ideas

Click this interactive calculator on page 143.

Engaging with the concepts

You can solve for force, mass, or acceleration.

Use the calculator to answer sample questions.

Click the [Run] button to see the hand apply a force to push the ball.

A net force of 500 N acts on a 100 kg cart. What is the acceleration?

\[ a = \frac{F}{m} \]

If you double the mass of the cart, what is the acceleration? 2.5 m/s\(^2\)

What if the force is doubled instead? 10 m/s\(^2\)

Engaging with the concepts

Exploring the ideas

Click this interactive simulation on page 146.
The interactive model shows position and velocity vs. time graphs. Red circles on the position-time graph are targets. Adjust initial velocity \( v_0 \), force \( F \), and mass \( m \) so the curves hits both targets.

**Investigation**

**Part 1: Modeling the action of a force**

The top score of 100 is achieved by hitting the center of each target. Try another problem: [Reset]

*How high can you get?*

Upload your solution to a real ErgoBot to observe the motion. [Print] a copy of your solution and score.

**A tougher challenge**

The second interactive simulation allows you to change the force at four different time intervals, but there are also four target circles.
The advanced simulation allows you to change the force at four different time intervals, but there are also four target circles. Can you solve a problem while keeping the velocity between -1.0 and +1.0 m/s?

A tougher challenge

Part 2: Dynamic modeling

Applying Newton’s second law

If you know the force on an object, you can predict changes in its motion. If you know the acceleration of an object, you can determine the net force on it.

\[ a = \frac{F}{m} \]
\[ F = ma \]

Finding motion from forces

If you know the force on an object, you can predict changes in its motion.

A 0.25 kg ball is traveling 40 m/s to the right when it is hit with a force of 3,000 N for 0.005 seconds. What is its final velocity?

Steps

1. Use force and mass to find acceleration through the second law.
2. Use the acceleration to find the change in velocity or position.

Solution

A 0.25 kg ball is traveling 40 m/s to the right when it is hit with a force of 3,000 N for 0.005 seconds. What is its final velocity?

1. Use force and mass to find acceleration through the second law.

\[ a = \frac{F}{m} = \frac{-3000 \text{ N}}{0.25 \text{ kg}} = -12,000 \text{ m/s}^2 \]

Impacts can cause very large accelerations for short times!

Solution

A 0.25 kg ball is traveling 40 m/s to the right when it is hit with a force of 3,000 N for 0.005 seconds. What is its final velocity?

1. Use force and mass to find acceleration through the second law.
2. Use the acceleration to find the change in velocity or position.

\[ v = v_0 + at = 40 \text{ m/s} + (-12,000 \text{ m/s}^2)(0.005 \text{ s}) = -20 \text{ m/s} \]

The ball reverses direction!
If you know the force on an object, you can predict changes in its motion. If you know the acceleration of an object, you can determine the net force on it.

Applying Newton’s second law

\[ F = ma \]

Steps

1. Use velocity, distance, and time to find the acceleration.
2. Use the acceleration and mass to find the force.

A 70,000 kg aircraft reaches a takeoff velocity of 67 m/s (150 mph) in 11 seconds. Calculate the minimum force required from the engines.

Solution

\[ a = \frac{\Delta v}{\Delta t} = \frac{67 \text{ m/s}}{11 \text{ s}} = 6.1 \text{ m/s}^2 \]

This is almost 2/3 of the aircraft’s weight!

Assessment

1. A net force of 10 N acts on a cart on a straight track. Label each statement below as true, possibly true, or false.
   a. The cart moves with constant velocity.
   b. The cart moves with constant acceleration.
   c. The cart speeds up.
   d. The cart slows down.
Assessment
1. A net force of 10 N acts on a cart on a straight track. Label each statement below as true, possibly true, or false.
   a. The cart moves with constant velocity. false
   b. The cart moves with constant acceleration. true
   c. The cart speeds up. possibly true
   d. The cart slows down. possibly true

Assessment
2. A 10 kg object is subject to a net force of 25 N. What is the acceleration of the object in m/s²?
The second law says $a = \frac{F}{m}$. Therefore $a = \frac{25 \text{ N}}{10 \text{ kg}} = 2.5 \text{ m/s}^2$.
If the object starts at rest, then how long will it be before its velocity is 25 m/s?
You know that $v = v_0 + at$ and $v_0 = 0$.
Rearranging gives $t = \frac{v}{a} = \frac{(25 \text{ m/s})}{(2.5 \text{ m/s}^2)} = 10 \text{ seconds}$.

Assessment
3. What is the minimum force required to increase the speed of a 1,000 kg vehicle by 10 m/s in 3 seconds?
$F = ma = (1,000 \text{ kg})(10 \text{ m/s} / 3 \text{ s}) = 3,333 \text{ N}$.