Module 2 · Week 2 · Lesson

Newton's Laws

PH11-9

ORIENTATION

Lesson goal: build accurate physics fluency for newton's laws and use that fluency to support clear HSC-style scientific writing.

This page is materialised into the MentorMind course shell from existing teaching, textbook, and eduKG material. Use it as the main lesson surface; use the tutor for targeted repair, worked examples, and concise writing feedback.

SYLLABUS INQUIRY QUESTION

- How do forces change the motion of objects?

From The Feynman Lectures on Physics, Vol I, Chapter 10:

Newton's laws are not explanations of why motion occurs. They are rules that connect force, mass, and acceleration so that motion can be calculated.

LEARNING OBJECTIVES

- State Newton's three laws in words and symbols.
- Apply $F_{net} = ma$ to solve motion problems.
- Identify action-reaction force pairs.
- Use free-body diagrams to justify equations.

CONTENT

Newton's First Law (Law of Inertia)

> **If the net force on an object is zero, it remains at rest or moves at constant velocity.**

This law describes **inertia**-the tendency of objects to resist changes in their motion.

Key implications:

- An object at rest stays at rest unless a net force acts
- An object in motion continues at constant velocity unless a net force acts
- "Constant velocity" means constant speed AND direction

When a car brakes suddenly, passengers continue forward-they have inertia. Seatbelts provide the force needed to decelerate you with the car.

Interactive: First Law Demonstration

A puck on a frictionless surface maintains constant velocity:

Observation: Equal spacing between positions means constant velocity. Zero net force → zero acceleration.

Newton's Second Law

> **The acceleration of an object is proportional to the net force and inversely proportional to its mass.**

$$\vec{F}_{net} = m\vec{a}$$

Or equivalently: $a = \frac{F_{net}}{m}$

This is the most-used equation in mechanics. It connects:

- **Force** (N) - the cause
- **Mass** (kg) - the resistance to acceleration
- **Acceleration** (m/s^2) - the effect

Interactive: Force, Mass, and Acceleration

See how doubling force or doubling mass affects acceleration:

Observation: Increasing spacing between positions indicates acceleration. The velocity arrows grow because $v = v_0 + at$.

Interactive: Free-Body Diagram with Net Force

A 12 kg crate with 30 N applied force:

With $F_{net} = 30$ N and $m = 12$ kg:

$$a = \frac{F_{net}}{m} = \frac{30}{12} = 2.5 \text{ m/s}^2$$

Newton's Third Law

> **For every action force, there is an equal and opposite reaction force acting on a different object.**

Key features of action-reaction pairs:

- **Equal magnitude** and **opposite direction**
- Act on **different objects**
- Same type of force (both gravitational, both contact, etc.)
- Exist simultaneously

Action-reaction pairs **never cancel** because they act on different objects. Forces only cancel when they act on the **same** object.

Interactive: Action-Reaction Pairs

When you push on a wall, the wall pushes back on you:

Important: These forces act on different objects-one on the wall, one on you.

Connecting the Laws

LAW	STATEMENT	KEY EQUATION
First	No net force → no acceleration	$\vec{F}_{net} = 0 \Rightarrow \vec{a} = 0$
Second	Net force causes acceleration	$\vec{F}_{net} = m\vec{a}$
Third	Forces come in pairs	$\vec{F}{AB} = -\|vec{F}{BA}$

WORKED EXAMPLES

Example 1: Acceleration from net force

A 12 kg crate is pushed with a net force of 30 N.

Solution:

1. Use Newton's Second Law: $F_{net} = ma$
2. Rearrange for acceleration: $a = \frac{F_{net}}{m} = \frac{30}{12} = 2.5$ m/s^2
3. Acceleration is in the direction of the net force

Example 2: Net force from acceleration

A 0.80 kg cart accelerates at 4.0 m/s^2.

Solution:

1. Use $F_{net} = ma$
2. $F_{net} = 0.80 \times 4.0 = 3.2$ N
3. Force acts in the direction of the acceleration

Example 3: Action-reaction pair (Skaters)

Two skaters push apart with equal force. Skater A has mass 50 kg, skater B has mass 70 kg. The push force is 140 N.

Solution:

1. Both experience 140 N force (Third Law)
2. Acceleration of A: $a_A = \frac{F}{m_A} = \frac{140}{50} = 2.8$ m/s^2
3. Acceleration of B: $a_B = \frac{F}{m_B} = \frac{140}{70} = 2.0$ m/s^2

Key insight: Same force, different masses → different accelerations. The lighter skater accelerates more.

Example 4: Connected carts

Two carts (6 kg and 4 kg) connected by a rope are pulled with 30 N on a frictionless surface.

Solution:

1. Total mass: $m_{total} = 6 + 4 = 10$ kg
2. System acceleration: $a = \frac{F}{m_{total}} = \frac{30}{10} = 3.0$ m/s^2

3. Tension in rope (analyse the 4 kg cart):
    - Only force on 4 kg cart is tension T
    - $T = m_2 \times a = 4 \times 3.0 = 12$ N

COMMON MISCONCEPTIONS

- **Misconception:** Action-reaction pairs cancel. **Correction:** They act on **different objects** and cannot cancel. Only forces on the same object can cancel.
- **Misconception:** A larger force always means a larger acceleration. **Correction:** Acceleration depends on both force AND mass: $a = F/m$
- **Misconception:** An object in motion must have a net force. **Correction:** An object can move at constant velocity with zero net force (First Law).
- **Misconception:** Heavier objects fall faster. **Correction:** In a vacuum, all objects have the same gravitational acceleration g. Mass cancels in $a = \frac{mg}{m} = g$.
- **Misconception:** The reaction to your weight is the normal force from the floor. **Correction:** The reaction to Earth pulling you down is you pulling Earth up. The normal force is a separate interaction.

PRACTICE QUESTIONS

Easy (2 marks)

A 5.0 kg object experiences a net force of 15 N. Calculate its acceleration.

- Use $a = F/m$ (1)
- Correct acceleration: $a = 15/5.0 = 3.0$ m/s^2 with units (1)

Answer: 3.0 m/s^2

Medium (4 marks)

A 20 kg box is pulled along a floor with 50 N while friction is 18 N. Find the acceleration.

- Net force calculation: $F_{net} = 50 - 18 = 32$ N (2)
- Acceleration calculation: $a = 32/20 = 1.6$ m/s^2 (2)

Answer: 1.6 m/s^2 in the direction of the pull

Hard (5 marks)

Two carts are connected by a light rope. The system of 6 kg and 4 kg carts is pulled with 30 N on a frictionless surface. Find the acceleration and the tension in the rope.

- Total mass and system approach: $m = 10$ kg (1)
- Acceleration: $a = 30/10 = 3.0$ m/s^2 (1)
- Isolate one cart for tension analysis (1)
- Tension calculation: $T = 4 \times 3.0 = 12$ N (1)
- Correct units throughout (1)

Solution:

Step 1: Treat system as one object

- Total mass = 6 + 4 = 10 kg
- $a = F/m = 30/10 = 3.0$ m/s^2

Step 2: Analyse the rear cart (4 kg)

- Only horizontal force is tension T
- $T = ma = 4 \times 3.0 = 12$ N

Answer: Acceleration = 3.0 m/s^2, Tension = 12 N

MULTIPLE CHOICE QUESTIONS

Test your understanding with these interactive questions:

SUMMARY

- **First Law:** Zero net force means zero acceleration (inertia)
- **Second Law:** $\vec{F}_{net} = m\vec{a}$ connects force, mass, and acceleration
- **Third Law:** Forces come in equal and opposite pairs on different objects
- Connected systems can be analysed as a whole or as separate free bodies
- Action-reaction pairs never cancel (they act on different objects)

SELF-ASSESSMENT

Check your understanding:

After studying this section, you should be able to:

- [ ] State all three laws in your own words
- [ ] Apply $F_{net} = ma$ to find force, mass, or acceleration
- [ ] Identify action-reaction pairs correctly
- [ ] Explain why action-reaction pairs don't cancel
- [ ] Analyse connected systems using Newton's Second Law

SCIENTIFIC WRITING AND EXAM SUPPORT

When answering questions from this lesson, separate:

- the physical quantity being discussed,
- the model or law being applied,
- the mathematical relationship, including units,
- the conclusion in words.

For explanation questions, write in the pattern: **claim -> physics reason -> consequence**. For calculation questions, state the formula, substitute with units, calculate, then interpret the answer.

MAINTENANCE LOOP

One-minute retrieval:

1. State the key law, model, or relationship used in this lesson.
2. Identify one common misconception that would lead to a wrong answer.
3. Write one sentence that links the calculation or evidence back to the physical meaning.

STUDENT WORKING
