Chapter 4: The laws of motion

Newton’s first law

If the net force exerted on an object is zero, the object continues in its original state of motion:

- an object at rest, remains at rest;
- an object moving with some velocity continues with that same velocity.

**Net force**: the sum of all external forces

\[ \sum \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots \]
Mass and inertia

**Inertia** is the tendency of an object to continue in its original motion in the absence of a force.

**Mass** is the resistance of an object to changes in its motion due to a force.

Newton’s second law

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

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

\[
\sum F_{ix} = ma_x \\
\sum F_{iy} = ma_y
\]

Units

\(1N \equiv 1Kgm/s^2\)
True (a) or false (b)?
1. If an object is at rest, no external forces act on it
2. If one single force acts on an object, the object accelerates
3. If an object experiences an acceleration, at least one force acts on it
4. If an object experiences no acceleration, no external force acts on it
5. If the net force acting on an object is in the x direction, the object moves in the x direction
Newton’s law of universal gravitation

\[ F_g = G \frac{m_1 m_2}{r^2} \]

The magnitude of the gravitational force acting on an object of mass \( m \) near the Earth’s surface is called the weight.

\[ w = G \frac{M_E m}{r^2} \]

How would you modify this formula for an object on the moon?
Elastic Force

\[ F_{el} = K \Delta x \]

Action and Reaction
Newton’s third law

If two objects interact, the force exerted by object 1 on object 2 is equal in magnitude but opposite direction to the force exerted by object 2 on 1.

\[ \text{Action} = -\text{Reaction} \]

Free body diagram

To study the crate’s motion, we should only consider the forces acting on the crate.
Free body diagram quiz

A horse pulls on a sled with a horizontal force to get the sled in motion. Newton’s 3rd law says that the sled exerts a force of equal magnitude and opposite direction on the horse. Which statement is true?

a) These 2 forces cancel so the sled cannot accelerate.
b) Newton’s 3rd law is not applicable.
c) None of the above

Equilibrium

- make a sketch
- draw a free-body diagram for the object under consideration and label ALL forces
- resolve all forces in x and y components
- use the equilibrium equations (keep track of signs)
- solve the simultaneous equations for the unknowns in terms of the known quantities

\[ \sum F_{ix} = 0 \]
\[ \sum F_{iy} = 0 \]
Equilibrium: example

A traffic light weighing 100 N hangs from the vertical cable tied to two other cables that are fastened to a support. Find the tension in each of the three cables.
Newton’s second law: strategy

- draw a diagram of the system
- isolate the object of interest that is being analyzed; draw a free-body diagram for this object showing all external forces (if more than one object, draw several free-body diagrams)
- establish convenient coordinate systems for each object and find the components of the forces along each axis (one of the axes should be parallel to the direction of motion)
- solve the component equations for the unknowns

\[
\sum F_{ix} = ma_x \\
\sum F_{iy} = ma_y
\]

Newton’s laws: application

The combined weight of the crate and the dolly is 300 N. If the person pulls on the rope with a constant force of 20.0 N, a) what is the acceleration of the crate and how far will it move in 2.00 s? Assume the system starts from rest and there are no friction forces; b) What is the reaction force from the floor on the crate?
Newton’s laws: application

A car of mass $m$ is on an icy driveway inclined at an angle of 20.0 deg. Determine the acceleration of the car, assuming there is no friction.

Newton’s laws: application

A person weighs a fish of mass $m$ on a spring scale attached to the ceiling of an elevator. The value read when the elevator is still is 100 N. What is the value read if the elevator accelerates upward $a=2\text{m/s}^2$? And if it accelerates downward?
Forces of friction: static and kinetic

Coefficient of static friction

\[ f_s \leq \mu_s N \]

\[ f_k = \mu_k N \]

Coefficient of kinetic friction

Forces of friction: example

You are playing with your younger sister in the snow. Which case a) or b) would be easier to push her?
Forces of friction: example

The hockey puck is given an initial speed of 20.0 m/s on a frozen pond. The puck remains on ice and slide 120 m before it comes to rest. Determine the coefficient of kinetic friction puck and ice.

Newton’s laws: more problems

Two packing crates of masses 10.0 kg and 5.0 kg are connected by a light string that passes over a frictionless pulley. The 5.00 kg crate lies on a smooth incline of angle 40.0°. Find the acceleration of the 5.00 kg crate and the tension in the string.

Repeat the problem considering a friction coefficient of 0.2!
Equilibrium: more problems

The leg and cast weigh 220 N \( (w_1) \). Determine the weight \( w_2 \) and the angle needed so that no force is exerted on the hip joint by the leg plus the cast.

Newton’s laws: More problems

The pelvis has a mass of 30 kg. Determine its acceleration, considering the typical forces exerted on it.