Chapter 10: The Nature of Force

Force – a push or a pull

Force is a vector (it has direction) just like velocity and acceleration

Newton – the SI unit for force = kg m/s²

Net force – the combination of all forces acting on an object

Unbalanced forces – result in a net force

An unbalanced net force causes objects to begin to move, stop moving, or change direction

Balanced force – the combination of all forces acting on an object sum up to zero

Friction and Gravity

Friction – the force that two surfaces exert on each other when they rub against one another

In general, smooth surfaces produce less friction than rough surfaces

The strength of the force of friction depends upon two factors

How hard the surfaces push together

Examples

Heavy cars have more traction on snow than lighter cars
Light boxes are easier to slide than heavy boxes

The types of surfaces involved

Examples

Sand produces more friction than snow even though both are rough
Glass produces more friction than ice even though both are smooth

Even very smooth surfaces are likely to appear rough under magnification

Both pictures to the right are cuprite but the one on the far right is a SEM

Four types of friction:

Static friction – friction that acts on objects that are not moving

You may have observed a box on a ramp

A box that is not moving has more friction

Once the box starts to slide, it gains speed quickly because there is less friction

Sliding friction – friction that acts on objects that are moving

Sliding friction is less than static friction (for the same surfaces)

Once a car starts to slip on ice, it is very hard to get the car to stop sliding

Rolling friction – friction that acts on objects that use ball bearings or wheels

Rolling friction is less than static or sliding friction (for the same surfaces)

Very heavy trains can still be pulled by an engine car because wheels roll easily

Fluid friction – occurs when a solid object moves through a fluid

Fluid friction is very easy to overcome

Car engines use oil and wet floors are very slippery because of fluid friction

Fluid friction increases as the speed of the object increases (your arm out a car window)
Gravity – a force that pulls two objects toward each other

Universal gravity – Sir Isaac Newton realized that gravity acts everywhere in the universe, not just on Earth.

Gravity causes apples to fall to the Earth and also causes the planets to stay in orbit around the sun.

Universal gravitation says that all objects in the universe attract each other.

Factors that affect gravity: mass and distance

- Mass – the amount of matter in an object
  - SI unit for mass is the kilogram (kg)
  - Mass does not change from place to place
    - A 100 kg person on Earth will still have a mass of 100 kg on the moon
  - Mass and weight are not the same thing
- Weight – the amount of force gravity exerts on an object
  - Weight can change from place to place
    - A 100 kg person has a weight of 980 N on Earth but will weigh 163 N on the moon
  - If the mass of an object doubles, then the force of gravity it exerts on another object will also double.

Distance – the distance between objects also affects the force of gravity

- Distance has a greater impact on gravity than mass
  - If the distance between two objects doubles, then the force of gravity will drop to $\frac{1}{4}$ the original force
  - If the distance is tripled, the force will drop to $\frac{1}{9}$ the original force

Gravity is reciprocal – if the Earth pulls on a person with a force of 980 N then the person pulls on the Earth with a force of 980 N.

Gravity and Motion

Free fall – condition in which the force of gravity is unbalanced causing the falling object to accelerate.

- Acceleration due to gravity, $g = 9.8 \text{ m/s}^2$

The slope of the Free Fall graph is $9.8 \text{ m/s}^2$ or the acceleration due to gravity.

The slope is a straight line, so acceleration due to gravity is a constant.

All objects (regardless of mass) should accelerate at the same rate on Earth.
Air Resistance – falling objects experience a type of fluid friction due to the air.

Air resistance explains why light objects with large surface areas fall slower in air than heavy objects with small surface areas.

Terminal velocity – occurs when the force of air resistance (which increases as speed increases) balances the force of gravity so that a falling object attains a constant speed.

Projectile Motion – a thrown object is called a projectile.
Horizontal and Vertical motion of a projectile:
- The horizontal and vertical motion of a projectile act independently.
- The speed in the x direction will be constant because no unbalanced forces (ignoring air resistance) act on the ball.
- The speed in the y direction changes because of gravity.
  - The speed in the upward direction will decrease until the ball comes to a stop and then the ball will drop with increasing speed until it hits the ground traveling at the same speed as its initial speed.
- The same thing is true for bullets and arrows (with minor corrections for air resistance) which explains why you must aim above the target because a bullet will fall at the same rate as a dropped (or thrown) object.

Newton’s First and Second Laws of Motion

Newton’s First Law of Motion – an object at rest or an object moving at constant velocity will remain at rest or at constant velocity unless acted upon by an unbalanced force.

Inertia – the tendency of an object to resist changes in motion.
- Inertia is directly related to mass.
- Newton’s first law of motion is often called the law of inertia.
Newton’s Second Law of Motion – the acceleration of an object acted on by an unbalanced force will be directly related to the force and inversely related to the mass of the object. 

This means there are two ways to increase the acceleration on any object:
1) increase the force
2) decrease the mass

\[
\text{Acceleration} = \frac{\text{Net Force}}{\text{Mass}}
\]

\[a = \frac{F}{m} \quad \text{or} \quad F = ma\]

Since the SI unit for mass is the kg and the SI unit for acceleration is m/s\(^2\), the SI units for acceleration is kg m/s\(^2\) = the newton (N)

Example: What force is exerted by a speedboat to accelerate a 55 kg skier at 2.0 m/s\(^2\)?

\[
m = 55 \text{ kg} \quad F = ma \\
\]

\[a = 2.0 \text{ m/s}^2 \quad = 55 \text{ kg} \times 2.0 \text{ m/s}^2 \\
= 110 \text{ kg m/s}^2 \quad \text{or} \quad 110 \text{ N}\]

Newton’s Third Law of Motion

Newton’s First Law of Motion – if one object exerts a force on a second object, then the second object exerts an equal force in the opposite direction on the first object.

“For every action, there is an equal and opposite reaction.”

Action-Reaction Pairs

Two skaters – describe what happens when two skaters face each other and push

Detecting motion

If a basketball is dropped toward the Earth, which one moves?

Answer: both move! The Earth moves such a small distance that it is not detectable

Do the equal and opposite reaction pair forces cancel?

Answer: No! These forces do not cancel. Equal and opposite forces cancel when they are acting on the same object. In action reaction pairs, the forces do not cancel out because they are acting on two separate objects.
Momentum

Momentum is the product of an object’s mass and velocity

\[ p = m \cdot v \]

Since velocity is a vector quantity, momentum is also a vector quantity

Conservation of Momentum

Law of Conservation of Momentum: the total momentum of any group of objects remains constant unless outside forces act on the objects

Two moving objects collide

Before collision:

Car A (2 kg \times 4 \text{ m/s} = 8 \text{ kg m/s})
Car B (2 kg \times 2 \text{ m/s} = 4 \text{ kg m/s})

Total momentum = 8 \text{ kg m/s} + 4 \text{ kg m/s} = 12 \text{ kg m/s}

Before:

Car A (2 kg \times 2 \text{ m/s} = 4 \text{ kg m/s})
Car B (2 kg \times 4 \text{ m/s} = 8 \text{ kg m/s})

Total momentum = 4 \text{ kg m/s} + 8 \text{ kg m/s} = 12 \text{ kg m/s}

One moving object collides with stationary object

Before collision:

Car A (2 kg \times 4 \text{ m/s} = 8 \text{ kg m/s})
Car B (2 kg \times 0 \text{ m/s} = 0 \text{ kg m/s})

Total momentum = 8 \text{ kg m/s} + 0 \text{ kg m/s} = 8 \text{ kg m/s}

Before:

Car A (2 kg \times 0 \text{ m/s} = 0 \text{ kg m/s})
Car B (2 kg \times 4 \text{ m/s} = 8 \text{ kg m/s})

Total momentum = 0 \text{ kg m/s} + 8 \text{ kg m/s} = 8 \text{ kg m/s}

One moving object collides and connects to a stationary object

Before collision:

Car A (2 kg \times 4 \text{ m/s} = 8 \text{ kg m/s})
Car B (2 kg \times 0 \text{ m/s} = 0 \text{ kg m/s})

Total momentum = 8 \text{ kg m/s} + 0 \text{ kg m/s} = 8 \text{ kg m/s}

Before:

Car A (2 kg \times 2 \text{ m/s} = 4 \text{ kg m/s})
Car B (2 kg \times 2 \text{ m/s} = 4 \text{ kg m/s})

Total momentum = 4 \text{ kg m/s} + 4 \text{ kg m/s} = 8 \text{ kg m/s}

Rockets and Satellites

Rockets can rise into the air (or space) because the gases it expels with a downward action force exert an equal but opposite reaction force upward on the rocket

These opposite but equal forces do not cancel out because they are acting on two separate objects; in this case, one force on the expelled gases and the other on the rocket

Satellite – any object that orbits another object in space

The moon in a natural satellite

Most artificial satellites orbit in a nearly circular orbit

Centripetal force: any force that causes an object to move in a circular path

Centripetal means “center seeking”

For satellites around Earth, the centripetal force is gravity
Newton’s cannon shows how an object stays in orbit based on both its forward velocity and the force of gravity.

The faster an object is thrown (or shot out of a cannon, see paths A and B) the farther it will travel; with enough velocity it will move in a circular orbit because the amount of distance it falls is exactly balanced by how far from Earth it would be if moving in a straight line (path C).

At E, the cannon ball escapes Earth altogether.

Satellite Location

Satellites are placed in Earth orbit based on their use.

Low orbit – space shuttle and mapping are 400 km to 1000 km (see the light blue area in the figure to the right).

Medium orbit – research and GPS satellites are 1000 km to 36 000 km (within the green dashed line in the figure).

High orbit – geostationary satellites (the dark blue dashed line at 36 000 km).