General Physical Science

Chapter 3
Force and Motion

Force and Net Force

- Quantity capable of producing a change in motion (acceleration).
  - Key word = capable
- Tug of War
  - Balanced forces
  - Unbalanced forces
- Forces are vector quantities

Learning Goals
- Relate force and motion
- Explain what is meant by a net (or unbalanced) force

Questions: 1, 2
Exercises: 1
Newton’s 1st Law of Motion

- **Aristotle**
  - The ‘natural’ state of an object is at rest.
  - Observation - all moving objects stop!
- **Galileo**
  - Tested with balls on an inclined plane.
  - Smoother surface = farther distance
  - Proposed infinitely smooth = no stopping!
  - Object ‘naturally’ remain in motion

- **Proposed infinitely smooth = no stopping!**
- **Smoother surface = farther distance**
- **Tested with balls on an inclined plane.**

Newton’s 1st Law of Motion

- An object will remain at rest or in uniform motion in a straight line unless acted upon by an external, unbalanced force.
  - uniform motion
  - unbalanced force
- **NASA**
  - no air resistance in space.

Force

- **Internal**
  - Pushing on floor board of car
  - Does not change velocity
- **External**
  - Car accident
  - Changes velocity
Motion and Inertia

- Inertia
  - Natural tendency of an object to remain at rest or in uniform motion in a straight line (Galileo)

- Mass
  - Measure of the inertia of an object (Newton)
  - Swing

- Newton’s First Law
  - Law of Inertia

Newton’s First Law of Motion

- Learning Goals
  - Explain Newton’s first law of motion.
  - Describe and give examples of the concept of inertia.

- Questions: 3-6

Newton’s 2nd Law of Motion

- What causes acceleration?
  - External, unbalanced force
  - Magnitude of force directly related to acceleration
    \[ a \propto F \]
  - Acceleration inversely proportional to the mass of the object.
    \[ a \propto \left( \frac{1}{m} \right) \]
Combining both equations
- \( \alpha \propto F/m \)
- Becomes an equality with appropriate units.
  - Using mks \( a = F/m \)
  - Rearranging: \( F = ma \)

- This derived unit is a newton (N).
  - This is ‘weight’ in SI system when \( a = g \)
  - English – pound
    - Mass in English is the ‘slug’
    - \( 1\text{lb} = \text{slug-ft/s}^2 \); 1 slug = 32 lbs (on Earth!)
Example

- Forces are applied to blocks connected by a string and resting on a frictionless surface. Each of the two blocks is 1.0 kg. To the left block a force of 5.0 N is applied to the left, and to the right block a force of 8.0 N right is applied. What is the acceleration of the system?
  - STEP 1 - DRAW A PICTURE (with units!)

Example

- STEP 2 - We want to find Acceleration
- STEP 3
  - \( a = \frac{F}{m} \)
  - Unbalanced force
    - Part of force is canceled (opposite direction)
    - 8.0 N - 5.0 N = 3.0 N right
  - Mass = 1.0 kg + 1.0 kg = 2.0 kg
  - \( a = 3.0 \text{ N right} / 2.0 \text{ kg} = 1.5 \text{ m/s}^2 \) right

Mass and Weight

- Mass
  - Amount of matter
  - Measure of inertia
- Weight is a measure of force
  - \( w = mg \)
- Mass does not change with a change in the gravitational field, but weight does!
  - For a 1 kg mass
    - Earth weight = 9.8 N
    - Lunar weight = 1.6 N
Free Fall

- Why doesn't a heavier object fall faster than a lighter object (ignoring air resistance)?
  - Newton’s Second Law - more massive object will have greater force acting upon it!
  - Newton’s First Law - more massive object has greater resistance to force
  - Two cancel, and fall at the same rate!!

Friction

- Resistance to motion
  - Whenever two materials are in contact with each other
  - Neither good nor bad – it just is.

- Friction between solids
  - Localized adhesion
  - ‘Welding’

Friction

- Static friction
  - Energy required to start to move an object

- Sliding friction
  - Energy required to keep the object moving at a constant speed

- Typically, static > sliding
Friction

- Frictional force depends on how hard surfaces are pressed together
  - Weight
  - Possible added force (clamp)
  - Orientation (horizontal vs. vertical)
- Coefficient of friction
  - Table 3.1
  - Note $\mu_s > \mu_k$

Newton’s Second Law of Motion

- Learning Goals
  - Describe the relationships in Newton’s second law of motion and apply the law to simple situations.
  - Differentiate between mass and weight using Newton’s second law.
- Questions: 7 - 12
- Exercises: 3-9 odd

Newton’s 3rd Law of Motion

- For every action there is an equal and opposite reaction.
- Whenever one object exerts a force upon a second object, the second object exerts an equal and opposite force upon the first.
- Jet Propulsion
Newton’s 3rd Law of Motion

- $F_1 = -F_2$
- $m_1a_1 = -m_2a_2$
  - If $m_1 > m_2$ then $a_1 < a_2$

- Dropping book
  - Book accelerates to earth
  - Earth accelerates to book!
- Forces on book on table.

Centripetal Acceleration

- Centripetal force from tires
  - Decrease force (black ice), decrease centripetal acceleration (ditch)
- Centrifugal force
  - Doesn’t exist
  - Newton’s 1st Law
Newton’s 3rd Law of Motion

- Learning Goals
  - Explain Newton’s 3rd law of motion
  - Identify the third law force pair in practical applications.
- Questions: 13-16

Newton’s Law of Gravitation

- Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.
  - \( F = \frac{(G m_1 m_2)}{r^2} \)
  - \( G = 6.67 \times 10^{-11} \text{ N m}^2 / \text{ kg}^2 \)
  - Proportionality constant

Newton’s Law of Gravitation

- Used law to explain lunar orbit.
- \( G \) was measured by Henry Cavendish
  - 70 years after Newton’s death
  - Delicate balance to measure the force between 2 masses
- Very, very small between ‘ordinary’ objects.
Example

Two objects with a mass of 1.0 kg and 2.0 kg are 1.0 m apart. What is the magnitude of the gravitational force between the masses?

\[ F = \frac{(G m_1 m_2)}{r^2} \]

- \( G = 6.67 \times 10^{-11} \text{ N m}^2 / \text{kg}^2 \)
- \( m_1 = 1.0 \text{ kg}; m_2 = 2.0 \text{ kg} \)
- \( r = 1.0 \text{ m} \)

\[ F = \frac{[(6.67 \times 10^{-11} \text{ N m}^2 / \text{kg}^2) (1.0 \text{ kg}) (2.0 \text{ kg})]}{(1.0 \text{ m})^2} \]

\[ F = 1.3 \times 10^{-10} \text{ N} \]

- Small chalk dust weighs 10,000 x more!

Example

\[ F = \frac{(G m_1 m_2)}{R_e^2} \]

- \( M_e = \text{mass of the Earth} \)
- \( R_e = \text{radius of the earth} \)

Force is objects weight.

- \( w = mg = \frac{(G m_1 m_e)}{R_e^2} \)
- \( g = \frac{(G M_e)}{R_e^2} \)

Distance is measured from the center of mass of objects

- At 1 mile from Earth’s surface, weight decreases by 0.05%!

Why is g constant on the Earth’s Surface?
Orbit

- Object in Free Fall
- Horizontal component just sufficient to follow earth’s curvature!
- Gravity provides the centripetal acceleration.
  - 'Not really 'zero g’
  - 'Vomit Comet

Newton’s Law of Gravitation

- Learning Goals
  - State and apply Newton’s law of gravitation.
  - Explain on what the acceleration due to gravity depends.
- Questions: 17-21
- Exercises: 11-15 odd

Buoyancy

- Fluids
  - Liquids and gases
  - Blimp
- Buoyant Force
  - Archimedes’ Principle
  - EUREKA!
Buoyancy

- An object will FLOAT if it's average density is less than the density of the fluid being displaced.
- An object will SINK if it's average density is greater than the density of the fluid being displaced.
- An object will be AT EQUILIBRIUM if it's average density is equal to the density of the fluid being displaced.

Buoyancy

- Amount of buoyancy is a function of fluid displaced.
- Iceberg:
  - 9/10 of an iceberg is underwater.
  - Average density of ice is about 0.9 g/mL.

Buoyancy

- Learning Goal:
  - Explain buoyancy in terms of density of the ‘buoyant’ object and the fluid providing the buoyant force.
- Questions: 22-27
- Problems: 17
### Momentum

- **Linear Momentum**
  - \( p = mv \)

- **Law of Conservation of Linear Momentum**
  - The total linear momentum of a system remains the same if there is no external unbalanced force acting on the system.
  - \( m_1v_1 = m_2v_2 \)

### Conservation of Momentum

- **Jumping to shore**
  - Internal force
  - Man goes forward
  - Boat goes backwards

### Conservation of Momentum

- **Jet/Rocket Propulsion**
  - Burning fuel = internal work
  - Gas out back
  - Plane or rocket goes forward!
Example

- A 1.0 kg mass is connected by a string and a spring to a 2.0 kg mass
- String burned
- Velocity of 1.0 kg mass is 1.8 m/s
- Calculate v for second mass

Example

\[ m_1v_1 = m_2v_2 \]
\[ 1.0 \text{ kg} \times 1.8 \text{ m/s} = 2.0 \text{ kg} \times X \]
\[ X = 1.0 \times 1.8 / 2.0 \]
\[ X = 0.90 \text{ m/s} \]

Angular Momentum

- Circular / elliptical path.
- Angular momentum changed by external, unbalanced torque
  - twisting effect
    - turning a steering wheel
    - Drill
    - Engine
  - \( T = rF \)
Law of Conservation of Angular Momentum

- The angular momentum of an object remains constant if there is no external, unbalanced torque acting upon it.
- $mv_1r_1 = mv_2r_2$
  - As $r$ decreases, $v$ increases
  - Earth in an elliptical orbit
  - Winter (NH) we are closer to the Sun
  - Speed of the earth increases

Law of Conservation of Angular Momentum

- Practical Applications
  - Helicopters
    - Large - counter rotating blades
    - Small - two blades
      - Large main rotor and smaller tail rotor perpendicular to the main rotor.
  - Ice skating (practical?)
    - Arms in, rate of turn increases dramatically!

Momentum and Inertia

- Learning Goals
  - Define linear momentum.
  - Define torque and angular momentum, and state their relationship.
  - Explain the conditions for conservation of linear and angular momentum, and give examples.
Momentum and Inertia

- Questions: 28 - 31
- Exercises: 19-23 odd
- Key Terms: Matching, Multiple Choice, and Fill-in-the-Blank Questions; Visual Connection and Applying your Knowledge
- TEST 2 following completion of CHAPTER 4!!!