3.1-Force-Fundamental Forces

What are the ways in which matter and energy can interact?

Matter and energy interact through four fundamental forces. Matter consists of fundamental particles, but not all particles experience all forces:

- The four fundamental forces are:
  - **gravity**
  - the electromagnetic force
  - the **strong nuclear force**
  - the weak nuclear force
- All forces and interactions can ultimately be broken down and explained in terms of the four fundamental forces.
- Matter can be broken down into tiny fundamental **subatomic** particles which mutually interact through the fundamental forces.
- Not all fundamental particles experience all of the fundamental forces.
- For example, electrically neutral particles do not experience the electromagnetic force.

What is plasma and how does it compare to other states of matter?

A plasma is similar to a very hot gas, but with ionized particles and electrons:

- A plasma is matter in a state similar to a gas but in which many of the particles are ionized.
- A plasma is matter containing charged particles: positively charged ions and negatively charged electrons.
- Plasmas can be created by heating gases until their atoms gain so much energy they start to lose electrons and become ionized.
- The temperature of plasmas is much higher than the temperature of gases, liquids, or solids.

How were the four fundamental forces discovered?

The four fundamental forces play different roles in the universe, and their affects show up best in different types of systems:

- Gravity was the first fundamental force to be understood. It is a long-range attractive force between masses that explains the motion of planets, stars and galaxies.
- Electromagnetism provides a unified description of electric and magnetic phenomena. It is an interaction between charged particles and electromagnetic fields that explains electricity, magnetism, **light** and forces between charged particles.

- The weak nuclear force is an interaction between subatomic particles which is responsible for radioactivity.
- The strong nuclear force is an interaction that holds together the protons and neutrons in atomic nuclei.
- Currently, researchers use one theory to describe all the forces except gravity:
    - The strong, weak and electromagnetic forces are described by the theory called the standard model.
    - Gravity is described by the theory called general relativity.

What factors determine the magnitude of the gravitational force between two objects?

Two massive objects feel an attractive force that can be approximately described by Newton's law of universal gravitation:

- Newton's law gives the force F_g between two masses m_1 and m_2 separated by a distance r. The **gravitational force** between them has a magnitude of:

$$F_{\mathrm{g}} = \frac{G m_1 m_2}{r^2}$$

- Gravity provides an attractive force that keeps planets in orbit around the sun.

How can atoms and molecules be identified by how they absorb and emit light?

Atoms and molecules each absorb and emit only certain wavelengths. Spectroscopy is the study of these properties:

- Atoms and molecules only absorb and emit particular wavelengths of light.
- Atoms only absorb or emit photons of light with energies that match the energy gap between their **electron** energy levels.
- The particular pattern of wavelengths that an atom or molecule absorbs or emits can be used to identify the atom or molecule.
- **Atomic spectroscopy** is the technique that allows atoms to be identified by the light they absorb or emit.

3.2- Gravity

How is the magnitude of the gravitational force between two objects related to their masses and the distance between them?

The magnitude of **gravitational force** between two objects is:

- proportional to their masses
- inversely proportional to the square of the **distance** between them

What is Newton's law of universal gravitation?

Newton's law of universal gravitation states the following:

- $$F_g = \frac{G m_1 m_2}{r^2}$$ where F_g is the magnitude of the gravitational **force** between two objects. G is Newton's gravitational constant. The variables m_1 and m_2 are the masses of the two objects, and r is the distance between them.
- The gravitational force between two masses is attractive. It is directed along the line that separates the masses.

How does Newton's law of gravitation relate the distance between two objects, their masses, and the force of attraction between them?

- **Gravity** is the attractive force between any two objects in the universe that have **mass**.
- The magnitude of the force of gravity is directly proportional to the masses of the two objects and inversely proportional to the square of the distance between the two objects.

What is the difference between center of mass and center of gravity?

The center of mass and the center of gravity of a system are related:

- The center of mass is the average location of the mass in the system.
- The center of gravity is the average location of the force of gravity on the system.
- The center of mass and the center of gravity may not be in the same location.
- The center of mass and center of gravity of an object may lie outside the object's boundaries.

How does the law of universal gravitation apply to objects near Earth's surface?

Objects near the Earth's surface are acted on by Earth’s gravitational force, which:

- pulls objects downward, toward the center of the Earth.
- is approximately constant over the range of heights encountered in everyday life.
- causes a downward acceleration of 9.8 m/s^2.

How do we solve problems that involve universal gravitation?

- You can use Newton's law of universal gravitation to find the attractive force between two masses. If gravitational force is given, Newton's second law can be used to describe the motion of the object.

How do we use Newton’s second law of motion and the law of universal gravitation to solve problems that involve the orbital motion of satellites?

- The gravitational force between the Earth and a satellite keeps the satellite in **orbit** around the Earth. If gravitational force on a satellite is given, Newton's second law can be used to determine the motion of the satellite.

4.1 Using Vectors and Scalars to Describe Motion

What are the differences between vector and scalar quantities?

The main difference between vectors and scalars is that, while both have magnitude, vectors also have direction.

- A **vector** is represented in writing by boldface and/or italicized type, and/or by a ray over its letter.
- A **vector** is represented by an arrow on a diagram. The arrow's length is proportional to the vector's magnitude. Its direction indicates the direction in which the quantity acts.
- Examples of **scalar** quantities include **mass**, time, **distance**, and electric charge.
- Examples of vector quantities include displacement, **velocity**, **force**, and **acceleration**.
- Vectors and scalars cannot be added to each other. Scalars can be added to scalars, and vectors can be added to vectors.

How may problems involving two-dimensional vectors and their components be solved?

- It is usually useful to draw a diagram for problems involving vectors.
- Vectors can be added directly if they act in opposite directions.
- If vectors act at right angles to one another, the Pythagorean theorem or one of the trigonometry functions can be used to find the resultant vector.
- If vectors act at other angles to one another, they may be added using the parallelogram or head-to-tail methods.
- Vectors can also be resolved into component vectors. For each vector, there are many components that could be used.
- Vectors are often resolved into components that are at right angles to each other; the components are also often aligned with the *x*- and *y*-axis of the diagram.

When a force is applied to an object in a direction perpendicular to its motion, what are the effects on its speed and direction?

- When a force is applied parallel to the velocity of an object, the velocity's magnitude will change, but not its direction.
- When a force is applied perpendicular to the velocity of an object, the velocity's direction will change, but not its magnitude.

4.2- Understanding and Describing Motion

What are frames of reference and how do they relate to motion?

- Frames of reference are coordinate systems for describing objects' **motion**.
- They often use *x*-, *y*-, and *z*-axes aligned with the room.
- Motion may occur along one, two, or all three of a reference frame's axes.
- One kind of reference frame is inertial, in which Newton's first law of motion applies.
- The other kind of reference frame is non-inertial, used when the reference frame itself is accelerating.

How can physicists use Newton's laws of motion and universal gravitation to predict objects' motions?

- The laws are used to predict objects' motions as forces act on them.
- They are valid without modification only within inertial reference frames, and only under everyday circumstances.

Law of Universal Gravitation:

- This law shows that the **gravitational force** between objects depends directly on their masses. For a given **distance**, objects with higher **mass** have higher gravitational attraction.
- It also shows that the gravitational **force** depends inversely on the square of the distances separating the objects. For given masses, those closer together have higher gravitational attraction.

4.3- Solving Motion Problems

How does an object's speed affect the distance it travels in time?

Speed is the rate at which **distance** is traveled. Therefore, a faster object travels a greater distance than does a slower object in the same amount of time. Objects often change speeds over time, traveling faster at certain moments in time and slower at others. It is often useful to know an objects' **average speed**.

- In equation form, the average speed of an object is the distance traveled divided by the time: $s = d/t$.
- The units for speed and velocity are meters per second (m/s).
- The speed or velocity of an object at a particular moment in time is known as the **instantaneous speed** or **instantaneous velocity**, respectively.
- The term used to describe a speed or velocity that does not vary over time is constant speed or constant velocity, respectively.
- When an object travels at constant speed, then its average speed is equal to the constant speed and its **instantaneous speed** is the same at every moment in time.
- Velocity is an object's speed as well as the direction in which it is moving (for instance, 24 m/s, West). An object moving at constant speed therefore may not be moving at constant velocity if the direction of motion is changing.
- The equation for speed can be rearranged to find distance or time: $d = st$, or $t = d/s$

How can position, velocity, and acceleration be used to describe the motion of an object?

An object's position, velocity, and **acceleration** need to be known to fully describe the object's motion. There are relationships between all three quantities that are described by the basic equations of motion.

- The displacement, or change in position, of an object is a vector and can be found by subtracting the initial position from the final position.
- The distance an object has traveled is a **scalar** and is equal to the sum of all the individual movements of an object regardless of the direction of those movements.
- If an object has changed direction during its motion, then the distance traveled and the displacement will be different.
- The average speed of an object is a scalar and is equal to the distance traveled divided by the time.
- The **average velocity** of an object is a vector and is equal to the displacement divided by the time.

- **Instantaneous velocity** is a vector that represents the velocity of an object at a particular moment in time.
- Acceleration is the rate at which velocity changes. The average acceleration of an object is equal to the change in velocity (the final velocity minus the initial velocity) divided by the amount of time during which that change took place.
- Acceleration is a vector quantity.

How can motion be represented graphically?

Motion can be represented graphically with position vs. time, velocity vs. time, and acceleration vs. time graphs. Each graph tells us something important about the object's motion. There are relationships between the object's position, velocity, and acceleration, which can be determined by analyzing the graphs.

- When the position graph is a horizontal line, the position of the object is not changing over time and the object is therefore at rest.
- The slope of the position vs. time graph is equal to the velocity of the object at that moment in time or during that interval of time.
- When the velocity graph is a horizontal line, the velocity of an object is not changing over time and therefore the object is moving at a constant velocity.
- The slope of the velocity vs. time graph is equal to the acceleration of the object at that moment in time or during that interval of time.
- The area under a velocity vs. time graph is equal to the displacement of the object during a certain time interval.
- Graphs can also be made to show the trajectory of an object in two dimensions. These show the actual position of an object; however, they do not represent the time over which the motion took place.

How do objects, such as a basketball, move in the air?

Objects in the air, known as projectiles, follow a parabolic path known as a trajectory. This motion of a projectile is referred to as projectile motion.

- Projectiles have a constant velocity in the horizontal direction since no forces act on the projectile in the horizontal direction.
- Projectiles accelerate downward in the vertical direction due to the **force** of gravity.
- The combination of constant velocity in the horizontal direction and acceleration in the vertical direction leads to the curved, parabolic path of the projectile.
- The horizontal and vertical motion components of a projectile's motion are independent of one another.