Competency 2

Conceptual and quantitative knowledge of forces and motion

1. Differentiate between the types and characteristics of contact forces and forces acting at a distance, and their interactions.
   A. Force – an influence (a push or pull) that changes the motion of a moving object or produces motion in a stationary object
      a. Calculated by multiplying the mass of the object by its acceleration; F = ma
      b. Measured in Newtons (N)
   B. Contact force – a force between objects that can only exist if the objects are in direct contact with one another
      a. Normal force – the reaction contact force acting on a body that is placed on any surface due to the action force that is the weight of the body; will always be normal to the surface it is placed on
         i. Equal to the weight of the body but opposite in direction
         ii. Normal force = mass × gravitational acceleration ($-9.81 m/s^2$)
      b. Friction – the force resisting the movement of one surface over another in opposite directions
         i. always parallel to the surface and in the opposite direction to the motion
            - Air resistance – the friction experienced by an object as it moves through the air; happens due to the interaction of an object with air molecules
               - Increases as the speed of the object increases
               - Dependent on the shape of the object
      c. Tension – the force acting within an object when it is pulled from both of its ends; the reaction force to the external pulling forces
         i. Always parallel to the external pulling forces
   C. Field force (non-contact force) – a force between objects that can exist without physical contact between the objects; must have an external field for the force to act; four fundamental forces:
      a. Gravity – the force of attraction between matter
         i. Affected by mass and distance
            - The force of gravity between two objects increases as their respective masses increase and the distance between them decreases
            - Summarized by Newton in his Law of Universal Gravitation
            - The weakest of the four fundamental forces
      b. Electromagnetic force – the forces of electricity and of magnetism; second strongest fundamental force
         i. Caused by electromagnetic fields, the regions that extend outward from a charged object
         ii. Can exist in space far from the charge that generated them, however they are not infinite in size and can be canceled out over long distances
         iii. Can both attract and repel
            - Electric force – exists between any two charged objects
               - Opposite charges attract and negative charges repel
               - The strength of the force between two charged objects depends on the size of the charges and the distance between objects
            - Magnetic force – only attract or repel electrically charged objects that are in motion
               - Also act on certain materials (such as iron)
               - Opposite charges attract and negative charges repel
               - The strength of the force between two charged objects depends on the size of the charges and the distance between objects
      c. Weak nuclear force – operates inside the nuclei of atoms; second weakest fundamental force
         i. Responsible for emitting certain types of particles during radioactive decay
         ii. Helps initiate the nuclear fusion reaction that fuels the sun
      d. Strong nuclear force – operates inside the nuclei of atoms; Strongest fundamental force

i. Strongest force in the universe; has the shortest range
ii. Acts to hold the protons and neutrons together inside the nucleus of an atom
- Because like-charged particles repel each other, the strong force must be strong enough to overcome this repulsion

2. Identify applications of Newton's laws of motion.
A. Newton's First Law of Motion (Inertia) – a body at rest tends to stay at rest, and a body in motion tends to stay in motion, unless acted upon by a net external force
a. Sometimes referred to as the Law of Inertia
i. Inertia – the property of a body to remain at rest or to remain in motion with constant velocity; dependent on an object's mass
B. Newton's Second Law of Motion (force and acceleration) – the net force on an object is equal to the rate of change of its linear momentum
a. The acceleration of an object is parallel and directly proportional to the net force acting on the object
i. Is in the direction of the net force
ii. Is inversely proportional to the mass of the object
b. F = ma
C. Newton's Third Law of Motion (symmetry in forces) – for every action, there is an equal and opposite reaction
a. When object A exerts a force on object B, object B simultaneously exerts a force on object A that is equal in magnitude but opposite in direction
b. FA = - FB

3. Solve problems involving force or motion.
A. Speed – the distance travelled in a period of time
B. Velocity – the speed and direction in which a given object is travelling, measured in distance per unit time (m/s)
a. $\Delta d/\Delta t$ or $d_2\text{-}d_1/t_2\text{-}t_1$
C. Acceleration – the change in an object's velocity over time, measure in distance per unit time per unit time (m/s^2)
a. $\Delta v/\Delta t$ or $v_2\text{-}v_1/t_2\text{-}t_1$
b. Acceleration due to gravity – $-9.81 m/s^2$
D. Force – a push or pull
a. F=ma

4. Identify types, characteristics, and properties of waves.
A. Waves – the motion of rising and falling in curves; undulation; a moving disturbance or vibration of energy
B. Parts of a wave:
a. Crest – the highest point of a wave
b. Trough – the lowest point of a wave
c. Amplitude – the vertical distance between the crest and the trough
d. Wavelength – the distance between corresponding points on two successive waves, generally measured from crest to crest or trough to trough
e. Frequency – the rate at which a vibration occurs that constitutes a wave; a measure of how often a wave cycle is completed in a given unit of time; usually measured in hertz (Hz)
f. Wave period – the time (in seconds) required for a given point on a wave to complete one full cycle of its motion, such as from crest to crest
C. Types of waves:
a. Longitudinal waves – the motion in the material of the wave is back and forth in the same direction as the motion of the wave

i. Compression – the region in the wave where the particles are closest together
ii. Rarefaction – the region in the wave where the particles are spread out
iii. Example: sound waves

b. Transverse waves – the motion of the material constituting the wave is up and down so that as the wave moves forward, the material moves perpendicular to the direction the wave moves
i. Examples: waves in water, secondary waves of an earthquake, electromagnetic waves

5. Analyze characteristics of wave phenomena (e.g., intensity, refraction, interference, Doppler effect, wave-particle duality) as they apply to real-world situations.

A. Intensity – the power delivered per unit area; proportional to the square of the amplitude of the wave

B. Reflection – when a wave hits a boundary and is reflected, the angle of incidence equals the angle of reflection
a. The angle of incidence is the angle between the direction of the motion of the wave and a line drawn perpendicular to the reflecting boundary

C. Refraction – the change in direction and usually speed of a wave as it crosses a boundary between two different media
a. The speed of a wave depends on the properties of the medium through which it travels
b. When a wave enters at an angle a medium in which its speed would be slower, the wave is bent toward the perpendicular

D. Diffraction – when a wave encounters a small obstacle or opening (compared with the wavelength of the wave), the wave can bend around the obstacle or pass through the opening and then spread out

E. Interference – the waves from two points of disturbance may reinforce each other in some directions and cancel in others
a. Constructive interference – when two sources produce waves of the same wavelength and are in phase with one another, the crests (or troughs) of both waves will reach a point equidistant from both sources (or if the distances are unequal but differ by one or more full wavelength) at the same time and reinforce each other
i. The crests become higher; the troughs become lower; the amplitude of the waves at that point increases
b. Destructive interference – when two sources produce waves of the same wavelength and are in phase with one another, the crests (or troughs) of both waves will reach a point (P). If the distances to point P are unequal and differ by half a wavelength (or an odd multiple of half wavelengths), the waves will cancel each other completely
i. If the distances travelled by the waves differ by some other fraction of a wavelength, the waves will either reinforce or cancel each other

F. Doppler Effect – when the source of a wave moves relative to an observer the observer notices a change in the frequency of the wave
a. When an ambulance passes by, an observer may notice a change in the pitch of the siren

G. Wave-particle duality – the concept that predicts that every elementary particle will exhibit the characteristics and properties of both a wave and a particle
a. Both particle theory and wave theory of light can explain a portion of the properties of light

6. Identify origins, characteristics, and examples of electricity.

A. Electricity – energy harnessed from the configuration (static) or movement (DC or AC) of electrons
a. Electric current (amperage) – the amount of electric charge flowing per second through a conductor
b. Electric charge – a fundamental physical property that causes objects to feel an attractive or repulsive force toward one another; measured in coulombs (C)

B. Types of electricity:
a. Static electricity (stationary) – the imbalance of electric charge on a surface of a material
b. Dynamic electricity (moving) – energy harnessed from the movement of electrons

i. Direct Current (DC) – an electric current that is uni-directional, so the flow of the charge is always in the same direction
   - Defined by the constant flow of electrons from an area of high electron density to an area of low electron density
   - Used in many household electronics and in all devices that use batteries

ii. Alternating Current (AC) – an electric current in which the direction and amperage of the current changes many times in a second (60 times/second in North America)
   - Generated by the majority of power plants; cheaper to generate and has fewer energy losses than DC when transmitting over long distances
   - Voltage can be modified relatively easily using a transformer
     - Allows power to be transmitted at very high voltages before being taken down to safer voltages for residential and commercial use

C. Alessandro Volta (1799) – showed that electricity could be generated by stacking copper and zinc discs submerged in sulfuric acid
   a. The reactions produced in his voltaic pile included both oxidation and reduction processes
      i. Oxidation – the loss of electrons; happens at the anode (-)
         - $Zn \rightarrow Zn^{+2} + 2e^-$
      ii. Reduction – the gain of electrons; happens at the cathode (+)
         - $2H^+ + 2e^- \rightarrow H_2$

D. The War of the Currents
   a. Thomas Edison – developed direct current (which was the U.S. standard in the early years of electricity)
      i. Began a campaign to discredit AC; spread misinformation that AC was more dangerous (including electrocuting stray animals using AC to prove his point)
   b. Nikola Tesla – discovered and patented the rotating magnetic field (the basis of most AC machinery)
      i. Sold the rights to his system of AC dynamos, transformers, and motors to George Westinghouse (Westinghouse Electric Company, which won out over Edison's DC systems)

7. Identify types of magnets and characteristics of magnetic fields.

A. Types of magnets:
   a. Permanent magnets – emit a magnetic field without the need for any external source of magnetism or power
   b. Temporary magnets – behave as magnets while attached or close to something that emits a magnetic field, but lose this characteristic when the source of the magnetic field is removed
   c. Electromagnets – require electricity in order to behave as a magnet
      i. Produced by placing a metal core (usually an iron alloy) inside a coil of wire that carries an electric current
      ii. The strength of the magnet depends on the strength of the electric current and the number of coils of wire

B. Characteristics of magnetic fields:
   a. Magnetic field – the space in which a magnetic force is exerted
   b. Magnetic lines of force – imaginary lines in the magnetic field indicating how strong the magnetic force is (the closer together the lines, the stronger the force)
      i. Seek the path of least resistance between opposite magnetic poles
      ii. Never cross one another
      iii. All have the same strength
      iv. Their density decreases when they move from an area of higher permeability to an area of lower permeability

v. Their density decreases with increasing distance from the poles
vi. They are considered to have direction as if flowing although no actual movement occurs
vii. They flow from the south pole to the north pole within a material and north pole to south pole within air

8. Apply knowledge of magnets and magnetic fields to real-world situations (e.g., generators, solenoids).
   A. Generators – magnets are used to transform mechanical energy into electrical energy
      a. Spinning a magnet near a coil of wire produces electricity
      b. Example: wind turbines
   B. Solenoids – a device comprised of a coil of wire, the housing, and a moveable plunger (armature)
      a. When an electrical current is introduced, a magnetic field forms around the coil which draws the armature in
      b. Converts electrical energy into mechanical work
9. Identify characteristics of motion as they apply to real-world situations (e.g., speed, velocity, acceleration, linear and angular momentum).
   A. Speed – the distance travelled in a period of time
      a. Average speed – the total distance traveled divided by the total travel time
      b. Instantaneous speed – the speed at a given moment in time
   B. Velocity – the speed and direction in which a given object is travelling, measured in distance per unit time (m/s)
      a. $\Delta d/\Delta t$ or $d_2\text{-}d_1/t_2\text{-}t_1$
   C. Acceleration – the change in an object's velocity over time, measure in distance per unit time per unit time (m/s^2)
      a. $\Delta v/\Delta t$ or $v_2\text{-}v_1/t_2\text{-}t_1$
      b. Acceleration due to gravity – $-9.81 m/s^2$
   D. Linear momentum – the product of a system's mass multiplied by its velocity
      a. Directly proportional to an object's mass and velocity
      b. $p = mv$
      c. SI unit: kg × m/s
   E. Angular momentum – the rotational analog of linear momentum

Glossary

Acceleration - the change in an object's velocity over time, measure in distance per unit time per unit time
Air Resistance - the friction experienced by an object as it moves through the air
Alternating Current - an electric current in which the direction and amperage of the current changes many times in a second (60 times/second in North America)
Amplitude - the vertical distance between the crest and the trough
Angular Momentum - the rotational analog of linear momentum
Average Speed - the total distance traveled divided by the total travel time
Compression - the region in a longitudinal wave where the particles are closest together
Constructive Interference - when two sources produce waves of the same wavelength and are in phase with one another, the crests (or troughs) of both waves will reach a point equidistant from both sources (or if the distances are unequal but differ by one or more full wavelength) at the same time and reinforce each other
Contact Force - a force between objects that can only exist if the objects are in direct contact with one another
Crest - the highest point of a wave
Destructive interference - when two sources produce waves of the same wavelength and are in phase with one another, the crests (or troughs) of both waves will reach a point (P). If the distances to point P are unequal and differ by half a wavelength (or an odd multiple of half wavelengths), the waves will cancel each other completely
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Direct Current - an electric current that is one directional, so the flow of the charge is always in the same direction
Doppler Effect - when the source of a wave moves relative to an observer the observer notices a change in the frequency of the wave
Dynamic Electricity - energy harnessed from the movement of electrons
Electric Charge - a fundamental physical property that causes objects to feel an attractive or repulsive force toward one another
Electric Current - the amount of electric charge flowing per second through a conductor
Electric Force - exists between any two charged objects
Electricity - energy harnessed from the configuration (static) or movement (DC or AC) of electrons
Electromagnetic Force - the forces of electricity and of magnetism; second strongest fundamental force
Electromagnets - require electricity in order to behave as a magnet
Field Force - a force between objects that can exist without physical contact between the objects
First Law of Motion - a body at rest tends to stay at rest, and a body in motion tends to stay in motion, unless acted upon by a net external force
Force - an influence (a push or pull) that changes the motion of a moving object or produces motion in a stationary object
Frequency - the rate at which a vibration occurs that constitutes a wave; a measure of how often a wave cycle is completed in a given unit of time
Friction - the force resisting the movement of one surface over another in opposite directions
Generator - a device in which magnets are used to transform mechanical energy into electrical energy
Gravity - the force of attraction between matter
Instantaneous Speed - the speed at a given moment in time
Intensity - the power delivered per unit area; proportional to the square of the amplitude of the wave

Interference - the waves from two points of disturbance may reinforce each other in some directions and cancel in others
Linear Momentum - the product of a system's mass multiplied by its velocity
Longituginal wave - the motion in the material of the wave is back and forth in the same direction as the motion of the wave
Magnetic Field - the space in which a magnetic force is exerted
Magnetic Force - only attract or repel electrically charged objects that are in motion
Magnetic Lines of Force - imaginary lines in the magnetic field indicating how strong the magnetic force is (the closer together the lines, the stronger the force)
Normal Force - the reaction contact force acting on a body that is placed on any surface due to the action force that is the weight of the body; will always be normal to the surface it is placed on
Permanent Magnets - emit a magnetic field without the need for any external source of magnetism or power
Rarefaction - the region in a longitudinal wave where the particles are spread out
Reflection - when a wave hits a boundary and is reflected, the angle of incidence equals the angle of reflection
Refraction - the change in direction and usually speed of a wave as it crosses a boundary between two different media
Second Law of Motion - the net force on an object is equal to the rate of change of its linear momentum
Solenoid - a device comprised of a coil of wire, the housing, and a moveable plunger (armature)
Speed - the distance travelled in a period of time
Static Electricity - the imbalance of electric charge on a surface of a material
Strong Nuclear Force - operates inside the nuclei of atoms; Strongest fundamental force
Temporary Magnets - behave as magnets while attached or close to something that emits a magnetic field, but lose this characteristic when the source of the magnetic field is removed
Tension - the force acting within an object when it is pulled from both of its ends; the reaction force to the external pulling forces
Third Law of Motion - for every action, there is an equal and opposite reaction
Transverse wave - the motion of the material constituting the wave is up and down so that as the wave moves forward, the material moves perpendicular to the direction the wave moves
Trough - the lowest point of a wave
Velocity - the speed and direction in which a given object is travelling, measured in distance per unit time
Wave - the motion of rising and falling in curves; undulation; a moving disturbance or vibration of energy
Wave Particle Duality - the concept that predicts that every elementary particle will exhibit the characteristics and properties of both a wave and a particle
Wave Period - the time (in seconds) required for a given point on a wave to complete one full cycle of its motion, such as from crest to crest
Wavelength - the distance between corresponding points on two successive waves, generally measured from crest to crest or trough to trough
Weak Nuclear Force - operates inside the nuclei of atoms; second weakest fundamental force

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