Competency 3

Conceptual and quantitative knowledge of energy and its effects

1. Differentiate between forms of energy and their transformations.
   A. Energy – an abstract property defined as the capacity to do work; there are a number of forms of energy, but most of them can be reduced to either kinetic energy or potential energy
      a. Kinetic energy – the energy an object possesses by virtue of its motion; $KE = \frac{1}{2} mv^2$
         i. Radiant energy – electromagnetic energy that travels in transverse waves
            - Includes visible light, x-rays, gamma rays, and radio waves
         ii. Thermal energy – the energy that comes from the movement of atoms and molecules in a substance; heat
         iii. Sound energy – energy moving through substances in longitudinal waves
            - Sound is produced when a force causes an object or substance to vibrate
         iv. Electrical energy – delivered by electrons, typically moving through a wire
      b. Potential energy – the energy an object possesses by virtue of its position relative to others, stresses within itself, electric charge, and other factors
         i. Gravitational potential energy – the energy stored within an object as the result of its vertical position or height; the energy is stored as a result of the gravitational attraction of the Earth; $PE_{grav} = mgh$
         ii. Elastic potential energy – the energy stored in elastic materials as the result of their stretching and compressing; $PE_{spring} = \frac{1}{2} kx^2$
         iii. Chemical energy – energy stored in the bonds of atoms and molecules
         iv. Nuclear energy – energy stored in the nucleus of an atom; can be released when the nuclei are combined or split apart
      c. Mechanical energy – the energy acquired by an object upon which work is done
         i. Can be either kinetic energy or potential energy
         ii. TME = PE + KE
   B. Thermodynamics – the study of how energy changes from one type to another
      a. First Law of Thermodynamics – energy cannot be created or destroyed, however it can be transformed from one type to another
         i. Energy transformations – processes that convert energy from one type into another; any type of energy use must involve some sort of energy transformation
            - Rubbing hands together to make them warm: kinetic energy → thermal energy
            - Using a battery powered flashlight: chemical energy → electrical energy → radiant energy
            - An object speeding up as it falls: gravitational potential energy → kinetic energy
      b. Second Law of Thermodynamics – some forms of energy are more useful than others; using energy always makes it less useful, even though no energy is actually destroyed
         i. Most useful: kinetic energy and electricity
         ii. Least useful: thermal energy
2. Relate energy to transitions between states of matter.
   A. Transitions involving an increase in energy – endothermic phase changes
      a. More ordered state → less ordered state
      b. Heat absorbed causes the molecules to move farther apart by overcoming the intermolecular forces of attraction
      c. Matter + thermal energy → endothermic phase change (kinetic energy ↑)
         i. Melting – solid → liquid
         ii. Evaporation – liquid → gas
         iii. Sublimation – solid → gas
   B. Transitions involving a decrease in energy – exothermic phase changes
      a. Less ordered state → more ordered state

b. Heat released allows the molecules to move closer together and the intermolecular forces of attraction become stronger
c. Matter – thermal energy → exothermic phase change (kinetic energy ↓)
i. Deposition – gas → solid
ii. Condensation – gas → liquid
iii. Freezing – liquid → solid

3. Distinguish between temperature, heat, and thermal energy.
A. Temperature – the average kinetic energy of molecules within a system or material; measured in Celsius (°C), Fahrenheit (°F), or Kelvin (K)
B. Heat – the transfer of thermal energy between molecules within a system; measures how energy moves or flows (Joules)
C. Thermal energy – energy contained in the motion and vibration of its molecules
4. Distinguish between the types of thermal energy transfer (e.g., radiation, conduction, convection).
A. Radiation – does not necessarily require a medium to transfer it; facilitated through a type of electromagnetic radiation
a. Emitted electromagnetic waves will move until they hit another particle
b. The particle receives this radiation as kinetic energy
i. How Earth gets energy from the sun
B. Conduction – the movement of kinetic energy in materials from higher temperature to lower temperature through a substance
a. Molecules will give their energy to adjacent molecules until equilibrium is reached
b. Does not deal with the movement of particles within the material
i. Transfer of heat through direct contact, such as on a stove
C. Convection – heat transfer through fluid motion
a. Motion usually occurs due to differences in density
b. Higher temperature particles → cooler areas
c. Lower temperature particles → warmer areas
d. The fluid will remain in motion until equilibrium is reached
i. The cooling of a room due to currents in the air
5. Apply the laws of thermodynamics to real-world situations.
A. Melting of ice in a beverage
a. A few hours after placing an ice cube in a warm beverage, the ice has melted and the beverage has cooled
b. The total amount of heat in the system has remained the same but has gravitated toward equilibrium
c. The melted ice and the beverage are now the same temperature
d. The beverage will eventually become warm again as heat from the environment is transferred into the glass and its contents
B. Sweating in a crowded room
a. While in a small, crowded room with lots of other people, you will start to feel warm and begin sweating
b. Heat from your body is transferred to the sweat
c. Sweat evaporates from your body as it absorbs more heat
d. Heat from the sweat is transferred to the surrounding air, increasing the air temperature of the room
e. No heat is lost, it is merely transferred and approaches equilibrium with maximum entropy
C. Taking a very long bath
a. Initially the temperature of the water is very hot and feels comfortably warm, as it is a higher temperature than that of the body

b. As time passes, some heat from the water is transferred to the person's body and the two temperatures will meet
c. As more time passes, the water will cool as heat is lost to the atmosphere
d. The person will also cool, but not to the same extent as the water

D. Charging a cell phone
a. Water is slowly released through a small opening in a dam and turns a turbine
b. The turbine is used to generate electricity with the help of a generator
c. The electricity (AC) is sent through high-voltage power lines
d. A transformer lowers the voltage to a safer range
e. An AC adapter is plugged into an outlet and the AC is converted to DC
f. The battery is charged

6. Differentiate between potential and kinetic energy.
A. Kinetic energy – the energy an object possesses by virtue of its motion
a. An object with a velocity of 30 m/s has more kinetic energy than an object of the same mass with a velocity of 15 m/s
B. Potential energy – the energy an object possesses by virtue of its position relative to others, stresses within itself, electric charge, and other factors
a. An object at a height of 100 m has more potential energy than an object of the same mass at a height of 50 m
C. Rollercoaster example:
a. At the top of the first hill, PE = max, KE = min
b. As the car goes down the hill, KE increases and PE decreases
c. At the bottom of the first hill, PE = min, KE = max
d. As the car goes up the next hill, PE increases and KE decreases

7. Identify characteristics of nuclear reactions.
A. Nuclear reaction – a change in identity or characteristics of an atomic nucleus
a. reacting particles (a heavy target nucleus and a light bombarding particle) and produces two new particles (a heavier product nucleus and a lighter ejected particle)
B. Types of nuclear reactions:
a. Fission – a heavy nucleus is "split" into two or more smaller nuclei
i. Exothermic and start with nuclei heavier than iron
ii. Widely used to generate electrical power using uranium as a fuel
b. Fusion – when two or more lighter nuclei come together to make a heavy nucleus
i. The fusion of four hydrogen atoms and two electrons into a single helium atom is the primary reaction in the sun
c. Nuclear decay – the process by which an unstable isotope of a particular element spontaneously transforms into a new element by emission of ionizing radiation; three common emissions occur:
i. Alpha particles (α) – $^{4}_{2}\alpha$ (mass number + 4; atomic number + 2)
- Penetrating power – very low
- Ionizing power – very high
- Shielding – paper skin

ii. Beta particles (β) – $^{0}_{-1}\beta$ (mass number + 0; atomic number – 1)
- Penetrating power – intermediate
- Ionizing power – very low
- Shielding – two inches lead

iii. Gamma rays (γ) – $^{0}_{0}\gamma$
- Penetrating power – very high
- Ionizing power – very high

- Shielding – paper skin

d. Transmutation – the non-spontaneous process where one element is transformed into another by bombarding it with high energy radiation or neutrons
   i. Allows for the creation of radioactive isotopes

8. Identify the regions of the electromagnetic spectrum and energy associated with each.

A. The electromagnetic spectrum – the range of all types of electromagnetic radiation (energy that travels and spreads out as it goes); the full range of frequencies (from radio waves to gamma rays) that characterizes light

Type	Wavelength (λ) – m	Frequency (v) – Hz	Energy (e) – eV
Radio waves	$> 1 \times 10^{-3}$	$< 3 \times 10^{11}$	0.001
Microwaves	$2.5 \times 10^{-5} – 1 \times 10^{-3}$	$3 \times 10^{11} – 10^{13}$	0.021
Infrared	$7.5 \times 10^{-7} – 2.5 \times 10^{-5}$	$10^{13} – 4 \times 10^{14}$	0.849
Visible light	$4 \times 10^{-7} – 7.5 \times 10^{-7}$	$4 \times 10^{14} – 7.5 \times 10^{14}$	2.381
Ultraviolet	$1 \times 10^{-9} – 4 \times 10^{-7}$	$10^{15} – 10^{17}$	209.070
X-rays	$1 \times 10^{-12} – 1 \times 10^{-9}$	$10^{17} – 10^{20}$	207207
Gamma rays	$< 1 \times 10^{-12}$	$10^{20} – 10^{24}$	2.07×10^{9}

a. Radio waves:
   i. Music on the radio
   ii. emitted by stars in space
   iii. can travel for a long distance, penetrate materials, cannot be felt, and travel at the speed of light in a vacuum

b. Microwaves:
   i. Used in communications, radio astronomy, remote sensing, radar, and heating (cooking)
   ii. Reflected by metal surfaces (why satellite dishes are made of metal)
   iii. Certain frequencies are absorbed by water; water in food absorbs the microwaves which causes the water to heat up, therefore cooking the food

c. Infrared waves:
   i. Can be detected as a sensation of warmth on the skin
   ii. Most of the radiation emitted by a moderately heated surface

d. Visible light – the segment of the electromagnetic spectrum that the human eye can view
   i. Most light we interact with is white light; shining white light through a prism causes the wavelengths to bed at slightly different angles due to optical refraction; the resulting light is split across the visible color spectrum

Color	Wavelength (nm)
Red	625 – 740
Orange	590 – 625
Yellow	565 – 590
Green	520 – 565
Blue	500 – 520
Indigo	435 – 500
Violet	380 – 435

e. Ultraviolet rays:
   i. Can cause certain materials to fluoresce (glow; emit electromagnetic radiation of lower energy)
   ii. Produced by high temperature surfaces (including the sun)
   iii. Causes sunburn

f. X-rays:
    i. A form of ionizing radiation; energetic enough to cause neutral atoms to eject electrons
    ii. Can pass through skin and tissue but not bone
g. Gamma rays:
    i. Produced in the disintegration of radioactive nuclei and in the decay of certain subatomic particles
    ii. A form of ionizing radiation
    iii. Used for PET scans and radiation therapies

9. Identify the use of light and optics in real-world applications (e.g., optical instruments, communication).
   A. Remote controls – contain a small laser that shoots across the room to the sensor on your TV, which also uses optics technology
   B. Cameras – photography uses light and shadow to create images
   C. 5G – uses fiber optic cables to transmit information, allowing radio signals to travel faster over longer distances and with less losses
   D. Barcode scanners – use lasers to read the pattern of lines and blank space on a barcode
   E. Traffic signals – use longer-lasting LED bulbs to be seen farther away
   F. Surveillance cameras – made it possible to record better video and make the technology more affordable
   G. LED light bulbs – last longer and use less energy than incandescent light bulbs
   H. Surgical machines – x-rays, MRI's, PET scans, laser surgery, high powered microscopes
10. Solve problems involving energy, work, power, mechanical advantage, and efficiency.
   A. Energy – the capacity to do work
   B. Work – a process that occurs when a force acts over a distance in the same direction as the movement
      a. $W = F \times d$; expressed in joules (J)
      b. Machines do not change the amount of work done, but they can reduce the force needed by increasing the distance
   C. Power – the rate at which work is done
      a. $P = W/t$; SI Unit: joules per second (J/s)
   D. Mechanical advantage – a measure of the ratio of output force to input force in a system
      a. $MA = F_o/F_i$; does not have a unit
   E. Efficiency – a way of describing the useful output a process or machine can generate as a percentage of the input required
      a. Efficiency $= E_o/E_i \times 100\%$
   F. Machine – any device that makes work easier by changing force
      a. Simple machines – a physical device that changes the magnitude or direction of a force; reduce the amount of force required to do work by increasing the distance; can use mechanical advantage to increase force
         i. Inclined plane – a sloping surface (ramp); offers a mechanical advantage in that the force required to move an object up the incline is less than the weight being raised
         ii. Lever – a rigid bar or board that rests on a fulcrum; a downward force exerted on one end of the lever can be transferred and increased in an upward direction at the other end, allowing a small force to lift heavy weight
         iii. Wedge – an object that tapers to a thin edge; pushing the wedge in one direction creates a force in a sideways direction; used for splitting, lifting, or tightening
         iv. Wheel and axel – a circular frame (wheel) that revolves on a rod or shaft (axel)
         v. Pulley – a wheel that carries a flexible rope, cord, cable, chain, or belt on its rim; used singly or in combination to transmit energy and motion

vi. Screw – an inclined plane wrapped around a rod or shaft; used either as a fastener or as a force and motion modifier

b. Compound machine – a machine that consists of more than one simple machine

11. Apply the laws of conservation of mass and energy to chemical reactions, nuclear reactions, physical processes, and biological processes.

A. Chemical reactions:
   a. Conservation of mass: mass is neither created nor destroyed during chemical reactions
      i. The mass of any one element at the beginning of the reaction is equal to the mass of that element at the end of the reaction
      ii. The total mass will be the same at any point during the reaction (in a closed system)
   b. Conservation of energy: energy may change form during a chemical reaction

B. Nuclear reactions:
   a. Conservation of mass: the law requires that during any nuclear reaction, radioactive decay, or chemical reaction in a closed system, the total mass of the reactants or starting materials must be equal to the mass of the products
   b. Conservation of energy: the total relativistic energy must be conserved
   c. Mass and energy are equivalent and convertible; $E = mc^2$

C. Physical processes:
   a. Conservation of mass: matter can change in form through a physical change, but the same amount of matter exists before and after the change
   b. Conservation of energy: the entire energy of the universe is conserved
      i. Endothermic: surroundings → system; heat is absorbed by the system and the surroundings get cooler
      ii. Exothermic: system → surroundings; heat is released by the system and the surroundings get warmer

D. Biological processes:
   a. Conservation of mass: living organisms are primarily made of six elements (oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorous) and each of these elements cycle through the earth system
   b. Conservation of energy: energy is transformed from one form to another
      i. Photosynthesis: energy from the sun → absorbed by cells in plants → chemical energy (stored as glucose) → complex carbohydrates
      ii. Cellular respiration: glucose + O_2 → CO_2 + H_2O; allows plant or animal organisms to access the energy stored in carbohydrates, lipids and other macromolecules through the production of ATP
      iii. The higher up an organism is on the food chain, the less available energy it receives from its food sources

12. Identify types, characteristics, and measurements of electrical quantities.

A. Electrical current (Amperes, A) – the flow of charge; number of charges per unit time passing through a boundary

B. Voltage (Volts, V) – electromotive force; the electric potential difference per unit charge between two points in an electric field (voltage = joule/coulomb)

C. Electrical charge (Coulombs, C) – the property of subatomic particles that causes them to experience a force when placed in an electric and magnetic field; one coulomb is the quantity of charge transferred in one second

D. Resistance (Ohms, Ω) – a force that counteracts the flow of current; how difficult it is for current to flow

E. Capacitance (Farads, F) – the ability of an electric conductor to store an electrical charge

F. Inductance (Henry, H) – property of a conductor that is measured by the voltage induced in it compared with the rate of change of the electric current that produces the voltage
G. Electric power (Watts, W) – the rate energy is transferred or transformed over time

13. Apply knowledge of currents, circuits, conductors, insulators, and resistors to real-world situations.
    A. Circuit – a closed conducting loop in which a charge can flow
        a. Parts of a circuit –
            i. Electrical conductor (wire) – connects to the power source to form a closed loop
            ii. Power source – source of electrical energy (such as a battery)
            iii. Switch – a device to open and close a circuit
            iv. Load – a device that the circuit is powering
            v. Capacitor – a device used to store an electric charge
            vi. Resistor – a device that limits or regulates the flow of an electric current
        b. Types of circuits –
            i. Series circuit – a circuit where the components are connected end-to-end to form a single path for current to flow
                - If one component breaks down, the whole circuit will burn out
            ii. Parallel circuit – a circuit in which all components are connected across each other with exactly two electrically common nodes with the same voltage across each component
                - Other components will function even if one component breaks down as each has its own independent circuit
    B. Conductor – materials that allow electrons to travel through
        a. Metals, aqueous solutions of salts, graphite, the human body
    C. Insulator – materials that inhibit the flow of electrons
        a. Plastics, Styrofoam, paper, rubber, glass, and dry air

14. Solve mathematical problems involving current, voltage, resistance, power, and energy in direct current (DC) circuits.
    A. Power Equation of Ohm's Law and Joule's Law
        a. Voltage (volts) – E
        b. Current (amperes) – I
        c. Resistance (ohms) – R
        d. Power (watts) – P
        e. Ohm's Law – $E = IR$
        f. Joule's Law – $P = IE$

Glossary

Capacitance - the ability of an electric conductor to store an electrical charge
Capacitor - a device used to store an electric charge
Chemical Energy - energy stored in the bonds of atoms and molecules
Circuit - a closed conducting loop in which a charge can flow
Compound Machine - a machine that consists of more than one simple machines
Conduction - the movement of kinetic energy in materials from higher temperature to lower temperature through a substance
Conductor - materials that allow electrons to travel through
Conservation of Energy - energy cannot be created or destroyed
Conservation of Mass - mass cannot be created or destroyed
Convection - heat transfer through fluid motion
Efficiency - a way of describing the useful output a process or machine can generate as a percentage of the input required
Elastic Potential Energy - the energy stored in elastic materials as the result of their stretching and compressing
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Sound Energy - energy moving through substances in longitudinal waves
Switch - a device to open and close a circuit
Temperature - the average kinetic energy of molecules within a system or material; measured in Celsius (°C), Fahrenheit (°F), or Kelvin (K)
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Thermodynamics - the study of how energy changes from one type to another
Transmutation - the non-spontaneous process where one element is transformed into another by bombarding it with high energy radiation or neutrons
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Wheel and Axle - a circular frame (wheel) that revolves on a rod or shaft (axel)
Work - a process that occurs when a force acts over a distance in the same direction as the movement

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