Ohio Science

Physics Content Elaborations: Grades 9-12

Adopted 2018

Physics

Motion

1. Motion graphs P.M.1
    1. Students understand that instantaneous velocity for an accelerating object can be determined by calculating the slope of the tangent line for some specific instant on a position vs. time graph. P.M.1.1
    2. Students understand that instantaneous velocity will be the same as average velocity for conditions of constant velocity, but this is rarely the case for accelerating objects. P.M.1.2
    3. Students understand that the position vs. time graph for objects increasing in speed will become steeper as they progress and the position vs. time graph for objects decreasing in speed will become less steep. P.M.1.3
    4. Students understand that on a velocity vs. time graph, objects increasing in speed will slope away from the x-axis and objects decreasing in speed will slope toward the x-axis. P.M.1.4
    5. Students understand that the slope of a velocity vs. time graph indicates the acceleration so the graph will be a straight line (not necessarily horizontal) when the acceleration is constant. P.M.1.5
    6. Students understand that acceleration is positive for objects speeding up in a positive direction or objects slowing down in a negative direction. P.M.1.6
    7. Students understand that acceleration is negative for objects slowing down in a positive direction or speeding up in a negative direction. P.M.1.7

    a. Students understand that these are not concepts that should be memorized, but can be developed from analyzing the definition of acceleration and the conditions under which acceleration would have these signs. P.M.1.7.A

    8. Students understand that the word "deceleration" should not be used since it provides confusion between slowing down and negative acceleration. P.M.1.8
    9. Students understand that the area under the curve for a velocity vs. time graph gives the change in position (displacement) but the absolute position cannot be determined from a velocity vs. time graph. P.M.1.9
    10. Students understand that objects moving with uniform acceleration will have a horizontal line on an acceleration vs. time graph. P.M.1.10
    11. Students understand that this line will be at the x-axis for objects that are either standing still or moving with constant velocity. P.M.1.11
    12. Students understand that the area under the curve of an acceleration vs. time graph gives the change in velocity for the object, but the displacement, position and the absolute velocity cannot be determined from an acceleration vs. time graph. P.M.1.12
    13. Students understand that the details about motion graphs should not be taught as rules to memorize, but rather as generalizations that can be developed from interpreting the graphs. P.M.1.13
2. Problem solving P.M.2

    1. Students understand that many problems can be solved from interpreting graphs and charts as detailed in the motion graphs section. P.M.2.1
    2. Students understand that in addition, when acceleration is constant, average velocity can be calculated by taking the average of the initial and final instantaneous velocities (v_{avg} = (v_f – v_i)/2). P.M.2.2
    3. Students understand that this relationship does not hold true when the acceleration changes. P.M.2.3
    4. Students understand that the equation can be used in conjunction with other kinematic equations to solve increasingly complex problems, including those involving free fall with negligible air resistance in which objects fall with uniform acceleration. P.M.2.4
    5. Students understand that near the surface of Earth, in the absence of other forces, the acceleration of freely falling objects is 9.81 m/s^2. P.M.2.5
    6. Students understand that assessments of motion problems, including projectile motion, will not include problems that require the quadratic equation to solve. P.M.2.6
3. Projectile motion P.M.3
    1. Students understand that when an object has both horizontal and vertical components of motion, as in a projectile, the components act independently of each other. P.M.3.1
    2. Students understand that for a projectile in the absence of air resistance, this means that horizontally, the projectile will continue to travel at constant speed just like it would if there were no vertical motion. P.M.3.2
    3. Students understand that likewise, vertically the object will accelerate just as it would without any horizontal motion. P.M.3.3
    4. Students understand that problem solving will be limited to solving for the range, time, initial height, initial velocity or final velocity of horizontally launched projectiles with negligible air resistance. P.M.3.4
    5. Students understand that while it is not inappropriate to explore more complex projectile problems, it must not be done at the expense of other parts of the curriculum P.M.3.5

Forces, Momentum And Motion

1. Newton's laws applied to complex problems P.F.1
    1. Students understand that Newton's laws of motion, especially the third law, can be used to solve complex problems that involve systems of many objects that move together as one (e.g., an Atwood machine). P.F.1.1
    2. Students understand that the equation a = F_{net}/m that was introduced in physical science can be used to solve more complex problems involving systems of objects and situations involving forces that must themselves be quantified (e.g., gravitational forces, elastic forces, friction forces). P.F.1.2
2. Gravitational force and fields P.F.2
    1. Students understand that gravitational interactions are very weak compared to other interactions and are difficult to observe unless one of the objects is extremely massive (e.g., the sun, planets, moons). P.F.2.1
    2. Students understand that the force law for gravitational interaction states that the strength of the gravitational force is proportional to the product of the two masses and inversely proportional to the square of the distance between the centers of the masses, F_g = (G·m₁ ·m₂)/r^2. P.F.2.2
    3. Students understand that the proportionality constant, G, is called the universal gravitational constant and has a value of 6.674 · 10⁻¹¹ $m^3/(kg·s^2)$. P.F.2.3
    4. Students understand that problem solving may involve calculating the net force for an object between two massive objects (e.g., Earth-moon system, planet-sun system) or calculating the position of such an object given the net force. P.F.2.4
    5. Students understand that the strength of an object's (i.e., the source's) gravitational field at a certain location, g, is given by the gravitational force per unit of mass experienced by another object placed at that location, g = F_g/m. P.F.2.5
        a. Students understand that comparing this equation to Newton's second law can be used to explain why all objects on Earth's surface accelerate at the same rate in the absence of air resistance. P.F.2.5.A
    6. Students understand that while the gravitational force from another object can be used to determine the field strength at a particular location, the field of the object is always there, even if the object is not interacting with anything else. P.F.2.6
    7. Students understand that the field direction is toward the center of the source. P.F.2.7
    8. Students understand that given the gravitational field strength at a certain location, the gravitational force between the source of that field and any object at that location can be calculated. P.F.2.8
    9. Students understand that greater gravitational field strengths result in larger gravitational forces on masses placed in the field. P.F.2.9

    10. Students understand that gravitational fields can be represented by field diagrams obtained by plotting field arrows at a series of locations. P.F.2.10
    11. Students understand that a scale indicates weight by measuring the normal force between the object and the surface supporting it. P.F.2.11
    12. Students understand that the reading on the scale accurately measures the weight if the system is not accelerating. However, if the scale is used in an accelerating system, as in an elevator, the reading on the scale does not equal the actual weight. P.F.2.12
    13. Students understand that the scale reading can be referred to as the "apparent weight." P.F.2.13
        a. Students understand that this apparent weight in accelerating elevators can be explained and calculated using force diagrams and Newton's laws. P.F.2.13.A

3. Elastic forces P.F.3
    1. Students understand that elastic materials stretch or compress in proportion to the load they support. P.F.3.1
    2. Students understand that the mathematical model for the force that a linearly elastic object exerts on another object is F_{elastic} = kΔx, where Δx is the displacement of the object from its relaxed position. P.F.3.2
    3. Students understand that the direction of the elastic force is always toward the relaxed position of the elastic object. P.F.3.3
    4. Students understand that the constant of proportionality, k, is the same for compression and extension and depends on the "stiffness" of the elastic object. P.F.3.4

4. Friction force (static and kinetic) P.F.4
    1. Students understand that the amount of kinetic friction between two objects depends on the electric forces between the atoms of the two surfaces sliding past each other. P.F.4.1
        a. Students understand that it also depends upon the magnitude of the normal force that pushes the two surfaces together. P.F.4.1.A
        b. Students understand that this can be represented mathematically as F_k = μkF_N, where μk is the coefficient of kinetic friction that depends upon the materials of which the two surfaces are made. P.F.4.1.B
    2. Students understand that sometimes friction forces can prevent objects from sliding past each other, even when an external force is applied parallel to the two surfaces that are in contact. P.F.4.2
        a. Students understand that this is called static friction, which is mathematically represented by F_s ≤ μsF_N. P.F.4.2.A
    3. Students understand that the maximum amount of static friction possible depends on the types of materials that make up the two surfaces and the

    magnitude of the normal force pushing the objects together, F_{smax} = μ_sF_N. P.F.4.3

    4. Students understand that as long as the external net force is less than or equal to the maximum force of static friction, the objects will not move relative to one another. P.F.4.4

        a. Students understand that in this case, the actual static friction force acting on the object will be equal to the net external force acting on the object, but in the opposite direction. P.F.4.4.A

    5. Students understand that if the external net force exceeds the maximum static friction force for the object, the objects will move relative to each other and the friction between them will no longer be static friction, but will be kinetic friction. P.F.4.5

5. Air resistance and drag P.F.5

    1. Students understand that liquids have more drag than gases. P.F.5.1

    2. Students understand that when an object pushes on the particles in a fluid, the fluid particles can push back on the object according to Newton's third law and cause a change in motion of the object. This is how helicopters experience lift and how swimmers propel themselves forward. P.F.5.2

    3. Students understand that forces from fluids are quantified using Newton's second law and force diagrams. P.F.5.3

    4. Students understand that factors that affect air resistance and drag and the determination of terminal velocity may be included. P.F.5.4

6. Forces in two dimensions P.F.6

    1. Students understand that net forces will be calculated for force vectors with directions between 0° and 360° or a certain angle from a reference (e.g., 37° above the horizontal). P.F.6.1

    2. Students understand that vector addition can be done with trigonometry or by drawing scaled diagrams. P.F.6.2

    3. Students understand that problems can be solved for objects sliding down inclines. P.F.6.3

    4. Students understand that the net force, final velocity, time, displacement and acceleration can be calculated. P.F.6.4

    5. Students understand that inclines will either be frictionless or the force of friction will already be quantified. P.F.6.5

    6. Students understand that calculations of friction forces down inclines from the coefficients of friction and the normal force will not be addressed in this course. P.F.6.6

    7. Students understand that an object moves at constant speed in a circular path when there is a constant net force that is always directed at right angles to the direction of motion toward the center of the circle. In this case, the net force causes an acceleration that shows up as a change in direction. P.F.6.7

    8. Students understand that if the force is removed, the object will continue in a straight-line path. P.F.6.8
    9. Students understand that the nearly circular orbits of planets and satellites result from the force of gravity. P.F.6.9
    10. Students understand that centripetal acceleration is directed toward the center of the circle and can be calculated by the equation a_c = v^2/r, where v is the speed of the object and r is the radius of the circle. P.F.6.10
    11. Students understand that this expression for acceleration can be substituted into Newton's second law to calculate the centripetal force. P.F.6.11
    12. Students understand that since the centripetal force is a net force, it can be equated to friction (unbanked curves), gravity, elastic force, etc., to perform more complex calculations. P.F.6.12

7. Momentum, impulse and conservation of momentum P.F.7
    1. Students understand that momentum, p, is a vector quantity that is directly proportional to the mass, m, and the velocity, v, of the object. P.F.7.1
    2. Students understand that momentum is in the same direction the object is moving and can be mathematically represented by the equation p = mv. P.F.7.2
    3. Students understand that the conservation of linear momentum states that the total (net) momentum before an interaction in a closed system is equal to the total momentum after the interaction. P.F.7.3
    4. Students understand that in a closed system, linear momentum is always conserved for elastic, inelastic and totally inelastic collisions. P.F.7.4
    5. Students understand that while total energy is conserved for any collision, in an elastic collision, the kinetic energy also is conserved. P.F.7.5
    6. Students understand that given the initial motions of two objects, qualitative predictions about the change in motion of the objects due to a collision can be made. P.F.7.6
    7. Students understand that problems can be solved for the initial or final velocities of objects involved in inelastic and totally inelastic collisions. P.F.7.7
    8. Students understand that momentum may be dealt with in two dimensions conceptually, but at this level calculations should be limited to only one dimension. P.F.7.8
    9. Students understand that impulse, Δp, is the total momentum transfer into or out of a system. P.F.7.9
    10. Students understand that any momentum transfer is the result of interactions with objects outside the system and is directly proportional to both the average net external force acting on the system, F_{avg}, and the time interval of the interaction, t. P.F.7.10
    11. Students understand that it can mathematically be represented by Δp = p_f – p_i = F_{avg} Δt. P.F.7.11
        a. Students understand that this equation can be used to justify why momentum changes due to the external force of friction can be ignored

when the time of interaction is extremely short. P.F.7.11.A

12. Students understand that average force, initial or final velocity, mass or time interval can be calculated in multi-step word problems. P.F.7.12
13. Students understand that for objects that experience a given impulse (e.g., a truck coming to a stop), a variety of force/time combinations are possible. P.F.7.13
    a. Students understand that the time could be small, which would require a large force (e.g., the truck crashing into a brick wall to a sudden stop). P.F.7.13.A
    b. Students understand that conversely, the time could be extended which would result in a much smaller force (e.g., the truck applying the brakes for a long period of time). P.F.7.13.B

Energy

1. Gravitational potential energy P.E.1
    1. Students understand that when two attracting masses interact, the kinetic energies of both objects change but neither is acting as the energy source or the receiver. Instead, the energy is transferred into or out of the gravitational field around the system as gravitational potential energy. P.E.1.1
    2. Students understand that a single mass does not have gravitational potential energy. P.E.1.2
    3. Students understand that only the system of attracting masses can have gravitational potential energy. P.E.1.3
    4. Students understand that when two masses are moved farther apart, energy is transferred into the field as gravitational potential energy. P.E.1.4
    5. Students understand that when two masses are moved closer together, gravitational potential energy is transferred out of the field. P.E.1.5
2. Energy in springs P.E.2
    1. Students understand that the approximation for the change in the potential elastic energy of an elastic object (e.g., a spring) is ΔE_{elastic} = ½ k Δx^2 where Δx is the distance the elastic object is stretched or compressed from its relaxed length. P.E.2.1
3. Work and power P.E.3
    1. Students understand that work can be calculated for situations in which the force and the displacement are at angles to one another using the equation $W = F\Delta x(\cos\theta)$ where W is the work, F is the force, Δx is the displacement, and θ is the angle between the force and the displacement. P.E.3.1
    2. Students understand that this means when the force and the displacement are at right angles, no work is done and no energy is transferred between the objects. Such is the case for circular motion. P.E.3.2
    3. Students understand that the rate of energy change or transfer is called power (P) and can be mathematically represented by $P = \Delta E/\Delta t$ or $P = W/\Delta t$. P.E.3.3
    4. Students understand that power is a scalar property. P.E.3.4
    5. Students understand that the unit of power is the watt (W), which is equivalent to one joule of energy transferred in one second (J/s). P.E.3.5
4. Conservation of energy P.E.4
    1. Students understand that the total initial energy of the system and the energy entering the system are equal to the total final energy of the system and the energy leaving the system. P.E.4.1
    2. Students understand that although the various forms of energy appear very different, each can be measured in a way that makes it possible to keep track of how much of one form is converted into another. P.E.4.2
    3. Students understand that situations involving energy transformations can be represented with verbal or written descriptions, energy diagrams and

mathematical equations. P.E.4.3

    a. Translations can be made between these representations. P.E.4.3.A

4. Students understand that the conservation of energy principle applies to any defined system and time interval within a situation or event in which there are no nuclear changes that involve mass-energy equivalency. P.E.4.4
5. Students understand that the system and time interval may be defined to focus on one particular aspect of the event. P.E.4.5
6. Students understand that the defined system and time interval may then be changed to obtain information about different aspects of the same event. P.E.4.6

5. Nuclear energy P.E.5
    1. Students understand that alpha, beta, gamma and positron emission each have different properties and result in different changes to the nucleus. P.E.5.1
    2. Students understand that the identity of new elements can be predicted for radioisotopes that undergo alpha or beta decay. P.E.5.2
    3. Students understand that nuclear reactions, such as fission and fusion, are accompanied by large energy changes that are much greater than those that accompany chemical reactions. P.E.5.3
    4. Students understand that nuclear fission reactions are used as a controlled source of energy in nuclear power plants. P.E.5.4
    5. Students understand that there are advantages and disadvantages of generating electricity from fission and fusion. P.E.5.5
    6. Students understand that during nuclear interactions, the transfer of energy out of a system is directly proportional to the change in mass of the system as expressed by E = mc2, which is known as the equation for mass-energy equivalence. P.E.5.6
    7. Students understand that a very small loss in mass is accompanied by a release of a large amount of energy. P.E.5.7
    8. Students understand that in nuclear processes such as nuclear decay, fission and fusion, the mass of the product is less than the mass of the original nuclei. P.E.5.8
        a. Students understand that the missing mass appears as energy. P.E.5.8.A
        b. Students also understand that this energy can be calculated for fission and fusion when given the masses of the particle(s) formed and the masses of the particle(s) that interacted to produce them. P.E.5.8.B

Waves

1. Wave properties P.W.1
    1. Students understand that when a wave reaches a barrier or a new medium, a portion of its energy is reflected at the boundary and a portion of the energy passes into the new medium. P.W.1.1
        a. Students understand that some of the energy that passes to the new medium may be absorbed by the medium and transformed to other forms of energy, usually thermal energy, and some continues as a wave in the new medium. P.W.1.1.A
        b. Students understand that some of the energy may also be dissipated and no longer be part of the wave since it has been transformed into thermal energy or transferred out of the system due to the interaction of the system with surrounding objects. P.W.1.1.B
        c. Students understand that usually all of these processes occur simultaneously, but the total amount of energy must remain constant. P.W.1.1.C
    2. Students understand that when waves bounce off barriers (reflection), the angle at which a wave approaches the barrier (angle of incidence) equals the angle at which the wave reflects off the barrier (angle of reflection). P.W.1.2
    3. Students understand that when a wave travels from a two-dimensional (e.g., surface water, seismic waves) or three-dimensional (e.g., sound, electromagnetic waves) medium into another medium in which the wave travels at a different speed, both the speed and the wavelength of the transferred wave change. P.W.1.3
    4. Students understand that depending on the angle between the wave and the boundary, the direction of the wave can also change, resulting in refraction. The amount of bending of waves around barriers or small openings (diffraction) increases with decreasing wavelength. P.W.1.4
    5. Students understand that when the wavelength is smaller than the obstacle or opening, no noticeable diffraction occurs. P.W.1.5
    6. Students understand that standing waves and interference patterns between two sources are included in this topic. P.W.1.6
    7. Students understand that as waves pass through a single or double slit, diffraction patterns are created with alternating lines of constructive and destructive interference. P.W.1.7
        a. Students understand that the diffraction patterns demonstrate predictable changes as the width of the slit(s), spacing between the slits and/or the wavelength of waves passing through the slits changes. P.W.1.7.A
2. Light phenomena P.W.2
    1. Students understand that the path of light waves can be represented with ray diagrams to show reflection and refraction through converging lenses, diverging lenses and plane mirrors. P.W.2.1

2. Students understand that since light is a wave, the law of reflection applies. Snell's law, $n_1 \sin\theta_1 = n_2 \sin\theta_2$, quantifies refraction in which n is the index of refraction of the medium and θ is the angle the wave enters or leaves the medium as measured from the normal line. P.W.2.2
3. Students understand that the index of refraction of a material can be calculated by the equation $n = c/v$, where n is the index of refraction of a material, v is the speed of light through the material, and c is the speed of light in a vacuum. P.W.2.3
4. Students understand that diffraction patterns of light are addressed, including patterns from diffraction gratings. P.W.2.4
5. Students understand that there are two models of how radiant energy travels through space at the speed of light. P.W.2.5
    a. Students understand that one model is that the radiation travels in discrete packets of energy called photons that are continuously emitted from an object in all directions. P.W.2.5.A
        i. Students understand that the energy of these photons is directly proportional to the frequency of the electromagnetic radiation. P.W.2.5.A.I
        ii. Students understand that this particle-like model is called the photon model of light energy transfer. P.W.2.5.A.II
    b. Students understand that a second model is that radiant energy travels like a wave that spreads out in all directions from a source. P.W.2.5.B
        i. Students understand that this wave-like model is called the electromagnetic wave model of light energy transfer. P.W.2.5.B.I
        ii. Students understand that strong scientific evidence supports both the particle-like model and wave-like model. P.W.2.5.B.II
6. Students understand that depending on the problem scientists are trying to solve, either the particle-like model or the wave-like model of radiant energy transfer is used. P.W.2.6
7. Students understand that humans can only perceive a very narrow portion of the electromagnetic spectrum. P.W.2.7
8. Students understand that radiant energy from the sun or a light bulb filament is a mixture of all the colors of light (visible light spectrum). P.W.2.8
9. Students understand that the different colors correspond to different radiant energies. P.W.2.9
10. Students understand that when white light hits an object, the pigments in the object reflect one or more colors in all directions and absorb the other colors. P.W.2.10

Electricity And Magnetism

1. Charging objects (friction, contact and induction) P.EM.1
    1. Students understand that for all methods of charging neutral objects, one object/system ends up with a surplus of positive charge and the other object/system ends up with the same amount of surplus of negative charge. P.EM.1.1
        a. Students understand that this supports the law of conservation of charge that states that charges cannot be created or destroyed. P.EM.1.1.A
    2. Students understand that tracing the movement of electrons for each step in different ways of charging objects (rubbing together two neutral materials to charge by friction; charging by contact and by induction) can explain the differences between them. P.EM.1.2
    3. Students understand that when an electrical conductor is charged, the charge "spreads out" over the surface. P.EM.1.3
    4. Students understand that when an electrical insulator is charged, the excess or deficit of electrons on the surface is localized to a small area of the insulator. P.EM.1.4
    5. Students understand that there can be electrical interactions between charged and neutral objects. P.EM.1.5
    6. Students understand that metal conductors have a lattice of fixed positively charged metal ions surrounded by a "sea" of negatively charged electrons that flow freely within the lattice. P.EM.1.6
    7. Students understand that if the neutral object is a metal conductor, the free electrons in the metal are attracted toward or repelled away from the charged object. As a result, one side of the conductor has an excess of electrons and the opposite side has an electron deficit. P.EM.1.7
        a. Students understand that this separation of charges on the neutral conductor can result in a net attractive force between the neutral conductor and the charged object. P.EM.1.7.A
    8. Students understand that when a charged object is near a neutral insulator, the electron cloud of each insulator atom shifts position slightly so it is no longer centered on the nucleus. P.EM.1.8
    9. Students understand that the separation of charge is very small, much less than the diameter of the atom. P.EM.1.9
        a. Students understand that this small separation of charges for billions of neutral insulator particles can result in a net attractive force between the neutral insulator and the charged object. P.EM.1.9.A
2. Coulomb's law P.EM.2
    1. Students understand that two charged objects, which are small compared to the distance between them, can be modeled as point charges. P.EM.2.1
    2. Students understand that the forces between point charges are proportional to the product of the charges and inversely proportional to the square of the

    distance between the point charges [F_e = (k_e q₁ q₂)/r^2]. P.EM.2.2

    3. Students understand that problems may be solved for the electric force, the amount of charge on one of the two objects or the distance between the two objects. P.EM.2.3
    4. Students understand that problems may also be solved for three- or four-point charges in a line if the vector sum of the forces is zero. P.EM.2.4
        a. Students understand that this can be explored experimentally through computer simulations. P.EM.2.4.A
    5. Students understand that electric forces acting within and between atoms are vastly stronger than the gravitational forces acting between the atoms. P.EM.2.5
        a. Students understand that however, gravitational forces are only attractive and can accumulate in massive objects to produce a large and noticeable effect. P.EM.2.5.A
        b. Students understand that conversely, electric forces are both attractive and repulsive and tend to cancel each other P.EM.2.5.B

3. Electric fields and electric potential energy P.EM.3
    1. Students understand that the strength of the electrical field of a charged object at a certain location is given by the electric force per unit charge experienced by another charged object placed at that location, E = F_e/q. P.EM.3.1
        a. Students understand that this equation can be used to calculate the electric field strength, the electric force or the electric charge. P.EM.3.1.A
        b. Students understand that however, the electric field is always there, even if the object is not interacting with anything else. P.EM.3.1.B
    2. Students understand that the direction of the electric field at a certain location is parallel to the direction of the electrical force on a positively charged object at that location. P.EM.3.2
    3. Students understand that the electric field caused by a collection of charges is equal to the vector sum of the electric fields caused by the individual charges (superposition of charge). P.EM.3.3
    4. Students understand that greater electric field strengths result in larger electric forces on electrically charged objects placed in the field. P.EM.3.4
    5. Students understand that electric fields can be represented by field diagrams obtained by plotting field arrows at a series of locations. P.EM.3.5
    6. Students understand that electric field diagrams for a dipole, two-point charges (both positive, both negative, one positive and one negative) and parallel capacitor plates are included. P.EM.3.6
    7. Students understand that field line diagrams are excluded from this course. P.EM.3.7
    8. Students understand that the concept of electric potential energy can be understood from the perspective of an electric field. P.EM.3.8

9. Students understand that when two attracting or repelling charges interact, the kinetic energies of both objects change but neither is acting as the energy source or the receiver. P.EM.3.9
10. Students understand that instead, the energy is transferred into or out of the electric field around the system as electric potential energy. P.EM.3.10
11. Students understand that a single charge does not have electric potential energy. P.EM.3.11
12. Students understand that only the system of attracting or repelling charges can have electric potential energy. P.EM.3.12
13. Students understand that when the distance between the attracting or repelling charges changes, there is a change in the electric potential energy of the system. P.EM.3.13
14. Students understand that when two opposite charges are moved farther apart or two like charges are moved close together, energy is transferred into the field as electric potential energy. P.EM.3.14
15. Students understand that when two opposite charges are moved closer together or two like charges are moved farther apart, electric potential energy is transferred out of the field. P.EM.3.15
16. Students understand that when a charge is transferred from one object to another, work is required to separate the positive and negative charges. P.EM.3.16
17. Students understand that if there is no change in kinetic energy and no energy is transferred out of the system, the work increases the electric potential energy of the system. P.EM.3.17

4. DC circuits P.EM.4
    1. Students understand that once a circuit is switched on, the current and potential difference are experienced almost instantaneously in all parts of the circuit even though the electrons are only moving at speeds of a few centimeters per hour in a current-carrying wire. P.EM.4.1
    2. Students understand that it is the electric field that travels instantaneously through all parts of the circuit, moving the electrons that are already present in the wire. P.EM.4.2
    3. Students understand that since electrical charge is conserved, in a closed system such as a circuit, the current flowing into a branch point junction must equal the total current flowing out of the junction (junction rule). P.EM.4.3
    4. Students understand that resistance is measured in ohms and has different cumulative effects when added to series and parallel circuits. P.EM.4.4
    5. Students understand that the potential difference, or voltage (ΔV), across an energy source is the potential energy difference (ΔE) supplied by the energy source per unit charge (q) ($\Delta V = \Delta E/q$). P.EM.4.5
    6. Students understand that the electric potential difference across a resistor is the product of the current and the resistance ($\Delta V = I R$). P.EM.4.6

    7. Students understand that in this course, only ohmic resistors will be studied. P.EM.4.7
    8. Students understand that when potential difference vs. current is plotted for an ohmic resistor, the graph will be a straight line and the value of the slope will be the resistance. P.EM.4.8
    9. Students understand that since energy is conserved for any closed loop, the energy put into the system by the battery must equal the energy that is transformed by the resistors. P.EM.4.9
    10. Students understand that for circuits with resistors in series, this means that V_{battery} = ΔV₁ + ΔV₂ + ΔV₃ +…. P.EM.4.10
    11. Students understand that the rate of energy transfer (power) across each resistor is equal to the product of the current through and the voltage drop across each resistor (P = ΔV I) and P_{battery} = I ΔV₁ + I ΔV₂ + I ΔV₃ +… = IΔV_{battery}. P.EM.4.11
    12. Students understand that equations should be understood conceptually and used to calculate the current or potential difference at different locations of a parallel, series or mixed circuit. P.EM.4.12
    13. Students understand that the names of the laws (e.g., Ohm's law,) are not the focus. Opportunities for measuring and analyzing current, voltage and resistance in parallel, series and mixed circuits should be provided. P.EM.4.13
        a. Students understand that this can be done with traditional laboratory equipment and through computer simulations. P.EM.4.13.A

5. Magnetic fields P.EM.5
    1. Students understand that the direction of the magnetic field at any point in space is the equilibrium direction of the north end of a compass placed at that point. P.EM.5.1
    2. Students understand that magnetic fields can be represented by field diagrams obtained by plotting field arrows at a series of locations. P.EM.5.2
    3. Students understand that field line diagrams are excluded from this course. P.EM.5.3
    4. Students understand that calculations for the magnetic field strength are not required at this grade level, but it is important to note that greater magnetic fields result in larger magnetic forces on magnetic objects or moving charges placed in the field. P.EM.5.4
6. Electromagnetic interactions P.EM.6
    1. Students understand that magnetic forces are very closely related to electric forces. P.EM.6.1
        a. Students understand that even though they appear to be distinct from each other, they are thought of as different aspects of a single electromagnetic force. P.EM.6.1.A

2. Students understand that a flow of charged particles (including an electric current) creates a magnetic field around the moving particles or the current carrying wire. P.EM.6.2
3. Students understand that motion in a nearby magnet is evidence of this field. P.EM.6.3
4. Students understand that electric currents in Earth's interior give Earth an extensive magnetic field, which is detected from the orientation of compass needles. P.EM.6.4
5. Students understand that the motion of electrically charged particles in atoms produces magnetic fields. P.EM.6.5
6. Students understand that usually these magnetic fields in an atom are randomly oriented and therefore cancel each other out. P.EM.6.6
7. Students understand that in magnetic materials, the subatomic magnetic fields are aligned, resulting in a macroscopic magnetic field. P.EM.6.7
8. Students understand that a moving charged particle interacts with a magnetic field. P.EM.6.8
9. Students understand that the magnetic force that acts on a moving charged particle in a magnetic field is perpendicular to both the magnetic field and to the direction of motion of the charged particle. P.EM.6.9
10. Students understand that the magnitude of the magnetic force depends on the speed of the moving particle, the magnitude of the charge of the particle, the strength of the magnetic field, and the angle between the velocity and the magnetic field. P.EM.6.10
11. Students understand that there is no magnetic force on a particle moving parallel to the magnetic field. P.EM.6.11
12. Students understand that calculations of the magnetic force acting on moving particles are not required at this grade level. P.EM.6.12
13. Students understand that moving charged particles in magnetic fields typically follow spiral trajectories since the force is perpendicular to the motion. P.EM.6.13
14. Students understand that a changing magnetic field creates an electric field. P.EM.6.14
15. Students understand that if a closed conducting path, such as a wire, is in the vicinity of a changing magnetic field, a current may flow through the wire. P.EM.6.15
16. Students understand that a changing magnetic field can be created in a closed loop of wire if the magnet and the wire move relative to one another. P.EM.6.16
17. Students understand that this can cause a current to be induced in the wire. P.EM.6.17
18. Students understand that the strength of the current depends upon the strength of the magnetic field, the velocity of the relative motion and the number of loops in the wire. P.EM.6.18

19. Students understand that calculations for current induced in a wire or coil of wire is not required at this level. P.EM.6.19

20. Students understand that a changing electric field creates a magnetic field and a changing magnetic field creates an electric field. P.EM.6.20

21. Students understand that radiant energy travels in electromagnetic are waves produced by changing the motion of charges or by changing magnetic fields. P.EM.6.21

    a. Students understand that therefore, electromagnetic radiation is a pattern of changing electric and magnetic fields that travel at the speed of light. P.EM.6.21.A

22. Students understand that the interplay of electric and magnetic forces is the basis for many modern technologies that convert mechanical energy to electrical energy (generators) or electrical energy to mechanical energy (electric motors) as well as devices that produce or receive electromagnetic waves. P.EM.6.22

    a. Students understand that therefore, coils of wire and magnets are found in many electronic devices including speakers, microphones, generators and electric motors. P.EM.6.22.A

23. Students understand that the interactions between electricity and magnetism should be explored in the laboratory setting. Experiments with the inner workings of motors, generators and electromagnets can be conducted. P.EM.6.23

24. Students understand that current technologies using these principles can be explored. P.EM.6.24