Verbs Used to Describe Student Performance

The verbs used in this document to describe what students are doing are used intentionally. They are linked to the cognition required based on the verbs in the Physics 20-30 Program of Studies, 2007. The following table summarizes the more common verbs in this document and what they require of the student.

Compare	Examine the character or qualities of two things by providing characteristics of both that point out their mutual similarities and differences
Define	Provide the essential qualities or meaning of a word or concept; make distinct and clear by marking out the limits
Describe	Give a written account or represent the characteristics of something by a figure, model, or picture
Design/Plan	Construct a plan, i.e, a detailed sequence of actions, for a specific purpose
Determine	Find a solution, to a specified degree of accuracy, to a problem by showing appropriate formulas, procedures, and calculations
Evaluate	Give the significance or worth of something by identifying the good and bad points or the advantages and disadvantages
Explain	Make clear what is not immediately obvious or entirely known; give the cause of or reason for; make known in detail
Identify	Recognize and select as having the characteristics of something
Infer	Form a generalization from sample data; arrive at a conclusion by reasoning from evidence
Interpret	Tell the meaning of something; present information in a new form that adds meaning to the original data
Justify/Show How	Show reasons for or give facts that support a position

The *Standard of Excellence* column also contains the phrase “explicitly communicate”. When a student does this, the observer does not have to fill in any blanks or make any connections between the ideas presented. In a Physics 20 setting, the following would be an example of implicit communication: “An object in orbit experiences a constant centre-seeking force and does not change its speed.” An explicit communication might look something like this: “An object in a circular orbit experiences a constant centre-seeking force. Because the force is perpendicular to the direction of the displacement, the force does no work on the object, so the object’s kinetic energy does not change; thus its speed is constant.”

Physics 20 General Outcome A1 *Students will* describe motion in terms of displacement, velocity, acceleration, and time.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- define "scalar"
- define "vector"
- identify similarities and differences between scalar and vector quantities
- define "displacement," "velocity," and "acceleration"
- classify distance, time, and speed as scalar values
- classify displacement, velocity, and acceleration as vector values
- relate SI units to physics quantities:
  $\vec{d}$ in m
  $\vec{v}$ in m/s
  $\vec{a}$ in m/s^2
- convert between m/s and km/h (using conversion factor of 3.6)
- use sign conventions (e.g., positive signs for right, up, north, or east and negative signs for left, down, south, or west)
- use delta notation appropriately
- describe motion as being uniform or uniformly accelerated given a written description or numeric values
- plot data and draw an appropriate line of best fit (straight or curve)

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

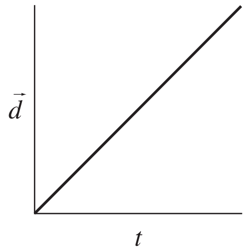
- explicitly communicate that:
  —velocity is dependent on the observer's reference frame
  —acceleration and velocity may be in different directions (e.g., linear or at an angle)
  —a negative velocity may mean an object is slowing down or speeding up, or a positive velocity is speeding up or slowing down
  —a negative acceleration may cause an object to slow down or speed up, and a positive acceleration may cause an object to slow down or speed up
  —the direction of motion may be in a different direction than that of the acceleration
  —a velocity of zero does not mean that the acceleration must be zero; an acceleration of zero does not mean that the velocity must be zero
- explicitly communicate the use of sign conventions to allow for the mathematical treatment of vectors
- calculate, describe, or determine the motion of one object relative to another when both objects are moving relative to a fixed reference point
- use unit analysis as a problem-solving technique (e.g., explicitly converts between m/s and km/h)
- interpret position as a function of time graphs and velocity as a function of time graphs for an object whose motion changes (e.g., uniformly accelerated motion followed by uniform motion)
- explicitly communicate that the shape of the object's trajectory is different than the shape of the graph of the motion

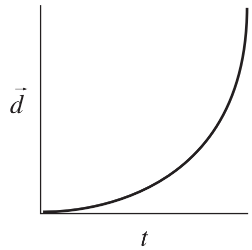
Physics 20 General Outcome A1 *Students will* describe motion in terms of displacement, velocity, acceleration, and time.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

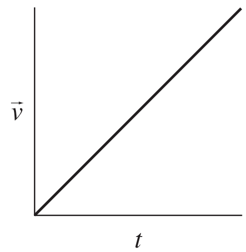
- sketch graph shapes limited to one quadrant given verbal descriptions of simple motion (uniform motion or uniformly accelerated motion)

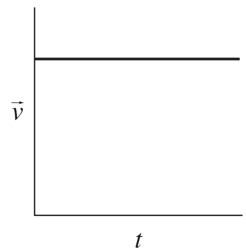
  e.g., Position as a Function of Time graphs

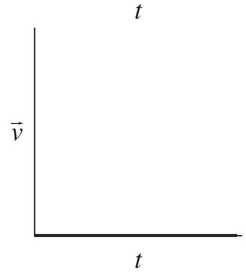




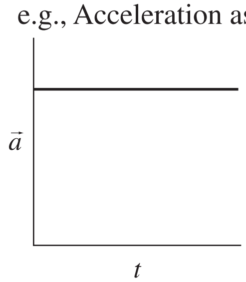
  e.g., Velocity as a Function of Time graphs

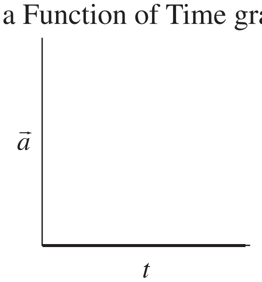






  e.g., Acceleration as a Function of Time graphs

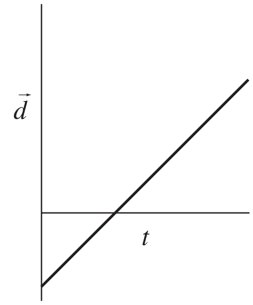




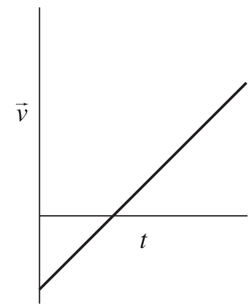
Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- sketch graph shapes that require two quadrants given verbal descriptions of motion

  e.g., Position as a Function of Time graph



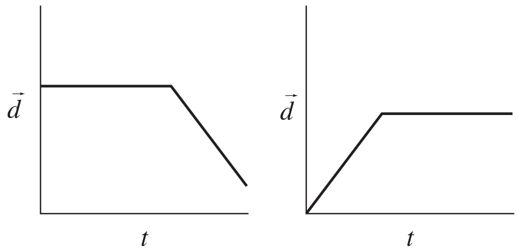
  e.g., Velocity as a Function of Time graph



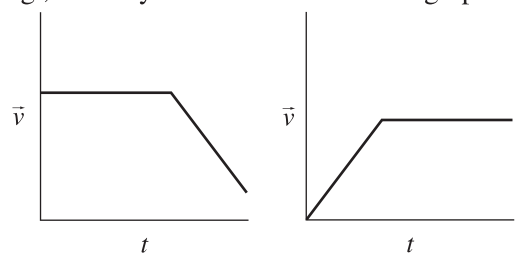
Physics 20 General Outcome A1 *Students will* describe motion in terms of displacement, velocity, acceleration, and time.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- interpret graph shapes describing uniform motion or uniformly accelerated motion or one change in motion
  e.g., Position as a Function of Time graphs



  e.g., Velocity as a Function of Time graphs

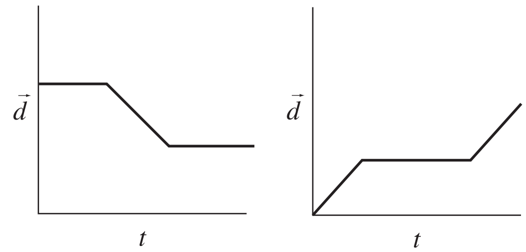


- use graphical analysis of slope
  —velocity from a position as a function of time graph
  —acceleration from a velocity as a function of time graph
- use graphical analysis of area for simple areas (e.g., two rectangles or two triangles or a trapezoid; also all positive area or all negative area)
  —displacement, $\Delta\vec{d}$, from a velocity as a function of time graph
  —velocity from an acceleration as a function of time graph
- identify manipulated, responding, and controlled variables given the analysis and procedure or apparatus
- follow instructions and collect data using available equipment or a computer simulation for an object undergoing uniform motion or uniformly accelerated motion
- measure distances and calculate speed from timed images (strobe photography, motion sensors, ticker-tape timer, etc.)

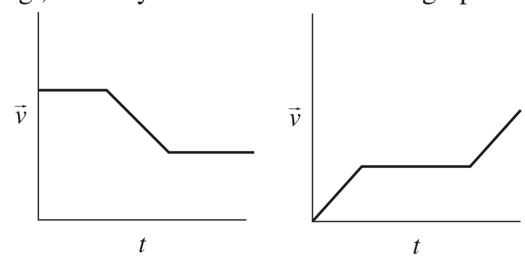
Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- interpret graph shapes for graphs that show more than two changes in type of motion

  e.g., Position as a Function of Time graphs



  e.g., Velocity as a Function of Time graphs



- explicitly communicate the meaning of positive and negative slopes
- interpret the meaning of x- and y-intercepts for position as a function of time, velocity as a function of time, and acceleration as a function of time graphs
- explicitly communicate the meaning of positive and negative areas
- use graphical analysis of area for complex areas (e.g., positive or negative areas, two rectangles, and a triangle)
- design an investigation to demonstrate the relationships among displacement, velocity, acceleration, and time, using available technologies
- make measurements to the appropriate significant digits based on the precision of the instruments used
- explain the analysis of experimental observations
- evaluate quality of experimental results

Physics 20 General Outcome A1 *Students will* describe motion in terms of displacement, velocity, acceleration, and time.

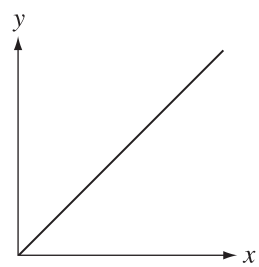
Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• for motion in one direction (vertical only or horizontal only), solve for the magnitude of any variable for motion in one direction ($v_i = 0$ m/s or $v_f = 0$ m/s) using one of $\vec{a} = \frac{\triangle \vec{v}}{t}$ $\vec{d} = \vec{v}_i t + \frac{1}{2}\vec{a}t^2$ $\vec{d} = \vec{v}_i t - \frac{1}{2}\vec{a}t^2$ $\vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2}\right)t$ $v_f^2 = v_i^2 + 2ad$	• for motion in one direction (vertical only or horizontal only), solve for any variable ($v_i \neq 0$ m/s and $v_f \neq 0$ m/s), using one or more equations, and use delta notation appropriately (i.e., $\triangle \vec{d}$, $\triangle \vec{v}$, and $\triangle t$)
• add perpendicular vectors by drawing a head-to-tail diagram and determining the resultant graphically or algebraically • determine the perpendicular components of a vector quantity	• add non-perpendicular, non-parallel vectors (displacement or velocity) by finding and adding components, drawing a head-to-tail diagram, and determining the resultant graphically or algebraically • apply the independence of perpendicular components appropriately in problem solving
• define "projectile" • define "trajectory" • identify the shape of the path followed by a projectile near Earth's surface as being parabolic • define "range" as the horizontal displacement of a projectile • analyze projectile motion for objects given that initial velocity is initially horizontal —identify type of motion in the horizontal and the vertical directions —given time and one null value of a speed, determine d_x, d_y, or $\lvert\vec{v}_f\rvert = \sqrt{\lvert\vec{v}_{fx}\rvert^2 + \lvert\vec{v}_{fy}\rvert^2}$	• analyze projectile motion for objects —solve for t, and then use t —solve for t when —solve for any variable in $\lvert\vec{v}_f\rvert = \sqrt{\lvert\vec{v}_{fx}\rvert^2 + \lvert\vec{v}_{fy}\rvert^2}$ and $\theta = \tan^{-1}\left(\frac{\lvert\vec{v}_{fy}\rvert}{\lvert\vec{v}_{fx}\rvert}\right)$
• state that scientific knowledge changes as a result of new evidence • identify a situation in which science provided knowledge about the natural world • state that the process for technological development includes testing and evaluating designs	• explain how scientific laws and theories are subject to change in response to new evidence • show initiative in exploring how science provides knowledge about the natural world • explain how the development of a technology required a process of testing and evaluating • volunteer a connection between the real world and the classroom activity
• work collaboratively in a group • take a positive leadership role in group activities • express answers with appropriate significant digits	

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 20 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 20 General Outcome B1 *Students will* explain the effects of balanced and unbalanced forces on velocity.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- define “force”
- classify force as a vector quantity
- state Newton’s first law of motion
- identify manipulated, responding, and controlled variables given the analysis and procedure or apparatus
- follow instructions and collect data using available equipment or a computer simulation to investigate relationships among acceleration, mass, and force acting on a moving object
- plot given data and draw line of best fit (straight or curve)
- match graph shape with mathematical relationship
  e.g.,

  $y \propto x \Rightarrow$ 

- determine slope of linear graph
- use delta notation appropriately
- state and apply Newton’s second law of motion to explain, qualitatively, the relationships among net force, mass, and acceleration
- solve for any variable in $\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$
- relate SI unit to physics quantity:
  F in N or in kg·m/s^2
- define “weight”
- define “apparent weight”
- solve for any variable in $\vec{g} = \frac{\vec{F}_{\text{g}}}{m}$
- state that the gravitational force acts on an object at all times (i.e., when rising, when at rest, and when falling)

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explicitly communicate that inertia is not a force that keeps objects in motion, and a force is not required to keep objects in motion
- design an investigation to determine the relationships among force, mass, and acceleration, using available technologies
- explain the analysis of experimental observations
- relate slope to physics formula to determine physics significance of slope
- explicitly communicate the relationship between graph shape and mathematical model
- evaluate the quality of experimental results, including discrepant or unexpected results
- explicitly communicate that:
  —an object’s direction of motion may be in a different direction than that of the net force
  —an object may have uniform motion and have several forces acting on it (i.e., the object is in equilibrium)
- explicitly communicate how the unit of newtons is a derived unit based on a proportionality
- determine the apparent weight of an object undergoing accelerated motion

Physics 20 General Outcome B1 *Students will* explain the effects of balanced and unbalanced forces on velocity.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• define “normal force” • sketch a vector addition diagram for linear analysis of forces	
• draw a free-body diagram (FBD) when two or more forces (linear or two-dimensional) are acting on an object and the object is: —in equilibrium —not in equilibrium	• describe the possible motion of an object, given its FBD (more than 2 forces)
• add two perpendicular forces by drawing a head-to-tail diagram and determine the resultant graphically or algebraically • determine perpendicular components of a force • determine the resultant, given perpendicular components of a force	• add non-perpendicular, non-parallel forces by finding and adding components and drawing a head-to-tail diagram, and determine the resultant graphically or algebraically • explicitly communicate that perpendicular components of a force are independent of each other
• define “equilibrant” • determine the equilibrant when one force acts on an object • draw the equilibrant using concepts of vector addition or a FBD when two forces act in a line on an object	• determine the equilibrant when more than 2 forces act on an object in a line or in two dimensions • explicitly communicate that equilibrium may be achieved by several forces that have unequal magnitudes
• state Newton’s third law of motion • state that the two forces in an action-reaction pair are equal in magnitude and opposite in direction, but do not act on the same object • draw and label the forces in an action-reaction pair	• apply the principle that the forces in an action-reaction pair act on different objects • explicitly communicate that each force in an action-reaction pair can cause a different acceleration if the objects have different masses
• determine the normal force for an object at rest on a horizontal surface where only the normal force and the gravitational force are acting on it • define “coefficient of friction” • state that μ depends on the properties of the two surfaces involved • determine the forces of static or kinetic friction acting on an object, using $\left\|\vec{F}_{\mathrm{F}}\right\| = \mu\left\|\vec{F}_{\mathrm{N}}\right\|$	• determine the normal force for an object on a horizontal surface when an external force is applied • determine the normal force on an object on an inclined plane • determine the direction and magnitude of the frictional force when the normal force is not equal to the gravitational force
• follow instructions and collect data using available equipment or a computer simulation to determine an average μ	• design an investigation to determine μ • explain the analysis of experimental observations • evaluate the quality of experimental results, including discrepant or unexpected results

Physics 20 General Outcome B1 *Students will* explain the effects of balanced and unbalanced forces on velocity.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- determine the parallel and perpendicular components of the gravitational force acting on an object on an inclined plane
- draw the FBD of the forces acting on an object on an inclined plane:
  —when there is no friction
  —when there is friction

- state that the use of technology is to solve practical problems
- state that the process for technological development includes testing and evaluating designs
- state that science and technology are developed to meet societal needs

- work collaboratively in a group
- take a positive leadership role in group activities
- express measured values and calculated values with appropriate significant digits

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- analyze the forces acting on an object that is on an inclined plane when the object experiences uniformly accelerated motion by calculating the:
  —acceleration
  —net force
  —frictional force
  —parallel and perpendicular components of the gravitational force
- design an investigation to investigate the application of Newton's laws in an everyday phenomenon
- explain how the development of a technology requires a process of testing and evaluating
- explain how science and technology have been responsive to societal needs
- explain how scientific laws and theories change as new evidence becomes apparent
- volunteer a connection between the real world and the classroom activity

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 20 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

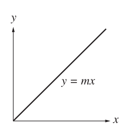
Physics 20 General Outcome B2 *Students will* explain that gravitational effects extend throughout the universe.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

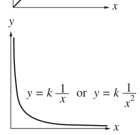
- identify the gravitational force as one of the fundamental forces of nature
- state Newton's law of universal gravitation, $\left|\vec{F}_{\mathrm{g}}\right| = \dfrac{Gm_1m_2}{r^2}$
- solve for the magnitude of F_{g}, m, or G, using $\left|\vec{F}_{\mathrm{g}}\right| = \dfrac{Gm_1m_2}{r^2}$, given m_1, m_2, and r
- draw a FBD representing the gravitational force acting on an object
- identify diagrams of Cavendish's torsion balance apparatus
- follow instructions and collect data using available equipment or a computer simulation to demonstrate relationships among variables in Newton's law of universal gravitation
- plot given data and draw line of best fit (straight or curve)
- match graph shape with mathematical relationship

  e.g.,

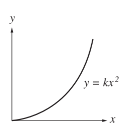
  $y \propto x \Rightarrow$



  $y \propto \dfrac{1}{x}$, $y \propto \dfrac{1}{x^2} \Rightarrow$



  $y \propto x^2 \Rightarrow$



- define "action at a distance"
- define "field"
- determine gravitational field strength by using $\left|\vec{g}\right| = \dfrac{\vec{F}_{\mathrm{g}}}{m}$

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explicitly communicate the requirement for G, the universal gravitational constant
- solve for r in Newton's universal law of gravitation
- analyze the effect of changing one or more variables in Newton's law of universal gravitation.
- determine ratio F_{g} old : F_{g} new
- draw FBDs, explicitly communicating the magnitude and direction of each force of an action-reaction pair for gravitational forces
- describe the method followed by Cavendish
  —manipulate m
  —manipulate r
  —use angle of rotation to infer F
- predict the results of changing any of the variables in a torsion balance experiment
- explain the analysis of experimental observations
- explicitly communicate the relationship between graph shape and mathematical model
- evaluate the quality of experimental results, including discrepant or unexpected results
- explicitly communicate the use of the field concept to describe gravitational effects

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 20 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 20 General Outcome B2 — *Students will* explain that gravitational effects extend throughout the universe.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- define the direction of the gravitational field as the direction of the gravitational force experienced by a test mass
- draw gravitational field lines around a single mass
- state that the gravitational field strength is equivalent to the acceleration due to gravity at a particular location
- relate SI units to physics quantities: $\vec{g}$ in m/s^2 or in $\frac{\text{N}}{\text{kg}}$

- identify manipulated, responding, and controlled variables given the analysis and procedure or apparatus
- follow instructions and collect data using available equipment or a computer simulation to measure $\vec{g}$

- solve for $\vec{g}$ or m using $\left|\vec{g}\right| = \frac{Gm}{r^2}$, given r, at a planetary surface or far away from the source

- determine the weight experienced by an object on different planets, given the local value of $\vec{g}$
- state that satellites are continually falling toward the body that they orbit

- identify a situation in which a concept, model, or theory has been used to interpret or explain observations or to make future predictions

- work collaboratively in a group
- take a positive leadership role in group activities
- state measured values and calculated values with appropriate significant digits

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- design an investigation to determine the local value of $\vec{g}$
- explain the analysis of experimental observations
- make measurements to the appropriate significant digits based on the precision of the instruments used
- evaluate quality of experimental results

- derive $\left|\vec{g}\right| = \frac{Gm}{r^2}$ from Newton's second law and Newton's universal law of gravitation
- solve for any variable in $\left|\vec{g}\right| = \frac{Gm}{r^2}$ where r is the sum of distances (i.e., planet radius + orbital height)

- compare the ideas of apparent weight, the "zero gravity" environment experienced by space-station astronauts, and relate to free fall
- explain how a concept, model, or theory was used in interpreting, explaining, or predicting observations
- volunteer a connection between the real world and the classroom activity

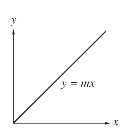
Physics 20 General Outcome C1 — *Students will* explain circular motion, using Newton's laws of motion.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

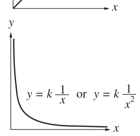
- state that circular motion is a special case of two-dimensional motion
- define "centripetal"
- identify as centripetal the direction of the force and resulting acceleration necessary to experience circular motion
- define "period" and "frequency"
- relate SI units to physics quantities: f in Hz or in s^{-1}
- identify manipulated, responding, and controlled variables given the analysis and procedure or apparatus
- follow instructions and collect data using available equipment or a computer simulation to measure v, f, T, and r for circular motion
- identify the relationships among v, f, T, and r for circular motion
- solve for any variable in circular motion
- follow instructions and collect data using available equipment or a computer simulation to determine the relationships among the net force acting on an object in uniform circular motion and the object's f, m, v, and r
- plot given data and draw line of best fit (straight or curve)
- match graph shape with mathematical relationship:

  e.g.,

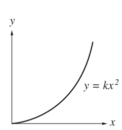
  $y \propto x \Rightarrow$



  $y \propto \frac{1}{x}$, $y \propto \frac{1}{x^2} \Rightarrow$



  $y \propto x^2 \Rightarrow$



- determine slope of linear graph
- use delta notation appropriately

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explain how circular motion is a special case of two-dimensional motion
- design an investigation to determine the relationship between v, f, T, and r for circular motion
- design an investigation to determine the relationships among the net force acting on an object in uniform circular motion and the object's f, m, v, and r
- explicitly communicate the relationship between graph shape and mathematical model
- demonstrate initiative during laboratory activities
- evaluate the quality of experimental results, including discrepant or unexpected results

Physics 20 General Outcome C1 — *Students will* explain circular motion, using Newton's laws of motion.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• follow instructions and collect data to determine the effect of removing a centripetal force from an object	• design an investigation to determine the effect of removing a centripetal force acting on an object • explain the analysis of experimental observations • make measurements to the appropriate significant digits based on the precision of the instruments used
• identify the direction of the instantaneous velocity of an object undergoing circular motion	• identify the direction of motion of an object when the centripetal force is removed • explain, qualitatively, uniform circular motion in terms of Newton's laws of motion • describe the role of inertia in circular motion
• construct graphs of given data to show relationships among f, m, v, and r	• analyze graphs of empirical data to infer the mathematical relationships among f, m, v, and r • use graph shape to manipulate data to produce a linear graph or use graph shape and an digital device to determine a best-fit regression (see p. 23) • explicitly communicate that circular motion can be caused by a variety of forces (e.g., tension, gravity, friction, etc.)
• solve for a_c, v, T, F_c, or m for circular motion problems in horizontal planes, using $\lvert\vec{v}\rvert = \frac{2\pi r}{T}$, $\lvert\vec{a}_c\rvert = \frac{v^2}{r}$, $\lvert\vec{a}_c\rvert = \frac{\lvert\vec{F}_c\rvert}{m}$	• solve for a_c, v, T, F_c, or m for circular motion problems in vertical planes, using $\lvert\vec{v}\rvert = \frac{2\pi r}{T}$, $\lvert\vec{a}_c\rvert = \frac{v^2}{r}$, $\lvert\vec{a}_c\rvert = \frac{\lvert\vec{F}_c\rvert}{m}$ • derive $a_c = \frac{4\pi^2 r}{T^2}$
• define "satellite" • state that circular motion can be used to approximate elliptical orbits • distinguish between revolution and rotation for satellite motion	• derive an equation for the mass of an orbiting satellite (natural or artificial) • explain the functions, applications, and societal impacts of geosynchronous satellites

Physics 20 General Outcome C1 — *Students will* explain circular motion, using Newton's laws of motion.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- describe Kepler's laws of planetary motion
  - —the orbit of a planet is an ellipse where the sun is at one focus
  - —a line joining a planet and the sun sweeps out equal areas in equal time intervals
  - —the square of a planet's orbital period is directly proportional to the cube of its orbital radius
- state that Kepler's laws were used in the development of Newton's law of universal gravitation
- state that scientific theories or concepts are based on the analysis of evidence
- identify a technology that solves a practical problem
- work collaboratively in a group
- take a positive leadership role in group activities
- state measured values and calculated values with appropriate significant digits

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explain how Kepler's laws were used in the development of Newton's law of universal gravitation
- derive Newton's version of Kepler's third law of planetary motion
- explicitly communicate the process of how the analysis of evidence is affected by scientific theories and concepts in a specific example
- show initiative in exploring how science and technology evolve to meet societal needs
- volunteer a connection between the real world and the classroom activity

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 20 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 20 General Outcome C2 ***Students will*** **explain that work is a transfer of energy and that conservation of energy in an isolated system is a fundamental physical concept.**

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- define "energy"
- relate SI units to physics quantities: E and W in J or in kg·m^2/s^2
- define "kinetic energy"
- solve for any variable in $E_k = \frac{1}{2}mv^2$
- define "gravitational potential energy"
- determine gravitational potential energy using $E_{p\,grav} = mgh$
- define "mechanical energy" as the sum of kinetic and potential energy
- define "isolated system"
- state the law of conservation of energy
- identify the law of conservation of energy as a fundamental physical concept
- define "conservative force"
- define "non-conservative force"
- identify non-conservative forces in a system
- follow instructions and collect data to demonstrate the law of conservation of energy
- determine maximum height or maximum speed of an object using conservation of mechanical energy
- describe the type and amount of energy at any point between maximum potential or kinetic energy (point by point)
- state the work-energy theorem: $W = \triangle E_k$
- define "power"
- solve for any variable in $W = Fd$
- solve for any variable in $P = \frac{W}{t}$
- relate SI units to physics quantities: P in W or in $\frac{\text{J}}{\text{s}}$ or in $\frac{\text{N·m}}{\text{s}}$

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explicitly relate energy to the ability to cause a change in shape, a change in velocity, or a change in location
- explain the necessity of identifying a reference point in the measurement of height for $E_{p\,grav}$
- design an investigation to demonstrate the law of conservation of energy
- explain the analysis of experimental observations
- make measurements to the appropriate significant digits based on the precision of the instruments used
- evaluate the quality of experimental results, including discrepant or unexpected results
- determine height or speed of an object at any point along its path using conservation of energy
- describe the gradual transformation of energy in a system, identifying the types of energy and what they are changing into at any point
- identify sources of loss of useful energy in a non-conservative system
- determine how work done to a system changes the overall energy of the system for both conservative and non-conservative forces
- explicitly communicate that work is done when a component of an applied force is in the same plane as the object's motion

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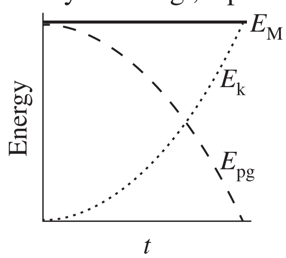
Physics 20 General Outcome C2 ***Students will*** **explain that work is a transfer of energy and that conservation of energy in an isolated system is a fundamental physical concept.**

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

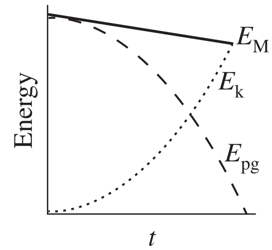
- follow instructions and collect data to demonstrate the effect of doing work on a system
- match the type of energy with the graph shape for an isolated system: e.g., a pendulum:



- state that theories and models can be used to explain observations and predict future observations
- identify a technology developed to meet societal needs
- state that some problems cannot be solved with existing technology
- state that there is a need to reconcile the energy needs of society with its responsibility to protect the environment and to use energy judiciously
- work collaboratively in a group
- take a positive leadership role in group activities
- state measured values and calculated values with appropriate significant digits

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- design an investigation to demonstrate the effect of doing work on a system
- explain the changes in energy in terms of graph shape for a non-isolated system: e.g., a portion of a roller coaster:



- use a free-body diagram to determine the net force acting on an object relative to its direction of motion and apply the results in the work-energy theorem
- use theories and models to analyze observations and predict future observations
- explicitly communicate the relationship between technologies and societal problems, and evaluate the degree to which a problem is solved by a particular technology
- show initiative in evaluating the sustainability of Canadian society
- volunteer a connection between the real world and the classroom activity

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 20 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

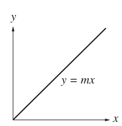
Physics 20 General Outcome D1 *Students will* describe the conditions that produce oscillatory motion.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

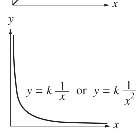
- define “oscillatory motion”
- describe oscillatory motion in terms of period and frequency
- define “equilibrium position”
- define “amplitude”
- follow instructions and collect data to
  - —demonstrate the relationship between the displacement and the restoring force of a spring
  - —determine the spring constant of a spring
  - —determine the relationship between the mass on a horizontal spring and its period of oscillation
  - —determine the relationships among kinetic, gravitational potential and total mechanical energies of a mass executing simple harmonic motion
  - —determine the relationship between the length of a pendulum and its period of oscillation
- match graph shape with mathematical relationship:

e.g.,

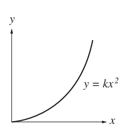
$y \propto x \Rightarrow$



$y \propto \frac{1}{x}$, $y \propto \frac{1}{x^2} \Rightarrow$



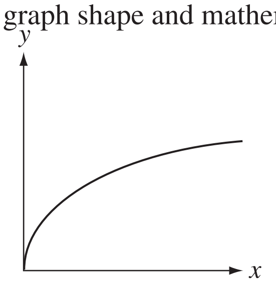
$y \propto x^2 \Rightarrow$



Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- design an investigation to
  - —demonstrate the relationship between the displacement and the restoring force of a spring
  - —determine the spring constant of a spring
  - —determine the relationship between the mass on a horizontal spring and its period of oscillation
  - —determine the relationships among kinetic, gravitational potential, and total mechanical energies of a mass executing simple harmonic motion
  - —determine the relationship between the length of a pendulum and its period of oscillation
- explicitly communicate the relationship between graph shape and mathematical model

$y \propto \sqrt{x} \Rightarrow$



- use graph shape to manipulate data to produce a linear graph
- use graph shape and a calculator to determine best-fit regression
- relate slope to physics formula to determine physics significance of slope
- explicitly communicate the process followed in analyzing experimental observations
- evaluate the quality of experimental results, including discrepant or unexpected results

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 20 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 20 General Outcome D1 *Students will* describe the conditions that produce oscillatory motion.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- state that the restoring force is directed toward the equilibrium position
- state that the restoring force is directly proportional to the displacement from equilibrium
- determine the period of oscillation for a mass oscillating on a horizontal spring using $T = 2\pi\sqrt{\frac{m}{k}}$
- determine the velocity, restoring force, displacement, or acceleration at the maximum and minimum amplitudes for a horizontal spring-mass system using $\vec{F}_{\mathrm{s}} = -k\vec{x}$, $E_{\mathrm{p}} = \frac{1}{2}kx^2$, $E_{\mathrm{k}} = \frac{1}{2}mv^2$
- determine the period of oscillation for a simple pendulum using $T = 2\pi\sqrt{\frac{1}{g}}$
- define “mechanical resonance”
- follow a procedure to illustrate the phenomenon of mechanical resonance
- identify a situation in which science provided knowledge about the natural world
- work collaboratively in a group
- take a positive leadership role in group activities
- make responsible risk-taking decisions
- state measured values and calculated values with appropriate significant digits

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- determine m or k using $T = 2\pi\sqrt{\frac{m}{k}}$
- determine the velocity, restoring force, displacement, or acceleration at any point along the path for a horizontal-spring system using $\vec{F}_{\mathrm{s}} = -k\vec{x}$, $E_{\mathrm{p}} = \frac{1}{2}kx^2$, $E_{\mathrm{k}} = \frac{1}{2}mv^2$
- determine l or g using $T = 2\pi\sqrt{\frac{l}{g}}$
- design an investigation to demonstrate the phenomenon of mechanical resonance
- show initiative in relating science to gaining knowledge about the natural world
- volunteer a connection between the real world and the classroom activity

Physics 20 General Outcome D2 *Students will* will describe the properties of mechanical waves and explain how mechanical waves transmit energy.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- describe mechanical waves as particles of a medium that are moving in simple harmonic motion
- state that the particles in the medium oscillate, but do not experience a net displacement
- define “transverse” and “longitudinal” waves
- define (as they apply to waves):
  —wavelength
  —period
  —frequency
  —wave front
  —wave velocity
  —medium
- solve for any variable in $v = f\lambda$
- state that the speed of a wave is dependent on the medium
- follow instructions to determine the speed of a mechanical wave
- draw wave-front and ray diagrams
- define “reflection”
- state that reflection is exhibited by mechanical waves
- define “interference”
- follow instructions to demonstrate
  —reflection
  —interference
- state that waves can undergo constructive or destructive interference
- draw a wave-front diagram of a two-point source interference pattern
- follow instructions to demonstrate the phenomenon of acoustic resonance
- describe the Doppler effect for a stationary observer and moving source
- solve for the observed frequency for the Doppler effect using $f = \left(\dfrac{v}{v \pm v_s}\right) f_s$

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- compare and contrast energy transport by matter and by waves
- derive $v = f\lambda$ from uniform motion principles
- predict and justify how the speed and wavelength of a wave will change as the wave changes medium
- design an investigation to determine the speed of a mechanical wave
- design an investigation to demonstrate
  —reflection
  —interference
- design an investigation to demonstrate the phenomenon of acoustic resonance
- predict and justify the conditions for constructive and destructive interference of waves and for acoustic resonance
- solve for the emitted frequency or the speed of the source for the Doppler effect using
  $f = \left(\dfrac{v}{v \pm v_s}\right) f_s$

Physics 20 General Outcome D2 *Students will* will describe the properties of mechanical waves and explain how mechanical waves transmit energy.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- identify a technology that provides a solution to a practical problem
- work collaboratively in a group
- take a positive leadership role in group activities
- state measured values and calculated values with appropriate significant digits

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explicitly communicate the relationship between technologies and practical problems and evaluate the degree to which a problem is solved by a particular technology
- volunteer a connection between the real world and the classroom activity

Physics 30 General Outcome A1 *Students will* explain how momentum is conserved when objects interact in an isolated system.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- state that momentum is equal to the product of mass times velocity
- define “vector”
- define “scalar”
- define “magnitude”
- classify momentum and velocity as vector quantities
- classify mass as a scalar quantity
- solve for any variable in $\vec{p} = m\vec{v}$
- relate SI units to physics quantities:
  $\vec{p}$ in N·s or kg·m/s
  m in kg
  $\vec{v}$ in m/s or in km/h
- state that the impulse of an object is equal to the change in its momentum
- classify impulse as a vector quantity
- classify force as a vector quantity
- classify acceleration as a vector quantity
- classify time as a scalar quantity
- define “time interval”
- classify speed as a scalar quantity
- solve for the magnitude of any variable in
  impulse = $\Delta\vec{p}$
  impulse = $m\Delta\vec{v}$ (v_i or $v_f = 0$ m/s)
  impulse = $\vec{F}_{net}\,\Delta t$ ($t_i = 0$ s)
- relate SI units to physics quantities:
  impulse in N·s or in kg·m/s
  F in N or in kg·m/s^2 or in $\frac{\text{J}}{\text{m}}$
  a in m/s^2
  t, Δt in s, or in h, or in min, or in a
- state that area under a F_{net} vs t graph is equal to the impulse
- determine simple areas (e.g., two rectangles or two triangles or a trapezoid; also all positive area or all negative area)
- determine impulse using the area of a F vs t graph
- use delta notation appropriately
- follow instructions and collect data using available equipment or computer simulation
  —measure distances and calculate speed and momentum from timed images (strobe photography, motion sensors, ticker-tape timer, etc.)
- identify a situation in which impulse is important

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- derive formulas for impulse from Newton’s third law $\left(\vec{F}_{AB} = -\vec{F}_{BA}\right)$ and Newton’s second law ($\vec{F} = m\vec{a}$) and kinematics formulas for acceleration
- solve for any variable, both v_i and $v_f \neq 0$, in
  impulse = $\Delta\vec{p}$
  impulse = $m\Delta\vec{v}$
  impulse = $\vec{F}\Delta t$
- determine complex areas
- use the area of a F vs t graph to solve for some other physics quantity (e.g., $\vec{v}_i$ or $\vec{v}_f$ or m)
- show understanding of what *positive* area and *negative* area mean
- design an experiment to determine the relationship between impulse and change in momentum
- explain analysis of experimental observations
- unit derivations
- explain STS/safety applications that address the importance of impulse

Physics 30 General Outcome A1 — *Students will* explain how momentum is conserved when objects interact in an isolated system.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- recall "isolated system" (P20 C2)
- define "conserved"
- state that momentum is conserved in an isolated system
- follow instructions and collect data using available equipment or a computer simulation for collisions:
  - — linear hit and bounce
  - — linear hit and stick
  - — linear explosions
  - — two objects moving toward each other at 90°, and hit and stick
  - —one object scattering off a stationary object with the angle between the paths after the collision being 90°
- define perpendicular components
- determine *x*- and *y*-components given the net vector's direction and magnitude
- determine any variable in a linear conservation of momentum situation
- determine one speed in a 2-D conservation of momentum 90° situation
- determine one rectilinear component or the resultant given one or more sides and/or angle
- draw vector addition diagrams for linear or 2-D interactions
- classify energy as scalar
- define "elastic collision"
- define "inelastic collision"
- solve for any variable in $E_k = \frac{1}{2}mv^2$
- determine ΣE_{k_i}, ΣE_{k_f} for up to two moving objects
- use E_k values to classify collisions
  - — $\Sigma E_{k_i} = \Sigma E_{k_f}$ means elastic
  - — $\Sigma E_{k_i} > \Sigma E_{k_f}$ means inelastic
- relate SI units to physics quantities: E in J or in kg·m^2/s^2 or in N·m
- use delta notation appropriately
- work cooperatively in a group
- take a positive leadership role in group activities

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- predict and explain whether or not momentum will be conserved given a description of a system
- design an experiment or investigation to investigate the conservation of momentum in a 2-D hit and bounce where one or both $v_i \neq 0$
- explain the analysis of experimental observations
- make measurements to the appropriate significant digits based on the precision of the instruments used
- evaluate quality of experimental results including discrepant or unexpected results
- analyze 2-D interactions
  - —two objects moving toward each other at an angle other than 90°, and hit and stick, or hit and bounce
  - —one object scattering off a stationary object with the angle between the paths after the collision being other than 90°
  - —explosions involving three objects
- draw scale vector diagrams
- explain vector analysis
- solve for any variable (not needing systems of equations or the quadratic formula) using the concept that in an elastic collision, $\Sigma E_{k_i} = \Sigma E_{k_f}$
- explain what has happened in terms of the work done by non-conservative forces to the E_{k_i} in an inelastic collision
- predict and explain whether or not kinetic energy will be conserved given a description of a collision
- compare and contrast the conservation of momentum and kinetic energy during any collision
- volunteer a connection between the real world and the classroom activity

Physics 30 General Outcome B1 *Students will* explain the behaviour of electric charges using the laws that govern electrical interactions.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• state that charge is conserved • state that there are two types of charge • state that neutral is not a type of charge • solve for charge remaining when identical conductors are touched • relate SI units to physics quantities: q in C or in μC	
• state that like charges repel and unlike charges attract • given the nature of the charges, predict attraction/repulsion • given attraction/repulsion, predict the nature of the charges	• given the attraction/repulsion of several objects, determine types of charge • explicitly communicate the analysis of experimental observations (for example, why attraction shows charges are oppositely charged or one is neutral and the other is charged)
• define “conduction” • define “induction” • state that any charge movement in solids involves only electrons • define “grounding” • state that producing a permanent charge by charging by conduction produces similarly charged objects • state that producing a permanent charge by charging by induction produces oppositely charged objects • state that charging by friction produces oppositely charged objects	
• predict the nature of charge on an object after a step-by-step process of charging (either conduction only or induction (with grounding) only) • follow instructions using available equipment or a computer simulation to conduct an investigation of induction/conduction	• predict and justify the nature of charge on an object after a multi-step process containing a combination of conduction and induction (with or without grounding) • explain processes of induction and conduction (describe what is being transferred and why)
• define “insulator” • define “conductor”	
• describe charge distribution on the surface area of a regularly shaped conductor • describe charge distribution on the surface of an insulator	• explain the charge distribution on the surface of an irregularly-shaped conductor

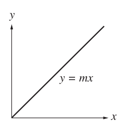
Physics 30 General Outcome B1 *Students will* explain the behaviour of electric charges using the laws that govern electrical interactions.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

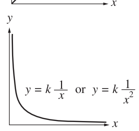
- identify diagrams of apparatus
  —Coulomb's torsion balance
  —Cavendish's torsion balance
- identify the significance of the Coulomb torsion balance experiments
- identify manipulated, responding, and controlled variables given the analysis and procedure or apparatus
- follow instructions and collect data using available equipment or a computer simulation to demonstrate relationships among variables in Coulomb's law
- state result:
  $F_{\mathrm{e}} \propto q$
  $F_{\mathrm{e}} \propto \frac{1}{r^2}$
- match graph shape with mathematical relationship:

  e.g.,

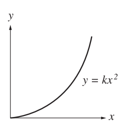
  $y \propto x \Rightarrow$



  $y \propto \frac{1}{x}$
  $y \propto \frac{1}{x^2}$ $\Rightarrow$



  $y \propto x^2 \Rightarrow$



- plot given data and draw line of best fit (straight or curve)
- determine slope of linear graph
- use delta notation appropriately
- draw scale or approximate free-body diagram (FBD), given the significant forces
- solve for $\left|\vec{F}_{\mathrm{e}}\right|$, q_1, q_2 in $\left|\vec{F}_{\mathrm{e}}\right| = \frac{kq_1q_2}{r^2}$
- solve for any variable in
  $\vec{F}_{\mathrm{net}} = m\vec{a}$ where $\vec{F}_{\mathrm{net}} = \vec{F}_{\mathrm{e}}$
- relate SI units to physics quantity:
  k in $\frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- describe the method followed by Coulomb
  —manipulate q
  —manipulate r
  —use twist to infer F
- design experiment given hypothesis
  or
  from design, determine valid hypothesis
- explicitly communicate the relationship between graph shape and mathematical model
- use graph shape to manipulate data to produce a linear graph
  or
  use graph shape and a calculator to determine best-fit regression
- explain analysis of experimental results
- make measurements to the appropriate significant digits based on the precision of the instruments used
- evaluate the quality of experimental results, including discrepant or unexpected results
- identify significant forces and draw corresponding FBD
- analyze the effect of changing one or more variables in Coulomb's law on the force ($F_{\mathrm{e\ old}} : F_{\mathrm{e\ new}}$)
- solve for r in $\left|\vec{F}_{\mathrm{e}}\right| = \frac{kq_1q_2}{r^2}$
- solve for q when they are multiples of each other (e.g., $q_1 = 2q_2$)
- derive units for k

Physics 30 General Outcome B1 ***Students will*** **explain the behaviour of electric charges using the laws that govern electrical interactions.**

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• determine direction of F_e given types of charge for charges in a line or plane with a right angle • sketch FBD showing electrostatic forces • sketch vector addition diagram for linear and 2-D analysis for perpendicular vectors • state that net force equals the sum of the forces acting • determine the net force on one charge that is the resultant of two collinear forces (e.g., three charges in a line) • state $F_g \propto \frac{1}{r^2}$	• analyze 2-D situations: —use of components —use of sine law/cosine law ($\theta \neq 90°$) —more than three charges —find a variable other than $\Sigma\vec{F}$ for three charges with $\theta = 90°$
• solve for $\lvert\vec{F}_g\rvert$, m_1, m_2 in $\lvert\vec{F}_g\rvert = \frac{Gm_1m_2}{r^2}$	• determine ratios $F_g : F_e$ or $F_{g\ old} : F_{g\ new}$ given a change in one or more variables or without a value for r
• determine $\vec{F}_g$ and $\vec{F}_e$ for two subatomic particles	• solve for r in $\lvert\vec{F}_g\rvert = \frac{Gm_1m_2}{r^2}$
• sketch FBD showing gravitational forces • determine the net gravitational force that is the resultant of two collinear forces (e.g., three masses in a line)	
• relate SI units to physics quantities: G in $\frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}$	• derive units for G
• identify an example that illustrates the relationship between technological advances and scientific discovery • identify that concepts, models, or theories are used to interpret and explain observations, and to predict possible observations • work cooperatively in a group • take a positive leadership role in group activities	• explain how technological advancement has led to scientific discovery or vice versa • volunteer a connection between the real world and the classroom activity

Physics 30 General Outcome B2 — *Students will* describe electrical phenomena using the electric field theory.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- define "force"
- define "vector field"
- compare forces and fields (i.e., forces exist, fields are a way of explaining observations)
- relate SI units to physics quantities:
  $\vec{E}$ in N/C or in V/m
  $\vec{g}$ in N/kg or in m/s^2
- define "work"
- use notations $\vec{E}$ for electric field and E for energy correctly
- state that change in gravitational potential energy is the result of a gravitational force acting over a distance parallel to a gravitational field
- state that change in electric potential energy is the result of an electric force acting over a distance parallel to an electric field
- define "electric potential difference"
- solve for any variable in $\Delta V = \frac{\Delta E}{q}$ or $|\vec{E}| = \frac{\Delta V}{\Delta d}$
- relate SI units to physics quantities:
  V in or $\frac{\text{J}}{\text{C}}$ or in $\frac{\text{N·m}}{\text{C}}$
- follow instructions and collect data using available equipment or a computer simulation to measure potential difference between a variety of locations in an electric field
- determine $|\vec{E}|$, q, $|\vec{F}|$ in $\vec{E} = \frac{\vec{F}_e}{q}$ or $|\vec{E}| = \frac{kq}{r^2}$
- define "test charge"
- state that the direction of $\vec{E}$ is defined as the direction of the electrostatic force on a positive test charge
- determine direction of $\vec{E}$ given nature of charges
- determine $\vec{E}$ direction at a point collinear with two charges or at 90° to the two charges
- state that $\vec{E}$ inside a conductor is zero
- draw an electric field around a point source (positive or negative)
- draw electric field created by two point sources (like or unlike but equal in magnitude)

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explicitly communicate that for a system to have an increase in potential energy, the force that does work is in the opposite direction to that of the force associated with the system
- explain why an increase in gravitational potential energy requires an object to be moved farther from the source of the field, whereas an increase in electric potential energy could require a position closer to or farther from the source of the field
- derive units beyond $\frac{\text{J}}{\text{C}} \left(\frac{\text{N·m}}{\text{C}}, \text{etc.}\right)$
- derive $|\vec{E}| = \frac{\Delta V}{\Delta d}$ from $\vec{E} = \frac{\vec{F}_e}{q}$
- determine ratios $V_{old} : V_{new}$, $|\vec{E}|_{old} : |\vec{E}|_{new}$, $\Delta E_{old} : \Delta E_{new}$
- solve for r in $|\vec{E}| = \frac{kq}{r^2}$
- determine nature of plate polarity given path of moving charged particles and nature of the charge
- use 2-D analysis to determine the $\vec{E}_{net}$ that results from two or more charges where the angle is not 90°

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 30 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

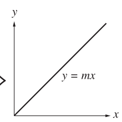
Physics 30 General Outcome B2 *Students will* describe electrical phenomena using the electric field theory.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

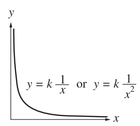
- describe the relationship between field line density and field strength
- draw electric field between oppositely charged parallel plates
- match graph shape with mathematical relationship:

  e.g.,

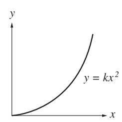
  $y \propto x \Rightarrow$



  $y \propto \frac{1}{x}$
  $y \propto \frac{1}{x^2}$ $\Rightarrow$



  $y \propto x^2 \Rightarrow$



- plot given data and draw line of best fit (straight or curve)
- determine slope of linear graph
- use delta notation appropriately
- define “current”
- solve for any variable in $I = \frac{q}{t}$ with q in coulombs
- classify I, q, and t as scalars
- relate SI units to physics quantities: I in $\frac{\text{C}}{\text{s}}$ or in A
- analyze trajectories of charged particles in uniform electric fields when the initial motion is parallel to the field direction
- determine $\vec{v}_{\text{f}}$ given $v_{\text{i}} \neq 0$ and motion parallel to the direction of a uniform electric field
- describe trajectories of charged particles in uniform electric fields when the initial motion is perpendicular to the field direction
  —classify shape of path as “parabolic trajectory”
  —identify type of motion in horizontal and vertical directions
  —given t and $\vec{v}_{\text{i}}$ or $\vec{v}_{\text{f}} = 0$, calculate d_{x}, d_{y}, etc.
  —solve $|\vec{v}_{\text{f}}| = \sqrt{\left|\vec{v}_{\text{f}_{\text{x}}}\right|^2 + \left|\vec{v}_{\text{f}_{\text{y}}}\right|^2}$

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explicitly communicate the relationship between graph shape and mathematical model
- use graph shape to manipulate data to produce a linear graph
  or
  use graph shape and a calculator to determine best-fit regression
- explain analysis of experimental results
- evaluate the quality of experimental results, including discrepant or unexpected results
- solve for any variable in $I = \frac{q}{t}$ with q in number of charged particles
- analyze trajectories of charged particles in uniform electric fields when the initial motion is perpendicular to the field direction
  —solve for time when $\vec{v}_{\text{i}}, \vec{v}_{\text{f}} \neq 0$
  —solve for any variable in $v_{\text{f}} = \sqrt{\left|\vec{v}_{\text{f}_{\text{x}}}\right|^2 + \left|\vec{v}_{\text{f}_{\text{y}}}\right|^2}$
  and $\theta = \tan^{-1}\frac{\left|\vec{v}_{\text{f}_{\text{y}}}\right|}{\left|\vec{v}_{\text{f}_{\text{x}}}\right|}$, with the added complexity that the directions of the electric field and gravitational field may be perpendicular

Physics 30 General Outcome B2 *Students will* describe electrical phenomena using the electric field theory.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- state that energy is conserved in electric fields
- solve for v using $\Delta E = \frac{1}{2}mv^2 = \Delta Vq$ or $\Delta E = F_e d \cos\theta$, $\theta = 0°$ or $180°$ with $\vec{v}_i$ or $\vec{v}_f = 0$
- given t, calculate ΔE_k, ΔE_p, with $\vec{v}_i$ or $\vec{v}_f = 0$
- convert energy values between units of eV and J
- describe the Millikan oil-drop experiment
  —identify the relevant forces
  —describe the procedure
  —describe the analysis
  —describe the key results
- solve for any variable beginning with $\left|\vec{F}_g\right| = \left|\vec{F}_e\right|$ using $mg = \frac{\Delta Vq}{\Delta d}$ or $\left|\vec{E}\right|q$
- state that charge is quantized
- state that elementary charge, e, is 1.60×10^{-19} C
- select from a list of apparatus those necessary to perform a given procedure
- match apparatus with procedure
  —Millikan oil-drop apparatus
- match procedure or apparatus with possible measurements
- sketch FBD for balanced and unbalanced forces for a charged object in a uniform electric field
- draw vector addition diagrams for balanced and unbalanced forces
- work cooperatively in a group setting
- take a positive leadership role in a group activity
- identify a technology that solves a practical problem

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- solve for any variable when $\vec{v}_i$ or $\vec{v}_f \neq 0$
- use conservation of energy where ΔE
  $= \frac{1}{2}m\left(v_f^2 - v_i^2\right)$
  $= \Delta Vq$
  $= \vec{F}_e d$ or $= \vec{E}qd$
  $= \vec{F}_e d \cos\theta$ for $\theta \neq 0°, 180°$
- explicitly communicate how ΔE could increase or decrease E_k or E_p
- solve for any variable beginning with $\vec{F}_{net} \neq 0$
- determine the number of elementary charges present
- explain the significance of the results of Millikan's oil-drop experiment
- given procedure and apparatus, justify the selection of replacement apparatus to make **better** measurements
- for a given procedure, select the best apparatus
- for specified measurements, select the best procedure
- given procedure and measurements, evaluate quality of support for the conclusion (e.g., systemic error, forgetting to control environment, etc.)
- explain how a technology solves a practical problem
- explore the relationship between technology, knowledge, and scientific discovery
- volunteer a connection between the real world and the classroom activity

Physics 30 General Outcome B3 *Students will* explain how the properties of electric and magnetic fields are applied in numerous devices.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• sketch magnetic fields (two magnetic poles, like or unlike, of equal magnitude) • define "magnetic field" • define "test object" • state that like magnetic poles repel and unlike magnetic poles attract • predict attraction or repulsion based on magnetic polarity • relate field line density to field strength • relate SI units to physics quantities: $\vec{F}_{\mathrm{m}}$ in N $\vec{B}$ in T • state that the direction of a magnetic field is defined as the direction of the force on a "N" pole at that location • determine direction of magnetic field given the polarity of the source • state sources for different field types: —gravitational field is mass —electric field is a stationary charge —magnetic field is moving charges • identify test object for each type of field • state direction for each type of field	• determine magnetic polarity based on interactions
• state that electricity and magnetism are related • state that a conductor in a changing magnetic field will have an electric potential difference induced • state that a changing magnetic field induces an electric field • follow instructions using available equipment or a computer simulation to observe a magnetic force on a current-carrying conductor, an induced current, or an induced electric potential difference • use a hand rule to determine the direction of the induced magnetic field around a current-carrying wire, or the direction of charge motion, or the nature of the charge	• show how discoveries lead to the relating of electricity and magnetism • design an experiment and identify required apparatus to observe (measure) a magnetic force on a current-carrying conductor or an induced current or electric potential difference
• use a hand rule to determine the direction of the magnetic field, the direction of the magnetic force, the direction of motion, or the nature of the charge	• describe the use of a hand rule to determine any of the magnetic field direction, magnetic force direction, velocity, or nature of charge

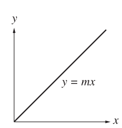
Physics 30 General Outcome B3 *Students will* explain how the properties of electric and magnetic fields are applied in numerous devices.

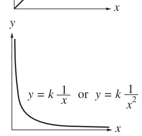
Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

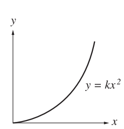
- solve for any variable in $|\vec{F}_{\mathrm{m}}| = |\vec{B}|v_{\perp}q$
- state that a force perpendicular to the direction of motion causes circular motion (constant speed, changing velocity)
- state that when the directions of the velocity of a charged particle and the magnetic field are parallel, the magnetic force is zero
- draw FBD of forces on a charge moving, without deflection, through perpendicular electric and magnetic fields
- given that the electric force is balanced by the magnetic force, calculate any variable
- solve for any variable in $|\vec{F}_{\mathrm{m}}| = Il_{\perp}|\vec{B}|$
- given that the magnetic force is balanced by the gravitational force, solve for any variable
- relate SI units to physics quantities:

  $\vec{B}$ in $\dfrac{\mathrm{N{\cdot}s}}{\mathrm{C{\cdot}m}}$, $\dfrac{\mathrm{N}}{\mathrm{A{\cdot}m}}$
- match graph shape with mathematical relationship

  e.g.,

  $y \propto x \Rightarrow$ 

  $y \propto \dfrac{1}{x}$, $y \propto \dfrac{1}{x^2} \Rightarrow$ 

  $y \propto x^2 \Rightarrow$ 

- plot given data and draw line of best fit (straight or curve)
- determine slope of linear graph
- use delta notation appropriately

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- solve for ratios: e.g., $\vec{F}_{\mathrm{m\ new}} : \vec{F}_{\mathrm{m\ old}}$, $\vec{B}_{\mathrm{new}}:\vec{B}_{\mathrm{old}}$ given a change in one or more variables
- explicitly communicate why the speed is constant when the direction of motion and the magnetic field direction are perpendicular
- derive from $\vec{F}_{\mathrm{net}} = m\vec{a} = \vec{F}_{\mathrm{m}}$ whatever is needed for a particular situation in which the directions of the velocity of the charged particle and the magnetic field are perpendicular
- explain why the magnetic force is zero when the velocity and magnetic field are parallel
- design an experiment to demonstrate the effect of a uniform magnetic field on a moving electric charge
- derive equations from force statements for both balanced and unbalanced forces
- derive units

  $\vec{B}$ in $\dfrac{\mathrm{N{\cdot}s}}{\mathrm{C{\cdot}m}}$, $\dfrac{\mathrm{N}}{\mathrm{A{\cdot}m}}$
- derive $|\vec{F}_{\mathrm{m}}| = Il_{\perp}|\vec{B}|$
- solve for any variable in derived equations for an electrical conductor in an external magnetic field (e.g., number of electrons)
- explicitly communicate the relationship between graph shape and mathematical model
- use graph shape to manipulate data to produce a linear graph

  or

  use graph shape and a calculator to determine best-fit regression
- explain analysis of experimental results
- make measurements to the appropriate significant digits based on the precision of the instruments used
- evaluate the quality of experimental results, including discrepant or unexpected results

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 30 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 30 General Outcome B3 *Students will* explain how the properties of electric and magnetic fields are applied in numerous devices.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• work cooperatively in a group • take a positive leadership role in a group activity	
• identify a relationship between concepts, models, theories, and observations	• explain how concepts, models, and theories affect and are affected by observations
• identify risks and benefits of a technological solution to a practical problem • research risks and benefits	• show initiative when exploring risks and benefits
• identify a technology that solves a practical problem	• explain how a technology provides a solution to a practical problem • explore the relationships among technology, knowledge, and scientific discovery • volunteer a connection between the real world and the classroom activity

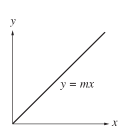
This list is a description of behaviours that illustrate performance at particular standards based on the Physics 30 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

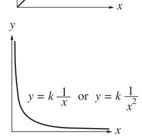
Physics 30 General Outcome C1 *Students will* explain the nature and behaviour of EMR using the wave model.

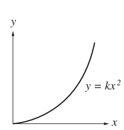
Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- state that all accelerating charges produce electromagnetic radiation
- classify the regions of the electromagnetic spectrum by λ or f
- state that the direction of EMR propagation is perpendicular to the changing electric field and to the changing magnetic field
- state that the speed of EMR in a vacuum is 3.00×10^8 m/s
- identify the need to measure d and t to determine v
- identify the need for a large distance and long time intervals for accurately determining the speed of EMR
- describe a method that could be used to determine the speed of EMR
- starting with $c = 2dnf$, solve for any variable for a single round trip
- observe and describe reflection off a plane surface
- state $\theta_i = \theta_r$, measured to the normal
- determine $\theta_i = \theta_r$, for one or two reflections from parallel plane surfaces or plane surfaces at 90º
- observe and describe refraction at a planar interface
- define refraction as the change in direction caused by a change in medium
- calculate any variable in $\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$
- follow instructions and collect data using available equipment or a computer simulation to determine an index of refraction
- match graph shape with mathematical relationship

  e.g.,

  $y \propto x \Rightarrow$ 

  $y \propto \frac{1}{x}$, $y \propto \frac{1}{x^2}$ $\Rightarrow$ 

  $y \propto x^2 \Rightarrow$ 

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- compare the fields produced by a charged object when it is at rest, travelling with uniform motion, and with accelerated motion
- explain that electromagnetic radiation is self-inducing and that the fields are changing in time
- design an experiment to measure the speed of EMR
- modify design to improve measurements
- explicitly communicate how the modifications will produce more-accurate results (e.g., systemic error, inherent error, etc.)
- derive an equation, using the principle of uniform motion, for the speed of light in terms of d, n, and f for a spinning mirror (light path could include more than one fixed plane mirror)
- explain that refraction is the change in speed that results when moving from one medium to the next, and that causes a change in direction if the incident angle is not zero and is less than the critical angle
- predict, based on calculations, the path of a ray showing refraction and reflection in a series of parallel mediums or in a triangular prism
- design an investigation to determine the index of refraction
- derive a mathematical representation of the law of refraction from empirical data
- explicitly communicate the relationship between graph shape and mathematical model
- use graph shape to manipulate data to produce a linear graph
  or
  use graph shape and a calculator to determine best-fit regression
- explain analysis of experimental results
- evaluate the quality of experimental results, including discrepant or unexpected results

Physics 30 General Outcome C1 *Students will* explain the nature and behaviour of EMR using the wave model.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- plot given data and draw line of best fit (straight or curve)
- determine slope of linear graph
- use delta notation appropriately
- trace a ray from one medium into another, labelling angles
- observe total internal reflection
- define θ_c
- determine θ_c when the second medium is air; i.e., $\theta_c = \sin^{-1}\left(\frac{1}{n_1}\right)$
- draw a scale ray diagram for a single convex or concave thin lens, or convex mirror to determine magnification d_i, d_0, h_i, or h_0
- use ray diagram to determine characteristics of image
- solve for any variable in $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$
- solve for any variable in $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$
- observe and describe reflection from curved surface
- observe and describe refraction by a curved lens
- follow instructions and collect data using available equipment or a computer simulation to determine *f* for a curved mirror or lens
- define "diffraction"
- state that diffraction provides evidence that supports wave nature
- define "polarization"
- state that polarization provides evidence that supports the transverse nature of waves
- predict the conditions necessary to produce refraction and diffraction
- state that the result of the double-slit experiment is an interference pattern
- state that results of the double-slit experiment support the wave nature of light (electromagnetic radiation)

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explain the significance of $\sin\theta_2 > 1$
- derive formula for θ_c
- determine critical angle when the second medium is **not** air; i.e., $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$
- predict conditions necessary for total internal reflection to occur
- use sign convention to interpret results in terms of virtual, real, inverted, or erect image
- evaluate properties of reflection, refraction, diffraction, and polarization in terms of support for wave model
- explain interference in terms of the principle of superposition
- compare the particle model with the wave model in terms of the observations of a double-slit experiment for each of the following situations:
  —light is a wave with a wavelength smaller than the slit separation
  —light is a wave with a wavelength larger than the slit separation
  —light is a stream of particles with a particle diameter smaller than the slits
  —light is a stream of particles with a particle diameter larger than the slits

Physics 30 General Outcome C1 *Students will* explain the nature and behaviour of EMR using the wave model.

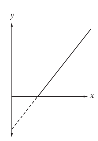
Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• observe and describe visible spectrum created by a diffraction grating • solve for any variable in $\lambda = \frac{xd}{nl} = \frac{d \sin \theta}{n}$ assuming the small-angle approximation to be valid • collect data using available equipment or a computer simulation to determine wavelength of EMR in air or another medium • follow instructions and collect data using available equipment or a computer simulation to determine the speed of EMR in a medium other than air or a vacuum • follow directions using available equipment or a computer simulation to observe the effect on x of changing λ, d, or l • observe and describe visible spectrum produced by prism • state order of visible light by λ or f and by colour • state that blue is more affected by refraction • state that red is more affected by diffraction • work cooperatively in a group • take a positive leadership role in a group activity	• use line density $\left(\frac{1}{\text{slit separation}}\right)$ for diffraction grating • use valid analysis for angles larger than 10° • determine ratios $\lambda_{\text{new}} : \lambda_{\text{old}}$, etc. given a change in one or more variables • explain why, in refraction, the change in speed means change in λ because frequency is a function of source • design an experiment to measure the speed of electromagnetic radiation in a medium other than air or a vacuum • predict and explain the relative locations of colours in a spectrum produced by refraction or diffraction (different index values for different λ; wavelength dependence)
• identify an occurrence when scientific knowledge or theory changed as a result of observations	• explain how new evidence requires scientific knowledge and theories to change • explore the relationships between technology, knowledge, and scientific discovery • relate physics content to personal experience • volunteer a connection between the real world and the classroom activity

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 30 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

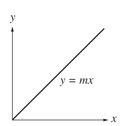
Physics 30 General Outcome C2 *Students will* explain the photoelectric effect using the quantum model.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

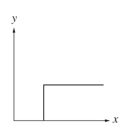
- define "photon"
- calculate any variable in
  $E = hf$
  $E = \frac{hc}{\lambda}$
- relate SI units to physics quantities:
  h in J·s and in eV·s
  E in eV or in J
- classify the regions of the electromagnetic spectrum by energy (in eV or J)
- state that the photoelectric effect occurs when incident frequency is greater than the threshold frequency or when the incident wavelength is shorter than the threshold wavelength or when the incident energy is greater than the work function
- state that intensity of incident light affects number of photoelectrons
- state that every photoelectric surface emits the same type of particle
- recognize graphs of photoelectric effect
  —maximum kinetic energy (or stopping voltage) as a function of frequency



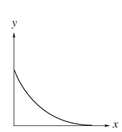
  —photocurrent as a function of intensity



  —photocurrent as a function of frequency



  —photocurrent as a function of stopping voltage



Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- determine number of photons in a beam given energy in J or eV or time and power in J/s
- compare mechanical waves with photons (e.g., energy distribution, amplitude versus number of photons, etc.)
- compare actual experimental results with expected (classical) results
- explain how observations support the quantum explanation of the photoelectric effect
- predict effect on photoemission when intensity, wavelength, frequency, or work function is changed
- design investigation and describe analysis for determining work function, threshold frequency, Planck's constant, stopping voltage, maximum speed, etc.
- explicitly communicate the relationship between graph shape and mathematical model
- use graph shape to manipulate data to produce a linear graph
  or
  use graph shape and a calculator to determine best-fit regression
- explain how graph shapes support the quantum explanation of photoelectric effect
- evaluate the quality of experimental results, including discrepant or unexpected results

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 30 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 30 General Outcome C2 *Students will* explain the photoelectric effect using the quantum model.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	**Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:**
• describe an apparatus and the observations which led to the discovery of the photoelectric effect —Hertz's apparatus • match apparatus with procedure —Millikan's cathode tube with variable electric potential, etc. • match effect of change in frequency on the kinetic energy of photoelectric electrons and/or on the photoelectric current (graphically or verbally) • match effect of change in intensity on the kinetic energy of photoelectric electrons and/or on the photoelectric current (graphically or verbally) • follow instructions and collect data using available equipment or a computer simulation • plot given data and draw line of best fit (straight or curve) • determine slope of linear graph • use delta notation appropriately	
• solve for any variable in $W = h f_0$ • solve for any variable in $E_{\mathrm{k\ max}} = V_{\mathrm{stop}}\, q$ • relate SI units to physics quantities: W in eV or in J • perform graphical analysis of photoelectric effect observations —use y-intercept to find the work function —use x-intercept to get f_0 —use slope to get a value for h	• use conservation of energy to calculate any variable (v_{f}, λ, λ_0, f_0, h, etc.) • solve for v_{max} from λ, λ_0 • describe changes to procedure or apparatus to improve accuracy of results
• state that the photoelectric effect supports the particle nature of electromagnetic radiation	• explicitly communicate how the observations of the photoelectric effect contradict the classical wave model (i.e., a wave model does not predict the near instantaneous emission when $f > f_0$ nor that there is no change in maximum energy regardless of the brightness of the light)
• define "wave-particle duality" • state that the Compton effect supports the particle nature of electromagnetic radiation • state that a particle nature shown by a photon is momentum • solve for any variable in $p = \frac{E}{c}$, $p = \frac{h}{\lambda}$	• summarize the development of physicists' understanding of the model of electromagnetic radiation

Physics 30 General Outcome C2 *Students will* explain the photoelectric effect using the quantum model.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- solve for $\Delta\lambda$ in $\Delta\lambda = \frac{h}{mc}(1 - \cos\theta)$
- state that energy and momentum are conserved in Compton scattering
- determine $\Sigma E_{k_i} = E_{photon} = pc$

  $\Sigma E_{k_f} = E_{photon} + E_{electron}$

  $= pc + \frac{1}{2}mv^2$

  for $v < 0.1c$
- classify elastic collisions based on conservation of (kinetic) energy
- draw vector addition diagrams for 2-D situations
- work cooperatively in a group
- take a positive leadership role in a group activity
- identify an instance in which scientific theory developed as a result of observation and exploration
- identify a concept, model, or theory that interprets, predicts, or explains observations
- identify a technology that solves a practical problem

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- determine θ, $\lambda_{incident}$, $\lambda_{scattered}$ in $\Delta\lambda = \frac{h}{mc}(1 - \cos\theta)$
- use conservation of momentum and conservation of energy to analyze 2-D Compton scattering for non-relativistic electrons
- explore the relationships between scientific knowledge, theories, hypotheses, observations, experimentation, and explanations
- explain how models and theories evolve as a result of observations
- explain how a technology solves a practical problem
- volunteer a connection between the real world and the classroom activity

Physics 30 General Outcome D1 *Students will* describe the electrical nature of the atom.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- recall that charge comes in discrete positive or negative pieces (30–B2.10k)
- state that positive charge is located in the nucleus in the form of protons
- state that cathode rays are emitted from a cathode
- state that as a result of the existence of cathode rays, the model of the atom changed from an indivisible "billiard ball" to a plum pudding/raisin bun model
- match apparatus with results
  —J.J. Thomson cathode ray tube with electric and/or magnetic fields
- describe the procedure followed by J.J. Thomson to determine the charge-to-mass ratio for the electron
- identify manipulated variable and responding variable
- state that cathode rays are deflected by electric fields and by magnetic fields, and therefore are charged
- solve for $\frac{q}{m}$, v, B, or r, starting with $\frac{q}{m} = \frac{v}{Br}$
- state that cathode rays consist of electrons
- determine m_e
- sketch FBD for situations in which the forces are balanced or unbalanced
- identify electron, proton, and alpha particles based on charge-to-mass ratio
- state that the quality of observations is affected by the procedure used to collect them
- follow instructions and collect data using available equipment or a computer simulation to determine the charge-to-mass ratio of an electron
- match apparatus with results
  —Rutherford alpha-particle scattering
- state that as a result of the scattering of alpha particles, the atomic model changed to a planetary/nuclear model
- state that the nucleus is
  —very dense, very small, and contains most of the mass of the atom
  —positively charged and significantly smaller than the atom
- state that the atom is
  —electrically neutral
- state that electrons exist outside of the nucleus

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explain that cathode rays are particles common to all types of matter
- describe analysis of experimental results that give experimental support that cathode rays are particles with charge and mass
- evaluate the operation of apparatus similar to those used by J.J. Thomson
- identify variables that need to be controlled in an experiment and those that do not because of significance to the physical phenomenon
- derive $\frac{q}{m} = \frac{v}{Br}$ from force statements
- solve for m from $\frac{q}{m}$ for charged particles with q other than $1e$
- identify a particle based on its $\frac{q}{m}$
- explain the significance of the angle of deflection of alpha particles in terms of electrostatic repulsion and distribution of matter within the atom
- summarize the evolution of the model of the atom

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 30 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 30 General Outcome D1 ***Students will*** **describe the electrical nature of the atom.**

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	**Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:**
• work cooperatively in a group	
• take a positive leadership role in a group activity	
• identify a technological advance contributing to scientific discovery or vice versa	• explain the interaction between technological advances and scientific discovery
	• volunteer a connection between the real world and the classroom activity

This list is a description of behaviours that illustrate performance at particular standards based on the Physics 30 Program of Studies. This list is neither prescriptive nor exhaustive. This document is NOT the PROGRAM OF STUDIES.

Physics 30 General Outcome D2 *Students will* describe the quantization of energy in atoms and nuclei.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• state that Rutherford's planetary/nuclear model is invalid	• use circular motion principles to explain how if an electron were in a planetary orbit, it would be accelerated, and relate this to the production of electromagnetic radiation to explain why Rutherford's model of the atom is invalid (i.e., planetary orbit = continuous emission. The system should lose energy continuously but does not)
• state that each element has a unique spectrum • identify chemical composition by matching spectra (Sc 9) • match spectrum type with method: continuous spectra are caused by a hot, glowing solid or a hot, glowing liquid or a hot, high-density gas (i.e., anything very energetic with atoms close together); emission spectra are caused by an excited, low-density gas; absorption spectra caused by passing a continuous spectrum through cool, low-density gas • match spectra with characteristics: continuous spectra contain all wavelengths; a bright-line (emission) spectrum contains selected wavelengths; a dark-line (absorption) spectrum contains all but selected wavelengths • observe and describe each spectrum type • define "stationary state"	
• state that an electron making a transition to a higher energy level results in a dark-line spectrum • state that an electron making a transition to a lower energy level results in a bright-line spectrum • draw arrows in a given energy level diagram showing electron transition to produce an emission or an absorption spectrum	• explain that a dark line in an absorption spectrum is just fainter than the rest of the spectrum; the low-energy material in the way gets excited, then re-emits the energy, but this re-emission is in every direction, so only a very small amount continues in the initial direction

Physics 30 General Outcome D2 *Students will* describe the quantization of energy in atoms and nuclei.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:
• determine the energy associated with a given electron transition based on a given energy level diagram • determine ΔE of an atom or molecule from λ or f of emitted or absorbed photon in eV and J • determine λ or f from ΔE • describe the relationships between photon energy, electron energy-level transition, and type of spectra produced	• use conservation of energy to determine the energy of the initial or final energy level (without an energy level diagram being given) given λ and one of E_f, E_i (eV and J) or any other unknown • label energy levels in energy-level diagrams • construct an energy-level diagram or model given experimental observations • explain the relationships between photon energy, electron energy-level transition, and type of spectra produced
• recall that diffraction gives support for wave nature (30–C1.7k) • state that the diffraction of electrons provides evidence that supports electrons having wave properties • state that when electrons are sent one at a time through a two-slit apparatus, an interference pattern is produced • work cooperatively in a group • take a positive leadership role in group activities	• explicitly communicate how electron and/or photon diffraction and interference provide support for wave-particle duality • explicitly communicate why the concept of wave-particle duality is counterintuitive
• identify a technological advance contributing to scientific discovery or vice versa	• explain the interaction between scientific discovery and technological advance • volunteer a connection between the real world and the classroom activity

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Physics 30 General Outcome D3 *Students will* **describe nuclear fission and fusion as the most powerful energy sources in nature.**

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- identify characteristics of α, β^+, β^-, and γ radiation
- state minimum shielding requirements in terms of penetrating ability
- research ionizing versus non-ionizing radiation
- rank the types of radiation by their ability to ionize
- balance decay equations for α, β^+, β^- decay; include neutrinos with positron decay and antineutrinos with beta negative decay
- state that A is mass number, and Z is atomic number in ${}^{A}_{Z}X$ isotope notation
- determine any one of element, number of protons, neutrons, atomic mass, isotope, notation from periodic table or isotope notation
- state that isotopes are atoms of the same elements (i.e., the number of protons is the same but the number of neutrons is different)
- balance decay equations given either isotope notation or isotope nomenclature
- analyze an incomplete decay chain by
  —identifying the type of decay
  —determining a daughter nucleus
  —determining a mother nucleus
- solve for any variable in $N = N_0\left(\frac{1}{2}\right)^n$, where n is a positive integer
- determine t or $t_{1/2}$ with $n = \frac{t}{t_{1/2}}$
- follow instructions and collect data using available equipment or a computer simulation to determine half-life
- plot data and draw curve
- estimate half-life from graph of amount (or activity, etc.) as a function of time
- define “fission”
- define “fusion”
- define “mass defect”
- state that nuclear reactions release more energy per unit mass than chemical reactions do
- state that energy is released in a nuclear reaction when the total measurable mass decreases
- state that mass-energy is conserved
- predict initial or final mass based on “energy in” (endothermic) or “energy out” (exothermic) situations

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- explain the use of conservation laws in balancing decay equations
- explain why the matter and antimatter pairs (e.g., positron and neutrino, electron and antineutrino) must be produced
- compare relative amounts of daughter nuclei in a decay chain
- determine N, N_0 with $n = \frac{t}{t_{1/2}}$, where n is a positive rational number
- use averaging to determine half-life from graph
- determine released energy per unit of reactant (i.e., per kilogram, atom, nucleon, etc.)

Physics 30 General Outcome D3 *Students will* describe nuclear fission and fusion as the most powerful energy sources in nature.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- determine ΔE or Δm from $\Delta E = \Delta mc^2$
- determine Δm given masses (in kg) of nuclei and particles involved in a nuclear reaction
- relate SI units to physics quantities: mass in eV, J, $\frac{\text{eV}}{\text{c}^2}$, $\frac{\text{MeV}}{\text{c}^2}$, or in $\frac{\text{J}}{\text{c}^2}$
- identify risks and benefits of a technological solution to a practical problem (e.g., nuclear power plant)

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- determine the energy released in a nuclear reaction given the masses (in kg) of the products and reactants
- volunteer a connection between the real world and the classroom activity
- show initiative in exploring a cost/benefit analysis

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Physics 30 General Outcome D4 — *Students will* describe the ongoing development of models of the structure of matter.

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:

- use a hand rule to determine nature of charge of a subatomic particle given track and magnetic field direction
- define "electromagnetic force"
- define "strong nuclear force"
- define "weak nuclear force"
- rank the four fundamental forces by strength: strong nuclear, electromagnetic, weak nuclear, and gravitational
- state that the nucleus is held together by the strong nuclear force
- relate the energy required to break apart the nucleus to the work that must be done on the nucleus
- define "quark"
- state that protons and neutrons are made up of quarks
- state that electrons are not made up of quarks
- state that electrons are elementary particles
- identify a nucleon using its constituent quarks or vice versa using a chart of quarks and their characteristics
- define "antiparticles"
- compare and contrast electron, positron, electron neutrino, electron antineutrino, up quark, antiup quark, down quark, and antidown quark
- state that β^- decay is caused by a neutron decaying into a proton, an electron, and an antineutrino
- state that β^+ decay is caused by a proton decaying into a neutron, a positron, and a neutrino
- state the quark changes that occur:

  $${}^{1}_{0}\mathrm{n} \rightarrow {}^{0}_{-1}\beta + {}^{1}_{1}\mathrm{p} + \overline{\nu}$$
  udd → beta + uud

  and

  $${}^{1}_{1}\mathrm{p} \rightarrow {}^{0}_{+1}\beta + {}^{1}_{0}\mathrm{n} + \nu$$
  uud → beta + udd

Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:

- use hand rule to explain how to determine nature of charge or direction of magnetic field given the other and the track for subatomic particles
- compare tracks in terms of the mass, charge (size or nature), speed, or energy of the particle
- compare decreasing relative strengths and ranges of effect of the strong nuclear force, the electromagnetic force, the weak nuclear force, and the gravitational force
- relate electric potential difference in particle accelerators to the energy of the incident particle to the energy needed to observe subatomic particles (explain why increasingly larger accelerators will be needed)
- continue the tracing of the evolution of atomic models
- given a chart of quarks and their characteristics, explain how to predict the quarks present in a proton or neutron
- explore current models of the atom
- predict the quarks or antiquarks present in nucleons or hypothetical nucleons

Physics 30 General Outcome D4 ***Students will*** **describe the ongoing development of models of the structure of matter.**

Behaviours of a student functioning at the Acceptable Standard include, but are not limited to, the following:	**Behaviours of a student functioning at the Standard of Excellence include, but are not limited to, the following:**
• work cooperatively in a group • take a positive leadership role in group activities	
• identify a situation in which scientific knowledge changed as a result of new evidence • identify a technological advance that produced a scientific discovery or vice versa	• explain that the goal of science is knowledge about the natural world • explain how concepts, models, or theories are used to explain or predict observations • explain how evidence changes scientific knowledge • explain how a technological advance produced a scientific discovery or vice versa • volunteer a connection between the real world and the classroom activity

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