GRADES 9-12

1a

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know how to solve problems that involve constant speed and average speed.

GRADES 9-12

1b

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law).

GRADES 9-12

1c

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know how to apply the law $F = ma$ to solve one-dimensional motion problems that involve constant forces (Newton's second law).

GRADES 9-12

1d

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).

GRADES 9-12

1e

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth.

GRADES 9-12

1f

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).

GRADES 9-12

1g

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know circular motion requires the application of a constant force directed toward the center of the circle.

GRADES 9-12

1h*

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know Newton's laws are not exact but provide very good approximations unless an object is moving close to the speed of light or is small enough that quantum effects are important.

GRADES 9-12

1i*

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know how to solve two-dimensional trajectory problems.

GRADES 9-12

1j*

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know how to resolve two-dimensional vectors into their components and calculate the magnitude and direction of a vector from its components.

GRADES 9-12

1k*

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know how to solve two-dimensional problems involving balanced forces (statics).

GRADES 9-12

11*

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know how to solve problems in circular motion by using the formula for centripetal acceleration in the following form: $a = v^2/r$.

GRADES 9-12

1m*

Physics: Motion and Forces

Newton's laws predict the motion of most objects. As a basis for understanding this concept:

Students know how to solve problems involving the forces between two electric charges at a distance (Coulomb's law) or the forces between two masses at a distance (universal gravitation).

GRADES 9-12

2a

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know how to calculate kinetic energy by using the formula $E = (1/2)mv^2$.

GRADES 9-12

2b

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know how to calculate changes in gravitational potential energy near Earth by using the formula (change in potential energy) = mgh (*h* is the change in the elevation).

GRADES 9-12

2c

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know how to solve problems involving conservation of energy in simple systems, such as falling objects.

GRADES 9-12

2d

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know how to calculate momentum as the product *mv*.

GRADES 9-12

2e

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know momentum is a separately conserved quantity different from energy.

GRADES 9-12

2f

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know an unbalanced force on an object produces a change in its momentum.

GRADES 9-12

2g

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know how to solve problems involving elastic and inelastic collisions in one dimension by using the principles of conservation of momentum and energy.

GRADES 9-12

2h*

Physics: Conservation of Energy and Momentum

The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

Students know how to solve problems involving conservation of energy in simple systems with various sources of potential energy, such as capacitors and springs.

GRADES 9-12

3a

Physics: Heat and

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

Students know heat flow and work are two forms of energy transfer between systems.

GRADES 9-12

3b

Physics: Heat and

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

Students know that the work done by a heat engine that is working in a cycle is the difference between the heat flow into the engine at high temperature and the heat flow out at a lower temperature (first law of thermodynamics) and that this is an example of the law of conservation of energy.

GRADES 9-12

3c

Physics: Heat and

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

Students know the internal energy of an object includes the energy of random motion of the object's atoms and molecules, often referred to as *thermal energy.* The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object.

GRADES 9-12

3d

Physics: Heat and

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

Students know that most processes tend to decrease the order of a system over time and that energy levels are eventually distributed uniformly.

GRADES 9-12

3e

Physics: Heat and

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

Students know that entropy is a quantity that measures the order or disorder of a system and that this quantity is larger for a more disordered system.

GRADES 9-12

3f*

Physics: Heat and

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

Students know the statement "Entropy tends to increase" is a law of statistical probability that governs all closed systems (second law of thermodynamics).

GRADES 9-12

3g*

Physics: Heat and

Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

Students know how to solve problems involving heat flow, work, and efficiency in a heat engine and know that all real engines lose some heat to their surroundings.

GRADES 9-12

4a

Physics: Waves

Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

Students know waves carry energy from one place to another.

GRADES 9-12

4b

Physics: Waves

Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

Students know how to identify transverse and longitudinal waves in mechanical media, such as springs and ropes, and on the earth (seismic waves).

GRADES 9-12

4c

Physics: Waves

Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

Students know how to solve problems involving wavelength, frequency, and wave speed.

GRADES 9-12

4d

Physics: Waves

Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

Students know sound is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.

GRADES 9-12

4e

Physics: Waves

Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

Students know radio waves, light, and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately 3×10^8 m/s (186,000 miles/second).

GRADES 9-12

4f

Physics: Waves

Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

Students know how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.

GRADES 9-12

5a

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know how to predict the voltage or current in simple direct current (DC) electric circuits constructed from batteries, wires, resistors, and capacitors.

GRADES 9-12

5b

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know how to solve problems involving Ohm's law.

GRADES 9-12

5c

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know any resistive element in a DC circuit dissipates energy, which heats the resistor. Students can calculate the power (rate of energy dissipation) in any resistive circuit element by using the formula Power = IR (potential difference) x I (current) = I^2R.

GRADES 9-12

5d

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know the properties of transistors and the role of transistors in electric circuits.

GRADES 9-12

5e

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know charged particles are sources of electric fields and are subject to the forces of the electric fields from other charges.

GRADES 9-12

5f

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.

GRADES 9-12

5g

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know how to determine the direction of a magnetic field produced by a current flowing in a straight wire or in a coil.

GRADES 9-12

5h

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know changing magnetic fields produce electric fields, thereby inducing currents in nearby conductors.

GRADES 9-12

5i

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know plasmas, the fourth state of matter, contain ions or free electrons or both and conduct electricity.

GRADES 9-12

5j*

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know electric and magnetic fields contain energy and act as vector force fields.

GRADES 9-12 5k*

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know the force on a charged particle in an electric field is qE, where E is the electric field at the position of the particle and q is the charge of the particle.

GRADES 9-12

51*

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know how to calculate the electric field resulting from a point charge.

GRADES 9-12

5m*

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know static electric fields have as their source some arrangement of electric charges.

GRADES 9-12

5n*

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know the magnitude of the force on a moving particle (with charge q) in a magnetic field is qvB sin(a), where a is the angle between v and B (v and B are the magnitudes of vectors v and B, respectively), and students use the right-hand rule to find the direction of this force.

GRADES 9-12

5o*

Physics: Electric and Magnetic Phenomena

Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

Students know how to apply the concepts of electrical and gravitational potential energy to solve problems involving conservation of energy.