Massachusetts Tests for Educator Licensure®

TEST INFORMATION BOOKLET

11 Physics

MA-SG-FLD011-05

Massachusetts Department of Education

Table of Contents

Physics (Field 11)

Test Overview Chart

Sample Test Items

Answer Key and Sample Responses

Test Objectives

Test Overview Chart: Physics (11)

Subareas	Approximate Number of Multiple-Choice Items	Number of Open-Response Items
I. Scientific Inquiry	14–16	2
II. Mechanics and Heat Energy	27–29	
III. Electricity and Magnetism	12–14	
IV. Waves, Sound, and Light	12–14	
V. Quantum Theory and the Atom	10–12	

The Physics test is designed to assess the candidate's knowledge of the subject matter required for the Massachusetts Physics Teacher certificate. This subject matter knowledge is delineated in the Massachusetts Department of Education *Regulations for the Certification of Educational Personnel in Massachusetts* (April 1995), 603 C.M.R. 7.12, "Competencies for Specific Certificates," Section (9) (a) 2. "Competency I: Subject Matter Knowledge."

The Physics test assesses the candidate's proficiency and depth of understanding of the subject at the level required for a baccalaureate major, according to Massachusetts standards. Candidates are typically nearing completion of or have completed their undergraduate work when they take the test.

The multiple-choice items on the test cover the subareas as indicated in the chart above. The open-response items may relate to topics covered in any of the subareas and will typically require breadth of understanding of the physics field and the ability to relate concepts from different aspects of the field. Responses to the open-response items are expected to be appropriate and accurate in the application of subject knowledge, to provide high-quality and relevant supporting evidence, and to demonstrate a soundness of argument and understanding of the physics field.

CONSTANTS

Description	Value
Acceleration of gravity on Earth (g)	9.8 m/s^2
Speed of light in a vacuum (c)	3.00×10^8 m/s
Planck's constant (h)	6.63×10^{-34} J•s = 4.14×10^{-15} eV•s
Electron rest mass	9.11×10^{-31} kg
Proton rest mass	1.67×10^{-27} kg
Charge of electron	-1.60×10^{-19} C
Coulomb's constant (k_e)	9.0×10^9 $N•m^2/C^2$
Boltzmann's constant (k)	1.38×10^{-23} J/K
Gas constant (R)	8.31 J/mol-K
Gravitational constant (G)	6.67×10^{-11} $N•m^2/kg^2$
Permeability of free space (μ_0)	$4\pi \times 10^{-7}$ T•m/A
Avogadro's number	6.02×10^{23} particles/mole

FORMULAS

Description	Formula
Constant acceleration	$v = v_i + at$ $x = x_i + v_i t + \frac{1}{2}at^2$ $v_f^2 - v_i^2 = 2a(x_f - x_i)$
Circular motion	$a = \frac{v^2}{r}$ $\theta = \theta_i + \omega_i t + \frac{1}{2}\alpha t^2$ $\omega = \omega_i + \alpha t$ $v = r\omega$ $a = r\alpha$ $\tau = I\alpha$

FORMULAS (continued)

Description	Formula
Spring	$F = {}^{-}kx$ $PE = \frac{1}{2}kx^2$ $T = 2\pi\sqrt{\frac{m}{k}}$
Pendulum	$T = 2\pi\sqrt{\frac{L}{g}}$
Relativity	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
Speed of sound in an ideal gas	$v = \sqrt{\frac{\gamma RT}{M}}$
Speed of waves in a string	$v = \sqrt{\frac{T}{\mu}}$
Standing wave condition for a string fixed at both ends	$2L = n\lambda$, n is an integer
Standing wave condition for a string fixed at one end	$4L = n\lambda$, n is odd
Optics	$n_1 \sin \theta_1 = n_2 \sin \theta_2$ $n = \frac{c}{v}$ $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$
Thermodynamics	$\Delta U = nC_v \, \Delta T$ $\Delta Q = mc \, \Delta T$ $PV = nRT$ $\frac{1}{2}m\overline{v}^2 = \frac{3}{2}kT$
Fluids	$p = \rho gh$
Magnetism	$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}$ $\boldsymbol{F} = I\ell \times \boldsymbol{B}$ $\oint \boldsymbol{B} \bullet d\ell = \mu_0 I$ $\varepsilon_{\alpha ve} = -\frac{\Delta\phi}{\Delta t}$ $\phi = B_{\perp}A$

FORMULAS (continued)

Description	Formula
Alternating circuit	$\mathcal{E} = -L\frac{dI}{dt}$ $\omega_0 = \frac{1}{\sqrt{LC}}$ $X_L = \omega L$ $X_C = \frac{1}{\omega C}$ $Z = \sqrt{(X_C - X_L)^2 + R^2}$
Photo electric effect	$hf = \phi + eV_s$
Wave-particle relations	$E = hf$ $h = p\lambda$

NOTES FOR PHYSICS TEST

Not all formulas necessary are listed, nor are all formulas listed used on this test.

In questions on electricity and magnetism, the term *current* refers to "conventional current" and the use of the right-hand rule is assumed.

While attention has been paid to significant figures, no answer should be considered incorrect solely because of the number of significant figures.

Sample Test Items: Physics (11)

All examinees taking the Physics test (Field 11) will be provided with a Texas Instruments TI 30X Solar Scientific calculator with functions that include the following: addition, subtraction, multiplication, division, square root, percent, sine, cosine, tangent, exponents, and logarithms. **You may NOT bring your own calculator to the test.**

1. **Use the description of an experiment below to answer the question that follows.**

   Tape a pencil to the edge of a table so that half of the pencil is hanging over the edge. Hang a rubber band on the pencil and attach a paper clip to the bottom of the rubber band. Measure the initial length of the rubber band. Attach a washer to the paper clip and measure the length of the band. Repeat with 2, 3, 4, and 5 identical washers. Graph your results.

   Which of the following is the independent variable in the experiment above?

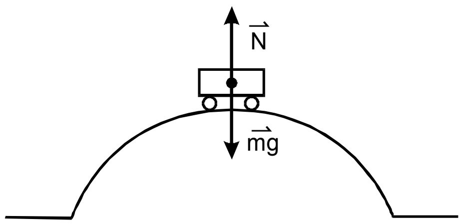
   A. the initial length of the rubber band

   B. the length of the rubber band after each washer is added

   C. the mass of a single washer

   D. the number of washers attached to the paper clip

2. **Use the diagram below to answer the question that follows.**



The diagram shows the forces on a 600 kg car as it moves at 10 m/s over the top of a circular bridge with a radius of 50 meters. What is the magnitude of the normal force on the car at the top of the bridge?

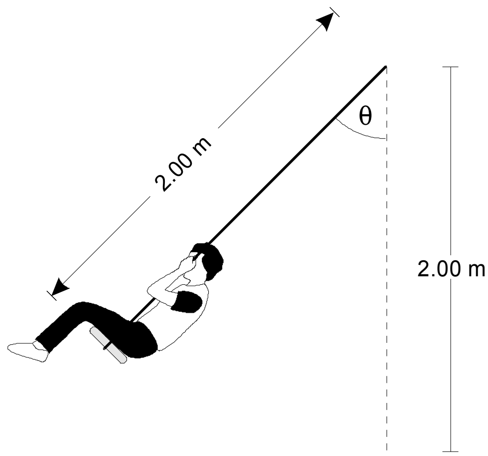
A. 1200 N

B. 4680 N

C. 5880 N

D. 7080 N

3. **Use the diagram below to answer the question that follows.**



The length of each of the ropes on a playground swing is 2.00 m. What is the maximum speed attainable on the swing if the maximum value of θ is 45.0°?

A. 1.41 m/s

B. 2.00 m/s

C. 3.39 m/s

D. 8.85 m/s

4. **Use the information below to answer the question that follows.**

Properties of Aluminum	
Melting Point	660°C
Heat of Fusion	4.0×10^2 J/g
Specific Heat	0.9 J/g°C

The amount of energy needed to produce 1 mole (27 g) of aluminum metal from bauxite ore is 297 kJ. Approximately how much energy could be saved per mole by recycling discarded aluminum (at an initial temperature of 20°C) by melting instead of producing it from bauxite ore?

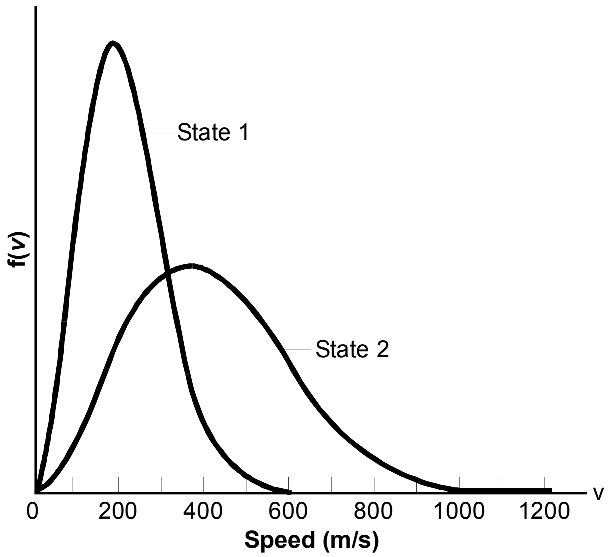
A. 262 kJ

B. 271 kJ

C. 281 kJ

D. 286 kJ

5. **Use the diagram below to answer the question that follows.**



An ideal gas at a constant volume is taken from State 1 to State 2. The diagram above shows the speed distribution curves f(*v*) for the gas in each of the states. Which of the following statements best describes how the gas was taken from State 1 to State 2?

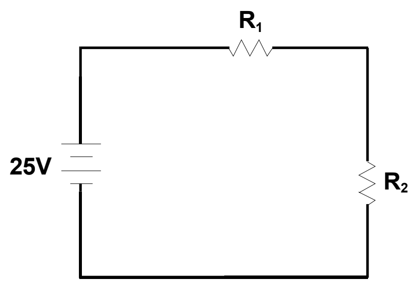
A. Thermal energy was added to the gas causing an increase in the temperature of the gas.

B. Work was done on the gas causing an increase in the temperature of the gas.

C. Thermal energy was removed from the gas causing a decrease in the temperature of the gas.

D. Work was done by the gas causing a decrease in the temperature of the gas.

6. **Use the circuit diagram below to answer the question that follows.**



In the DC circuit above, R_1 = 5 Ω and R_2 = 10 Ω. Which of the following changes to the circuit would result in a current flow of 2 amperes through R_2?

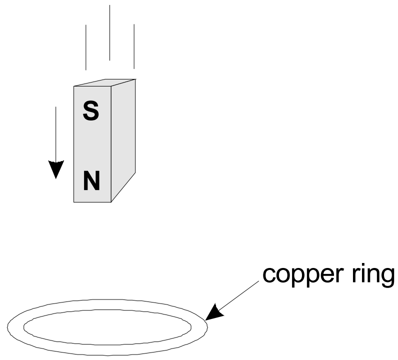
A. Connect a 5 Ω resistor in series with R_1 and R_2.

B. Connect a 5 Ω resistor in parallel with R_1.

C. Connect a 5 Ω resistor in parallel with R_2.

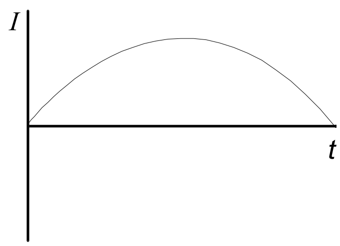
D. Connect a 10 Ω resistor in parallel with R_1.

7. **Use the diagram below to answer the question that follows.**

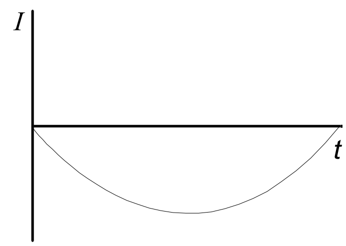


A magnet is passed through a copper ring at a constant speed. If current in the counter-clockwise direction is considered positive, which of the following graphs best represents the current (I) in the ring as a function of time (t)?

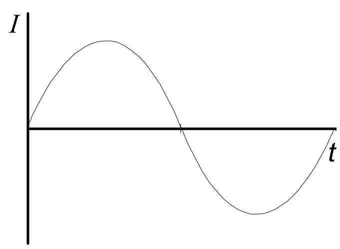
A.



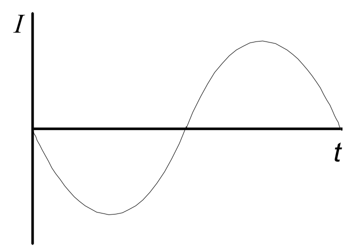
B.



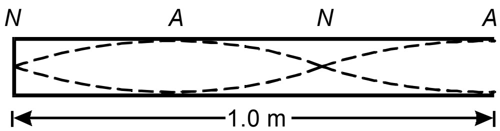
C.



D.



8. **Use the diagram below to answer the question that follows.**



A diagram shows a pipe that is open at one end. The dotted lines inside the pipe represent a standing wave associated with an oscillating column of air. The pressure nodes (*N*) and antinodes (*A*) are also shown. The length of the pipe is 1.0 m and the speed of sound in air is 330 m/s. What is the frequency of the wave in the pipe?

A. 220 Hz

B. 248 Hz

C. 340 Hz

D. 440 Hz

9. An object is placed 8 cm in front of a thin lens that has a focal length of 6 cm. At what distance from the lens will the image of the object be located?

   A. 2 cm

   B. 3.4 cm

   C. 7 cm

   D. 24 cm

10. Which of the following best explains why macroscopic objects have properties that are more particle-like than wave-like?

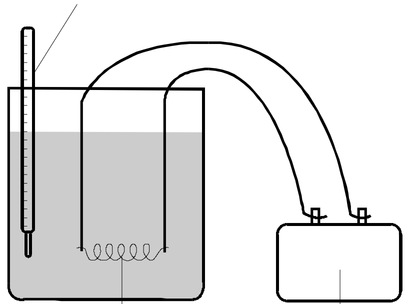
    A. The wavelength of a macroscopic object is too small for the object to be diffracted.

    B. The laws of quantum mechanics are valid only for quantities of the order of Planck's constant.

    C. The uncertainty principle implies a small value for the position and momentum of macroscopic objects.

    D. The wave function for a macroscopic object has both a real and an imaginary part.

11. **Use the diagram and the information below to complete the exercise that follows.**



The diagram shows an experimental setup for investigating the relationship between electrical energy and thermal energy. A 2.0 Ω resistor is connected in series with a 4.5 volt DC battery. The resistor is immersed in 5.0 × 10 g of water initially at 20°C. The water, resistor, and thermometer are thermally insulated from the surroundings. The thermometer is read every 60 seconds to determine the rate of change in the temperature of the water with respect to time. The specific heat of water is 4.19 J/g°C.

Using your knowledge of Ohm's law and heat and thermodynamics, write a response in which you analyze the energy transformations that occur in this situation. Assume that the heat capacity of the container, resistor, and thermometer is negligible. In your response:

- describe qualitatively (i.e., non-numerically) the energy changes occurring in the battery, the resistor, and the water;
- explain how the processes of convection, conduction, and radiation are each involved in the transfer of heat energy through the water;
- predict the temperature of the water after 5 minutes; and
- identify two sources of potential experimental error, and describe how each source could cause the experimental data to differ from the theoretical data.

Answer Key and Sample Responses: Physics (11)

Question Number	Correct Response	Test Objective*
1.	**D**	Understand the processes of gathering, organizing, reporting, and analyzing scientific data in the context of physics investigations.
2.	**B**	Understand the characteristics of circular motion and simple harmonic motion, and solve problems involving these types of motion.
3.	**C**	Apply the principle of conservation of energy and the concepts of energy, work, and power.
4.	**B**	Understand the principles of the first and second laws of thermodynamics, the relationship between temperature and heat, and the principles of thermal expansion, thermal contraction, and heat transfer.
5.	**A**	Understand the kinetic-molecular theory and its relationship to thermodynamics and the characteristics of solids, liquids, and gases.
6.	**B**	Understand characteristics of electric current and components of electric circuits.
7.	**C**	Understand and apply the principles of electromagnetic induction and AC circuits.
8.	**B**	Apply the principles of wave reflection, refraction, diffraction, interference, polarization, dispersion, and the Doppler effect.
9.	**D**	Understand the principles of lenses and mirrors.
10.	**A**	Understand the principles and concepts of the photoelectric effect, quantum theory, and the dual nature of light and matter.

*Each test objective is clarified and further described by a descriptive statement, which provides examples of the types of knowledge and skills covered by the test objective. The test objectives for the Physics test begin on page 49.

The sample response below reflects a weak knowledge and understanding of the subject matter.

The experimental setup shown provides an excellent demonstration of the relationship between electrical energy and thermal energy.

In this particular experimental setup, the battery contains electrical energy and the thermometer measures thermal energy. The resistor "resists" the flow of electricity from the water to the thermometer for safety reasons (this is necessary since water reacts with electrical energy, as evidenced by the fact that you should never use a hair dryer in the bathtub). In addition, because the resistor resists the mixing of electrical and thermal energy, comparisons between the two types of energy can be made, and the fundamental relationship between electrical and thermal energy can be easily observed and measured in the laboratory.

Conduction, convection, and radiation are all involved in the process of transferring heat energy throughout the water.

The power dissipated by the resistor can be found by the following calculation.

$$P = (4.5)(2) = 9\Omega.$$

From this information it is possible to predict the temperature change in the water.

$$\text{temperature change} = \frac{9}{60} = 0.15°\text{C}.$$

Adding this to 20 and multiplying by 5 gives the temperature after 5 minutes, $20.15 \times 5 = 100.75°\text{C}$.

There are at least two sources of potential experimental error in this experiment. One is in the battery, and the other is in the thermometer. The potential error in the battery is likely to result in a divergence in agreement between the theoretical data and the experimental data. The error in the thermometer, on the other hand, when combined with the error of the battery, could result in a closer agreement between the theoretical data and the experiment data, since the law of averages states that errors tend to cancel each other out. This is one of the reasons why experimental data almost always agrees with theoretical data.

The sample response below reflects a strong knowledge and understanding of the subject matter.

Energy is stored in the battery in the form of chemical potential energy. Since chemical reactions involve the transfer and/or sharing of electrons, this energy is fundamentally electrical in nature. When the circuit is closed, chemical reactions occur in the battery, setting up a potential difference that cause electrons to flow through the wire from the negative terminal of the battery to the resistor, and back to the battery through the positive terminal. There is a voltage drop across the resistor, which means that the battery must do work to move the electrons through the resistor. This work, or energy, is dissipated as thermal energy in the resistor in what is called Joule heating. Due to the conservation of energy, the energy converted to heat in the resistor is equal to the chemical potential energy lost in the battery. In principle, as long as the circuit remains closed, all of the energy in the battery will eventually be converted into heat energy.

Since heat is related to the random motion of molecules, the Joule heating causes the resistor's molecules to begin moving faster and faster, each oscillating about a fixed point (the resistor is a solid). These molecules collide with the water molecules in contact with the resistor, transferring part of their kinetic energy to the water molecules. Since warmer water is less dense than cooler water, the warmer water around the resistor will rise to the surface, and cooler water will move in to replace it, causing convection currents. Heat will also be transferred through the water by conduction, which is the transfer of molecular kinetic energy by the collisions of water molecules with each other. Also, according to classical electrodynamics, accelerating charges emit electromagnetic waves with a frequency proportional to their acceleration. The acceleration of the electrons in the resistor, along with the that of the resistor and water molecules, will produce electromagnetic waves with frequencies in the infrared range of the electromagnetic spectrum. Most of this electromagnetic energy will be re-absorbed by the water.

To find the amount of heat added to the water we can use the expression $\Delta Q = mc\Delta T$. By one of Kirchhoff's laws (the conservation of energy), the voltage drop across the resistor must equal the voltage increase across the battery terminal, which is 4.5 volts. The power dissipated in the resistor can be determined by combining Ohm's law $V = IR$ and the expression for electrical power $P = IV$. Solving Ohm's law for I and substituting results in

$$P = \frac{V^2}{R}.$$

Since $P = \frac{\Delta E}{\Delta t}$,

$$\Delta E = P\Delta t = \frac{V^2}{R}\Delta t.$$

(continued on next page)

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From the conservation of energy, all the heat dissipated in the resistor goes into heating the water $\Delta Q = \Delta E = P\Delta t = mc\Delta T$, or,

$$\Delta T = \frac{P\Delta t}{mc} = \frac{V^2\Delta t}{mcR} = \frac{(4.5\text{ V})^2(60\text{ s})}{(50\text{ g})(4.19\text{ J/g°C})(2.0\ \Omega)} = 2.9°\text{C}$$

Hence the temperature will increase 2.9°C every 60 seconds until the water starts to boil at 100°C. Since the initial temperature of the water is 20°C, the temperature after 5 minutes will be $T = 20 + 2.9(5) = 34.5$°C.

There are many sources of experimental error. One is the assumption that all of the heat dissipated in the resistor goes into the water. It is likely that the container, the thermometer, and the resistor will absorb some of this heat, resulting in a temperature change lower than predicted. Another potential source of error is the assumption that the resistor has a constant resistance of 2 Ω. As the temperature of the resistor increases, its resistance will increase. Since $P = \frac{V^2}{R}$, less power will be dissipated in the resistor as the resistance increases (assuming constant V). This will also have the effect of reducing the temperature change of the water.

SUBAREAS:

SCIENTIFIC INQUIRY
MECHANICS AND HEAT ENERGY
ELECTRICITY AND MAGNETISM
WAVES, SOUND, AND LIGHT
QUANTUM THEORY AND THE ATOM

SCIENTIFIC INQUIRY

0001 Understand the historical and contemporary contexts of the study of physics and the applications of physics to everyday life.

For example: the significance of key events, theories, and individuals in the history of physics; and the societal implications of developments in physics (e.g., nuclear technology, solid state technology).

0002 Understand the nature of scientific inquiry, scientific processes, and the role of observation and experimentation in science.

For example: processes by which new scientific knowledge and hypotheses are generated; ethical issues related to scientific processes (e.g., accurately reporting experimental results); the appropriateness of a specified experimental design to test a given physics hypothesis; and the role of communication among scientists and between scientists and the public in promoting scientific progress.

0003 Understand the processes of gathering, organizing, reporting, and analyzing scientific data in the context of physics investigations.

For example: the appropriateness of a given method or procedure for collecting data for a specified purpose; appropriate and effective graphic representations (e.g., graph, table, diagram) for organizing and reporting experimental data; procedures and criteria for formally reporting experimental procedures and data to the scientific community; and relationships between factors (e.g., linear, direct, inverse, direct squared, inverse squared) as indicated by experimental data.

0004 Understand principles and procedures of measurement and the use of mathematics in physics (e.g., vector analysis, calculus).

For example: SI units; measuring devices; proper methods of measurement for given situations; analyzing uncertainty in measurements; applying dimensional analysis; deriving equations; and applying principles of graphing, trigonometry, vector analysis, and calculus to analyze, model, and solve problems.

0005 Understand the interrelationships among physics, society, technology, and other sciences and disciplines.

For example: the impact of physics and technology on society; similarities and differences between science and technology (e.g., science as investigating the natural world, technology as solving human adaptation problems); the technological design process; ethical considerations related to science and technology; and the application of scientific and technological decision making at the community, state, national, and international level.

0006 Understand safe and proper use of equipment, materials, and chemicals used in physics investigations.

For example: the principles upon which given laboratory instruments are based (e.g., oscilloscopes, Geiger counters); hazards associated with given laboratory materials (e.g., projectiles, lasers, radioactive materials, heat sources); safety rules for electricity and electrical equipment; and proper procedures for dealing with accidents and injuries in the physics laboratory.

MECHANICS AND HEAT ENERGY

0007 Understand concepts related to motion in one and two dimensions, and apply this knowledge to solve problems that require the use of algebra, calculus, and graphing.

For example: the terminology, units, and equations used to describe and analyze one- and two-dimensional motion; the movement of freely falling objects near the surface of the earth; solving problems involving distance, displacement, speed, velocity, and constant acceleration; and interpreting information presented in one or more graphic representations related to distance, displacement, speed, velocity, and constant acceleration.

0008 Understand characteristics of forces and methods used to measure force, and solve algebraic problems involving forces.

For example: identifying forces acting in a given situation; experimental designs for measuring forces; and solving problems involving gravitational and frictional forces.

0009 Apply knowledge of vectors and trigonometric functions to solve problems involving concurrent, parallel, resultant, equilibrant, and component forces and torque.

For example: applying graphic solutions to solve problems involving concurrent and equilibrant forces; and solving problems involving torque.

0010 Understand the laws of motion (including relativity) and conservation of momentum.

For example: the characteristics and examples of each of Newton's laws of motion; applying Newton's laws of motion and the conservation of momentum in solving problems; and the implications of special relativity for the laws of motion.

0011 Understand the characteristics of circular motion and simple harmonic motion, and solve problems involving these types of motion.

For example: applying vector analysis to describe uniform circular motion in radians; determining the magnitude and direction of the force acting on a particle in uniform circular motion; the relationships among displacement, velocity, and acceleration in simple harmonic motion (e.g., simple pendulum); and solving involving springs and force constants.

0012 Understand Kepler's laws and the law of universal gravitation, and apply them to satellite motion.

For example: the geometric characteristics of planetary orbits; applying Kepler's law of equal areas to solve problems involving satellite motion; applying Kepler's laws to relate the radius of a planet's orbit to its period of revolution; and using the law of universal gravitation to interpret the relationship among force, mass, and the distance between masses.

0013 Apply the principle of conservation of energy and the concepts of energy, work, and power.

For example: analyzing mechanical systems in terms of work, power, and conservation of energy; using the concept of conservation of energy to solve problems; and determining power, mechanical advantage, and efficiency as they relate to work and energy in operations such as simple machines.

0014 Understand the dynamics of rotational motion, including torque, angular momentum, motion with constant angular acceleration, rotational kinetic energy, center of mass, and moment of inertia.

For example: the principles of motion with constant angular acceleration; the law of conservation of angular momentum; and the concepts of center of mass, moment of inertia, and rotational kinetic energy.

0015 Understand the statics and dynamics of fluids.

For example: the concepts of force, pressure, and density; using Bernoulli's principle to analyze fluid dynamics; and applying Archimedes' principle to solve problems involving buoyancy and flotation.

0016 Understand the principles of the first and second laws of thermodynamics, the relationship between temperature and heat, and the principles of thermal expansion, thermal contraction, and heat transfer.

For example: solving calorimetry problems involving heat capacity, specific heat, heat of fusion, and heat of vaporization; analyzing methods of heat transfer (i.e., conduction, convection, radiation) in practical situations; solving problems involving thermal expansion and thermal contraction of solids; and using the principle of entropy to analyze the operation of heat engines (e.g., Carnot cycle).

0017 Understand the kinetic-molecular theory and its relationship to thermodynamics and the characteristics of solids, liquids, and gases.

For example: analyzing the behavior of a gas in terms of the kinetic-molecular theory (i.e., ideal gas law); and analyzing phase changes in terms of kinetic-molecular theory and molecular structure.

ELECTRICITY AND MAGNETISM

0018 Understand characteristics and units of electric charge, electric fields, electric potential, and capacitance; and apply principles of static electricity to solve problems involving Coulomb's law and electric field intensity.

For example: analyzing the behavior of an electroscope in given situations; applying Coulomb's law to determine the forces between charges; applying principles of electrostatics to determine electric field intensity; and the relationships between capacitance, charge, and potential difference.

0019 Understand characteristics of electric current and components of electric circuits.

For example: analyzing a DC circuit in terms of conservation of energy and conservation of charge (i.e., Kirchhoff's law, Ohm's law); factors that affect resistance; schematic diagrams of electric circuits; and applying principles of DC circuits to reduce a complex circuit to a simpler equivalent circuit.

0020 Understand magnets, electromagnets, and magnetic fields; the effects of magnetic fields on moving electric charges; and the applications of electromagnetism.

For example: factors that affect the strength of an electromagnet; the orientation and magnitude of a magnetic field; the magnitude and direction of the force on a charge or charges moving in a magnetic field; and the use of electromagnetism in technology (e.g., motors, generators, meters).

0021 Understand and apply the principles of electromagnetic induction and AC circuits.

For example: factors that affect the magnitude of an induced electromotive force (EMF); analyzing an AC circuit, including relationships involving impedance and reactance; determining the direction of an induced current; and the functions of transformers and generators.

0022 Understand the principles of conductors, semiconductors, and superconductors.

For example: analyzing current-voltage characteristics of typical solid state diodes and zener diodes; the function of a diode in a given electric circuit; comparing NPN and PNP transistors and identifying correct terminal connections in a given circuit; and the function of a transistor in a given electrical circuit.

WAVES, SOUND, AND LIGHT

0023 Understand waves and wave motion, and solve problems involving wave motion.

For example: types (e.g., longitudinal, transverse) and characteristics (e.g., frequency, period, amplitude, wavelength) of waves; and applying the wave equation to determine a wave's velocity, wavelength, or frequency.

0024 Apply the principles of wave reflection, refraction, diffraction, interference, polarization, dispersion, and the Doppler effect.

For example: applications of wave reflection, refraction, diffraction, interference, polarization, dispersion, and the Doppler effect (e.g., radar, sonar, polarizers); applying Snell's law to determine index of refraction, angle of incidence, angle of refraction, or critical angle; solving problems involving diffraction and interference in single and multiple slits; and applying the superposition principle to determine characteristics of a resultant wave.

0025 Understand the characteristics of sound waves and the means by which sound waves are produced and transmitted.

For example: the physical nature of sound waves (including intensity and intensity level); factors that affect the speed of sound in different media; and solving problems involving resonance, harmonics, and overtones.

0026 Understand the production and characteristics of electromagnetic waves.

For example: the properties (e.g., energy, frequency, wavelength) of components (e.g., visible light, ultraviolet radiation) of the electromagnetic spectrum; and applications of the components of the electromagnetic spectrum (e.g., infrared detectors, solar heating, x-ray machines).

0027 Understand the principles of lenses and mirrors.

For example: types and characteristics of lenses and mirrors; using a ray diagram to locate the focal point or point of image formation of a lens or mirror; applying the lens and mirror equations to solve problems involving lenses and mirrors; and applications of lenses and mirrors (e.g., telescopes, compound microscopes, eyeglasses).

QUANTUM THEORY AND THE ATOM

0028 Understand the principles and concepts of the photoelectric effect, quantum theory, and the dual nature of light and matter.

For example: applying the laws of photoelectric emission to explain photoelectric phenomena; analyzing bright-line spectra in terms of electron transitions; the principles of stimulated emission of radiation as applied to lasers and masers; and the dual nature of light and matter.

0029 Understand physical models of atomic structure and the nature of elementary particles.

For example: historic and contemporary models of atomic structure (e.g., Bohr, Schrödinger, Heisenberg, Mayer, Bhabha); notation used to represent elements, molecules, ions, and isotopes; and the relationship between the design of particle accelerators and elementary particle characteristics.

0030 Understand the principles of radioactivity and types and characteristics of radiation, and the process of radioactive decay.

For example: applying principles of the conservation of mass-energy and charge to balance equations for nuclear reactions; analyzing radioactive decay in terms of the half-life concept; analyzing the nuclear disintegration series for a given isotope; and the basic operation of types of radiation detectors.

0031 Understand types and characteristics of nuclear reactions, methods of initiating and controlling them, and applications of nuclear reactions to the generation of electricity.

For example: characteristics of fission and fusion reactions; the operation of components of a nuclear reactor (e.g., moderator, fuel rods, control rods); calculating nuclear mass defect and binding energy; the isotopes commonly used to fuel nuclear reactors; and the problems associated with the waste products generated by nuclear reactions.