PHYSICS 2

SECTION I

Time—80 minutes

40 Questions

Note: To simplify calculations, you may use $g = 10\ \text{m/s}^2$ in all problems.

Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and mark it on your sheet.

Questions 1 and 2 refer to the following situation.

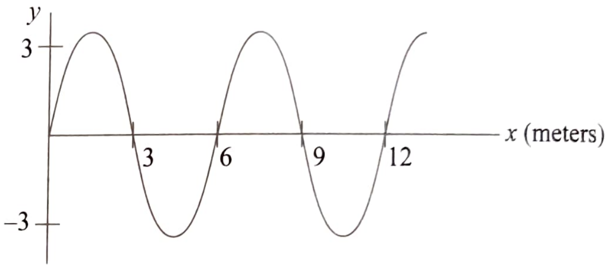
A proton is traveling along a straight line at a constant speed through a uniform electric field near the surface of the Earth.

1. Which of the following choices correctly describes the direction of the electric field and the relative magnitudes of the electric and gravitational fields?

	Electric Field Direction	Field Strength
(A)	Down	$E_g = E_{el}$
(B)	Down	$E_g > E_{el}$
(C)	Up	$E_g = E_{el}$
(D)	Up	$E_g > E_{el}$

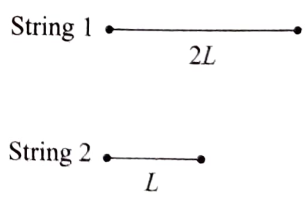
2. Which of the following describes the equipotential lines for the electric and gravitational fields that the proton experiences?

   (A) Equipotential lines are straight, horizontal lines for both fields.
   (B) Equipotential lines are straight, vertical lines for both fields.
   (C) Equipotential lines are straight, horizontal lines for the electric field and curve upward for the gravitational field.
   (D) Equipotential lines are straight, horizontal lines for the gravitational field and curve upward for the electric field.



3. The graph above depicts a medium's instantaneous displacement from equilibrium, caused by a wave, as a function of distance from the source. If the wave has a speed of 600 m/s, which of the following is the best approximation of the wave's frequency?

   (A) 50 Hz
   (B) 100 Hz
   (C) 200 Hz
   (D) Cannot be determined without additional information



4. Both of the above strings have their ends locked in place. The two strings have the same linear density, but the first string, S_1, is twice as long as the second string, S_2. If sound waves are going to be sent through both, what is the correct ratio of the fundamental frequency of S_1 to the fundamental frequency of S_2?

   (A) 2:1
   (B) $\sqrt{2}$:1
   (C) 1:$\sqrt{2}$
   (D) 1:2

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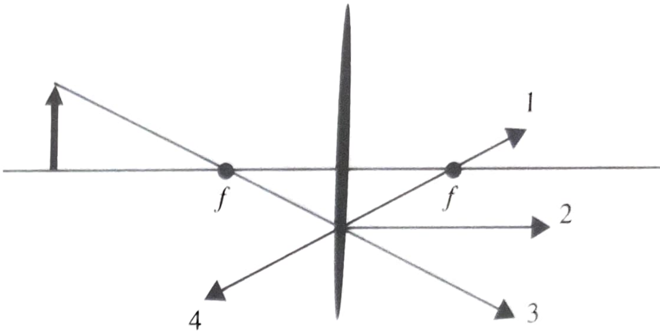
5. An ohmmeter is used to measure resistance. Measurements are made of the cross-sectional area, A, and length, L, of each resistor. What should be plotted so that the slope of the plot will yield the resistivity, ρ, of the resistors?

(A) Resistance on the y-axis versus ratio of L to A on the x-axis
(B) Resistance on the y-axis versus ratio of A to L on the x-axis
(C) Ratio of L to A on the y-axis versus resistance on the x-axis
(D) Ratio of A to L on the y-axis versus resistance on the x-axis

6. An ideal gas is taken from an initial set of conditions with pressure P_i and volume V_i, to a final set of conditions, with pressure P_f and volume V_f, through several different processes. At the end of the process, the gas is at both a higher pressure and a larger volume than when it started. Which process requires the least amount of work on the system?

(A) First, expansion at constant pressure P_i from V_i to V_f followed by increasing pressure from P_i to P_f at constant volume V_f
(B) First, increasing pressure from P_i to P_f at constant V_i volume followed by expansion at constant pressure P_f from V_i to V_f
(C) A series of small increases in volume alternating with small increases in pressure, resulting in a nearly straight line on a PV graph from the beginning to the end of the process
(D) Any set of steps will require the same amount of work because all gases have the same change in pressure and volume.

Questions 7 and 8 refer to the following diagram.



7. The image above shows a converging lens and an object represented as a bold vertical arrow. Which line correctly depicts the output path of the ray that is incident on the lens coming in through the focus?

(A) 1
(B) 2
(C) 3
(D) 4

8. The converging lens above has a focal length of 25 cm. The object is located at a distance of 65 cm from the lens. Where should a screen be placed so that the observer will see a focused image on the screen?

(A) 65 cm to the right side of the lens
(B) 40.6 cm to the right side of the lens
(C) At the focus of the lens
(D) The image in such an arrangement will be virtual and cannot be seen on a screen.

9. You are tasked with creating a real image using a concave mirror as your imaging system. Which of the following criteria is true about both the image and the object?

(A) A real image can be created only if the object is farther away from the lens than the radius of curvature of the lens.
(B) A real image can be created only with the object located between the center of the lens and the focal length of the lens.
(C) A real image can be created with the object located anywhere farther from the lens than the focal point.
(D) A real image cannot be created using only a concave lens.

10. An atom has its lowest four energy levels at –10 eV, –5 eV, –3.5 eV, and –2 eV. Which of the following photons could NOT be absorbed by the atom?

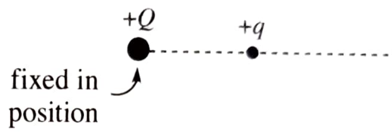
(A) A 10 eV photon
(B) A 5 eV photon
(C) A 2.5 eV photon
(D) A 1.5 eV photon

11. A radioactive particle undergoes beta decay, emitting an electron from its nucleus. Which of the following explanations correctly explains why this process must also involve a neutron turning into a proton within the nucleus?

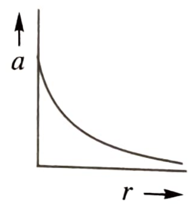
(A) The total charge of the system before and after is not the same if the proton is not created.
(B) The mass energy of the system is not conserved if the proton is not created.
(C) The momentum of the system could not be conserved without the generation of a proton.
(D) All nuclear decay processes involve the generation of two particles.

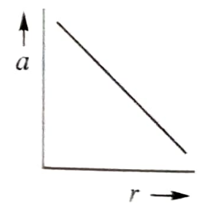
12. A circuit consists of a 50 V battery, a 100 Ω resistor, and a 25 μF capacitor. Once the capacitor has become fully charged, how much energy is stored in the capacitor?

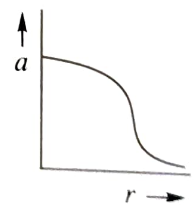
(A) 0.0013 J
(B) 0.031 J
(C) 0.062 J
(D) 0.125 J

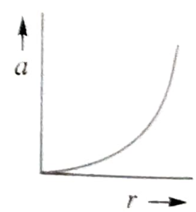


13. As shown above, the +Q charge is fixed in position, and the +q charge is brought close to +Q and then released from rest. Which graph best shows the acceleration of the +q charge as a function of its distance r from +Q?

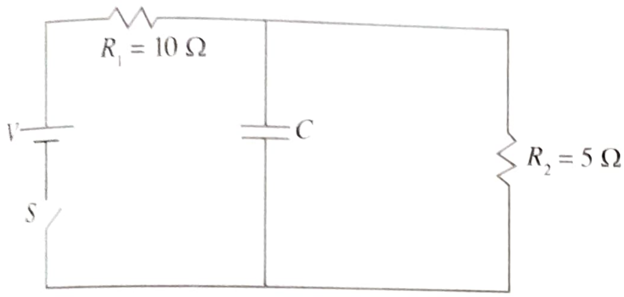
(A)


(C)


(B)


(D)


Questions 14, 15, and 16 refer to the following diagram.



14. Voltmeters are placed across the Resistor R_1, the capacitor C, and the resistor R_2. The switch S has been closed a long time. What is the rank of the value readings on the voltmeters?

(A) $V_{R_1} > (V_C = V_{R_2})$
(B) $(V_{R_1} = V_C = V_{R_2})$
(C) $(V_C = V_{R_2}) > V_{R_1}$
(D) $V_{R_1} > V_C > V_{R_2}$

15. The circuit is reset and the capacitor is discharged. Then, the switch is closed again. At what time will the current through the resistor R_2 be greatest?

(A) The current through the resistor will be constant.
(B) The current through the resistor will be greatest before closing the switch.
(A) The current through the resistor will be greatest immediately after closing the switch.
(D) The current through the resistor will be greatest a long time after closing the switch.

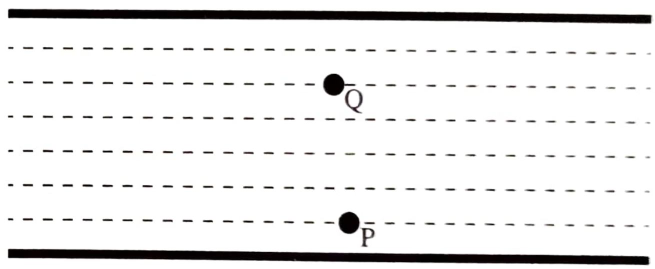
16. The capacitance of the capacitor is known initially. The capacitor is now altered to have a larger capacitance. Which of the following observations will occur with the new capacitor in the circuit a long time after the switch is closed as compared to what was observed a long time after the switch was closed with the original capacitor?

(A) The current flowing in R_1 will be greater.
(B) The current flowing in R_2 will be greater.
(C) The current flowing into the capacitor will be greater.
(D) The charge stored in the capacitor will be greater.

17. An ideal gas is confined within a cube-shaped container. In addition to the length of the side of the container, which of the following sets of measurements will allow a student to determine the pressure of the gas in the container?

I. The mass of gas in the container and the average speed of a gas molecule
II. The impulse delivered to the gas by a wall in a measured time period
III. The force of the gas against one of the walls

(A) I only
(B) III only
(C) II or III
(D) I, II, or III

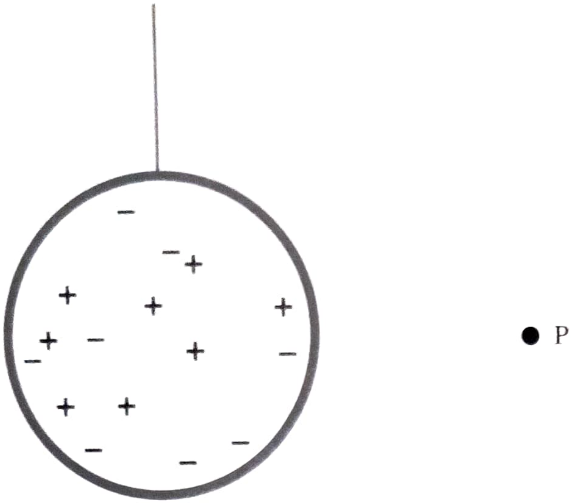


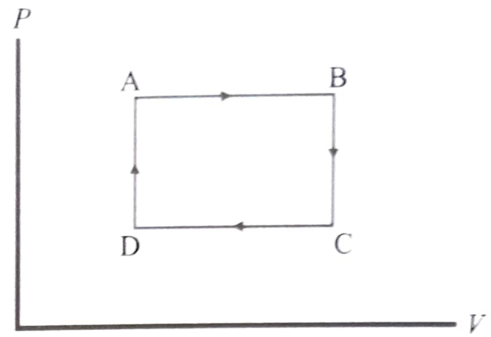
18. Points P and Q lie between the plates of a fully charged parallel-plate capacitor as shown above. The lower plate is negatively charged, and the upper plate is positively charged. How do the magnitudes of the electric fields at points P and Q compare?

(A) The field is 0 N/C at both points.
(B) The field is the same at both points, but not 0 N/C.
(C) $E_P > E_Q$
(D) $E_Q > E_P$

19. A wire carries a constant current to the right. A positively charged particle is a distance d above the wire, and it is moving in the same direction as the current. The particle will experience a magnetic force in which direction?

(A) To the right
(B) To the top of the page
(C) To the left
(D) To the bottom of the page





20. A neutral conducting sphere is hung from a thin insulating string. A positively charged object is brought to point P. The two objects are not allowed to touch. What is true about the string when the positively charged object is present at point P?

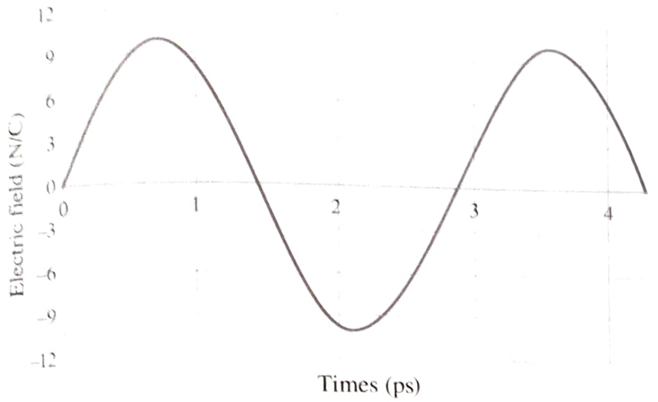
(A) The tension is the same as before the object was present at point P.
(B) The tension is greater than when the object was not at point P, and the string stretches to the left of its original orientation.
(C) The tension is greater than when the object was not at point P, and the string stretches to the right of its original orientation.
(D) The tension is less than when the object was not at point P, and the string stretches to the left of its original orientation.

21. An experiment is performed on a fixed volume of an ideal gas. The pressure, in pascals, of the gas is plotted on the vertical axis and the temperature of the gas, in degrees Kelvin, is plotted on the horizontal axis. During a second performance of the experiment at a greater volume, the pressure-temperature graph is expected to

(A) have a greater slope and the same intercept
(B) have a smaller slope and the same intercept
(C) have a greater slope and a greater intercept
(D) have a smaller slope and a greater intercept

22. Which statement correctly characterizes the work done by the gas during the ABCDA cycle shown in the above P–V diagram?

(A) There is no work done by the gas because the system both starts and concludes in state A.
(B) There is no work done because the work done during the transition from A→B cancels out the work done in transition from C→D.
(C) The work done by the gas is positive because the work done during the transition from A→B is greater than the work done in transition from C→D.
(D) The work done by the gas is positive because the work done during the transition from B→C is greater than the work done in transition from D→A.



23. The electric field crosses the axis at times 0 ps, 1.43 ps, 2.85 ps, and 4.28 ps. What is the equation for the electric field given by the above plot?

(A) $E = \left(\frac{0\text{ N}}{\text{C}}\right)\sin((2.85\text{ THz})t)$

(B) $E = \left(\frac{10\text{ N}}{\text{C}}\right)\sin((2.85\text{ THz})t)$

(C) $E = \left(\frac{10\text{ N}}{\text{C}}\right)\sin((2.20\text{ THz})t)$

(D) $E = \left(\frac{10\text{ N}}{\text{C}}\right)\cos((0.45\text{ THz})t)$

24. You are standing on a railroad track as a train approaches at a constant velocity. Suddenly the engineer sees you, applies the brakes, and sounds the whistle. Which of the following describes the sound of the whistle while the train is slowing down, as you hear it?

(A) Loudness increasing, pitch increasing
(B) Loudness increasing, pitch constant
(C) Loudness decreasing, pitch increasing
(D) Loudness increasing, pitch decreasing

25. Which of the following relationships, when plotted, will yield a curve which is inverse to the first power?

I. The electric potential versus distance from a positive point particle
II. The volume versus pressure for an ideal gas
III. The magnetic field from a current-carrying wire versus distance from the wire

(A) I only
(B) I and III
(C) II only
(D) I, II, or III

26. Two massive charged objects are fixed in space with a separation of d meters. The quantity R is defined as the ratio of the gravitational force to the electric force between the two objects. The separation is then increased slowly. What happens to R?

(A) R is constant for all separations.
(B) R increases as the separation increases.
(C) R decreases as the separation increases.
(D) R increases up to a distance D; then R decreases back to its original value.

27. An ideal gas is at a pressure P and a volume V. The gas is in a fixed volume, but is heated until the pressure doubles. What happens to the average speed of the molecules in the gas?

(A) The speed of the molecules on average remains unchanged.
(B) The speed of the molecules on average increases by a factor of $\sqrt{2}$.
(C) The speed of the molecules on average increases by a factor of 2.
(D) The speed of the molecules on average increases by a factor of 4.

28. Which of the following changes to a double-slit interference experiment would increase the widths of the fringes in the interference pattern that appears on the screen?

(A) Use light of a shorter wavelength.
(B) Move the screen closer to the slits.
(C) Move the slits closer together.
(D) Use light with a lower wave speed.

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29. Tritium is an isotope of hydrogen consisting of one proton and two neutrons. The isotope has a mass of 5.008×10^{-27} kg. The mass of a proton is 1.673×10^{-27} kg and a neutron has a mass of 1.675×10^{-27} kg. What is the binding energy of tritium?

(A) 1.500×10^{-29} J
(B) 1.350×10^{-12} J
(C) 4.507×10^{-10} J
(D) 4.521×10^{-10} J

30. In an experiment designed to study the photoelectric effect, it is observed that low-intensity visible light of wavelength 550 nm produced no photoelectrons. Which of the following best describes what would occur if the intensity of this light were increased dramatically?

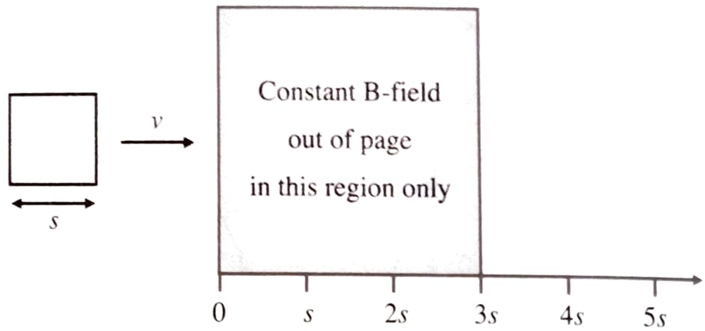
(A) Almost immediately, photoelectrons would be produced with a kinetic energy equal to the energy of the incident photons.
(B) Almost immediately, photoelectrons would be produced with a kinetic energy equal to the energy of the incident photons minus the work function of the metal.
(C) After several seconds, the electrons absorb sufficient energy from the incident light, and photoelectrons would be produced with a kinetic energy equal to the energy of the incident photons minus the work function of the metal.
(D) Nothing would happen.

31. Radioactive carbon-14 undergoes β^- decay. The atomic number of carbon is 6. The number of nucleons in the products after the beta decay is

(A) 6
(B) 7
(C) 13
(D) 14

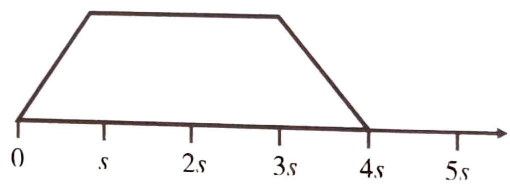
32. The speed of sound in air is 343 m/s. If the wavelength of a certain sound wave is 20.0 cm, what is its frequency?

(A) 171.5 Hz
(B) 1,715 Hz
(C) 3,430 Hz
(D) 17,150 Hz

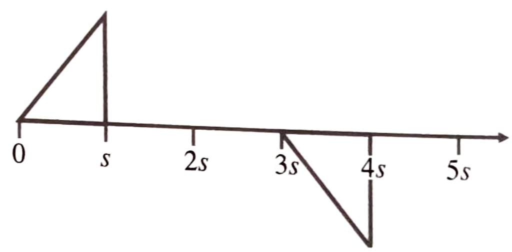


33. A square loop of conducting wire with side s is moved at a constant rate v to the right into a region where there is a constant magnetic field directed out of the page. Which of the following graphs shows the flux through the loop as a function of distance?

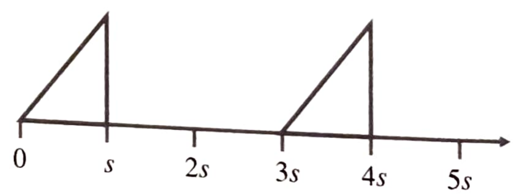
(A)



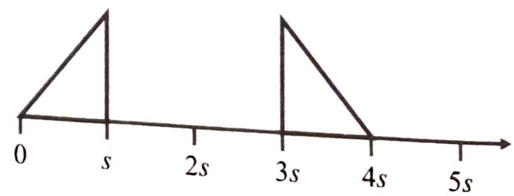
(B)

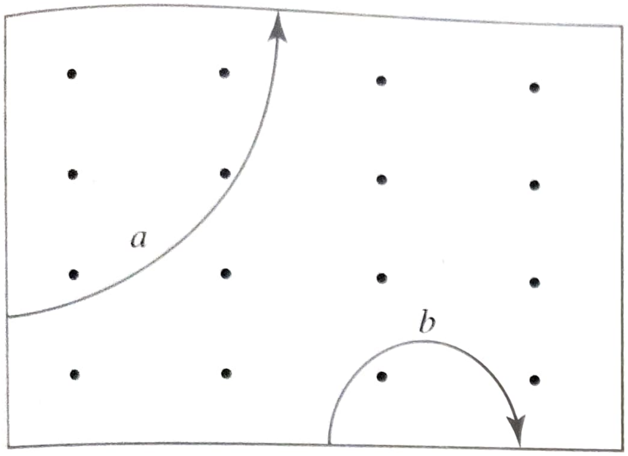


(C)



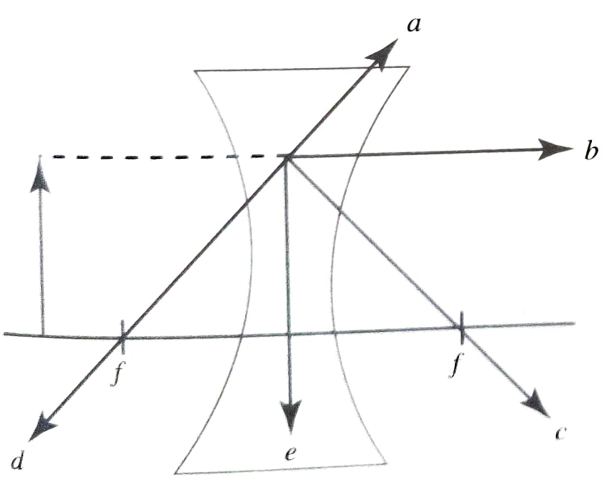
(D)





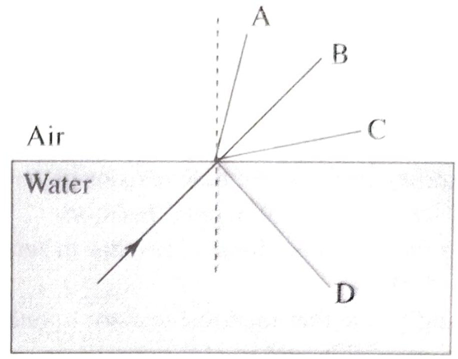
34. A machine shoots a proton, a neutron, or an electron into a magnetic field at various locations. The paths of two particles are shown above. Assume they are far enough apart so that they do not intersect and the magnetic field is going out of the page, as shown. What can you say about the paths that represent each particle?

(A) *a* is the proton and *b* is the electron.
(B) *b* is the proton and *a* is the electron.
(C) Either may be a neutron.
(D) You cannot make any conclusions without knowing the velocities.



35. In the figure above, a ray of light hits an object and travels parallel to the principal axis as shown by the dotted line. Which line shows the correct continuation of the ray after it hits the concave lens?

(A) *a*
(B) *b*
(C) *c*
(D) *d*



36. A beam of light goes from water to air. Depending on the actual angle that the light strikes the surface, which of the following is a possible outcome?

(A) A only
(B) B only
(C) A or D
(D) C or D

37. An electron traveling east at a constant speed enters a region of constant electric field pointed up. A constant magnetic field exists in the same region as the electric field. Which direction would the magnetic field of an appropriate magnitude have to point for the electron to continue with the same velocity?

(A) Up
(B) Down
(C) North
(D) South

38. A capacitor is fully charged by connecting it to a battery of voltage V_0. The capacitor is then disconnected from the battery. A material with a dielectric constant $\kappa = 2$ is inserted into the capacitor. What is the voltage across the plates of the capacitor after inserting the dielectric?

(A) $\frac{1}{2}V_0$

(B) V_0

(C) $2V_0$

(D) $4V_0$

39. A circuit is created with a battery of negligible internal resistance and three identical resistors with resistance of R. The resistors are originally arranged so that one is in series with the battery, and the other two are in parallel with each other. Which of the following changes to the circuit will result in an increase in the amount of current in the circuit?

(A) Adding another identical resistor in parallel with the existing pair of parallel resistors
(B) Adding another identical resistor in series with the battery
(C) Adding another identical resistor to one of the parallel branches of the circuit, in series with the resistor that was already in that branch
(D) Removing one of the two parallel branches entirely from the circuit

40. Which of the following correctly describes a refrigerator in terms of the Second Law of Thermodynamics?

(A) The refrigerator maximizes entropy by maintaining thermal equilibrium with the environment.
(B) The refrigerator increases entropy by moving thermal energy from the cold interior of the refrigerator to the outside environment.
(C) The entropy of the environment increases by at least as much as the entropy in the refrigerator decreases.
(D) The refrigerator is a closed system, so its entropy cannot decrease.

PHYSICS 2

SECTION II

Time—100 minutes

4 Questions

Directions: These free-response questions cover 4 important areas of Physics 2. Question 1 is about Mathematical Routines. Question 2 is about Translation Between Representations. Question 3 is about Experimental Design. Question 4 is about Qualitative/Quantitative Translation. You have 100 minutes total to answer all 4 questions. On test day, you will be asked to show your work for each part in the space provided after that part. For this practice test, you may use scrap paper.

1. An unplugged freezer is at room temperature. The door is closed and the freezer is plugged in.

(a) You set out to perform an experimental investigation of the relationship between gas density and temperature. The following equipment is available. Place an X beside each item you will need to use:

	Chamber with sliding piston lid with a known area
	Pressure monitor
	Meter stick
	Large tub of boiling water

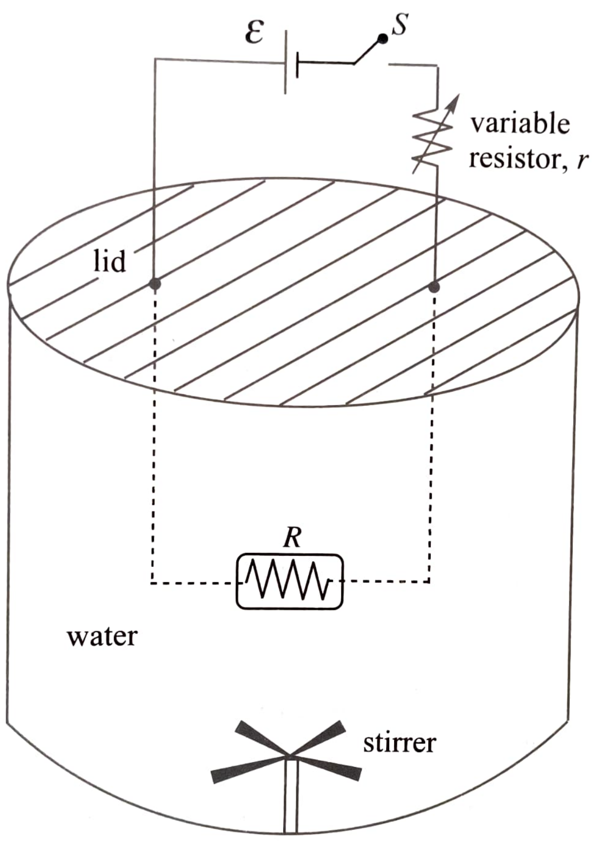
	Chamber with fixed lid with a known area
	Thermometer
	Stopwatch
	Large tub of ice water

(b) Write out a numbered procedure you will use to gather necessary data. Your description should be detailed enough that another student could reproduce your experiment.

(c) Your data analysis must include a graph. Explain what you would graph on the x-axis and the y-axis. Justify your decision and explain how your graph will help you understand the relationship between density of a gas and its temperature.

(d) What shape graph do you expect to see?

2. The figure below shows an electric circuit containing a source of emf, (e), a variable resistor (r), and a resistor of fixed resistance (R). The resistor R is immersed in a sealed beaker containing a mass m of water, currently at temperature T_i. When the switch S is closed, current through the circuit causes the resistor in the water to dissipate heat, which is absorbed by the water. A stirrer at the bottom of the beaker simply ensures that the temperature is uniform throughout the water at any given moment. The apparatus is well-insulated (insulation not shown), and it may be assumed that no heat is lost to the walls or lid of the beaker or to the stirrer.



(a) Determine the current in the circuit once S is closed. Write your answer in terms of e, r, and R.

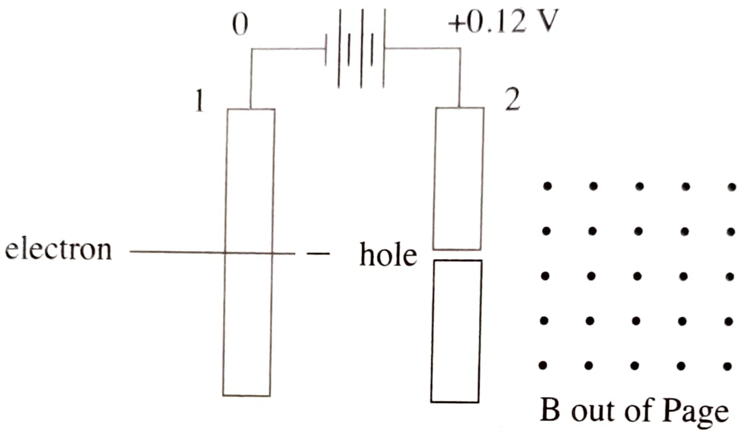
(b) Determine the power dissipated by the resistor R in terms of e, r, and R.

(c) Explain at the microscopic level why the water heats up when the switch is closed and how the stirrer helps ensure a constant temperature throughout.

(d) Assume the stirrer has a knob, which changes its speed. How can the temperature of the water be increased more rapidly by adjusting the rotation rate of the stirrer?

(e) As the temperature of the water increases, whether from the resistor or from the stirrer rate, explain the microscopic interactions responsible for the changing pressure in the container.

3. In an experiment, two tests are run. In both trials you may ignore the effect of gravity. The following is a diagram of the tests.



Test 1: There are two large parallel plates separated by a distance $d = 0.5$ m with a potential difference of 0.12 V across them. There is a uniform magnetic field **B** pointing perpendicularly out of the paper of strength 0.002 T starting to the right of plate 2. An electron is released from rest at plate 1 as shown above. It passes through a hole in plate 2 and enters the magnetic field and only experiences forces due to the magnetic field.

Test 2: The same setup is run with the following two exceptions.

1. The battery is switched so that plate 1 becomes positive and plate 2 becomes negative.

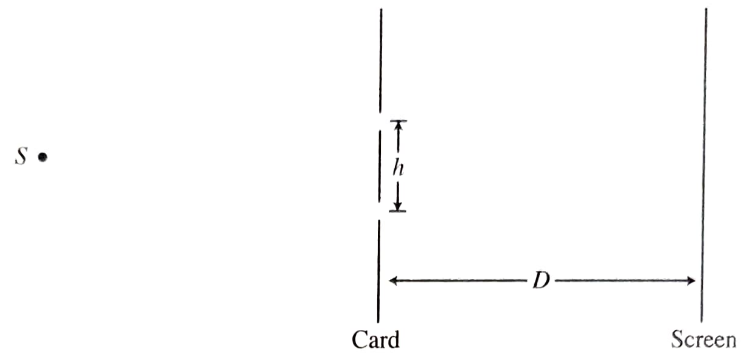
2. A proton is used instead of an electron.

(a) As the particles move from plate 1 toward plate 2 in each test, they experience unbalanced forces, causing their speed to change. After plate 2, each particle still experiences unbalanced forces, but no longer changes speed. Use the concept of work to explain how this occurs.

(b) Find the ratio of the speed of the proton as it emerges from the hole to the speed of the electron as it emerges from the hole.

(c) Make a sketch of each path each particle will follow after emerging from the hole in plate 2.

(d) A third test is conducted similar to test 2, except an alpha particle is used instead of a proton. Explain how the path of the alpha particle after emerging from the hole will differ from the proton's path.



Note: Figure not drawn to scale.

4. In a double-slit interference experiment, a parallel beam of monochromatic light is needed to illuminate two narrow parallel slits of width w that are a distance h apart, where $h >> w$, in an opaque card as shown in the figure above. The interference pattern is formed on a screen a distance D from the slits, where $D >> h$.

(a) Draw the first three wavefronts that emerge from each slit after the card.

(b) In a clear, coherent, paragraph-length response, explain why a series of bright spots are seen on the screen after the light shines through the card.

(c) In the interference patterns on the screen, the distance from the central bright fringe to the third bright fringe on one side is measured to be y_3. In terms of D, h, y_3, and S, what is the wavelength of the light emitted from the source S?

(d) If the space between the slits and the screen was filled with a material having an index of refraction $n > 1$, would the distance between the bright fringes increase, decrease, or remain the same? Explain your reasoning.

STOP

END OF EXAM

PRACTICE TEST 2: ANSWERS AND EXPLANATIONS

Section I: Multiple Choice

1. **D** The forces must balance in order for the proton to travel along a straight line. If the forces balance, $m(E_g) = q(E_{el})$. Since m is less than q for a proton, the gravitation field is stronger. Gravity points down, so the electric force must be up, and for a positive particle, the field must also be up.

2. **A** Equipotential lines will be perpendicular to the force lines. Gravitational force lines point vertically downward. The equipotential lines for the electric field must also be horizontal lines for the particle to move in a straight line at a constant speed.

3. **B** The distance from one crest to another is the wavelength. In this case, that distance is 6 m. Furthermore, you know that $v = f\lambda$ for any wave. Solving for f gives $f = v/\lambda$. Plugging in the known values gives $f = (600)/(6) = 100$ Hz.

4. **D** A wave passing along a string with both ends held in place will have a fundamental frequency of $f = v/(2l)$, where v is the speed of the wave and l is the length of the string. Thus, fundamental frequency is inversely proportional to the length of the string, so the first string, which is twice as long as the second, will have a fundamental frequency that is half of the second string's. Expressed as a ratio, that is 1:2.

5. **A** For any linear equation, $y = mx + b$, the slope is multiplied by the quantity that is graphed on the horizontal axis. In order to have the slope equal the resistivity, the horizontal axis must be the ratio of length to area.

$$R = \rho\frac{L}{A}$$

6. **A** All processes that end at higher volumes will require removing work to be done on the system. When pressure is constant, the work is found from $W = P\Delta V$, so to minimize the work required, you want the change in volume to occur at the lowest pressure possible.

7. **B** A ray which travels into a converging lens along a line that goes through the focal point will refract to travel along a line parallel to the optical axis upon leaving the lens.

8. **B** The screen must be placed at the image location in order for the image to appear in focus on the screen. Use the equation $\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$

$$\frac{1}{s_i} = \frac{1}{25\text{ cm}} - \frac{1}{65\text{ cm}} \rightarrow s_i = 40.6\text{ cm}$$

9. **C** A concave mirror can make a real image only when the object is placed beyond the focus.

10. **C** Any photon that has energy that matches an energy difference in that atom can be absorbed. The 10 eV photon can be absorbed if there is an electron in the –10 eV state by ionizing the atom. A 5 eV photon can excite a photon from the –10 eV state to the –5 eV state or ionize an electron from the –5 eV state. The 1.5 eV photon can cause a transition from the –3.5 eV state to the –2 eV state.

11. **A** During nuclear decay processes, the total charge in the system before and after the decay must be the same.

12. **B** The internal energy stored in a fully charged capacitor is $U_C = \frac{1}{2}CV^2$. The voltage of the battery will be the voltage across the capacitor when the capacitor is fully charged.

$$U_C = \frac{1}{2}(25 \times 10^{-6}\text{ F})(50\text{ V})^2 = 0.03125\text{ J}$$

13. **A** The acceleration of an object with charge $+q$ and mass m is given by $a = \frac{F_E}{m} = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{mr^2}\right)$. The graph in (A) shows an inverse square law.

14. **A** The capacitor will be fully charged a long time after the switch has been closed. So, no current will pass down the branch with the capacitor, and the circuit will behave like a battery connected to two resistors in series. Therefore, the voltage of the battery will be split between R_1 and R_2. Since, $R_1 > R_2$, the voltage drop across R_1 will be greater than that across R_2. Finally, the capacitor is in parallel with R_2, so the capacitor will have the same voltage as R_2.

15. **D** You can eliminate (A) immediately. The current that flows into the capacitor changes over time, so the current in a parallel branch will also change over time. You can eliminate (B) as well, because before the switch is closed, no current flows in the circuit at all. Because the capacitor is discharged, as soon as the switch is closed, the parallel branch with the capacitor will receive all of the current, eliminating (C). In both the cases of (B) and (C), the current through R_2 is zero. Once the capacitor is fully charged, current flows around the loop creating the outside of the circuit, and whatever value it has at that time is greater than 0 A.

16. **D** In both scenarios, the capacitor will be fully charged a long time after the switch has been closed. So, no current will pass down the branch with the capacitor, and the circuit will behave like a battery connected to two resistors in series. Therefore, you can eliminate (A), (B), and (C). The charged stored in the capacitor is given by $Q = CV$. Since the voltage of the capacitor in both scenarios will be the same, matching that of resistor R_2, a greater capacitance will result in a greater stored charge in the capacitor.

17. **C** One way to find the pressure is with the Ideal Gas Law. The Ideal Gas Law states that $PV = nRT$, so in addition to the volume, found from the length, one needs n and T to find the pressure. Temperature depends on the average speed of a gas molecule and the mass of the molecule. Without knowing the number of molecules in the container or the molar mass of the gas, the mass of each molecule is unknown, so I is incorrect. The impulse and time lets us calculate the force applied against the gas in that time. Newton's Third Law states that this must be the same magnitude as the force applied to the wall. The force and area allow us to calculate the pressure. So II and III are also correct.

18. **B** A fully charged parallel-plate capacitor will have a uniform, nonzero electric field between its plates.

19. **D** Use the right-hand rule to find the magnetic field produced by the wire. The current is to the right, so at a position above the wire, the magnetic field points outward. Then use the right-hand rule again to find the force on the particle. The particle moves to the right in a magnetic field pointed outward. The force is toward the bottom.

20. **C** The positive charge at point P will draw negative charges toward the right side of the neutral sphere, resulting in an attraction between the two objects. This will cause the string to be pulled to the right. The vertical component of tension will still balance the weight of the neutral sphere, but now there will be a horizontal component of tension balancing the electrostatic attraction.

21. **B** The Ideal Gas Law is $PV = nRT$, or $P = (\frac{nR}{V})T$. Comparing this to $y = mx + b$, the intercept is 0 and the slope is related to $1/V$.

22. **C** Work is done when there is a change in volume. At constant pressure, the equation $W = -P\Delta V$ indicates that when P is higher (as it is at path A→B), a greater amount of negative work is done on the gas than at a lower P (as it is at C→D). Furthermore, no work is done along the constant volume paths. Thus, the work done by the gas during the entire cycle is positive.

23. **C** The field is a sine curve with an amplitude of 10 N/C. From the graph, the period, T, of the wave is 2.85 ps. The argument of sine needs to be $2\pi t/T = (2 \times 3.14/2.85 \text{ ps})t = (2.20 \text{ THz})t$.

24. **D** Intensity is inversely related to the square of the separation between source and detector, so the fact that the train is approaching you means the intensity (loudness) will increase. The pitch, however, is dictated by the Doppler effect. In this case, the detector is motionless, but the source is moving toward the detector. This motion results in a higher pitch at the detector. The brakes of the train (which will, of course, reduce the speed of the train) will continually diminish this effect, so the pitch will decrease.

25. **D** The Ideal Gas Law is $P = (nRT)\left(\frac{1}{V}\right)$.

The potential from a point particle is $V = \frac{q_1}{4\pi\varepsilon_0}\left(\frac{1}{r}\right)$.

The magnetic field from a wire is $B = \frac{\mu_0 I}{2\pi}\left(\frac{1}{r}\right)$.

All of these are inverse to the first power.

26. **A** The quantity R is defined as the ratio of the gravitational force to the electric force between the two objects, so $R = \left(\frac{GMm}{r^2}\right) / \left(\frac{1}{4\pi\varepsilon_0}\left(\frac{Qq}{r^2}\right)\right)$

$$R = GMm \,/ \left(\frac{1}{4\pi\varepsilon_0} Qq\right)$$

R is constant.

27. **B** Doubling pressure at constant volume causes temperature to double. Doubling temperature doubles the average kinetic energy of the molecules. The speed squared is proportional to the kinetic energy, so the speed increases by a factor of $\sqrt{2}$.

28. **C** Relative to the central maximum, the locations of the bright fringes on the screen are given by the expression $m\left(\frac{\lambda L}{d}\right)$, where λ is the wavelength, L is the distance to the screen, d is the slit separation, and m is any integer. The width of a fringe is therefore $(m + 1)\left(\frac{\lambda L}{d}\right) - m\left(\frac{\lambda L}{d}\right) = \left(\frac{\lambda L}{d}\right)$. The slit spacing will increase if there is a decrease in d.

29. **B** The binding energy is the mass defect, the difference in the mass of the constituent components and the mass of the nucleus, multiplied by c^2. That mass defect is

$m_p + 2m_n - m_{Tr} = 1.673 \times 10^{-27} + 2 * 1.675 \times 10^{-27} - 5.008 \times 10^{-27} = 1.500 \times 10^{-29}$ kg

$E = \Delta mc^2 = 1.500 \times 10^{-29} * (3 \times 10^8)^2 = 1.35 \times 10^{-12}$ J

30. **D** If the photons of the incident light have insufficient energy to liberate electrons from the metal's surface, then simply increasing the number of these weak photons (that is, increasing the intensity of the light) will do nothing. In order to produce photoelectrons, each photon of the incident light must have an energy at least as great as the work function of the metal.

31. **D** Beta-minus decay occurs when a neutron turns into a proton and a beta particle. The number of nucleons does not change in this process.

32. **B** The frequency can be calculated using the following equation:

$$v = \lambda f \Rightarrow f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{20 \times 10^{-2} \text{ m}} = 1{,}715 \text{ Hz}$$

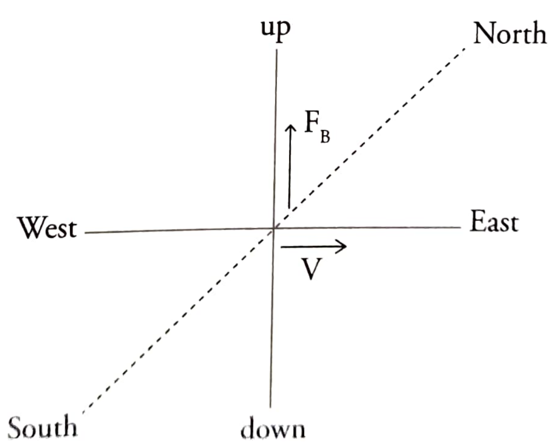
33. **A** Flux is the product of the area enclosed by the loop of wire and the field strength. The flux will increase linearly up to a maximum value when the wire is completely within the field, and it will begin to decrease once the wire begins to leave the region within the field.

34. **B** Path *b* follows the right-hand rule, so it must be positively charged. Path *a* is opposite the right-hand rule, so it must be negatively charged. Neutrons would follow a straight-line path, so it is impossible for either *a* or *b* to be a neutron.

35. **A** The rules for ray-tracing diagrams for diverging lenses state that a line parallel to the principal axis bends away from the focal point as shown.

36. **D** Water has a higher index of refraction than air, so if light refracts through the water, the light will bend away from the normal—so C is possible. Another possibility is D, total internal reflection when the angle in water is greater than the critical angle.

37. **D** The electron is negatively charged, so the electric field exerts a downward force on the electron. For the electron to continue with the same velocity, the net force acting on it must be zero, so the magnetic field should exert an upward force.



Apply the right-hand rule by pointing your thumb to the west (in the direction opposite **v** for the negative charge) with your palm facing up. In this configuration, your fingers should point south.

38. **A** When the fully charged capacitor is connected to the battery, the capacitor's voltage is the same as that of the battery, V_0. When the battery is disconnected, the voltage of the capacitor can change, but the charge cannot. These two quantities are related by $Q = CV$, so the voltage is inversely proportional to the capacitance. Inserting a dielectric with $\kappa = 2$ into the capacitor doubles its capacitance, so its voltage is half of what it used to be.

39. **A** From Ohm's Law, the current in the circuit will increase when the total resistance of the circuit decreases. Determine the equivalent resistance of the set of resistors in the original circuit and in each answer choice using the rules for combining series and parallel circuits. In the original circuit, the set of parallel resistors have an equivalent resistance R_p is given by $\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$, so $R_p = \frac{R}{2}$. The parallel resistors combine with the third resistor in series, so the equivalent resistance of the entire circuit is $R_{eq} = \frac{R}{2} + R = \frac{3}{2}R$. After adding another resistor in parallel with the existing pair of parallel resistors, the equivalent resistance of the set of three parallel resistors is $\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R}$, so $R_p = \frac{R}{3}$. Thus, the new equivalent resistance for the scenario in (A) is $R_A = \frac{R}{3} + R = \frac{4}{3}R$. This new equivalent resistance is less than that of the original circuit, making (A) correct. Adding another identical resistor in series with the batter makes the equivalent resistance $R_B = \frac{R}{2} + R + R = \frac{5}{2}R$, which is greater than that of the original circuit, so (B) is incorrect. Adding another identical resistor to one of the parallel branches of the circuit in series with the resistor that was already in that branch makes the resistance of that branch $2R$. Thus, the new equivalent resistance of the parallel branches is given by $\frac{1}{R_{p,C}} = \frac{1}{R} + \frac{1}{2R} = \frac{3}{2R}$, so $R_p = \frac{2R}{3}$. Thus, the new equivalent resistance for the scenario in (C) is $R_C = \frac{2R}{3} + R = \frac{5}{3}R$, which is greater than that of the original circuit, so (C) is incorrect. Removing one of the two parallel branches of the circuit leaves two resistors connected in parallel, with a resistance of $2R$, which is greater than that of the original circuit, so (D) is incorrect.

40. **C** The entropy of a closed system stays the same or increases. Entropy increases as a system approaches thermal equilibrium. Thermal equilibrium corresponds to objects having the same temperature. The refrigerator maintains a cooler temperature than its surroundings, so it is not in thermal equilibrium with its environment, making (A) incorrect. Objects approach thermal equilibrium when thermal energy moves from hot regions to cold regions, so moving energy from a colder to a warmer region does not increase entropy, making (B) incorrect. The entropy of the refrigerator decreases as heat is removed, which does not violate the second law as long as the entropy of the environment increases by an equivalent amount, making (C) correct. A closed system exchanges neither heat nor matter with its environment. The refrigerator exchanges thermal energy with its environment, so it is not a closed system, making (D) incorrect.

Section II: Free Response

1. (a) Using the chamber with the sliding lid allows for a changing volume at a constant amount of air, so that density can be the dependent variable in the experiment. The area of the lid is constant, so you can determine volume—using the meter stick—as the piston length changes. Using the large tubs of boiling water and ice water to heat and cool the chamber allows the independent variable to be the temperature, measured with the thermometer.

X	Chamber with sliding piston lid with a known area
	Pressure monitor
X	Meter stick
X	Large tub of boiling water

	Chamber with fixed lid with a known area
X	Thermometer
	Stopwatch
X	Large tub of ice water

(b) 1. Place the thermometer in the chamber with the sliding piston.
2. Place the chamber in the ice water and let it cool.
3. Record the temperature with the thermometer and the piston length with the meter stick.
4. Heat the chamber by placing it in the hot water.
5. Record the temperature and the piston length.
6. Repeat steps 4 and 5 to get temperature and volume data.

(c) The density is n/V, so since you have data for Δx and you know area, plot $\frac{1}{\Delta x}$ versus temperature. The shape of the graph will tell you whether the increase in temperature causes the density to increase or decrease.

(d) Based on the Ideal Gas Law,

$$PV = nRT$$

$$P = (n/V)RT$$

$$(n/V)^{-1} = \left(\frac{R}{P}\right)T$$

you can expect to see an inverse relationship.

2. (a) The total resistance in the circuit is $r + R$. Using Ohm's Law, the current is then $I = \frac{\varepsilon}{r + R}$.

(b) Power is $P = IV = \left(\frac{\varepsilon}{r + R}\right)\varepsilon = \frac{\varepsilon^2}{r + R}$.

(c) Temperature increases when the average kinetic energy of a molecule increases. When the switch is closed, the electrons move through the circuit. As the electrons move within the metal of the circuit, they collide with the positive nuclei of the atoms. The nuclei are set into motion, so the resistor heats up. The Second Law of Thermodynamics states that energy will flow from high energy to low energy parts of a system. The molecules in the water are moving with a lower energy than the hot resistor, so as the water molecules collide with the resistor, energy transfers into the water molecules. The now heated water molecules transfer energy to one another through further collisions, with the colder, slower molecules heating up and speeding up. The stirrer helps to ensure that the average energy is equal throughout the water by dispersing the fast-moving water molecules so that they transfer energy throughout the container and not just locally near the resistor.

(d) Energy can be transferred to the water molecules by the motion of the stirrer as well as by the high temperature molecules in the resistor. If the stirrer spins at a rapid enough rate, on average, the water molecules will be sped up simply by its motion, thus increasing the temperature of the water.

(e) The pressure in the container is a result of the collisions between the molecules within the container and its walls. As the molecules heat up and move more rapidly, they will collide more frequently with walls of the container and cause the pressure against the walls to increase.

3. (a) Between the plates, there is an electric field that points from one of the plates toward the other plate. As the particles change their position within a potential difference, work is done on the particles, causing them to accelerate. After leaving plate 2, the particles are subjected to a magnetic field. Because the magnetic field is always perpendicular to the direction of motion, the magnetic field does no work and the particles do not change their speed.

(b) Using the Work-Energy Theorem for each particle

$$W = q\Delta V = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

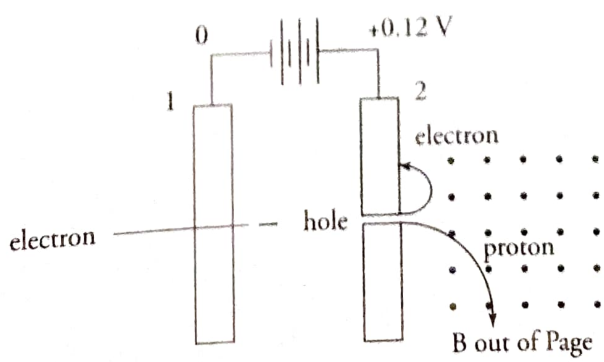
v_i is zero for each particle, and each particle has the same ΔV and q, so

$$v_f = \sqrt{\frac{2q\Delta V}{m}}$$

The ratio for the speed of the proton to the electron is the square root reciprocal ratio of the masses:

$$\frac{v_{fp}}{v_{fe}} = \sqrt{\frac{m_e}{m_p}} = \sqrt{\frac{9.11 \times 10^{-31}\text{ kg}}{1.67 \times 10^{-27}\text{ kg}}} = 0.023$$

(c) Both charges will travel on circular paths; however, the radius of the proton's path will be greater due to its greater mass.



(d) The alpha particle will have twice the charge and four times the mass of the proton. Because

$$v_f = \sqrt{\frac{2q\Delta V}{m}}$$

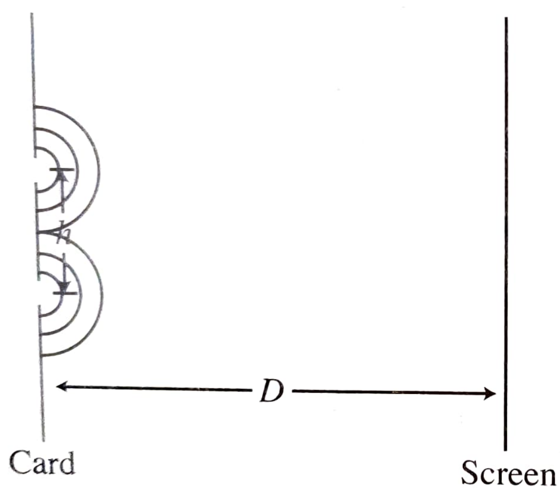
the final speed coming out of the hole will decrease by $\sqrt{2}$. The path curves because of the magnetic force being the centripetal force.

$$\frac{mv^2}{r} = qvB$$

$$r = \frac{mv}{qB} = \frac{4m_p\left(\frac{v_p}{\sqrt{2}}\right)}{2q_pB} = \sqrt{2}r_p$$

The radius of the circle will be $\sqrt{2}$ times as large, but the curve will be in the same direction.

4. (a)



(b) The double-slit experiment works by producing coherent spherical wavefronts that interfere with each other. A spherical wavefront is produced when a plane wave impinges upon a small slit, such as either of the slits in the card, as shown in part (a). The two spherical wavefronts then propagate to the screen and because there are two waves, they interfere with one another. Bright spots occur whenever there is constructive interference, while dark spots indicate that the interference is destructive. The interference will be constructive whenever the difference in the distance that the two waves travel is an integer multiple of the wavelength of the initial plane wave. There will be bright spots when the difference in traveled distance is 0 (in the middle), or ±1 wavelength, etc. There are a series of bright spots because there are many different possible locations on the card where constructive interference occurs.

(c) In the double-slit experiment, $m\lambda = dx/L$. Solving for λ,

$$\lambda = \frac{dx}{Lm}$$

d is the distance between the slits, x is the distance measured between fringes, L is the space from the slits to the screen, and m is the "order" or the number of dark spots between fringes. Using the given variables,

$$\lambda = \frac{hy_3}{3D}$$

(d) When light enters a medium with a different index of refraction, its speed changes. The light wave will have a constant frequency, so this change in speed results from a change in its wavelength. When light goes from an index of $n = 1$ to an index of $n > 1$, the wave speed decreases, resulting in a decreased wavelength.

$$\lambda = \frac{dx}{Lm}$$

So x is directly proportional to λ, and the distance between fringes will decrease.