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.

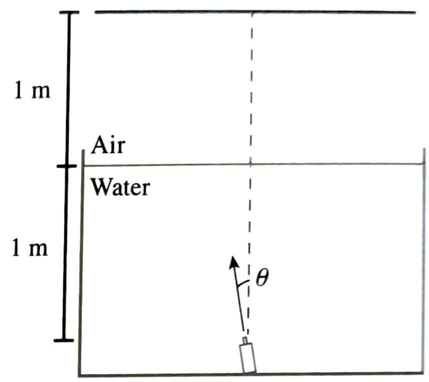
1. A green light ($\lambda = 550$ nm) is focused on a material with a work function of $\varphi = 3$ eV. What is the maximum kinetic energy of a photoelectron emitted from the material?

   (A) 0.74 eV
   (B) 2.3 eV
   (C) Electrons will not be emitted in this scenario.
   (D) Cannot be determined without additional information

2. Two different ideal gases are brought to the same temperature. The molecules of the first gas are four times more massive compared to the second gas. How do the average speeds of the molecules of the two gases compare?

   (A) The average speeds are the same.
   (B) The average speed of the molecules of the first gas are higher by a factor of 2.
   (C) The average speed of the molecules of the second gas are higher by a factor of 2.
   (D) The average speed of the molecules of the first gas are higher by a factor of 4.

Questions 3 and 4 refer to the following diagram.



A laser pointer is placed in a tank of water with no lid so that the light is emitted at a depth of 1 m from the surface. 1 m above the surface, a projection screen is positioned so that the center of the screen is directly above the laser pointer. The pointer is tilted at an angle, θ, from the vertical.

3. If the angle, θ, is 20 degrees, and given that the index of refraction of water is $n = 1.3$, How far from the center would the laser hit the screen?

   (A) 79 cm from the center
   (B) 86 cm from the center
   (C) 184 cm from the center
   (D) Cannot be determined without more information

4. If a plane of glass ($n = 1.5$) is used as a lid, with no gap between the water and the glass, what will happen to the position of the laser on the screen?

   (A) There will be no change in position.
   (B) The laser will hit farther from the center.
   (C) The laser will hit closer to the center.
   (D) Cannot be determined without knowing the thickness of the glass

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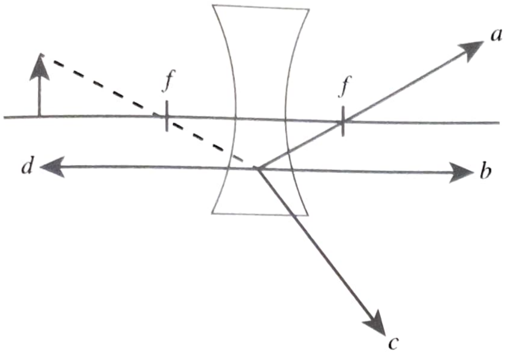
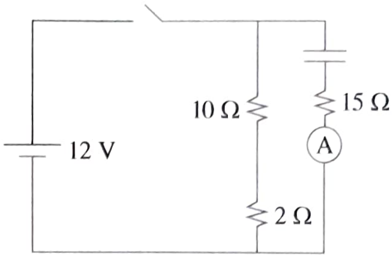


5. In the figure above, a ray of light hits an object and travels through the focal point of a concave lens as shown by the dotted line. Which line best shows the correct continuation of the ray after it hits the lens?
   (A) *a*
   (B) *b*
   (C) *c*
   (D) *d*

6. An experiment is performed where standing sound waves are produced in open-ended cylinders of varying length. The frequencies of the waves are adjusted until the first harmonic is reached in a 1 m cylinder, the second harmonic is reached in a 2 m cylinder, and the third harmonic is reached in a 3 m cylinder. If the frequencies are f_1, f_2, and f_3, respectively, what is the relationship between these frequencies?
   (A) $f_1 = f_2 = f_3$
   (B) $f_1 < f_2 < f_3$
   (C) $f_1 > f_2 > f_3$
   (D) $f_1 = f_2 < f_3$

7. An ideal gas undergoes an isothermal compression. What best describes the heat flow during this process?
   (A) No heat flows.
   (B) Heat flows out of the gas.
   (C) Heat flows into the gas.
   (D) Heat initially flows out of the gas, but the same amount of heat then flows into the gas.

Questions 8–10 refer to the following circuit diagram.



8. In the above circuit, the capacitor is initially uncharged and the switch is closed. What best describes the current through the ammeter after the switch is closed?
   (A) The current starts at a maximum and decreases to zero.
   (B) The current starts at a maximum and decreases to a non-zero amount.
   (C) The current starts at zero and increases to a set amount.
   (D) Cannot be determined without knowing the capacitance of the capacitor

9. After a long period of time, the switch is opened. What is the current through the ammeter immediately after the switch is opened?
   (A) 0 A
   (B) 0.44 A
   (C) 0.8 A
   (D) 1.8 A

10. The capacitor is replaced with a piece of wire with negligible resistance. If the switch is again closed, what is the voltage across the 2 Ω resistor?
   (A) 1 V
   (B) 2 V
   (C) 6 V
   (D) 12 V

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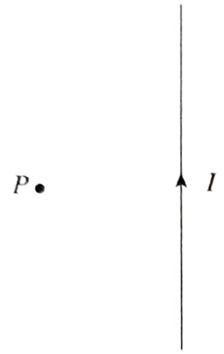
11. An electron in an atom transitions from an excited state of −16 eV down to a ground state of −20 eV. What is the wavelength of the emitted photon?

(A) 31 nm
(B) 78 nm
(C) 311 nm
(D) 780 nm



12. In the diagram above, a straight wire with a current I points vertically upward. At point P, which direction is the magnetic field pointing?

(A) Up
(B) Left
(C) Into the page
(D) Out of the page

13. Two point charges, q_1 and q_2, are separated by a distance r in a vacuum. What change would cause the magnitude of the electric force between the charges to double?

(A) q_1 is doubled.
(B) r is halved.
(C) Both q_1 and q_2 are doubled.
(D) The sign of the charge on q_1 is flipped.

14. Two positive point charges with charge $+Q$ and $+2Q$ are placed on a horizontal x-axis separated by a distance r in vacuum. At which of these points could the electric field be zero?

(A) To the left of both charges
(B) To the right of both charges
(C) In between the charges, closer to the $+Q$ charge
(D) In between the charges, closer to the $+2Q$ charge

15. A student preforms a double-slit experiment and successfully creates an interference pattern on the screen. Which of the following will occur if the distance between the slits, d, is increased?

(A) The fringes will spread out.
(B) The fringes will get closer.
(C) The intensity of the pattern will increase.
(D) The width of the central peak will widen.

16. An observer stands at rest as a car with a siren drives directly towards them at a constant speed. Which of the following is correct regarding the sound of the siren heard by the observer as the car approaches?

(A) The frequency of the sound is increasing.
(B) The frequency of the sound is constant.
(C) The frequency of the sound is decreasing.
(D) The amplitude of the sound is constant.

17. Plutonium undergoes alpha decay to form uranium as shown below.

$$^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^{4}_{2}\text{He}$$

This process causes the daughter nuclei to gain energy. What is the best explanation for this?

(A) The combined mass of the uranium and helium is greater than that of the plutonium.
(B) The combined mass of the uranium and helium is less than that of the plutonium.
(C) Conservation of momentum requires that the velocities of the products cancel out.
(D) Conservation of charge requires that the electrostatic force pushes the products away from each other.

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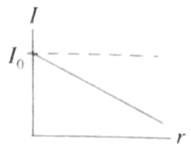
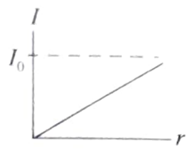
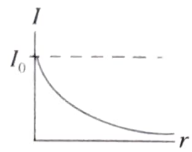
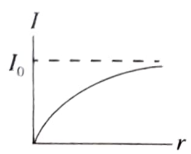
18. A sound wave has an initial intensity of I_0. Which of the following correctly shows the relationship between the intensity of the sound wave, I, and distance, r?

(A)


(B)


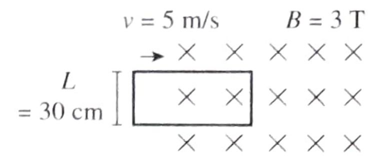
(C)


(D)


19. An ideal gas initially has a pressure of 2×10^5 Pa and a volume of 0.5 m^3. It then expands at a constant pressure to a volume of 2 m^3, and after expanding its pressure is increased to 5×10^5 Pa while it's held at a constant volume. What is the total work done by the gas during both transitions?

(A) 3×10^5 J
(B) 4.5×10^5 J
(C) 6×10^5 J
(D) 7.5×10^5 J

Questions 20–22 refer to the following material.



In the above diagram, a rectangular loop of wire is traveling to the right at a constant velocity into a constant magnetic field pointing into the page.

20. What is the emf induced in the loop as it enters the magnetic field?

(A) 0.5 V
(B) 4.5 V
(C) 50 V
(D) 450 V

21. What is the direction of the current in and force on the wire on the right side of the loop as it enters the field?

(A) Current is flowing up and force is to the right.
(B) Current is flowing down and force is to the right.
(C) Current is flowing up and force is to the left.
(D) Current is flowing down and force is to the left.

22. After fully entering the field, the loop comes to a stop and starts to rotate at a constant rate about a horizontal axis. Which choice correctly describes the emf as it spins?

(A) Because it is spinning at a constant rate, the emf will be constant but non-zero.
(B) Because the magnetic field is constant, the emf will be zero.
(C) The emf will be at a maximum when the loop is parallel to the page, because this is where the flux is at a maximum.
(D) The emf will be at a minimum when the loop is parallel to the page, because this is where the change in flux is at a minimum.

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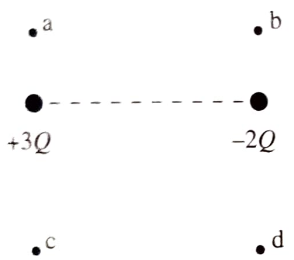
23. A convex lens with a focal length of 20 cm is used to form an image of an object paced 15 cm behind the lens. Which of the following is true about the image formed?

(A) The image is virtual and located 8.6 cm behind the lens.
(B) The image is virtual and located 60 cm behind the lens.
(C) The image is real and located 8.6 cm in front of the lens.
(D) The image is real and located 60 cm in front of the lens.

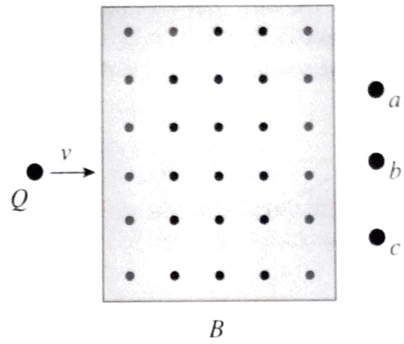


24. A positive charge of $3Q$ and a negative charge of $2Q$ are arranged as shown above. If the electric potentials are compared between two of the four labeled points, which of the following would have the greatest change in potential?

(A) $|V_a - V_b|$
(B) $|V_a - V_c|$
(C) $|V_c - V_b|$
(D) $|V_c - V_d|$

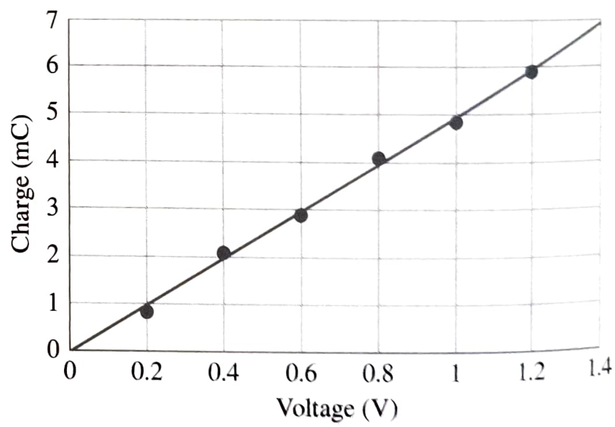
25. An image is created by placing an object in front of a concave lens. If the lens is replaced with one of identical shape but with a lower index of refraction, which of the following changes would occur?

(A) The focal length would increase and the image would be formed farther from the lens.
(B) The focal length would increase and the image would be formed closer to the lens.
(C) The focal length would decrease and the image would be formed farther from the lens.
(D) The focal length would decrease and the image would be formed closer to the lens.



26. In the above figure, an unknown charge, Q, with negligible mass travels to the right with speed v through a region with uniform magnetic field, B, pointing out of the page. Which of the following is possible?

(A) The charge passes through point a with a speed lower than v.
(B) The charge passes through point b with a speed equal to v.
(C) The charge passes through point c with a speed higher than v.
(D) The charge passes through point a with a speed equal to v.



27. An experiment was performed that measured the charge on a capacitor while connected to a variable battery at several voltages. What is the capacitance of the capacitor that produced the graph above?

(A) 0.5 mF
(B) 1 mF
(C) 5 mF
(D) 10 mF

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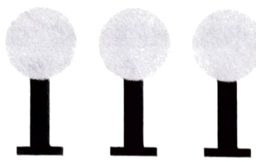
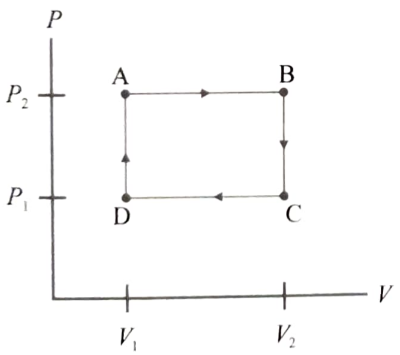
28. Three resistors are connected to a battery in parallel. If $R_1 < R_2 < R_3$, what is the relationship between the voltages across each resistor?

(A) $V_1 < V_2 < V_3$
(B) $V_1 > V_2 > V_3$
(C) $V_1 = V_2 = V_3$
(D) Cannot be determined without more information



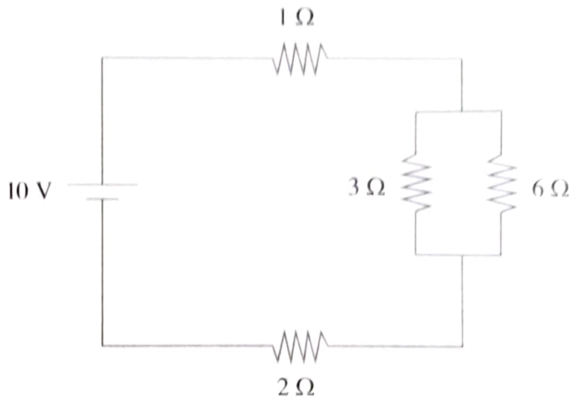
29. Three neutral conducting spheres sit on insulating bases. The first sphere is given a positive charge. It is then brought in contact with the second sphere and allowed to reach equilibrium. The two spheres are then separated. Finally, the second sphere is brought into contact with the third sphere and allowed to reach equilibrium. If the charge on the first, second, and third spheres after this process is Q_1, Q_2, and Q_3, respectively, what is the correct relationship between these charges?

(A) $Q_1 = Q_2 = Q_3$
(B) $Q_1 > Q_2 > Q_3$
(C) $Q_1 < Q_2 < Q_3$
(D) $Q_1 > Q_2 = Q_3$



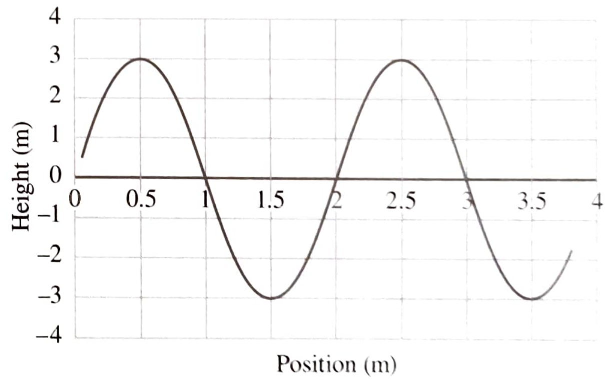
30. In the above diagram, in ideal gas undergoes the cycle ABCDA. What is the change in internal energy after the cycle?

(A) $(V_2-V_1)(P_2-P_1)$
(B) $(V_2-V_1)P_2$
(C) $(P_2-P_1)V_2$
(D) 0



31. In the circuit shown above, what is the current through the 3 Ω resistor?

(A) 0.83 A
(B) 1.3 A
(C) 2.9 A
(D) 3.3 A



32. The above graph shows the displacement height of a string against its horizontal position as a wave travels along its length. If the period of the wave is 5 ms, what is the speed of the wave?

(A) 10 m/s
(B) 40 m/s
(C) 200 m/s
(D) 400 m/s

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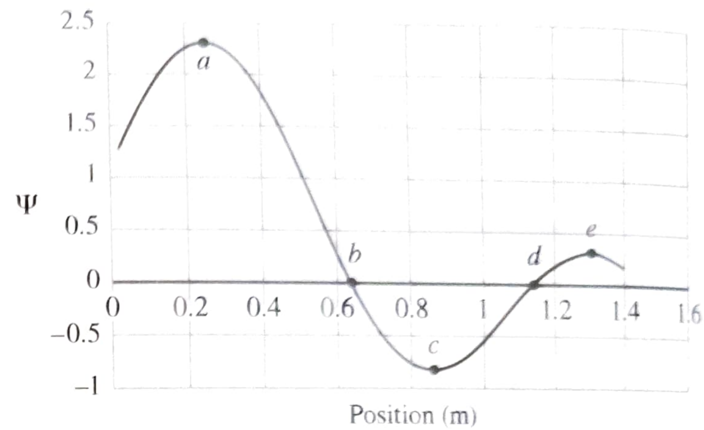
33. During an isothermal expansion, an ideal gas pushes a piston with a mass of 2 kg up a height of 20 cm. Approximately what is the amount of heat that flows into the gas during this process?
   (A) 0 J
   (B) 4 J
   (C) 10 J
   (D) 400 J

34. Two point charges, Q_1 and Q_2, are placed 3 m apart. If $Q_1 = +5\ \mu C$ and $Q_2 = -2\ \mu C$, what is the magnitude and direction of the electric field at the midpoint between the charges?
   (A) 28 kN/C, towards Q_1
   (B) 28 kN/C, towards Q_2
   (C) 12 kN/C, towards Q_1
   (D) 12 kN/C, towards Q_2

35. A bar magnet is moved toward a coil of wire at a constant speed. As a result, a current is induced in the coil. If the bar magnet suddenly changes direction and moves away from the coil at the same constant speed, what happens to the induced current?
   (A) The induced current increases.
   (B) The induced current decreases.
   (C) The induced changes direction.
   (D) The induced current does not change.

36. A 6 μF capacitor and 15 μF capacitor are connected in series to a 12 V battery. After the circuit reaches equilibrium, what is the approximate charge on the 6 μF capacitor?
   (A) 26 μC
   (B) 51.5 μC
   (C) 126 μC
   (D) 252 μC



37. The above graph shows the wave function of a certain particle. Of the labeled points, which one(s) are the least likely to be the particle's position when observed?
   (A) *a*
   (B) *b* and *d*
   (C) *c*
   (D) *a*, *c*, and *e*

38. A cooling fan is used to reduce the temperature of a system by blowing air past it and carrying heat away. Why does this not violate the Second Law of Thermodynamics?
   (A) The second law only applies to isolated systems and since the air is leaving the area, this is an open system.
   (B) The temperature decrease does not mean an entropy decrease in this scenario.
   (C) The entropy of the surroundings will increase less than the entropy of the object decreases.
   (D) The heat lost will match the loss of internal energy.

39. Two charges, one with a mass of 5 kg and a charge of +3 C and the other with a mass of 2 kg and a charge of +2 C, are positioned next to each other. What would the resulting motion be?

(A) The charges move away from each other with the same acceleration.
(B) The charges move away from each other and the +3 C charge has greater acceleration.
(C) The charges move away from each other and the +2 C charge has greater acceleration.
(D) The charges move towards each other with the same acceleration.

40. A detector is positioned to measure the intensity of an object's blackbody radiation at a distance, *d*, from the object. If the temperature of the object is increased by a factor of 2, what will happen to the intensity measured by the detector?

(A) The intensity will increase by a factor of 2.
(B) The intensity will increase by a factor of 4.
(C) The intensity will increase by a factor of 8.
(D) The intensity will increase by a factor of 16.

END OF SECTION I

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. Students perform a double-slit experiment with the goal of precisely measuring the distance between the slits. They set up the wall with a variable monochromatic light source shining through the slit and a projection screen 2 m away from the wall on the opposite side of the light source. They set the wavelength of the light, λ, and measure the distance from the central peak of the diffraction pattern to the first bright fringe, x. They repeat this measurement for several different wavelengths. Additionally, they use the x-value to mathematically derive the angle to the bright fringe, θ. Their data are shown in the table below:

Wavelength of the light (nm)	Distance from central peak to first bright fringe (cm)	Angle from the slit to the first bright fringe	
400	14.4	4.118°	
450	16.5	4.745°	
500	18.0	5.143°	
550	19.8	5.654°	
600	22.1	6.334°	

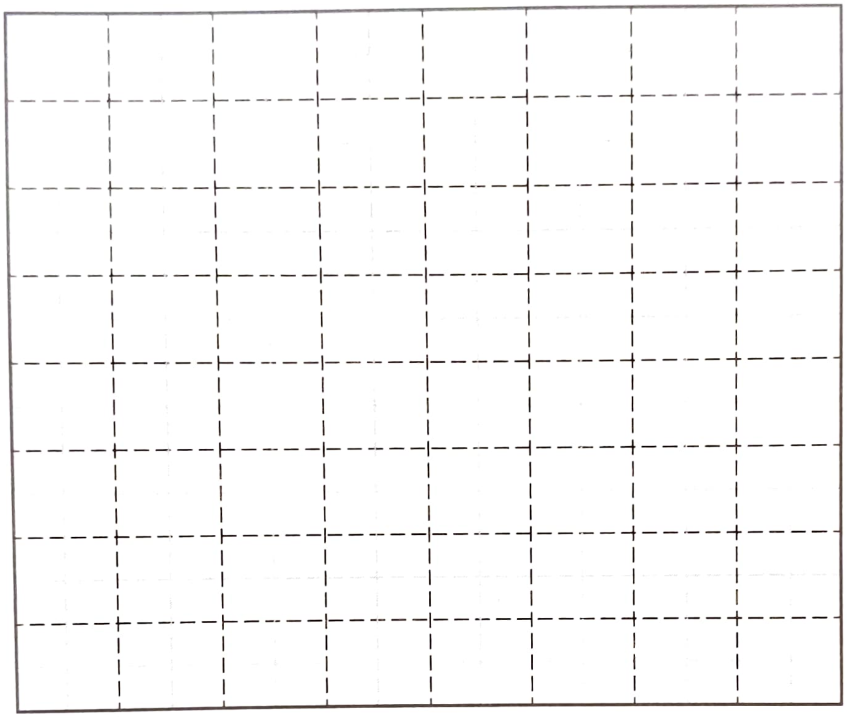
(a) Derive an equation for the angle, θ, in terms of λ, x, and known values, as appropriate.

(b) The students want to produce a linear graph of the data so that the distance between the slits, d, can be determined from the line of best fit.

i. Indicate two quantities that could be plotted to produce the desired graph. Use empty columns of the data table in part (a) to record any values that you need to calculate.

Vertical axis________________ Horizontal axis________________

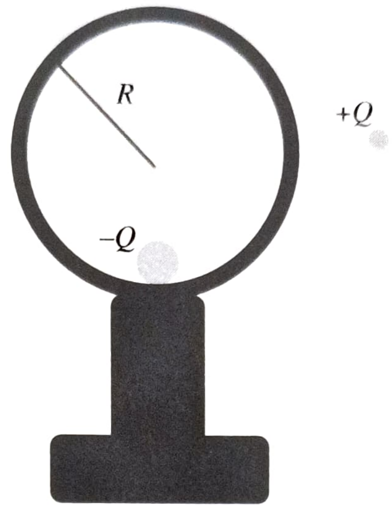
ii. Label the axes below and provide an appropriate scale with units. Plot the data points for the quantities indicated in part (b)(i) on the axes and draw a best-fit line.



iii. Using your best-fit line, determine the distance between the slits, d.

(c) A student finds a different wall with one slit. A rough measurement of the slit's width shows that it is 1 cm wide. The student has the idea of setting up an experiment similar to that described in part (a) to get a more precise measurement of the slit's width, using diffraction instead of interference. Is this feasible? Briefly explain why or why not.

2.



In the figure above, a negatively charged ball of mass m and charge magnitude Q is placed in a spherical container with inner radius R made of insulating glass; the ball comes to a rest at the bottom of the container. A positive charge of magnitude Q is then positioned next to the container and held in place. This causes the negative charge to move a brief distance before coming to a stop.

(a)

i. Below, create two force diagrams. The first showing the forces on the ball immediately after the positive charge was introduced, and the second the forces on the ball after it has moved and come to a stop.

ii. Briefly explain why the ball moves and why it comes to a stop.

(b) When the ball is at the bottom of the container, the distance between the ball and the positive charge is r_1. After the ball has moved and come to a stop, the distance between the ball and the positive charge is r_2.

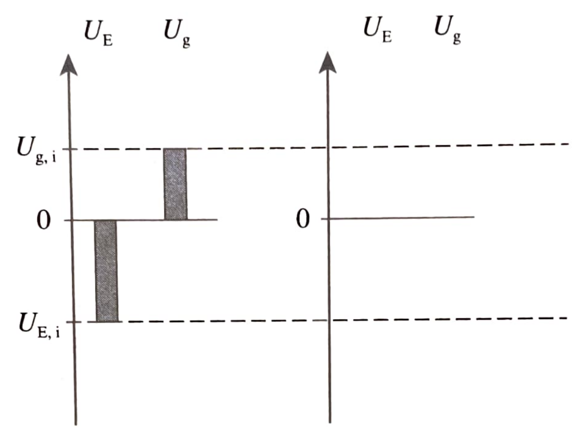
i. Which is larger, r_1 or r_2?

ii. Find an expression for ΔV, the change in electric potential created by the positive charge from the ball's starting position to its position after it has moved and come to a stop.

iii. Does this change in potential agree with your description in part (a)(ii)? Briefly explain why or why not.

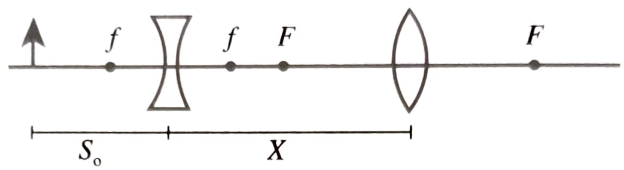
(c) Assume the energy lost to frictional and drag forces during the ball's motion is negligible.

i. Using conservation of energy, derive an equation for the height the ball will rise, h, from the bottom of the container in terms of m, Q, R, r_1, r_2, and physical constants, as appropriate.



ii. The left bar chart in the figure above is complete and represents the initial electric potential energy $U_{E,i}$ and initial gravitational potential energy $U_{g,i}$ of the ball before it starts to move. In the space provided on the right, draw a bar chart to represent a possible final electric potential energy and final gravitational potential energy of the ball after it has moved and come to a stop.

3.



In the above figure, a concave lens and a convex lens are used together to project an image of an object onto the screen on the right. The focal length of the concave lens is f, the focal length of the convex lens is F, the object is positioned a distance of s_o to the left of the concave lens, the distance between the lenses is x, and the screen is positioned a distance of $s_{i,\ final}$ to the right of the convex lens.

(a) Derive an equation for $s_{i,\ initial}$ the distance from the concave lens to the image of the object created solely by the concave lens. The equation should be in terms of s_o and f. Is this image real or virtual? Upright or inverted?

(b) Use ray tracing to create a diagram with the object, concave lens, f, and $s_{i,\ initial}$ clearly labeled. Do not include the convex lens in the diagram.

(c) The convex lens will use the image created by the concave lens as its object. With this in mind, derive an equation for $s_{i,\ final}$ in terms of s_o, f, F, and x. Is this image real or virtual? Upright or inverted?

(d) The concave lens is made of a flexible material so that it can be stretched and compressed to change F, the focal length of the convex lens. The screen will always be to the right of the convex lens, but it can be moved to different positions to focus the image onto the screen.

i. Is there a maximum value of F? If so, express it in terms of s_o, f, and x and briefly explain what happens if F becomes too large. If not, briefly explain what happens as F approaches infinity.

ii. Is there a minimum value of F? If so, express it in terms of s_o, f, and x and briefly explain what happens if F becomes too small. If not, briefly explain what happens as F goes to zero.

4. An isolated container is filled halfway with a liquid and the remainder is filled with an ideal gas. The condensation point of the ideal gas is the same as the boiling point of the liquid, T_{bp}. Initially the ideal gas has a temperature of $T_1 > T_{bp}$ and the liquid has a temperature of $T_2 < T_{bp}$.

(a) After the container is filled, the lid is quickly pressed down, slightly compressing the gas. Assume the liquid is incompressible.

i. Will the temperature of the gas change during the compression? If so, does it increase or decrease? Briefly justify your answer using the First Law of Thermodynamics.

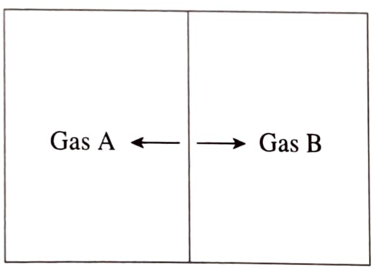
ii. After a short time, the lid is brought back to its original position. How will the temperature of the gas compare to T_1? Briefly justify your answer.

(b) After a long time has passed and thermal equilibrium is reached, the temperature inside the container is measured.

i. How will this measurement compare to T_1 and T_2? Briefly justify your answer.

ii. It is found that the measured temperature is above T_{bp}, so that both materials are now gasses. What about the respective initial energies of the liquid and gas could have led to this result?

(c)



The container is emptied and a partition that is free to move left and right is placed in the middle. Ideal gas *A* is put into the left side of the container and ideal gas *B* into the right side, as shown in the figure above. The partition does not allow the gasses to mix, but it does allow heat to flow between the two gasses. Gas *A* and gas *B* have the same molar density, but gas *A* has twice the mass and 1/4th the temperature of gas *B*. If the partition is initially placed in the center of the container, will it feel a net force? If so, which way? Briefly justify your answer.

(d) After a long time, thermal equilibrium is reached and the partition is found to be at rest.

i. What fraction of the container does gas A now occupy?

ii. Justify your answer.

iii. Does your answer to the previous question contradict your answer in part (c). Briefly explain why or why not.

STOP

END OF EXAM

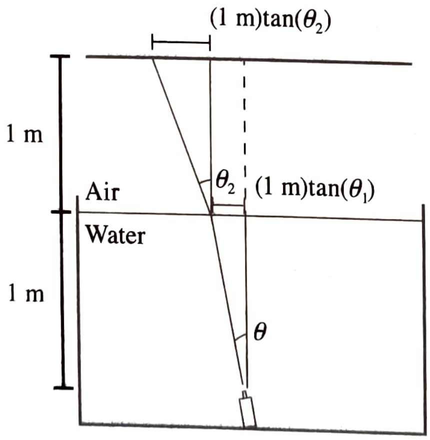
PRACTICE TEST 1: ANSWERS AND EXPLANATIONS

Section I: Multiple Choice

1. **C** To use $K_{max} = hf - \varphi$, find the frequency of the photons by using $\lambda = \frac{v}{f}$. Thus, $f = \frac{3 \times 10^8 \, m/s}{550 \times 10^{-9} m} = 5.45 \times 10^{14} \text{Hz}$, plugging into the photoelectric effect equation gives you $K_{max} = (4.14 \times 10^{-15} \text{eV} \cdot \text{s})(5.45 \times 10^{14} \text{Hz}) - 3 \text{ eV} = -0.74 \text{ eV}$. This is a negative value, which means that the energy of the photon is less than the energy of the work function. Therefore, no electrons would be emitted.

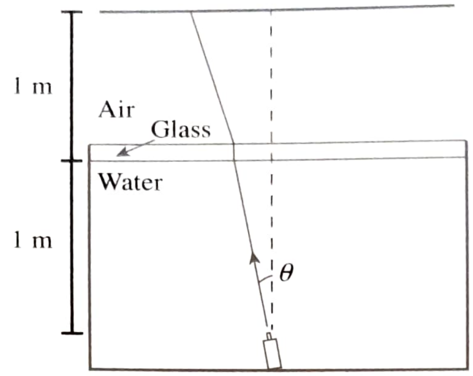
2. **C** Because the temperatures are the same, the average kinetic energy of the molecules are the same. Since $K = \frac{1}{2}mv^2$, it must be that $v^2 \propto \frac{1}{m}$ or $v \propto \frac{1}{\sqrt{m}}$. Thus, if m is less by a factor of 4, v increases by a factor of 2.

3. **B**



As seen in the above diagram, you can use trigonometry to see that the distance from the center will be (1 m)tan(θ_1) + (1 m)tan(θ_2). θ_1 is the angle given in the problem, 20°, and to find θ_2, apply Snell's Law $n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \rightarrow \theta_2 = \sin^{-1}(\frac{n_1 \sin(\theta_1)}{n_2}) = \sin^{-1}(\frac{1.3 \sin(20°)}{1}) = 26.4°$. Plug this in to get d = (1 m)tan(20°) + (1 m)tan(26.4°) = 0.86 m.

4. **C**



As seen in the image above, adding a glass will introduce a portion where the light travels closer than 20° to the vertical, since the index of glass is higher than that of the index of water and the angle from the vertical will decrease as it transitions from water to glass. This means that the light will not travel as far horizontally while traveling in the glass. After exiting the glass, it will travel at the same angle as when the glass wasn't there because an intermediate medium does not affect the final angle, but it now has a shorter vertical distance to travel. Therefore, the light will not go as far horizontally and will end up closer to the center.

5. **C** A concave lens is diverging. The light will therefore diverge away from the center line after passing through.

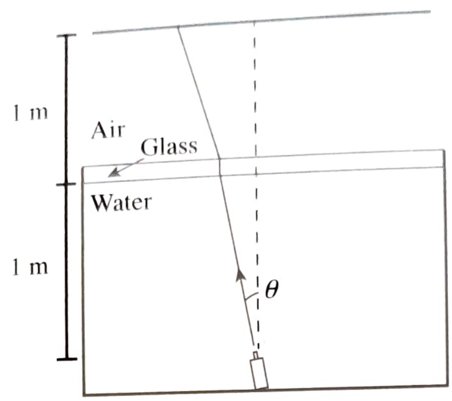
6. **A** For an open-ended pipe, the resonant frequency is given by $f_n = n\frac{v}{4L}$. When plugging in the given n and L values, they end up canceling and $f = \frac{v}{n}$ for all three cases.

7. **B** The First Law of Thermodynamics states $\Delta U = Q + W$, and in the case of an isothermal process, temperature is not changing and the energy of the ideal gas would not change. This means $Q = -W$. When the gas is compressed, positive work is done on the system, which means Q is negative and heat is leaving the system.

8. **A** When a capacitor is uncharged, it acts as a wire and current is allowed to flow freely. Therefore, at the start, the current will be at a maximum. As the capacitor is charged, it gains voltage and resists the current more and more until it reaches equilibrium. At equilibrium, charge no longer moves and the current drops to zero.

9. **B** With the switch closed, after a long time, there will be no current in the part of the circuit with the capacitor, and therefore all 12 volts must be across the capacitor. Once the switch is opened, the capacitor will initially act as a 12-volt voltage source for the three resistors, and since no current flows across the open switch, you can ignore that part of the circuit so the three resistors act like they are in series. This means the equivalent resistance is given by $15\ \Omega + 2\ \Omega + 10\ \Omega = 27\ \Omega$ and the current is given by $I = (12\text{ V})/(27\ \Omega) = 0.44\text{ A}$.

4. C



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10. **B** Because it is in parallel with the battery, the part of the circuit with the 10 Ω and 2 Ω resistors must have a total of 12 V across it. Combining them in series, there will be a total of 12 V across an equivalent resistance of 12 Ω. Therefore, the current through that part of the circuit is I = (12 V)/(12 Ω) = 1 A. The voltage must therefore be V = (1 A)(2 Ω) = 2 V.

11. **C** The change of energy here is –20 eV – (–16 eV) = –4 eV. Since the electron lost 4 eV of energy, that is the energy of the emitted photon. By $E = hf$, $f = \frac{E}{h} = \frac{4\text{ eV}}{4.14 \times 10^{-15}\text{ eV}\cdot\text{s}} = 9.66 \times 10^{14}\text{ Hz}$.
Thus, $\lambda = \frac{v}{f} = \frac{3 \times 10^{8}\ \text{m/s}}{9.66 \times 10^{14}\text{ Hz}} = 3.11 \times 10^{-7}\text{ m} = 311\text{ nm}$.

12. **D** Apply the right-hand rule for a current-generated magnetic field. The thumb of the right hand points upward and the fingers curl so that on the left side they are coming out of the page.

13. **A** By Coulomb's Law, $F_E = k\frac{q_1q_2}{r^2}$. Thus, doubling q_1 would double the magnitude of the force. Halving r or doubling both charges would increase the force by a factor of 4, and flipping the sign of a charge would change the direction of the force without affect its magnitude.

14. **C** The electric field points away from positive charge. For the field to be zero, the directions of the field from each of the two charges must be opposite. This will only happen when in between the charges. Additionally, to balance the magnitudes of the fields, the point must be farther away from the more powerful charge and closer to the weaker charge.

15. **B** The fringes in a double-slit experiment are given by $\sin\theta = \pm m\frac{\lambda}{d}$, where d is the distance between the slits. Increasing d will therefore decrease the angle and the fringes will get closer together.

16. **B** The Doppler effect changes the frequency based on the relative speeds of the source and the detector. Because the car is driving at a constant speed, the frequency heard will not be changing, though it would be higher than how it would sound if everything were stationary.

17. **B** Mass can be converted to energy through $E = mc^2$, so a decrease of mass matches an increase in energy. While momentum would be conserved here, it is not a good explanation of why there's a gain of energy, because everything staying stationary would also conserve momentum.

18. **C** The intensity of a wave from a point source is given by $I = \frac{P}{4\pi r^2}$, where r is the distance from the source. As a wave travels, its intensity therefore drops as the distance is squared.

19. **A** The work done on the gas during an isobaric process is given by $W = -P\Delta V = -(2 \times 10^5\text{ Pa})(2\text{ m}^3 - 0.5\text{ m}^3) = -3 \times 10^5\text{ J}$, and no work is done during an isochoric process. The work done by the gas would then be 3×10^5 J.

20. **B** The magnitude of the emf is the change of the magnetic flux over the change in time. In this case, this is given by $\varepsilon = BLv = (3\text{ T})(0.3\text{ m})(5\,\text{m/s}) = 4.5\text{ V}$.

21. **C** The emf will act to counter the change in magnetic flux. This means the induced current will flow to create a magnetic field pointing out of the page in the middle of the loop. To accomplish this, the current must flow counter-clockwise by the right-hand rule. Thus, the current in the right wire would flow up. Applying the right-hand rule again to find force on the upward-flowing current reveals that the force would be going to the left.

22. **D** The magnitude of emf is the change in magnetic flux over the change in time. As the loop is spinning, the area the magnetic field is passing through would be changing. Eliminate (A) and (B). Choice (C) is eliminated because it does not matter what the flux currently is, just how it is changing. Indeed, the change in flux would be zero at the point the loop is parallel to the page, as that is the point where the magnitude of flux changes from increasing to decreasing.

23. **B** Because convex lenses are converging, $f = +20$ cm. From the lens equation, $\frac{1}{i} = \frac{1}{f} - \frac{1}{o} = \frac{1}{20\text{ cm}} - \frac{1}{15\text{ cm}} = -\frac{1}{60\text{ cm}} \rightarrow i = -60\text{ cm}$. The negative sign indicates that the image is on the same side as the object and is virtual.

24. **A** The potential is more positive the closer the point is to a positive charge and more negative the closer the point is to a negative charge. Therefore, moving from the point closest to the positive charge to the point closest to the negative charge would give the biggest change of potential.

25. **A** The focal length for a concave lens represents where parallel light diverges away from. Having a lower index means the index more closely matches that of air ($n = 1$) and the light would bend less. This means the point it is diverging from is farther from the lens. If the focal length increases, f would become more negative. From the lens equation $\frac{1}{i} = \frac{1}{f} - \frac{1}{o}$, if f is more negative, $1/f$ would be less negative, and therefore the magnitude of $1/i$ would be smaller and i would be larger.

26. **D** The magnetic force never does work and therefore the speed of the charge would not be affected. Eliminate (A) and (C). Additionally, the magnetic force will cause the charge to turn so it cannot go in a straight line through point b. Eliminate (B), and the correct answer must be (D).

27. **C** $Q = CV \rightarrow C = \frac{Q}{V}$, so use any point on the line to get the charge and matching voltage. Using the point (1 V, 5 mC), for example, gives $C = \frac{5\text{ mC}}{1\text{ V}} = 5\text{ mF}$.

28. **C** Objects in parallel always have the same voltage regardless of their resistance.

29. **D** If the initial charge given to the first sphere is Q_{tot}, then after it is brought in contact with the second sphere, it will be evenly distributed, so the charge on the first sphere will be $1/2Q_{tot}$ and the charge on the second sphere is also $1/2Q_{tot}$. After the second sphere is brought into contact with the third sphere, it will once again evenly distribute the charge of $1/2Q_{tot}$. This means at the end $Q_1 = 1/2Q_{tot}$, and $Q_2 = Q_3 = 1/4Q_{tot}$.

30. **D** For an ideal gas, internal energy is related to temperature. Completing the loop and coming back to the same pressure and volume means that it is back at the same temperature and internal energy would not change.

31. **B** Start by combining the two resistors in parallel: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{3\ \Omega} + \frac{1}{6\ \Omega} = \frac{1}{2\ \Omega} \rightarrow R_{eq} = 2\ \Omega$. Then combine the result with the other two resistors in series: $R_{eq} = 1\ \Omega + 2\ \Omega + 2\ \Omega = 5\ \Omega$. Use this to find the current through the circuit: $I = \frac{V}{R} = \frac{10\ \text{V}}{5\ \Omega} = 2\ \text{A}$. This will be the current through the three series resistors, including the 2 Ω equivalent resistor from the two parallel resistors. This means the voltage across the two parallel resistors is $V = IR = (2\ \text{A})(2\ \Omega) = 4\ \text{V}$. Thus, the current through the 3 Ω resistor is $I = \frac{V}{R} = \frac{4\ \text{V}}{3\ \Omega} = 1.3\ \text{A}$.

32. **D** From the graph, you can see $\lambda = 2$ m. Because $f = \frac{1}{T}$, you get $v = \lambda f = \frac{\lambda}{T} = \frac{2\ \text{m}}{5 \times 10^{-3}\ \text{s}} = 400$ m/s.

33. **B** During an isothermal process, $\Delta U = 0$ and the first law becomes $Q = -W$. To find the work done, examine the change of potential energy $\Delta U_g = mg\Delta h = (2\ \text{kg})(9.8\ \text{m/s}^2)(0.2\ \text{m}) \approx 4\ \text{J}$. This is the work done by the gas, so the work done on the gas is -4 J and the heat is $Q = -(-4\ \text{J}) = 4$ J.

34. **B** Find the magnitude of each electric field with $|E| = \frac{|q|}{4\pi\varepsilon_0 r^2} = k\frac{|q|}{r^2}$.

$$E_1 = (9 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)\frac{|5 \times 10^{-6}\ \text{C}|}{(1.5\ \text{m})^2} = 2 \times 10^4\ \text{N/C}$$

$$E_2 = (9 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)\frac{|-2 \times 10^{-6}\ \text{C}|}{(1.5\ \text{m})^2} = 8 \times 10^3\ \text{N/C}$$

The electric field from a positive charge points away from the positive charge, and the electric field from a negative charge points toward the negative charge. When in between the two charges, these would be the same direction, so add all the magnitudes together: $E_{tot} = E_1 + E_2 = 2 \times 10^4 + 8 \times 10^3 = 28$ kN/C.

35. **C** The magnitude of the emf and induced current is the change of magnetic flux over the change in time. If the magnet moves away at the same speed that it was approaching, the rate of change would be the same and the magnitude of the current would be the same. However, the emf acts to counter the changing flux, so changing from an increase in the flux (moving toward) to a decrease in the flux (moving away) would flip the direction of the induced current.

36. **B** To combine capacitors in series use $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{6\ \mu\text{F}} + \frac{1}{15\ \mu\text{F}} = \frac{7}{30\ \mu\text{F}} \rightarrow C_{eq} = 4.29\ \mu\text{F}$. The charge on the equivalent capacitor is given by $Q = CV = (4.29\ \mu\text{F})(12\ \text{V}) = 51.5\ \mu\text{C}$.

Because these capacitors are in series, they would both have this charge.

37. **B** The probability of finding a particle at a position is based on the absolute value of the wave function. The smallest possible probability is therefore where the wave function is zero.

38. **A** The Second Law of Thermodynamics states that the entropy of an isolated system cannot decrease. This drop of temperature would be a drop of entropy, but the second law does not apply to open systems. Choice (C) can be eliminated since it implies an overall decrease of entropy, which does violate the second law.

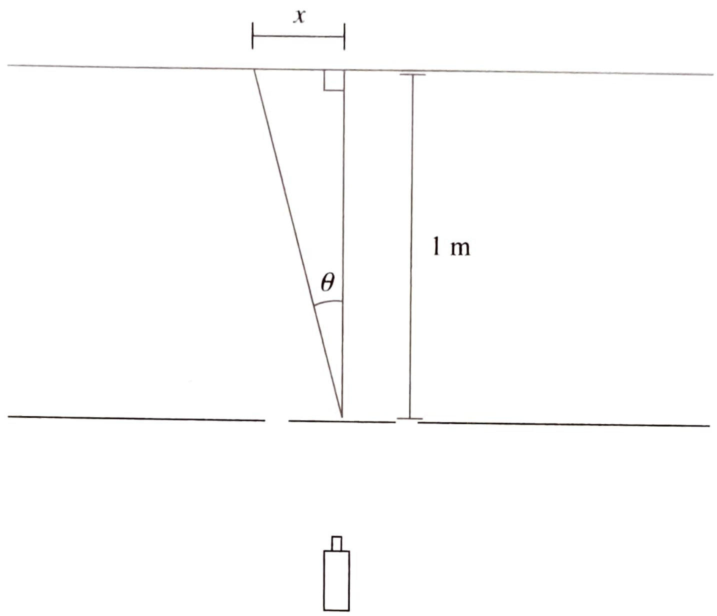
39. **C** By Newton's Third Law, the two charges would feel equal and opposite forces, and by Newton's Second Law, $F_{net} = ma$. The smaller mass must therefore have greater acceleration.

40. **D** For black-body radiation, $E \propto T^4$, and because intensity is directly related to energy, increasing temperature by a factor of 2 would increase intensity by a factor of $2^4 = 16$.

Section II: Free Response Questions

1.

(a)



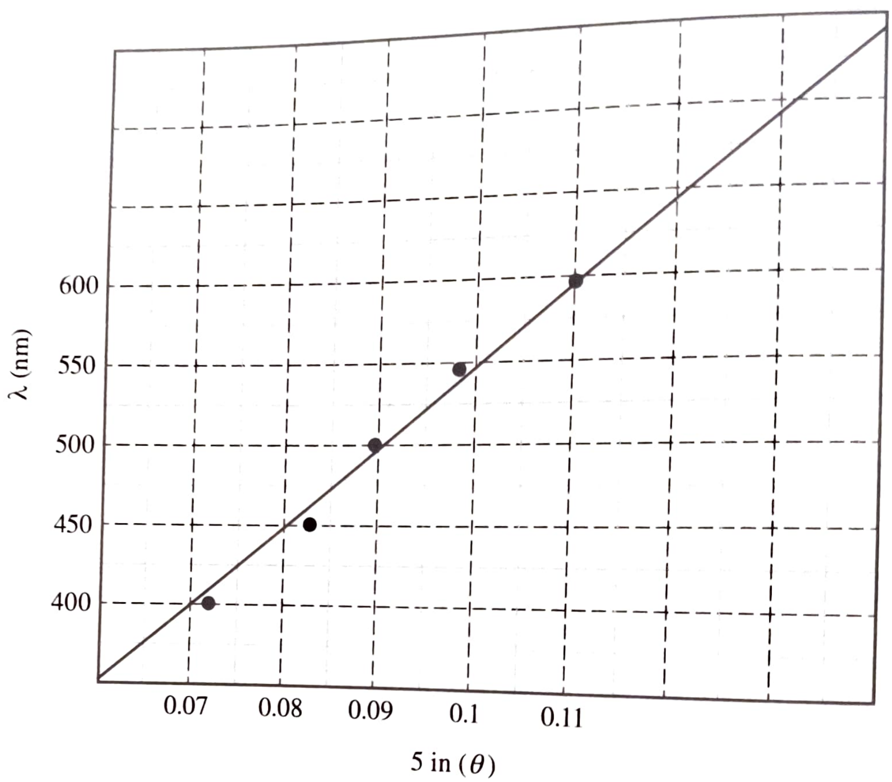
As seen in the image above, the angle can be found by using $\theta = \tan^{-1}(x/1\text{ m})$.

(b)

i. Vertical axis: λ Horizontal axis: $\sin(\theta)$

Wavelength of the light (nm)	Distance from central peak to first bright fringe (cm)	Angle from the slit to the first bright fringe	$\sin(\theta)$
400	14.4	4.118°	0.0718
450	16.5	4.745°	0.0827
500	18.0	5.143°	0.0896
550	19.8	5.654°	0.0985
600	22.1	6.334°	0.110

ii.

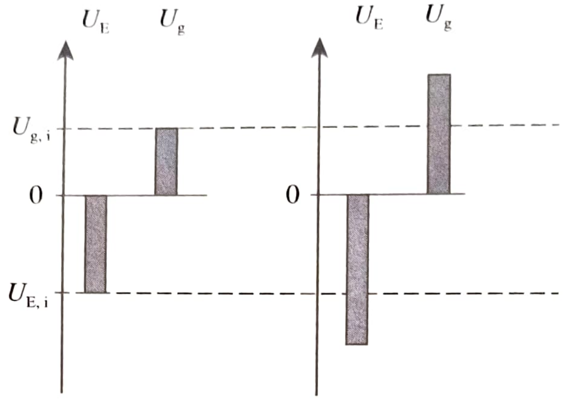


iii. Using the start and end points of the line in the graph above, $\text{Slope} = \dfrac{\text{Rise}}{\text{Run}} =$

$$\frac{650 \times 10^{-9}\ \text{m} - 375 \times 10^{-9}\ \text{m}}{0.122 - 0.065} = 4.83 \times 10^{-6}\ \text{m}$$

(c) No this is not feasible. Diffraction interference only occurs when the size of the hole is roughly the same size as the wavelength of the light. The longest visible wavelength is about 700 nm, which is much smaller than 1 cm.

ii.



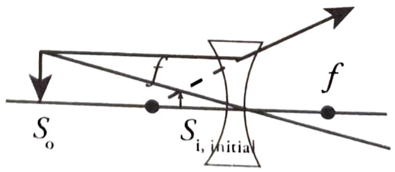
The gravity potential energy increases as the ball moves up the side of the container, and the electric potential decrease as the negative charge moves to a higher electric potential. The two changes in potential energy must cancel out since no energy is lost to friction.

3.

(a) From the lens equation, $\frac{1}{i} = \frac{1}{f} - \frac{1}{o}$, so $\frac{1}{s_{\text{i, initial}}} = \frac{1}{f} - \frac{1}{s_o} \rightarrow s_{\text{i, initial}} = \frac{1}{\frac{1}{f} - \frac{1}{s_o}} = \frac{fs_o}{s_o - f}$.

Because f for a concave lens is negative, $s_{\text{i, initial}}$ will be negative, which indicates that it is a virtual, upright image.

(b)



(c) The distance from the convex lens to the image created by the concave lens will be $x + s_{\text{i, initial}} = x + \frac{fs_o}{s_o - f}$. Plug this value into the lens equation for o and solve for i:

$$\frac{1}{i} = \frac{1}{f} - \frac{1}{o} \rightarrow s_{\text{i, final}} = \frac{fo}{o - f} = \frac{F\left(x + \frac{fs_o}{s_o - f}\right)}{\left(x + \frac{fs_o}{s_o - f}\right) - F} = F\frac{xs_o - xf + fs_o}{xs_o - xf - Fs_o + Ff + fs_o}$$

(d)

i. Yes, there is a maximum value of F. It is $F_{max} = x + s_{i,\,initial} = x + \dfrac{fs}{s_o - f}$. If F is larger than this value, then the effective object for the convex lens, $s_{i,\,initial}$ will be closer to the convex lens than the focal point. When an object is closer than the focal length for a convex lens, it creates a virtual image so the image cannot be projected onto the screen on the right.

ii. No there is no minimum value of F. As F approaches zero, the real image will form closer and closer to the convex lens, but it will always be to the right of the convex lens.

4.

(a)

i. The temperature will increase. This is because the First Law of Thermodynamics states $\Delta E = Q + W$, since the system is isolated, heat won't flow to the environment. Additionally, since the compression happens quickly, there won't be time for heat to flow between the gas and liquid. This means $Q = 0$ and $\Delta E = W$. When the lid is compressed, positive work is done on the system, the energy increases, and the temperature of the ideal gas increases.

ii. The new temperature will be lower than T_1. During the time it's compressed, heat will flow from the ideal gas to the liquid because the liquid is at a lower temperature. Therefore, when the lid comes back to its original position, there will be less energy in the gas and its temperature will be lower.

(b)

i. The temperature will be between T_1 and T_2. Heat will flow from the higher temperature gas to the lower temperature liquid until they reach the same temperature. This means the gas decreases in temperature and the liquid increases in temperature, making the final temperature between the two initial temperatures.

ii. For the liquid to become a gas, it needs to gain enough energy to raise its temperature to the boiling point and then undergo a phase change. This must happen before the gas lowers its temperature to the boiling point. Therefore, the amount of energy required to drop the gas's temperature to T_{bp} must have been more than the amount of energy required to change the liquid to a gas.

(c) The partition will feel a force to the left. If the partition is in the center, then the two volumes of the gases are the same. Therefore, the ideal gas law $PV = nRT$ becomes the proportion $P \propto nT$. Gas A has twice the mass and so twice the number of moles, but it only has 1/4 the temperature. Thus, the pressure of gas A is half of that of gas B and the imbalance in pressure causes a net force to the left.

(d)

i. Gas A occupies 2/3 of the container.

ii. If the system is in thermal equilibrium, the temperatures of the gases are the same. Additionally, since the partition is a rest, the pressures must be the same. Therefore, the ideal gas law $PV = nRT$ becomes the proportion $V \propto n$. Gas A has twice the mass and so twice the number of moles. Thus, gas A has twice the volume of gas B. Gas A occupies 2/3 and gas B occupies 1/3 of the container.

iii. No it does not contradict the previous answer. While the partition will initially feel a force to the left and move in that direction, heat will flow from the higher temperature gas B to the lower temperature gas A. As it does so, gas A will momentarily gain pressure and push the partition to the left to equalize the pressures. This continues to happen until equilibrium is reached and the partition has overall moved to the right.