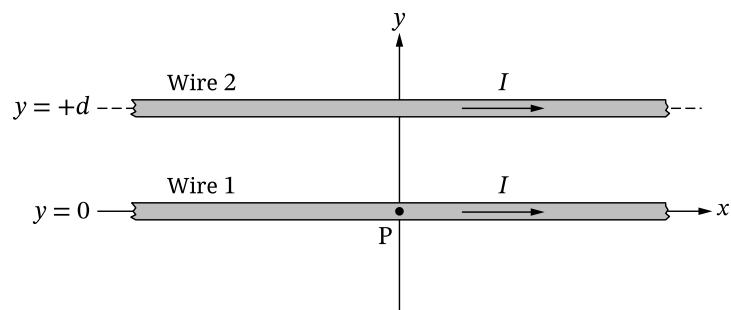


Question 1: Version J

1. Very long Wire 1 carries current I in the $+x$ -direction along the line $y = 0$. Very long Wire 2 carries current I in the $+x$ -direction along the line $y = +d$. Point P is located along Wire 1 at the origin, as shown in Figure 1. The diameters of the wires are small compared to the distance between the wires. Both wires are in the xy -plane.

Figure 1

Note: Figure not drawn to scale.

A.

- i. Complete the following tasks in figures 2 and 3. Use either arrows or the symbols shown in the box above the figures for your response.

- **Indicate** the direction of the magnetic field from Wire 2 at Point P in Figure 2.
- **Indicate** the direction of the magnetic force that is exerted on Wire 1 by Wire 2 in Figure 3.

Symbols

✕ Into the page ● Out of the page

Magnetic Field from
Wire 2 at Point P



Figure 2

Magnetic Force on Wire 1
by Wire 2



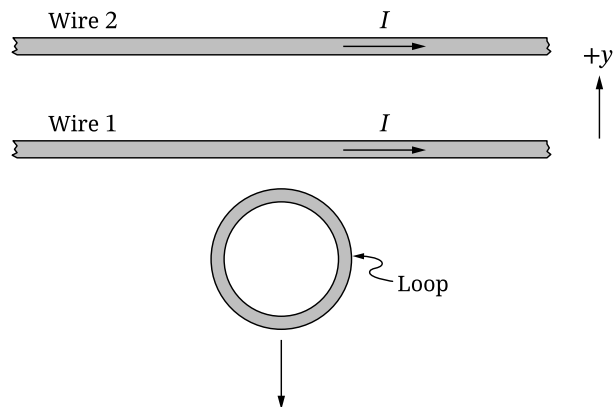
Figure 3

- ii. Very long Wire 3 carrying current $2I$ in the $+x$ -direction is placed in the xy -plane along the line $y = y_3$. The net magnetic force exerted on Wire 1 by the currents in wires 2 and 3 is zero.

Derive an expression for y_3 in terms of d . Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

- B. Wire 3 is moved very far away from wires 1 and 2. A circular conducting loop in the xy -plane is initially held at rest below Wire 1. The loop is then moved at a constant speed in the $-y$ -direction, as shown in Figure 4.

Figure 4



Note: Figure not drawn to scale.

Indicate whether there is a clockwise induced current in the loop, a counterclockwise induced current in the loop, or no induced current in the loop.

_____ Clockwise

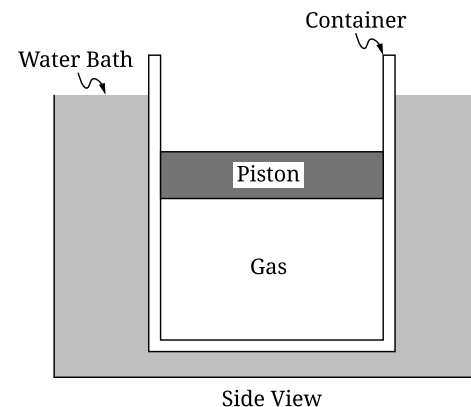
_____ Counterclockwise

_____ There is no induced current in the loop.

Justify your answer.

Question 2: Version J

2. A sample of a monatomic ideal gas is sealed in a thermally conducting container by a movable piston of mass M and area A . The container is in a large water bath that is held at a constant temperature T_0 . The piston is free to move with negligible friction. At the instant shown, the gas is in thermal equilibrium with the water bath, the piston is at rest, and the gas occupies volume V_0 . The pressure of the air above the piston is P_{atm} .



Note: Figure not drawn to scale.

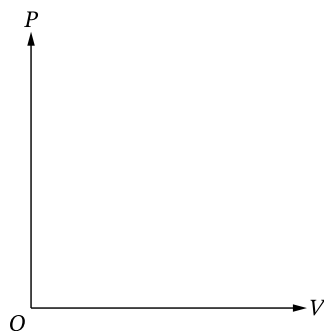
- A. On the dot shown, representing the piston, draw and label the forces that are exerted on the piston. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



B. Derive an expression for the internal energy of the gas in terms of M , A , V_0 , P_{atm} , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. A block, also of mass M , is placed on the piston at time $t = t_0$ and is slowly lowered. The piston comes to rest at $t = t_f$ when the block is completely released.

On the axes provided, **sketch** the expected relationship between the pressure P and volume V of the gas for the thermodynamic process that the gas undergoes during time interval $t_0 \leq t \leq t_f$. **Draw** an arrow on your sketch to represent the direction of the thermodynamic process.



D. With the block still on the piston, the temperature of the water bath is changed to a new constant temperature T_{new} . The gas occupies the original volume V_0 when the sample of gas and the water bath come to thermal equilibrium.

Indicate whether T_{new} is greater than, less than, or equal to T_0 .

_____ $T_{\text{new}} > T_0$

_____ $T_{\text{new}} < T_0$

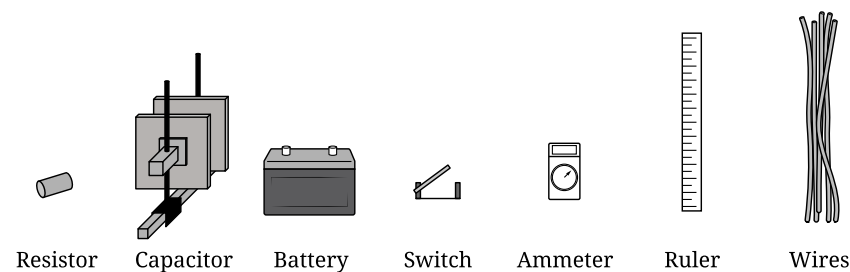
_____ $T_{\text{new}} = T_0$

Briefly **justify** your answer by referencing at least one feature of your answers to parts A, B, or C.

Question 3

3. In Experiment 1, a student is given a resistor of unknown resistance and an air-filled parallel-plate capacitor of unknown capacitance. The student is asked to predict the expected time constant τ of a circuit if these two circuit elements were connected in series with a battery. The student has access to a battery of known emf, a switch, an ammeter, a ruler, and wires, as shown in Figure 1. The plates of the capacitor are square, and the separation between the plates is small compared to the dimensions of the plates. The capacitor is initially uncharged. Assume that the dielectric constant of air is 1.

Figure 1



Note: Figure not drawn to scale.

A. Describe a procedure for collecting data that would allow the student to determine the expected time constant τ . In your description, include the measurements to be made. Include any steps necessary to reduce experimental uncertainty.

B. Describe how the collected data could be analyzed to determine τ . Include references to appropriate equations and to relationships between measured and known quantities.

C. In Experiment 2, the student is asked to determine the capacitance C of a new parallel-plate capacitor. For each trial, the absolute value $|\Delta V|$ of the potential difference across the capacitor is varied and the charge q stored on one plate of the fully charged capacitor is measured. Table 1 contains the data collected.

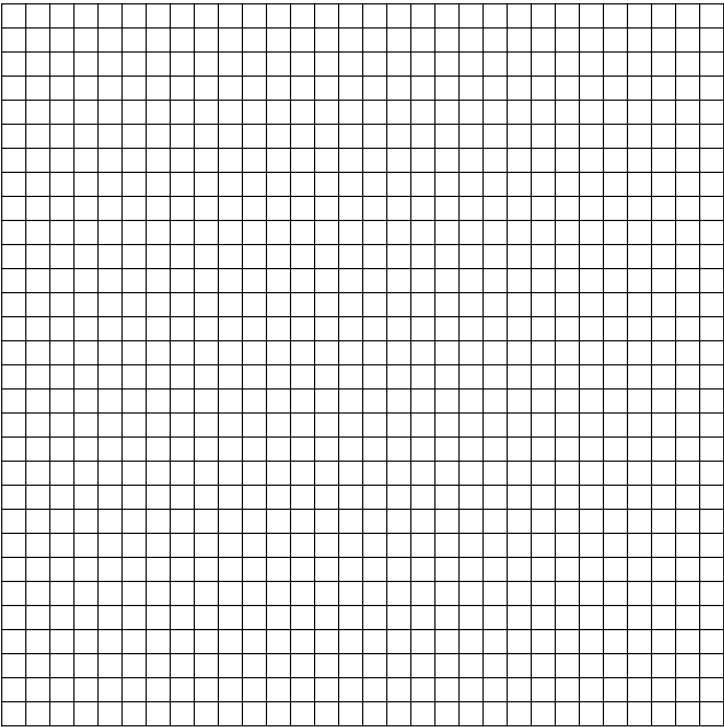
Table 1

$ \Delta V $ (V)	q ($\times 10^{-10}$ C)
3.0	2.4
5.0	4.2
7.2	5.6
8.0	6.6
10.0	8.0

i. **Indicate** two quantities, either measured quantities from Table 1 or additional calculated quantities, that could be graphed to produce a straight line that could be used to determine C .

Vertical axis: _____ Horizontal axis: _____

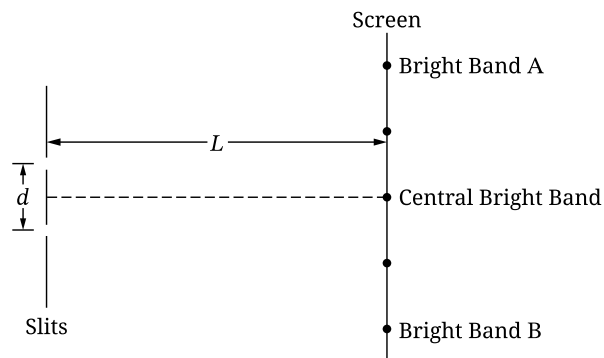
- ii. On the grid provided, create a graph of the quantities indicated in part C (i).
- Use Table 2 to record the measured or calculated quantities that you will plot.
 - Clearly **label** the axes, including units as appropriate.
 - **Plot** the points you recorded in Table 2.



- iii. **Draw** a best-fit line for the data graphed in part C (ii).
- D. Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for capacitance C .

Question 4

4. Two narrow slits are a distance d apart. A screen is a distance L from the midpoint of the slits, where $L \gg d$. When a laser emits monochromatic light toward the slits, a pattern of narrow bright and dark bands is observed on the screen. The centers of bright bands A and B are indicated. Three additional bright bands, including the central bright band, are observed on the screen between bands A and B, as shown.



Note: Figure not drawn to scale.

A student claims that the distance between the center of Band A and the center of the central bright band is smaller when using a laser that emits violet light than when using a laser that emits red light.

- A. Indicate** whether the student's claim is correct or incorrect. Without manipulating equations, **justify** your answer by referencing the difference in path length traveled by the light from each slit to the center of Band A.
- B. Derive** an expression for the distance between the centers of bands A and B when light of frequency f is emitted toward the slits. Express your answer in terms of d , L , f , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.
- C. Indicate** whether the expression you derived in part B is or is not consistent with your answer from part A. Briefly **justify** your answer.

STOP
END OF EXAM

Begin your response to **QUESTION 1** on this page.

PHYSICS 2

SECTION II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

1. (10 points, suggested time 20 minutes)

In each trial of a photoelectric experiment, a scientist uses a device to shine light of a single frequency on two different metals, 1 and 2. The device can emit light with frequency f_A , f_B , or f_C . Each frequency of light is used to test both metals.

The scientist determines the minimum de Broglie wavelength λ_e of the electrons ejected from the metal in each trial of the experiment. The following table summarizes the results of the experiment. For each trial, the scientist analyzes only the electrons with the minimum de Broglie wavelength.

Trial	Frequency of Light	Metal Tested	λ_e ($\times 10^{-10}$ m)
1	f_A	Metal 1	6.9
2	f_A	Metal 2	9.4
3	f_B	Metal 1	No electrons ejected
4	f_B	Metal 2	No electrons ejected
5	f_C	Metal 1	5.3
6	f_C	Metal 2	6.3

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

- (a) In a coherent, paragraph-length response, **indicate** which frequency, f_A , f_B , or f_C , is greatest and which frequency is least. **Justify** your answer using physics principles.

- (b) **Calculate** the maximum kinetic energy of the electrons ejected from Metal 1 in Trial 1. Assume that the momentum p of an ejected electron can be described by the classical definition $p = mv$.

- (c) **Indicate** whether the work function of Metal 1 is greater than, less than, or equal to the work function of Metal 2. **Justify** your answer by referring to the table of results.

GO ON TO THE NEXT PAGE.

PHYSICS 2

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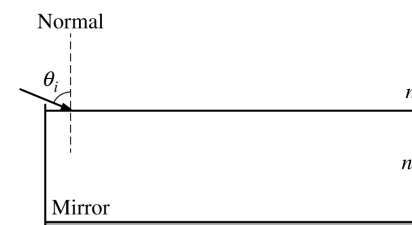
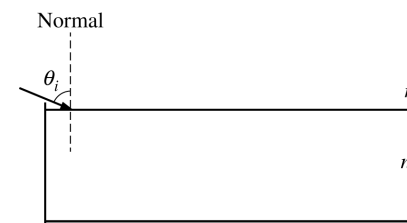


Figure 1

(10 points, suggested time 20 minutes)

A rectangular tank with a mirrored bottom is filled with water (index of refraction n_w). A beam of light passes from air (index of refraction n_a) into the water at angle θ_i from the normal, as shown in Figure 1. Index of refraction n_w is greater than index of refraction n_a .

- (a) On the following diagram, sketch the entire path of the beam as the beam enters, travels through, and then exits the water.



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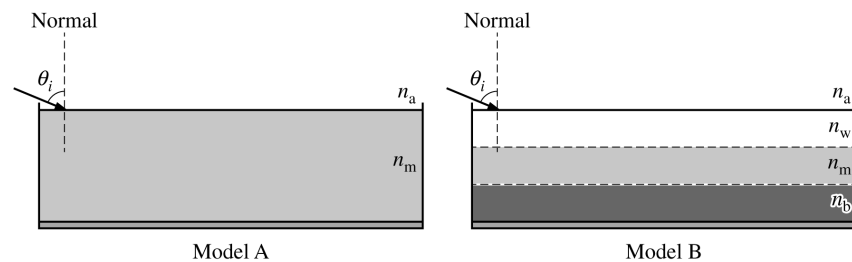
Continue your response to **QUESTION 1** on this page.

Figure 2

Sugar is then added to the water, resulting in a mixture that has a different index of refraction than water. A student considers two models, Model A and Model B, for how the sugar mixes with water. The models are shown in Figure 2.

Model A: The sugar is uniformly mixed throughout the water, resulting in a mixture with index of refraction n_m such that $n_m > n_w$.

Model B: Layers are formed of varying concentrations of sugar in the water. There are three distinct layers of equal volume. The top layer is only water (index of refraction n_w). The middle layer has the same concentration of sugar as the mixture in Model A (index of refraction n_m). The bottom layer has the highest concentration of sugar (index of refraction n_b).

(b) Consider Model A. Briefly describe how the observed wavelength of light changes, if at all, as the beam travels from air into the mixture.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

(c) Relevant angles between the beam and the normal for the various layers present in models A and B are defined in the following table.

Model A		Model B	
θ_i	Incident angle of the beam in air	θ_i	Incident angle of the beam in air
θ_1	Angle the beam makes with the normal in the mixture in Model A	θ_2	Angle the beam makes with the normal in the top layer in Model B
		θ_3	Angle the beam makes with the normal in the middle layer in Model B
		θ_4	Angle the beam makes with the normal in the bottom layer in Model B

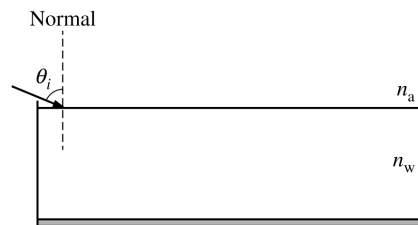
i. Determine an expression for θ_4 in terms of θ_i , n_a , and n_b .

ii. Rank the angles from greatest to least, with 1 being greatest. If two angles are the same value, give them the same ranking.

_____ θ_1 _____ θ_2 _____ θ_3 _____ θ_4

Briefly explain your reasoning using appropriate physics principles and/or mathematical models.

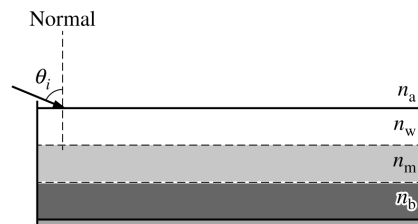
GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

Original Tank



Model A



Model B

For the original tank filled with water, the beam is observed to exit the surface of the water a horizontal distance d_w from the entry point. For models A and B, the horizontal distances are d_A and d_B , respectively.

- (d) Determine whether d_A and d_B are each greater than, less than, or equal to d_w . It is NOT necessary to compare d_A to d_B . Briefly justify your answer.

GO ON TO THE NEXT PAGE.