CollegeBoard
Advanced Placement Program

AP® Physics B
2005 Sample Student Responses
Form B

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1A

PHYSICS B

SECTION II

Time—90 minutes

7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 11 minutes for answering each of questions 1-2 and 5-7, and about 17 minutes for answering each of questions 3-4. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the lavender insert.

1. (10 points)

A student of mass m stands on a platform scale in an elevator in a tall building. The positive direction for all vector quantities is upward.

(a) Draw a free-body diagram showing and labeling all the forces acting on the student, who is represented by the dot below.

(b) Derive an expression for the reading on the scale in terms of the acceleration a of the elevator, the mass m of the student, and fundamental constants.

$\Sigma F = ma$

$F_n - mg = ma$

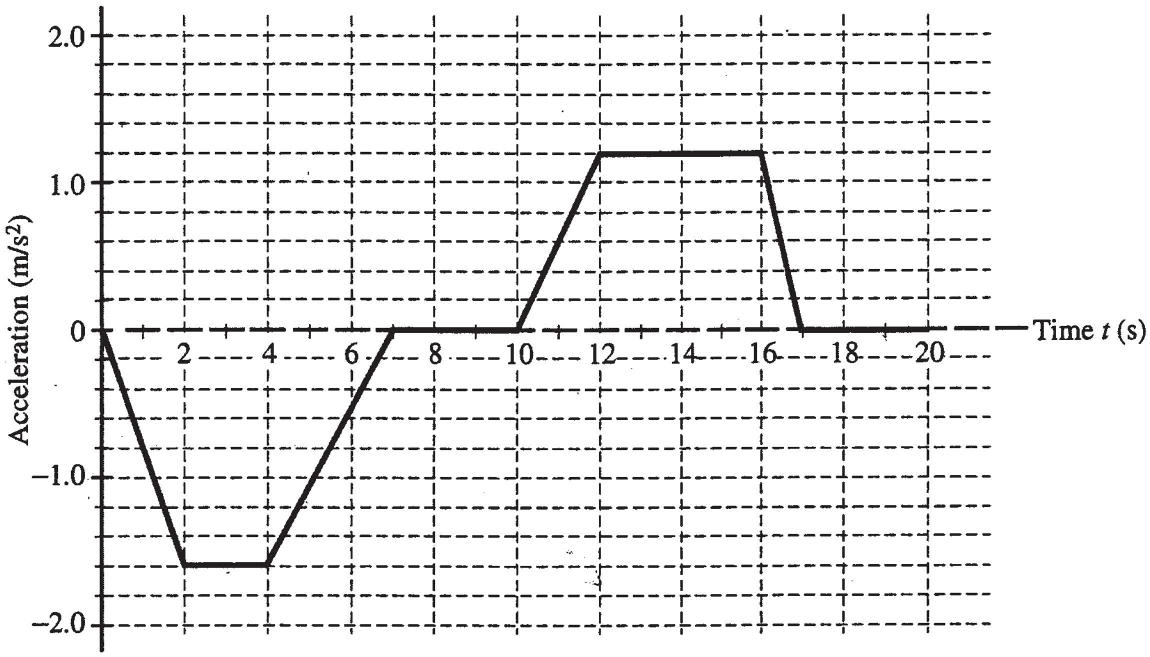
$F_n = ma + mg$

$F_n = m(a+g)$

GO ON TO THE NEXT PAGE.

1A

An inspector provides the student with the following graph showing the acceleration a of the elevator as a function of time t.



(c)

i. During what time interval(s) is the force exerted by the platform scale on the student a maximum value?

12s. to 16s.

ii. Calculate the magnitude of that maximum force for a 45 kg student.

$m = 45\,kg$
$a = 1.2\,m/s^2$
$g = 10\,m/s^2$

$F_n = m(a+g)$
$F_n = 45(1.2+10)$
$F_n = 45(11.2)$
$F_n = 504\,N$

(d) During what time interval(s) is the speed of the elevator constant?

$a = 0 \therefore v$ is constant

7 seconds to 10 seconds
and
17 seconds to 20 seconds

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PHYSICS B
SECTION II
Time—90 minutes
7 Questions

1B

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 11 minutes for answering each of questions 1-2 and 5-7, and about 17 minutes for answering each of questions 3-4. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the lavender insert.

1. (10 points)

A student of mass m stands on a platform scale in an elevator in a tall building. The positive direction for all vector quantities is upward.

(a) Draw a free-body diagram showing and labeling all the forces acting on the student, who is represented by the dot below.

(b) Derive an expression for the reading on the scale in terms of the acceleration a of the elevator, the mass m of the student, and fundamental constants.

$a = m/s^2$ $\quad m = kg$. $\quad F = kg\text{-}m/s^2$.

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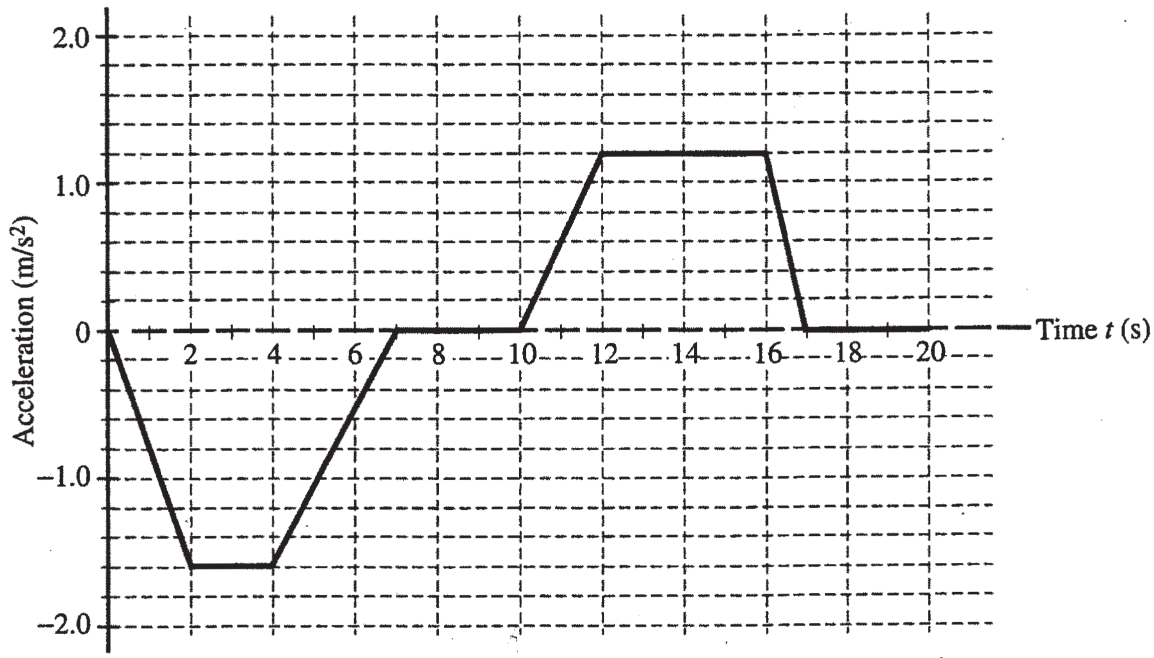
1B

An inspector provides the student with the following graph showing the acceleration a of the elevator as a function of time t.



(c)

i. During what time interval(s) is the force exerted by the platform scale on the student a maximum value?

12s ~ 16s :

ii. Calculate the magnitude of that maximum force for a 45 kg student.

$F = ma$

mg

$F = 45kg \times 1.2\,m/s^2 = 54N$

$45 \times 1.2 = 90 + 450 = 540$

(d) During what time interval(s) is the speed of the elevator constant?

At. ~~t~~ 7s ~ 10s and 17s to 20s. the acceleration is 0. so the velocity is constant at ~~to~~ those time intervals.

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PHYSICS B
SECTION II
Time—90 minutes
7 Questions

1C

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 11 minutes for answering each of questions 1-2 and 5-7, and about 17 minutes for answering each of questions 3-4. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the lavender insert.

1. (10 points)

A student of mass m stands on a platform scale in an elevator in a tall building. The positive direction for all vector quantities is upward.

(a) Draw a free-body diagram showing and labeling all the forces acting on the student, who is represented by the dot below.

(b) Derive an expression for the reading on the scale in terms of the acceleration a of the elevator, the mass m of the student, and fundamental constants.

F = force
m = mass
a = acceleration

$$\boxed{F = m \cdot a}$$

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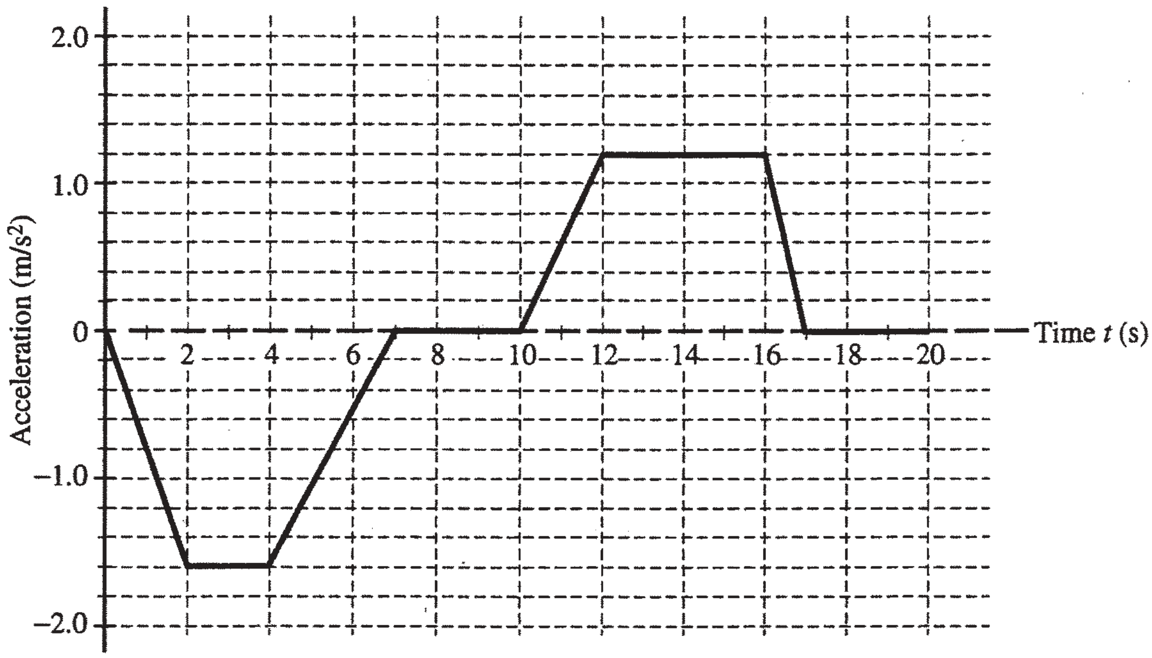
1C

An inspector provides the student with the following graph showing the acceleration a of the elevator as a function of time t.



(c)

i. During what time interval(s) is the force exerted by the platform scale on the student a maximum value?

$t = 12 - t = \cancel{16}\ 15$

ii. Calculate the magnitude of that maximum force for a 45 kg student.

$W = mg$
$W = (45)(9.8)$
$W = 441\ N$

(d) During what time interval(s) is the speed of the elevator constant?

$t = 2, 3, 4, 7, 8, 9, 10, 12, 13, 14, 15, \cancel{16}, 18, 19, +20$

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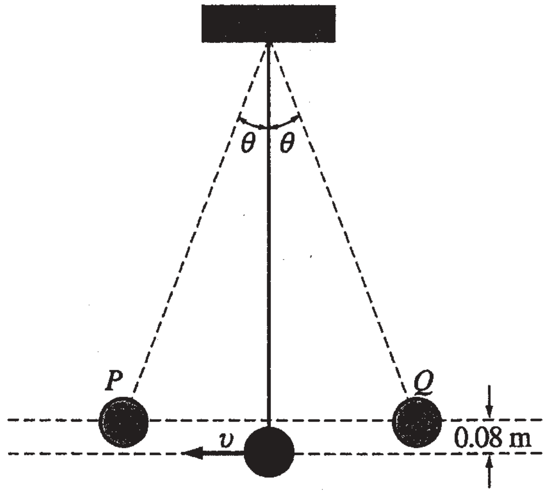
2A

2. (10 points)

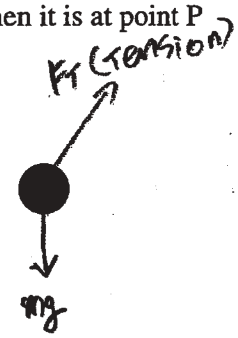
A simple pendulum consists of a bob of mass 0.085 kg attached to a string of length 1.5 m. The pendulum is raised to point Q, which is 0.08 m above its lowest position, and released so that it oscillates with small amplitude θ between the points P and Q as shown below.



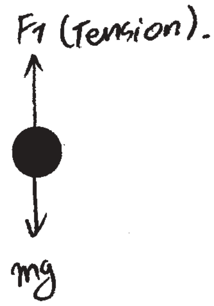
Note: Figure not drawn to scale.

(a) On the figures below, draw free-body diagrams showing and labeling the forces acting on the bob in each of the situations described.

i. When it is at point P



ii. When it is in motion at its lowest position



(b) Calculate the speed v of the bob at its lowest position.

Since, the mechanical energy is conserved during the Process, $U_p = U_{\text{lowest postion}}$

$$mgh_p + \frac{1}{2}mv_p^2 = \frac{1}{2}mv_{\text{lowest}}^2$$

$$v_p = 0 \Rightarrow \cancel{m}gh_p = \frac{1}{2}\cancel{m}v_{\text{lowest}}^2$$

$$9.8 \times 0.08 = \frac{1}{2}v_{\text{lowest}}^2$$

$$\boxed{\therefore v_{\text{lowest}} = 1.252 \text{ m/s}}$$

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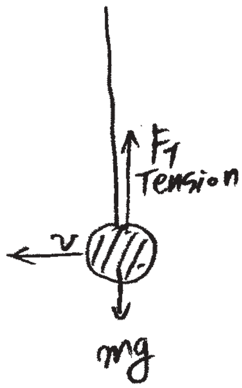
2A

(c) Calculate the tension in the string when the bob is passing through its lowest position.



Since, the direction of Velocity and Tension is vertical at its lowest position, the bob is experiencing circular motion.

Thus, $F_T - mg = F_c$ (centripetal force).

$$F_T - mg = m\frac{v^2}{r}$$

$$\boxed{\therefore F_T = m\left(\frac{1.252^2}{1.5} + 9.8\right) = 0.921\ N}$$

(d) Describe one modification that could be made to double the period of oscillation.

Since Period (T) can be expressed by

$2\pi\sqrt{\frac{l}{g}}$ in pendulum motion,

in order to double the period, the length (l) of the pendulum should be extended to $4l$ (quadrupled) so that

Period can be $2\pi\sqrt{\frac{4l}{g}} = 2 \times 2\pi\sqrt{\frac{l}{g}} = 2T$

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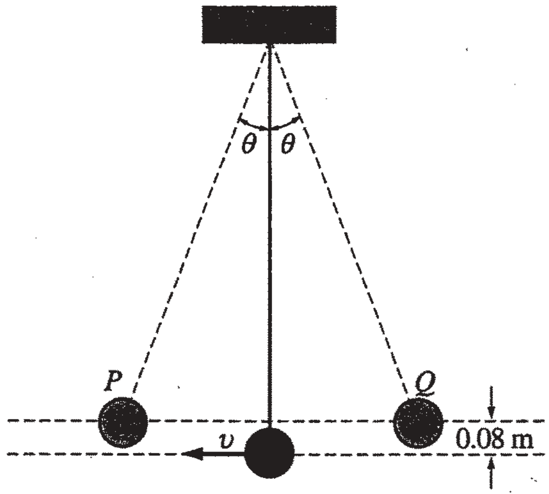
2. (10 points) **2B**

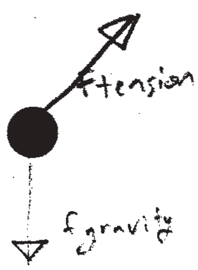
A simple pendulum consists of a bob of mass 0.085 kg attached to a string of length 1.5 m. The pendulum is raised to point Q, which is 0.08 m above its lowest position, and released so that it oscillates with small amplitude θ between the points P and Q as shown below.



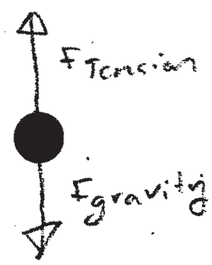
Note: Figure not drawn to scale.

(a) On the figures below, draw free-body diagrams showing and labeling the forces acting on the bob in each of the situations described.

i. When it is at point P



ii. When it is in motion at its lowest position



(b) Calculate the speed v of the bob at its lowest position.

$U = K$

$\cancel{m}gh = \frac{1}{2}\cancel{m}v^2$

$9.8\frac{m}{s^2} \times .08m = \frac{1}{2}v^2$

$v = 1.25\frac{m}{s}$

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2B

(c) Calculate the tension in the string when the bob is passing through its lowest position.

Tension = $F_{gravity}$ = mg

m = .085 kg   g = 9.8 $\frac{m}{s^2}$

Tension = .833 N

(d) Describe one modification that could be made to double the period of oscillation.

quadruple the length of the pendulum arm

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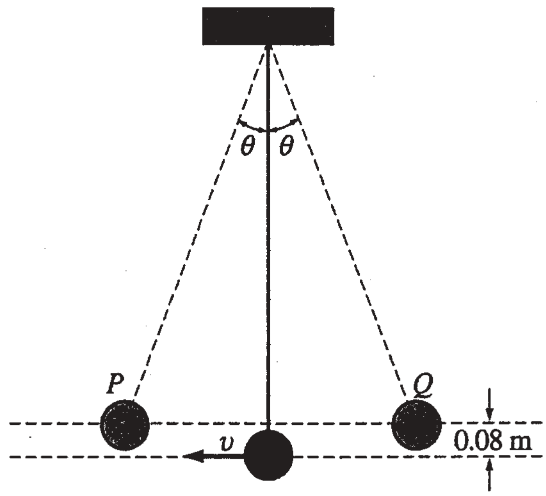
2. (10 points) **2C**

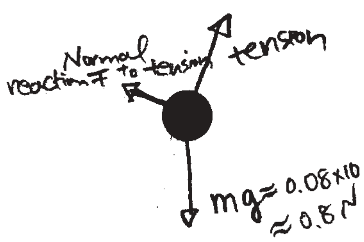
A simple pendulum consists of a bob of mass 0.085 kg attached to a string of length 1.5 m. The pendulum is raised to point Q, which is 0.08 m above its lowest position, and released so that it oscillates with small amplitude θ between the points P and Q as shown below.



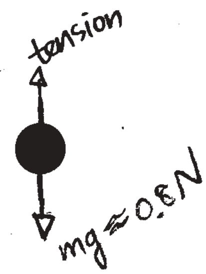
Note: Figure not drawn to scale.

(a) On the figures below, draw free-body diagrams showing and labeling the forces acting on the bob in each of the situations described.

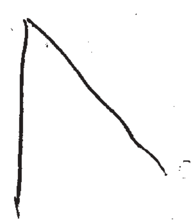
i. When it is at point P



ii. When it is in motion at its lowest position



(b) Calculate the speed v of the bob at its lowest position.



$E_{k\,gained} = E_p$ lost in equilibrium position.

$\frac{1}{2}mv^2 = mgh$

$\rightarrow v = \sqrt{2gh} = 0$ for $h=0$.

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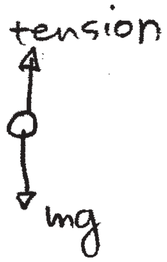
2C

(c) Calculate the tension in the string when the bob is passing through its lowest position.

At the lowest point, tension = mg.



$mg = 0.08 \times 9.81 = 0.7848\,N$

(d) Describe one modification that could be made to double the period of oscillation.

$T_{\text{of oscillation}} = 2\pi\sqrt{\frac{l}{g}}$ — string length

Time of oscillation can be doubled by multiplying l by 4.

$$2T = 2\pi\sqrt{\frac{4l}{g}} = 2 \times 2\pi\sqrt{\frac{l}{g}}$$

g can't be changed because its constant in this system.

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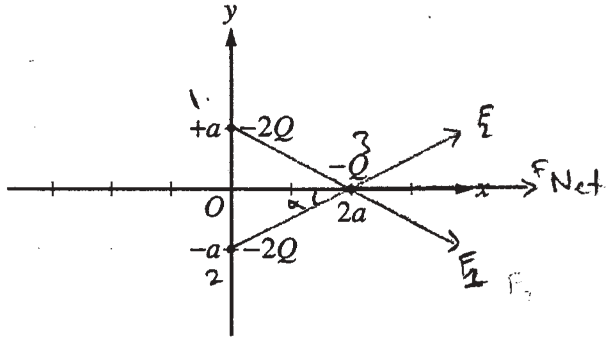
3A



3. (15 points)

The figure above shows two point charges, each of charge $-2Q$, fixed on the y-axis at $y = +a$ and at $y = -a$. A third point charge of charge $-Q$ is placed on the x-axis at $x = 2a$. Express all algebraic answers in terms of Q, a, and fundamental constants.

(a) Derive an expression for the magnitude of the net force on the charge $-Q$ due to the other two charges, and state its direction.

Force exerted by one of the charges

$\Rightarrow F_1 = \frac{Kq_1q_2}{r^2} = \frac{K(-2Q)(-Q)}{r^2}$ $\quad \left(\begin{array}{l} r^2 = (2a)^2 + (a)^2 \\ r^2 = 4a^2 + a^2 \\ = 5a^2 \end{array} \right)$

$= \frac{2Q^2K}{5a^2}$

Since there is symmetry along the x-axis then $F_2 = F_1$

~~the~~ Magnitude ~~net force~~, $F_{~~Net~~} =$ are equal so net force exists along the x-axis only
vertical components

$\Rightarrow \cos\alpha = \frac{2a}{5a^2} = \frac{2}{5a} \Rightarrow F_{Net} = 2F_1\cos\alpha = 2\,\frac{4Q^2K}{5a^2}\left(\frac{2}{5a}\right) = \frac{8Q^2K}{25a^3}$ to the right

(b) Derive an expression for the magnitude of the net electric field at the origin due to all three charges, and state its direction.

$E = \frac{Kq}{r^2}$

$\Rightarrow E_1 = \frac{K(-2Q)}{a^2}$
$E_2 = \frac{K(-2Q)}{a^2}$ $\Big\} \Rightarrow$ Electric fields are equal and opposite in direction then the net electric field ~~at the origin is zero~~ along y-axis $= 0$

$E_3 = \frac{K(-Q)}{4a^2}$ $\quad \Rightarrow |E_{net}| = \left|-\frac{KQ}{4a^2}\right| \Rightarrow E_{net} = \frac{KQ}{4a^2}$ to the right

~~$E_{net} = 0$~~

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3A

(c) Derive an expression for the electrical potential at the origin due to all three charges.

$V = \frac{Kq}{r}$

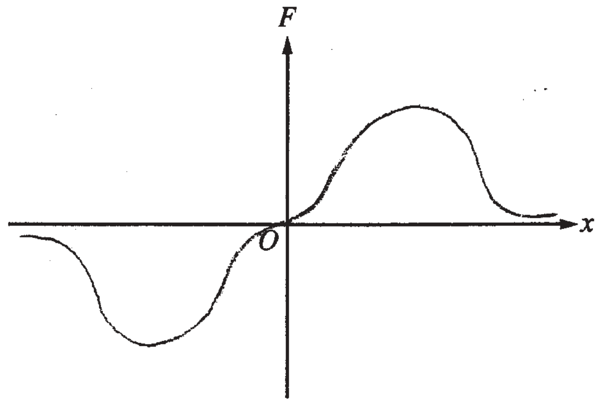
$V_1 = \frac{K(-2Q)}{a}$

$V_2 = \frac{K(-2Q)}{a}$ $\Rightarrow$ $V_{at\,O} = \frac{2}{2}\left(\frac{-2KQ}{a} + \frac{-2KQ}{a} + \frac{-KQ}{2a}\right)$

$= \frac{-4KQ}{2a} - \frac{4KQ}{2a} - \frac{KQ}{2a} = -\frac{9KQ}{2a}$

$V_3 = \frac{K(-Q)}{2a}$

(d) On the axes below, sketch a graph of the force F on the $-Q$ charge caused by the other two charges as it is moved along the x-axis from a large positive position to a large negative position. Let the force be positive when it acts to the right and negative when it acts to the left.



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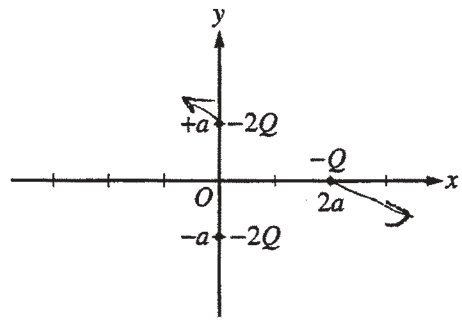
3B

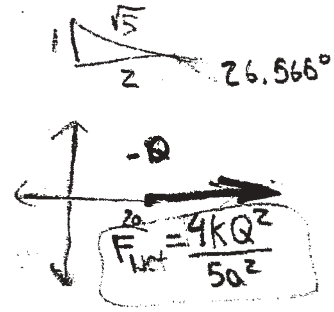


3. (15 points)

The figure above shows two point charges, each of charge $-2Q$, fixed on the y-axis at $y = +a$ and at $y = -a$. A third point charge of charge $-Q$ is placed on the x-axis at $x = 2a$. Express all algebraic answers in terms of Q, a, and fundamental constants.

(a) Derive an expression for the magnitude of the net force on the charge $-Q$ due to the other two charges, and state its direction.

$F_{Net} = F_{+a} + F_{-a}$ $\quad K = \frac{1}{4\pi\epsilon_0}$



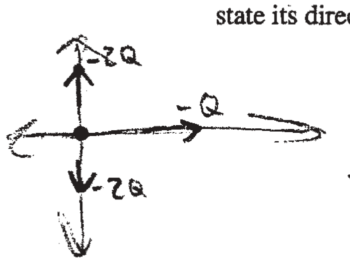
$F_{+a} = \frac{1}{4\pi\epsilon_0} \cdot \frac{(-2Q)\cdot(-Q)}{(\sqrt{a^2+(2a)^2})^2} = K \cdot \frac{2Q^2}{5a^2}$ at 26.565°

$F_{-a} = K \cdot \frac{(-2Q)\cdot(-Q)}{(\sqrt{a^2+(2a)^2})^2} = K \cdot \frac{2Q^2}{5a^2}$

Since the vectors are ↗ and ↘, the y directions cancel out.

$2\,\frac{K \cdot 2Q^2}{5a^2} \cdot \cos 26.565°$ at $0°$ $\simeq$ $\boxed{\frac{4KQ^2}{5a^2} \text{ at } 0°}$

(b) Derive an expression for the magnitude of the net electric field at the origin due to all three charges, and state its direction.



- The net electric fields of the two −2Q charges cancel out.
- The net electric field of −Q is → at 0°

Net electric Force $= \frac{1}{4\pi\epsilon_0} \cdot \frac{(-Q)}{(2a)^2} = \boxed{\frac{-KQ}{4a^2} \text{ at } 0°}$

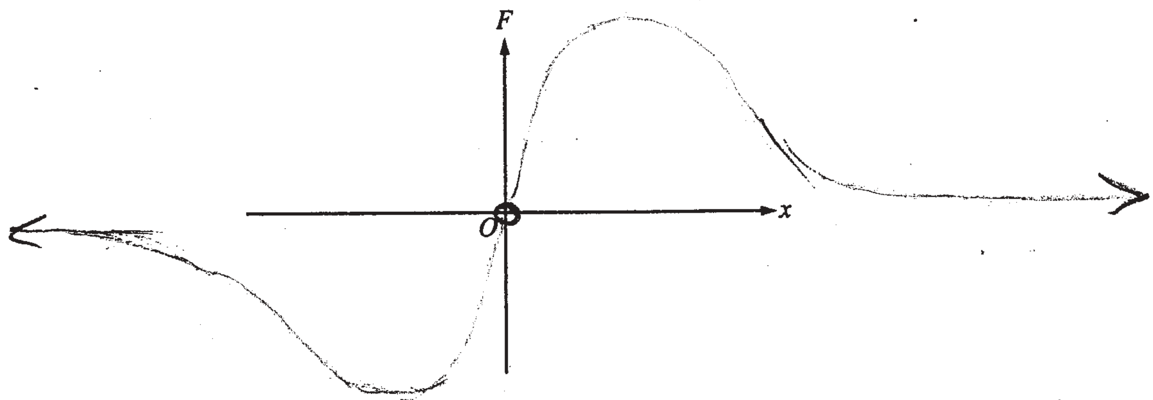
GO ON TO THE NEXT PAGE.

(c) Derive an expression for the electrical potential at the origin due to all three charges.

- similarly to the previous question, the electric potential of the two (-2Q) charges will cancel out.

Electric Potential $= \frac{1}{4\pi\varepsilon_0} \cdot \frac{(-Q)}{2a} = \frac{k \cdot -Q}{2a} = \boxed{\frac{-kQ}{2a}}$

(d) On the axes below, sketch a graph of the force F on the $-Q$ charge caused by the other two charges as it is moved along the x-axis from a large positive position to a large negative position. Let the force be positive when it acts to the right and negative when it acts to the left.



as the -Q charge is moved from being on the left side of to the right side of the x-axis, there is a hole, where the forces from the charges cancel out.

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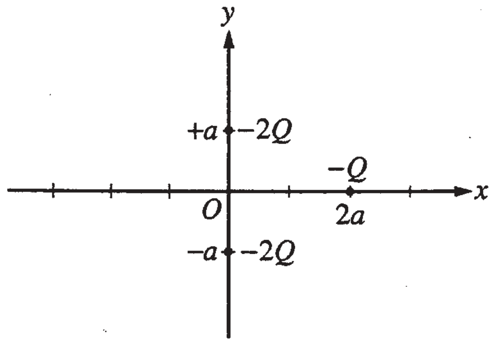

3C

3. (15 points)

The figure above shows two point charges, each of charge $-2Q$, fixed on the y-axis at $y = +a$ and at $y = -a$. A third point charge of charge $-Q$ is placed on the x-axis at $x = 2a$. Express all algebraic answers in terms of Q, a, and fundamental constants.

(a) Derive an expression for the magnitude of the net force on the charge $-Q$ due to the other two charges, and state its direction.

$F_Q = F_{a_1-Q} + F_{a_2-Q}$ $\quad F = k\frac{q_1 q_2}{r^2}$ $\quad k = 9.0\times10^9$

$$F_Q = \frac{(9.0\times10^9)(-Q)(-2Q)}{(2a)^2} + \frac{(9.0\times10^9)(-Q)(-2Q)}{(2a)^2}$$

$$F_Q = 2\left[\frac{(9.0\times10^9)(Q)(2Q)}{(2a)^2}\right]$$

The force will be to the left, away from the -Q charge, due to repulsion.

(b) Derive an expression for the magnitude of the net electric field at the origin due to all three charges, and state its direction.

$E = \frac{F}{q}$ $\quad \Sigma E = \frac{F_{of}Q}{Q} + \frac{F_{of}(-2Q)}{-2Q} - \frac{F_{of}(-2Q)}{(-2Q)}$

$$\Sigma E = \frac{F\,of\,Q}{Q}$$

The direction will be towards the -Q charge, because the others cancel each other out.

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3C

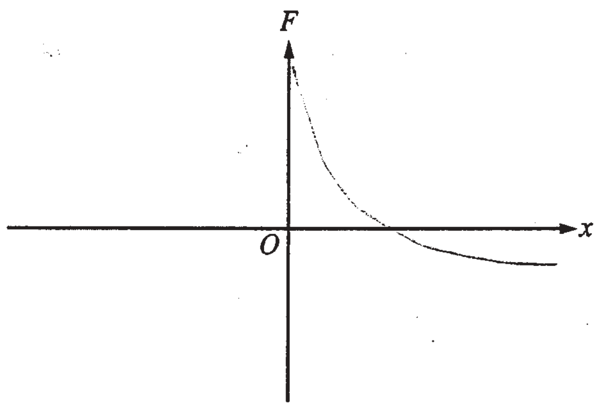
(c) Derive an expression for the electrical potential at the origin due to all three charges.

$$U_E = \frac{k q_1 q_2}{r}$$

$$\Sigma U_E = \frac{(9.0\times10^9)(Q)}{2a} + \frac{(9.0\times10^9)(2Q)}{a} - \frac{(9.0\times10^9)(2Q)}{a}$$

$$\Sigma U_E = \frac{(9.0\times10^9)(Q)}{2a}$$

(d) On the axes below, sketch a graph of the force F on the $-Q$ charge caused by the other two charges as it is moved along the x-axis from a large positive position to a large negative position. Let the force be positive when it acts to the right and negative when it acts to the left.



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4A

4. (15 points)

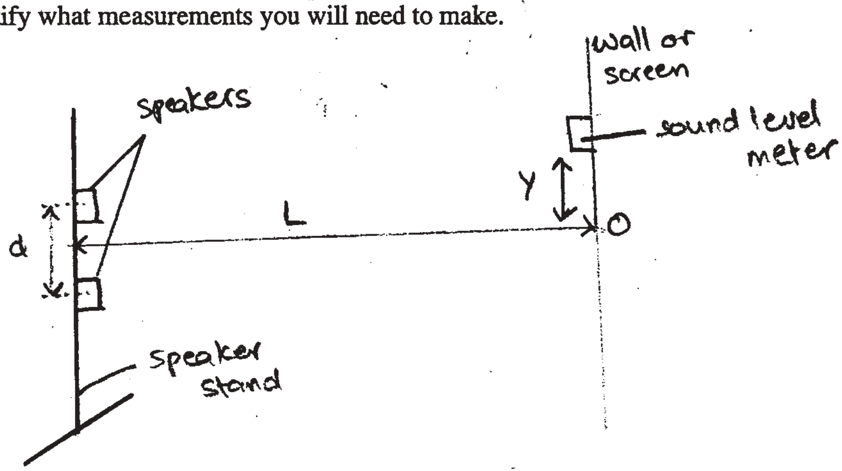
Your teacher gives you two speakers that are in phase and are emitting the same frequency of sound, which is between 5000 and 10,000 Hz. She asks you to determine this frequency more precisely. She does not have a frequency or wavelength meter in the lab, so she asks you to design an interference experiment to determine the frequency. The speed of sound is 340 m/s at the temperature of the lab room.

(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.

✓ Speaker stand ___ Meterstick ✓ Ruler ✓ Tape measure

___ Stopwatch ✓ Sound-level meter

(b) Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify what measurements you will need to make.



(c) Briefly outline the procedure that you would use to make the needed measurements, including how you would use each piece of equipment you checked in (a).

The two speakers are fixed at a distance d on the speaker stand; the distance between them is measured using a ruler. An observer ~~either holding~~ may hold a sound-level meter in his/her hand or ~~attaching~~ attach it to a wall opposite the speakers. The distance between the speaker stand and the wall ~~so~~ (L) is measured ~~by the~~ using the ~~met~~ tape measure. The speakers are switched on. The point ~~at the level~~ on the wall at a level exactly ~~the sm~~ midway between the two speakers is marked O. The sound level meter should register a ~~high~~ loud sound at O. The meter is next move upwards along the wall in the same plane, until it registers zero sound and then a maximum sound level again. The distance Y between this point and O is measured.

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4A

(d) Using equations, show explicitly how you would use your measurements to calculate the frequency of the sound produced by the speakers.

At the point Y units above O, constructive interference occurs. The equation for the first maximum is:

$$d \cdot \frac{Y}{L} = m\lambda, \quad m=1$$

$$\Rightarrow \lambda = \frac{dY}{L}.$$

We also know that for waves $v = f\lambda \Rightarrow f = \frac{v}{\lambda}$, and $v = 340\,ms^{-1}$.

$\therefore$ The frequency would be given by $f = \frac{340}{\frac{dY}{L}} = \frac{340L}{dY}$, where L, d and Y have been measured.

(e) If the frequency is decreased, describe how this would affect your measurements.

If the frequency is decreased, ~~the wavelength of the sound increases (v=fλ). Hence~~, as d and L are fixed, Y will increase:

$$f = \frac{340L}{dY} \Rightarrow fY = \frac{340L}{d} = k$$

$$\Rightarrow f \propto 1/Y.$$

The sound level meter will ~~not~~ register a maximum ~~intensity~~ intensity sound at a greater height Y_2 above O.

GO ON TO THE NEXT PAGE.

4B

4. (15 points)

Your teacher gives you two speakers that are in phase and are emitting the same frequency of sound, which is between 5000 and 10,000 Hz. She asks you to determine this frequency more precisely. She does not have a frequency or wavelength meter in the lab, so she asks you to design an interference experiment to determine the frequency. The speed of sound is 340 m/s at the temperature of the lab room.

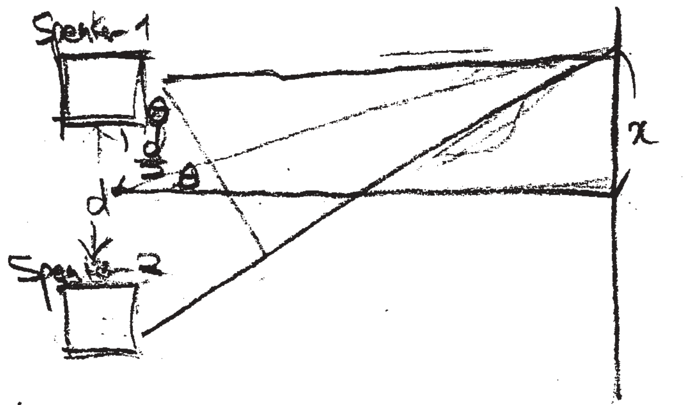
(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.

✓ Speaker stand   ___ Meterstick   ___ Ruler   ✓ Tape measure

___ Stopwatch   ✓ Sound-level meter

$v = f\lambda$

(b) Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify what measurements you will need to make.



$d \sin\theta = \frac{\lambda}{2}$

$d \sin\theta =$

(c) Briefly outline the procedure that you would use to make the needed measurements, including how you would use each piece of equipment you checked in (a).

First, the two speakers are place at a distance d apart from each other on a stand. Then, the two speakers are turned on. From a point that is L meters away from the half-point ($\frac{d}{2}$), we measure the sound-level with the sound-level meter. There, it should be at 0. We slowly move along the line that is parallel to the imaginary line connecting the speakers until the sound levels are again 0. We measure the minimum distance moved, x, with the tape measure. d and L are also measured. We can use the values of d, L, x to find the wavelength and then using the known value of v, the frequency.

GO ON TO THE NEXT PAGE.

4B

(d) Using equations, show explicitly how you would use your measurements to calculate the frequency of the sound produced by the speakers.

$$d\sin\theta = \frac{\lambda}{2}$$

$$\sin\theta \approx \tan\theta = \frac{x}{L}$$

$$d \times \frac{x}{L} = \frac{\lambda}{2}$$

$$\lambda = \frac{2dx}{L}$$

$$f = \frac{v}{\lambda} = \frac{v}{\frac{2dx}{L}} = \frac{vL}{2dx}$$

(e) If the frequency is decreased, describe how this would affect your measurements.

The value of x, which is variable, will change because the rest of the values of d, v, L are held constant in the equation $f = \frac{vL}{2dx}$ and f is inversely proportional to the value of x. If f decreases, then x must increase

4C

4. (15 points)

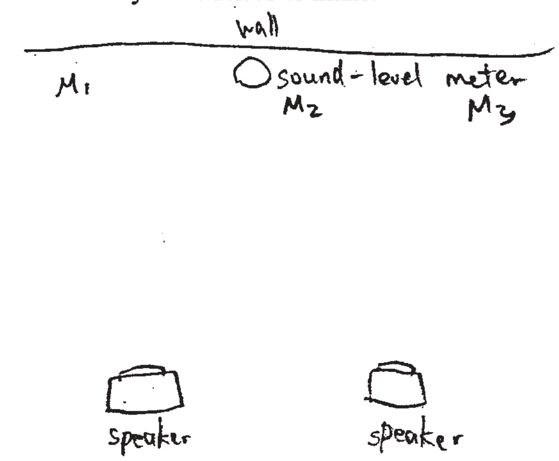
Your teacher gives you two speakers that are in phase and are emitting the same frequency of sound, which is between 5000 and 10,000 Hz. She asks you to determine this frequency more precisely. She does not have a frequency or wavelength meter in the lab, so she asks you to design an interference experiment to determine the frequency. The speed of sound is 340 m/s at the temperature of the lab room.

(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.

✓ Speaker stand   ___ Meterstick   ___ Ruler   ✓ Tape measure

___ Stopwatch   ✓ Sound-level meter

(b) Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify what measurements you will need to make.



M = measurements

(c) Briefly outline the procedure that you would use to make the needed measurements, including how you would use each piece of equipment you checked in (a).

- use tape measure the distance from the speakers to each other
- measure distance from speakers to sound level meter
- place sound-level meter at the 3 "M" positions
- turn on the speakers and take measurements by sound-level meter

GO ON TO THE NEXT PAGE.

4C

(d) Using equations, show explicitly how you would use your measurements to calculate the frequency of the sound produced by the speakers.

$v = f\lambda \rightarrow f = \frac{v}{\lambda}$

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$

$f = \frac{340}{\lambda}$

$T = \frac{1}{f}$

$f = \frac{R}{2}$

$d \sin\theta = m\lambda$

(e) If the frequency is decreased, describe how this would affect your measurements.

- may have to move the positions of the speakers

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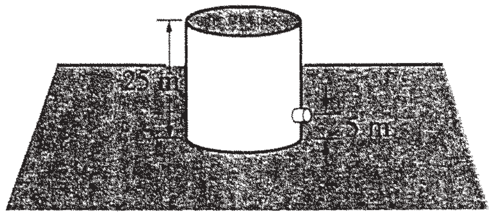

5A

5. (10 points)

A large tank, 25 m in height and open at the top, is completely filled with saltwater (density 1025 kg/m^3). A small drain plug with a cross-sectional area of 4.0×10^{-5} m^2 is located 5.0 m from the bottom of the tank. The plug breaks loose from the tank, and water flows from the drain.

(a) Calculate the force exerted by the water on the plug before the plug breaks free.

$$P = P_0 + \rho g h$$
$$= 1 + (1025)(9.8)(20\text{m})$$
$$= 1.0 \times 10^5 \text{Pa} + 2.009 \times 10^5 \text{ Pa}$$
$$= 3.009 \times 10^5 \text{ Pa}$$

$$P = \frac{F_\perp}{A} \qquad F_\perp = PA = (3.009 \times 10^5)(4 \times 10^{-5})$$
$$= 12.04 \text{ N}$$

(b) Calculate the speed of the water as it leaves the hole in the side of the tank.

$$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$

$$\cancel{\rho} g y_1 = \cancel{\rho} g y_2 + \frac{1}{2}\cancel{\rho} v_2^2$$

$$\frac{v_2^2}{2} = g y_1 - g y_2$$

$$v_2^2 = 2g(y_1 - y_2)$$

$$v_2 = \sqrt{2g(y_1 - y_2)}$$

$$v_2 = \sqrt{2g(25 - 5)}$$

$$v_2 = 19.79 \text{ m/s or } \sqrt{392} \text{ m/s}$$

GO ON TO THE NEXT PAGE.

5A

(c) Calculate the volume flow rate of the water from the hole.

$\underline{\underline{A\vec{V}}}$ - volume flow rate

because A = cross sectional area

$\vec{v}$ = velocity = $\frac{d}{t}$

Area $\cdot d$ = volume

$A\vec{V} = (4 \times 10^{-5})(\sqrt{392})$

$= 7.92 \times 10^{-4}$ m^3/sec

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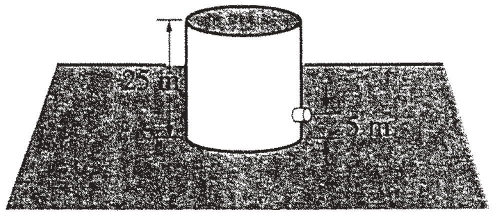

5B

5. (10 points)

A large tank, 25 m in height and open at the top, is completely filled with saltwater (density 1025 kg/m^3). A small drain plug with a cross-sectional area of 4.0×10^{-5} m^2 is located 5.0 m from the bottom of the tank. The plug breaks loose from the tank, and water flows from the drain.

(a) Calculate the force exerted by the water on the plug before the plug breaks free.

$$P = \frac{F}{A} \Rightarrow F = AP = A\rho g h = 4*10^{-5} * 1025 * 9.5 * 5$$

$$F = 2.009 \text{ N}$$

(b) Calculate the speed of the water as it leaves the hole in the side of the tank.

$$\cancel{P} + \rho g h + \cancel{\tfrac{1}{2}\rho v^2} = \cancel{P} + \rho g h + \tfrac{1}{2}\rho v^2$$

$$1025 * 9.8 * 25 = 1025 * 9.8 * 5 + \tfrac{1}{2} * 1025 \, v^2$$

$$251125 - 50225 = \tfrac{1}{2} \times 1025 \times v^2$$

$$\frac{2(200900)}{1025} = v^2$$

$$v = \sqrt{392} = 19.799 \ \frac{m}{s}$$

GO ON TO THE NEXT PAGE.

5B

(c) Calculate the volume flow rate of the water from the hole.

$$V = \frac{m}{\rho} = \frac{25}{1025} = 0.02439 \ m^3$$

$$\boxed{\frac{dV}{dt} = \frac{1}{\rho}\frac{dm}{dt}}$$

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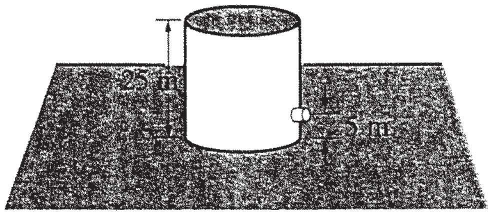

SC

5. (10 points)

A large tank, 25 m in height and open at the top, is completely filled with saltwater (density 1025 kg/m^3). A small drain plug with a cross-sectional area of 4.0×10^{-5} m^2 is located 5.0 m from the bottom of the tank. The plug breaks loose from the tank, and water flows from the drain.

(a) Calculate the force exerted by the water on the plug before the plug breaks free.

$P = \frac{F}{A}$ $\qquad$ $P = \rho g h$

$F = PA$ $\qquad$ $= (1025)(10)(20)$

$= 205000$

$F = 8.2N$ $\qquad$ $P \cdot A$

$(205000) \cdot (4 \times 10^{-5}) = 8.2N$

(b) Calculate the speed of the water as it leaves the hole in the side of the tank.

~~$P \rho g$~~ ρg

$P + \rho g y + \frac{1}{2}\rho v^2 = P + \rho g y + \frac{1}{2}\rho v^2$

$A_1 V_1 = A_2 V_2$

GO ON TO THE NEXT PAGE.

5C

(c) Calculate the volume flow rate of the water from the hole.

$P + \rho g y + \frac{1}{2}\rho v^2$

$PV = nRT$

$PV = NKT$

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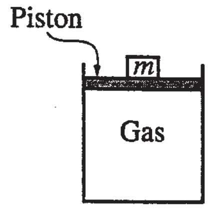

Note: Figure not drawn to scale.

6A

6. (10 points)

You are given a cylinder of cross-sectional area A containing n moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass m can be placed on top of it, as shown in the figure above. In order to determine n, you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature T before measuring the new volume V. The data collected are given in the table below.

m (kg)	$V\left(m^3\right)$	$1/V\left(m^{-3}\right)$	P (Pa)
0	6.0×10^{-5}	1.7×10^{4}	1.0×10^5
1	4.5×10^{-5}	2.2×10^{4}	1.32×10^5
2	3.6×10^{-5}	2.8×10^{4}	1.65×10^5
3	3.0×10^{-5}	3.3×10^{4}	1.98×10^5
4	2.6×10^{-5}	3.8×10^{4}	2.30×10^5

(a) Write a relationship between total pressure P and volume V in terms of the given quantities and fundamental constants that will allow you to determine n.

$PV = nRT \quad \therefore \quad n = \frac{PV}{RT}$

You also determine that $A = 3.0 \times 10^{-4}\ m^2$ and $T = 300$ K.

(b) Calculate the value of P for each value of m and record your values in the data table above.

$P = P_0 + \frac{F}{A}$ $\quad P_0$: atmospheric pressure $(1.0\times10^5\ Pa)$

for $m=0$, $P = P_0 = 1.0\times10^5\ (Pa)$

for $m=1$, $P = P_0 + \frac{1\times9.8}{3.0\times10^{-4}} = 1.32\times10^5\ (Pa)$

for $m=2$, $P = P_0 + \frac{2\times9.8}{3.0\times10^{-4}} = 1.65\times10^5\ (Pa)$

for $m=3$, $P = P_0 + \frac{3\times9.8}{3.0\times10^{-4}} = 1.98\times10^5\ (Pa)$

for $m=4$, $P = P_0 + \frac{4\times9.8}{3.0\times10^{-4}} = 2.30\times10^5\ (Pa)$

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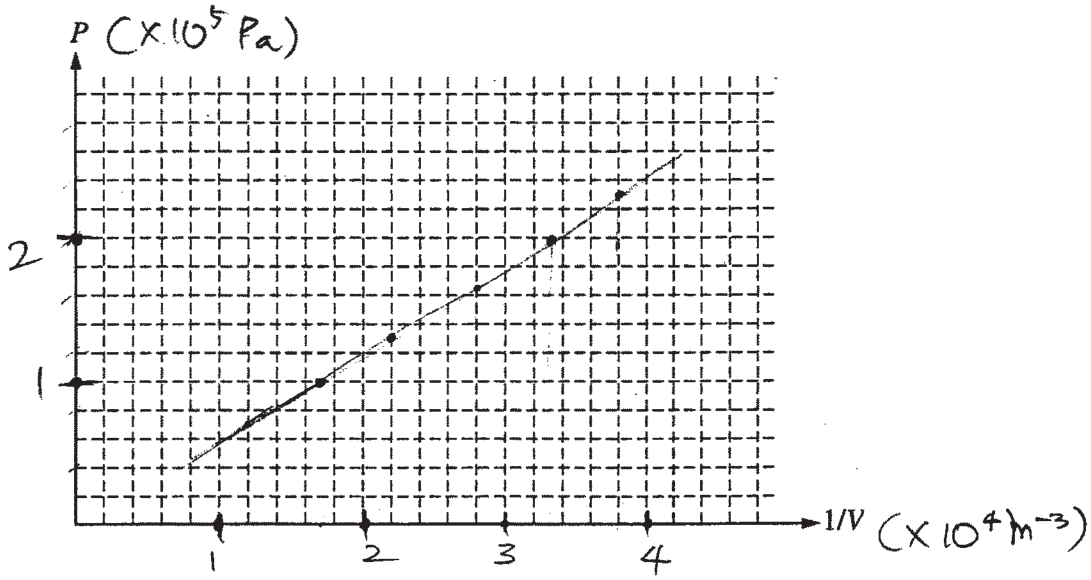
6A

(c) Plot the data on the graph below, labeling the axes with appropriate numbers to indicate the scale.



(d) Using your graph in part (c), calculate the experimental value of n .

$$\frac{P}{1/V} = PV = \frac{(2.3-1.0)\times10^5}{(3.8-1.7)\times10^4} = \frac{1.3\times10^5}{2.1\times10^4} = 6.1905 \text{ (J)}$$

$$n = \frac{PV}{RT} = \frac{6.1905}{8.31 \times 300} = 0.00248 \text{ (mol)}$$

$\therefore n \approx 0.0025$ mol

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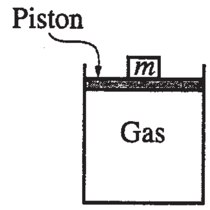


6B

Note: Figure not drawn to scale.

6. (10 points)

You are given a cylinder of cross-sectional area A containing n moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass m can be placed on top of it, as shown in the figure above. In order to determine n, you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature T before measuring the new volume V. The data collected are given in the table below.

m (kg)	$V\left(\text{m}^3\right)$	$1/V\left(\text{m}^{-3}\right)$	P (Pa)
0	6.0×10^{-5}	1.7×10^{4}	0
1	4.5×10^{-5}	2.2×10^{4}	32666.66
2	3.6×10^{-5}	2.8×10^{4}	65333.33
3	3.0×10^{-5}	3.3×10^{4}	98,000
4	2.6×10^{-5}	3.8×10^{4}	130,666.66

$P = \frac{F}{A}$

(a) Write a relationship between total pressure P and volume V in terms of the given quantities and fundamental constants that will allow you to determine n.

$PV = nrt \rightarrow PV = n(8.31)t$

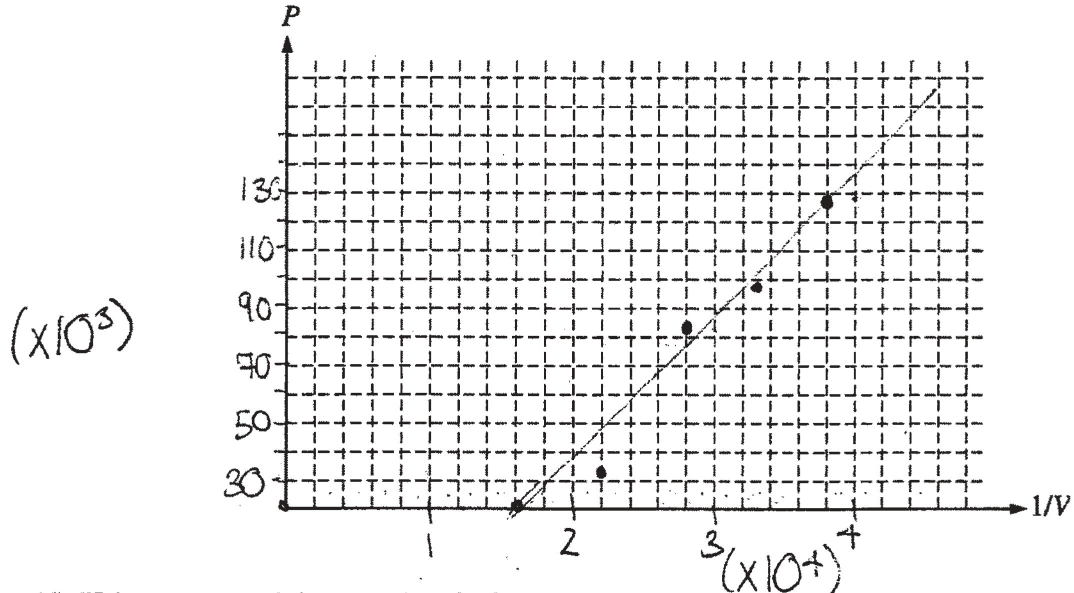
You also determine that $A = 3.0 \times 10^{-4}\ \text{m}^2$ and $T = 300$ K.

(b) Calculate the value of P for each value of m and record your values in the data table above.

GO ON TO THE NEXT PAGE.

6B

(c) Plot the data on the graph below, labeling the axes with appropriate numbers to indicate the scale.



(d) Using your graph in part (c), calculate the experimental value of n.

$$\frac{\text{rise}}{\text{run}} = \frac{(130{,}666.66)}{(3.8\times10^{4} - 1.7\times10^{4}} = \boxed{6.22\text{ mol}}$$

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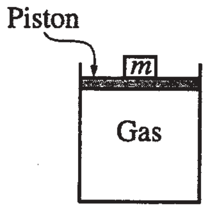

$PV = nRT$ 6C

$8.31 = R$

Note: Figure not drawn to scale.

6. (10 points)

You are given a cylinder of cross-sectional area A containing n moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass m can be placed on top of it, as shown in the figure above. In order to determine n, you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature T before measuring the new volume V. The data collected are given in the table below.

m (kg)	$V\left(m^3\right)$	$1/V\left(m^{-3}\right)$	P (Pa)
0	6.0×10^{-5}	1.7×10^4	$4.2 \times 10^7 n$
1	4.5×10^{-5}	2.2×10^4	$5.5 \times 10^7 n$
2	3.6×10^{-5}	2.8×10^4	$6.9 \times 10^7 n$
3	3.0×10^{-5}	3.3×10^4	$8.3 \times 10^7 n$
4	2.6×10^{-5}	3.8×10^4	$9.6 \times 10^7 n$

$R = 6.08$

(a) Write a relationship between total pressure P and volume V in terms of the given quantities and fundamental constants that will allow you to determine n.

$\frac{PV}{RT} = N$ T is constant so $\frac{PV}{R} = N$

$P = \frac{nR(T)}{V}$ $R = 8.31$ $P = \frac{(300)(8.31)n}{V}$

You also determine that $A = 3.0 \times 10^{-4}\ m^2$ and $T = 300$ K.

(b) Calculate the value of P for each value of m and record your values in the data table above.

$P = (300)$

$P = \frac{NRT}{V}$

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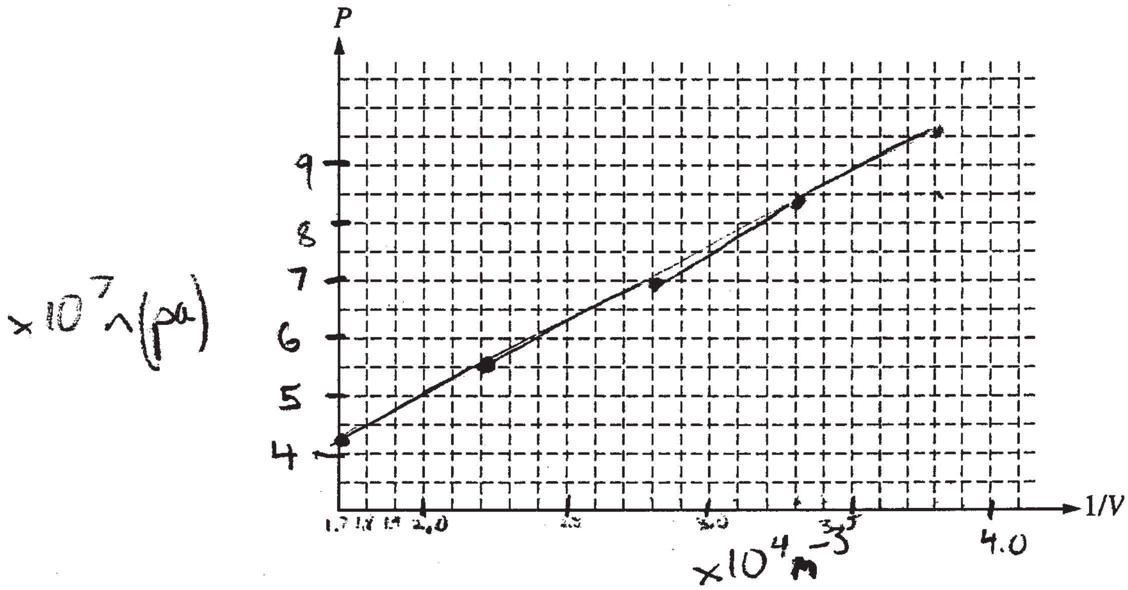
6C

(c) Plot the data on the graph below, labeling the axes with appropriate numbers to indicate the scale.



(d) Using your graph in part (c), calculate the experimental value of n.

$n = 1.01$ moles

$$P = \frac{nRT}{V}$$

$$n = \frac{PV}{RT}$$

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7A

7. (10 points)

A monochromatic source emits a 2.5 mW beam of light of wavelength 450 nm.

(a) Calculate the energy of a photon in the beam.

$$f = \frac{v}{\lambda} = \frac{3.0 \times 10^8 \text{ m/s}}{450 \times 10^{-9} \text{ m}} = 6.67 \times 10^{14} \text{ Hz}$$

$$E_{photon} = hf = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})(6.67 \times 10^{14} \text{ Hz})$$

$$= \underline{4.42 \times 10^{-19}} \text{ J/photon}$$

(b) Calculate the number of photons emitted by the source in 5 minutes.

$$(2.5 \times 10^{-3} \text{ J/s}) \times (\underbrace{5 \cdot 60 \text{s}}_{300 \text{s}}) = 0.75 \text{ J emitted}$$

$$\frac{0.75 \text{ J emitted}}{4.42 \times 10^{-19} \text{ J/photon}} = \underline{1.7 \times 10^{18} \text{ photons emitted}}$$

The beam is incident on the surface of a metal in a photoelectric-effect experiment. The stopping potential for the emitted electron is measured to be 0.86 V.

(c) Calculate the maximum speed of the emitted electrons. $\underbrace{V \cdot q_{el}}$ $= KE_{el}$

$$(0.86 \text{ J/C})(1.6 \times 10^{-19} \text{ C}) = 1.38 \times 10^{-19} \text{ J/electron}$$

energy of electrons = kinetic energy.

$$1.38 \times 10^{-19} \text{ J} = \frac{1}{2}(9.11 \times 10^{-31} \text{ kg})(V)^2$$

$$V = \sqrt{\frac{2(1.38 \times 10^{-19} \text{ J})}{9.11 \times 10^{-31} \text{ kg}}} = \underline{5.5 \times 10^5 \text{ m/s}}$$

GO ON TO THE NEXT PAGE.

7A

(d) Calculate the de Broglie wavelength of the most energetic electrons.

$$\lambda = \frac{h}{\vec{p}} \qquad \vec{p} = (M_{electron})(V_{electron})$$

$$= (9.11 \times 10^{-31}\ kg)(5.5 \times 10^{5}\ m/s)$$

$$= 5.01 \times 10^{-25}\ \frac{kg \cdot m}{s}$$

$$\lambda = \frac{6.626 \times 10^{-34}\ J \cdot s}{5.01 \times 10^{-25}\ \frac{kg \cdot m}{s}} = \underline{1.3 \times 10^{-9}\ m}$$

GO ON TO THE NEXT PAGE.

7. (10 points)

7B

A monochromatic source emits a 2.5 mW beam of light of wavelength 450 nm.

(a) Calculate the energy of a photon in the beam.

$$E = \frac{hc}{\lambda}$$

$$= \frac{(1.99 \times 10^{-25})}{450}$$

$$\boxed{= 4.42 \times 10^{-28}\ J}$$

(b) Calculate the number of photons emitted by the source in 5 minutes.

$2.5 \times 10^{6}\ J/s$ $\quad$ 5 mins = 300s

$$(2.5 \times 10^{6}\ J/s)(300s) = 7.5 \times 10^{8}\ J$$

$$\frac{(7.5 \times 10^{8})}{4.42 \times 10^{-28}} = \# \text{ of photons}$$

$$= 1.7 \times 10^{36} \text{ photons}$$

The beam is incident on the surface of a metal in a photoelectric-effect experiment. The stopping potential for the emitted electron is measured to be 0.86 V.

(c) Calculate the maximum speed of the emitted electrons.

V_q = Energy

$$(.86)(1.6 \times 10^{-19}) = 1.376 \times 10^{-19}\ J$$

$$KE = 1.376 \times 10^{-19}\ J$$

$$v = \sqrt{\frac{2KE}{m}}$$

$$= \sqrt{\frac{2(1.4 \times 10^{-19})}{9.11 \times 10^{-31}}}$$

$$\boxed{= 5.5 \times 10^{5}\ m/s}$$

GO ON TO THE NEXT PAGE.

7B

(d) Calculate the de Broglie wavelength of the most energetic electrons.

$$\lambda = \frac{h}{p}$$

$$= \frac{h}{(5.5\times10^{5})(9.11\times10^{-31})}$$

$$= \boxed{1.32\times10^{-9}\ \text{m}}$$

GO ON TO THE NEXT PAGE.

7C

7. (10 points)

A monochromatic source emits a 2.5 mW beam of light of wavelength 450 nm.

(a) Calculate the energy of a photon in the beam.

$E = hf$

$= 6.63 \times 10^{-34} \cdot 6.67 \times 10^{14}$

$= \boxed{4.42 \times 10^{-19}\ J}$

$v = f\lambda$

$f = \frac{v}{\lambda} = \frac{c}{\lambda}$

$= \frac{3 \times 10^{8}}{450 \times 10^{-9}} = 6.67 \times 10^{14}$

(b) Calculate the number of photons emitted by the source in 5 minutes.

$Power = \frac{W}{\Delta t}$ $\quad$ $work = 2.5 \times 10^{-3} \cdot 5 \cdot 60 = 0.75\ J$

$\frac{0.75\ J}{1\ eV} = \frac{0.75\ J}{1.60 \times 10^{-19}\ J} = \boxed{4.6875 \times 10^{18}}$

The beam is incident on the surface of a metal in a photoelectric-effect experiment. The stopping potential for the emitted electron is measured to be 0.86 V.

(c) Calculate the maximum speed of the emitted electrons.

$K_{max} = hf - \phi$

$\frac{1}{2}mv^2 = 4.42 \times 10^{-19}\ J - \phi$

$v = \sqrt{\frac{2(4.42 \times 10^{-19} - \phi)}{m}}$ m/s

GO ON TO THE NEXT PAGE.

7C

(d) Calculate the de Broglie wavelength of the most energetic electrons.

$$\lambda = \frac{h}{p}$$

$$= \frac{6.63 \times 10^{-34}\ J \cdot S}{m\ V}$$

for velocity, use the speed from previous part

$$= \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})\left(\sqrt{\frac{2(4.42 \times 10^{-19} - \cancel{0})}{m}}\right)}$$ meters.

GO ON TO THE NEXT PAGE.