1. A. The 2nd harmonic of a string of length 60.0 cm and linear mass density of 1.20 g/m has the same frequency as the 3rd harmonic of a closed pipe of length of 1.00 m. Find the tension in the string. Take the speed of sound in air to be 340 m/s.

B. An organ pipe is 4.50 m long. Take the speed of sound in air to be 340 m/s.
   i. Determine the fundamental frequency if the pipe is closed at one end.
   ii. Find the fundamental frequency if the pipe is open at both ends.

2. A. The first three natural frequencies of a certain organ pipe are 68.0 Hz, 204 Hz and 340 Hz. Take the speed of sound in air to be \( v_{\text{sound}} = 340 \text{ m/s} \).
   i. Is the pipe open or closed?
   ii. How long is the pipe?
   iii. What is the wavelength of the fundamental mode of vibration?

B. A suspension bridge has two cables. Each is 400 m long between supports across its main span, and the mass of each cable is \( 2.00 \times 10^6 \text{ kg} \). Assume that this mass is distributed evenly along each cable and that the tension in the cable is \( 6.50 \times 10^7 \text{ N} \).
   i. Use above data to calculate the cable density.
   ii. What is the fundamental frequency of vibration of the bridge?
   iii. What frequency will generate a standing wave pattern in the cables with 2 antinodes (3 nodes)?

3. A string is stretched tightly between two posts. The string is 2.00 m long and has a mass of 4.80 grams. The tension in the string is maintained at 0.240 N. A standing wave pattern with three nodes, including the ones at each end, is set up on the string. Initially the string is flat with the left side of the string moving down.

A. Determine:
   1. The speed of the separate waves.
   2. The wavelength of the separate waves.
   3. The frequency of oscillation of the pattern.
   4. The period of oscillation.

B. Draw the standing wave pattern on the string at the requested times.

\[ t = 0.0 \text{ s} \quad \quad \quad t = 0.050 \text{ s} \quad \quad \quad t = 0.250 \text{ s} \]

C. To what value must the tension be increased, without changing the frequency, to display a different standing wave pattern on the string. Describe the pattern.
4. A standing wave is set up on a string tied between 2 posts. The following data are given:
L = 2.40 m, at time t = 0.0 s the string is flat and the central section of the string is moving upward. There are 3 antinodes. The speed of the individual waves making up the standing wave pattern is 8.00 m/s.

1. In the setups below draw the standing wave pattern at the indicated times.

   ![Standing Wave Diagram]

   \( t = 0.00 \) s \hspace{1cm} \( t = 0.10 \) s \hspace{1cm} \( t = 0.20 \) s

2. \__________\ The number of nodes on the standing wave.
3. \__________\ The wavelength of the separate waves.
4. \__________\ The frequency of the separate waves.

5. A long plexiglass tube is filled to its top with water. The level of water can be adjusted through a drain plug. At the top of the tube is a speaker connected to a variable frequency audio generator. See figure. Use \( v_{\text{sound}} = 340 \) m/s.

A. \( f = 1000 \) Hz. To what position must the water level be lowered in order to hear the second resonance, i.e., the second loud sound. Assume one antinode of the standing sound wave falls exactly at the top end of the tube.

B. Suppose the water level is fixed at the position calculated in A. To what frequency would the generator have to be changed so that the new standing sound wave in the tube has 4 nodes (including the one at the water barrier)? If you were not able to do part A, assume a water level at \( L = 1.00 \) m to do this part.

6. A. The following shows the \( \vec{E} \)-field pattern around a pair of charges. The charges are identified as A and B.

1. \_____ is the positive charge.
2. \_____ has the largest amount of charge.
3. At point x in the diagram draw an arrow showing the force a -3.00 nC charge feels.
4. On the diagram indicate clearly a point where the value of the \( \vec{E} \)-field is zero.
5. At point y draw an arrow indicating the direction of acceleration of a 4.00 \( \mu \)C placed there.
6. Through point z draw a single equipotential. Make this equipotential a single closed loop.

B. The following diagram shows a collection of equipotentials. Various points in the diagram are identified about which questions will be asked.

1. Through points A, B and C draw \( \vec{E} \)-field lines that pass through all 5 equipotentials shown.
2. The amount of work needed to move a 1.00 \( \mu \)C charge from A to B along the 10 V equipotential is \__________.
3. The amount of work needed to move a 1.00 \( \mu \)C charge from C to D is \__________.
4. The change in electric potential energy of a charge that moves from A to B to D to E and then back to A is \__________.
5. A -1.00 \( \mu \)C charge released from rest at D will accelerate toward which closest equipotential?
7. Data about 3 charges is given below. Charge $q_2$ will be placed at the origin later. The data are:

<table>
<thead>
<tr>
<th>Charges</th>
<th>Charge</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_1$</td>
<td>$5.00 \times 10^{-6}$ C</td>
<td>0, 5.00 cm</td>
</tr>
<tr>
<td>$q_2$</td>
<td>$-8.00 \times 10^{-6}$ C</td>
<td></td>
</tr>
<tr>
<td>$q_3$</td>
<td>$10.00 \times 10^{-6}$ C</td>
<td>-8.00 cm, 0</td>
</tr>
</tbody>
</table>

A. Determine the electric potential at the origin due to $q_1$ and $q_3$.
B. Now suppose $q_2$ is moved from a very, very great distance to the origin. At (0, 0) determine the work done on $q_2$ or by $q_2$ in moving $q_2$ from its starting position to (0, 0).
C. How much work must be done on $q_2$ to move it from (0, 0) to (-4.494 cm, 7.191 cm)?

8. Two point charges, $q$ (0,0) and $-5q$ (1.20 cm,0), are situated as shown in the diagram ($q = 2.00 \mu$C).

A. The points A, B, C and D are marked on the diagram: A = (-0.300 cm, 0), B = (0.200 cm, 0), C = (0.600 cm, 0) and D = (0, 0.600 cm). The electric field is zero at (-0.371 cm, 0).

1. ____________ Point(s) on x axis at which $V= 0$.
2. ____________ Point along x axis at which $\frac{|V|}{|E|}$ is largest.
3. ____________ An electron placed at (-0.371 cm, 0) will experience a force in which direction (left, right, up, down or not at all)?
4. ____________ At point C, the direction along the x axis that a proton will have to be moved to increase its electrical PE.

B. 1. Determine the electric potential at point D due to the two charges.
2. How much work must be done on a 1.50 $\mu$C charge to move it from point D to point B?

9. A metallic conducting sphere of radius 1.00 cm carries a charge of 60.0 $\mu$C.

A. At the point (15.0 cm, 0) what are the electric field $\vec{E}$ and the electric potential $V$ due to this charged sphere?
B. What is the value of the electric field and the electric potential at the center of this sphere?
C. Now suppose a second metallic, but initially uncharged sphere of radius 3.00 cm is placed at (30.0 cm,0). Then a thin wire lead is used to connect the first spheres to the second sphere. After equilibrium is reached and charged is no longer moving, how much charge resides on each sphere?
10. Three point charges are arranged as shown below. The charge on each object and their positions are given in the table below.

<table>
<thead>
<tr>
<th>Charge in μC</th>
<th>Position (x,y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>q₁ 3.00</td>
<td>0, 0.500 m</td>
</tr>
<tr>
<td>q₂ -6.00</td>
<td>0, -0.500 m</td>
</tr>
<tr>
<td>q₃ 5.00</td>
<td>0.500 m, 0</td>
</tr>
</tbody>
</table>

(a) On the above diagram use arrows to show the two electrostatic force q₁ feels from q₂ and q₂. Make sure the lengths of these arrows reflect the magnitudes of these forces.

(b) Determine the total force (a vector) felt by q₃ due to the electrostatic forces exerted on q₃ by q₁ and q₂. Draw this force on the above diagram.

(c) This is a qualitative question: NO CALCULATIONS. Suppose you had access to a fourth charge q₄ = -8.00 μC. On the above diagram show approximately where q₄ would have to be placed so that the total force on q₃ due to q₁, q₂, and q₄ would be zero.

11. A 1.00 gm ball is suspended from a string (L = 0.750 m) as shown. The ball has a charge of q = +14.0 μC placed on it.

(a) What uniform electric field, \( \vec{E} \) (magnitude and direction) would have to be placed upon the ball to reduce the tension in the rope to zero?

(b) Suppose this electric field you determined in part (a) were turned so that it pointed from right to left (perfectly horizontal). At what angle, measured from the vertical, would the string hang?

(c) Where would a -20.0 nC charge have to be placed so that the original +14.0 μC charge now hangs vertically? The uniform \( \vec{E} \) described in part (b) is still "on."

12. Two identical spheres (see figure to left) having the same mass, m = 0.60 kg and the same positive charge, q, are suspended from the same point by strings of length 20.0 cm.

(a) What charge q resides on each sphere? (Note \( \vec{E} \) is not applied until you do part b.)

(b) The apparatus is now placed (see figure at right) in an upward directed but unknown electric field. The angle, measured from the vertical from which the strings hang is 45°. What is \( \vec{E} \)?
13. A parallel plate capacitor with a plate separation d is connected to a battery with a potential difference V. Two changes are now made independent of each other. First, the plates are pulled apart until the separation is 2d. Second, a dielectric material of constant $\kappa$ is inserted between the plates with plate separation kept at d. The battery stays connected in both cases. Fill in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>&quot;d&quot; Doubled</th>
<th>Dielectric Added</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charge</td>
<td>CV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>$\frac{1}{2} CV^2$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Show all work!

14. A 20.0 gram conducting ball bearing (m) is charged to $Q = +15.0 \mu C$. An insulating string connects the ball to a parallel plate capacitor across which a uniform electric field is maintained. The tension in the insulating string is measured to be 1.00 N. See figure. Assume plate area $A = 2.25 \times 10^{-2} \text{ m}^2$.

A. What must be the direction of the $\vec{E}$ field between the plates of the capacitor for the above situation to be possible. Answer this by drawing a few $\vec{E}$ lines between the plates.
B. Which plate is the positive plate?
C. Draw the force diagram for the 20.0 gram mass. Then determine the magnitude of the electric field the charged mass feels from the capacitor?
D. What is the difference in electric potential between the plates of the capacitor?
E.* **Qualitative Question.** Suppose the interior of the capacitor were filled with a dielectric material, e.g., a gas, $\kappa > 1$. Assume the charge on the capacitor plates does not change, and all interactions between the dielectric material and the charged mass can be neglected. As a result of adding the dielectric material, does the tension on the string increase, decrease, or remain the same? You must provide an explanation for your answer.

* Regard E as an Exam 3 Review item.

15. A. At the position of the $-Q$ charge on the lower right corner of the triangle draw two arrows: (1) the direction of the electric field at this location due to the charges on the other corners of the triangle; and (2) the direction of the force the $-Q$ charge on this corner feels.
B. Determine the value of the electric potential difference $V_B - V_A$ between points A and B. Points A and B are halfway between the pair of charges on their sides of the triangles.
C. Suppose a $+2.0 \mu C$ charge moves from A to B. What is the change in this charge's PE in going from A to B?
D. What is the total electrostatic PE of the 3-charge assembly?

16. A. A 10 gram spherical mass hangs from a string. The mass carries a -5.0 $\mu C$ charge. A vertically downward uniform electric field is now applied. For the items that follow, circle the entry in parenthesis that best completes the statement.

1. The electric force the charge feels is __________the weight of the hanging mass.
2. The electric field is now turned until it points directly to the left, i.e., from right to left.
3. The electric force the charge feels is __________the weight of the hanging mass.
4. The string with mass now hangs __________the center line, vertically just as it hung before $\vec{E}$ was turned to the left.
5. The tension in the string is __________the weight of the hanging mass.
B. The drawing shows a partial picture of equipotential lines drawn for an unseen arrangement of charge. Values of the electric potential for each curve are shown. Through points A, B and C sketch (carefully) \( \vec{E} \) field lines, each one passing through all 3 equipotentials. Include arrows showing the directions of each \( \vec{E} \) line.

C.* A parallel plate capacitor is in the shape of a pair of circular plates of radius \( r \). The initial separation is \( d \). The leads are now hooked to a 10 V battery. For the following questions enter increase, decrease, stays the same, or cannot tell, that best describes each statement.

1. _______ What happens to the charge on the plates if \( d \) is reduced?
2. _______ What happens to the charge on the plates if \( r \) is halved?
3. _______ What happens to the charge on the plates if both \( r \) and \( d \) are doubled?
4. _______ What happens to the charge on the plates if a dielectric \((\kappa > 1)\) is inserted between the plates assuming the battery remains connected?
5. _______ What happens to the potential between the plates if a dielectric is inserted after the battery is disconnected?
6. _______ What happens to the energy the capacitor stores if a dielectric is inserted after the battery is disconnected?

* Regard C as an Exam 3 Review item.

17. A. Four equal and opposite 50.0 \( \mu \text{C} \) charges are located at the corners of a square. See figure. The square is 5.00 cm on a side. Five points, A, B, C, D, and E are marked on the square. A, B, C, and D are at the midpoints of the sides the square and E is at the very center of the square.

\[
\begin{align*}
q_1 &= -50.0 \mu\text{C} \\
q_2 &= +50.0 \mu\text{C} \\
q_3 &= -50.0 \mu\text{C} \\
q_4 &= +50.0 \mu\text{C}
\end{align*}
\]

1. At which of the marked points is the electric potential of this collection of charges equal to zero?
2. Calculate the electric potential due to the 4-charge collection at B.
3. A proton \((p' = 1.6 \times 10^{-19} \text{ C})\) is placed at E and moved from E to A to B. Does the electrostatic potential energy of the proton increase, decrease, or stay the same on this trip? By how many joules does its energy change? This means calculate \( \Delta \text{PE}_e \) of the proton for the described trip.

B. A charge of \( 2.0 \times 10^{-6} \text{ C} \) is located at the center of an uncharged, solid conducting spherical shell of inner radius \( R_1 = 3.00 \text{ cm} \) and outer radius \( R_2 = 4.00 \text{ cm} \). See figure.

1. What is \( E \) at 2.00 cm from the charge?
2. What is \( E \) at 3.50 cm from the charge?
3. What is \( E \) at 5.00 cm from the charge?
18.  

A. The pattern below is the electric field pattern associated with unequal charges A and B. A number of points a, b, etc. are marked on the pattern. The questions below relate to this electric field. A identifies the charge on the left and B the one on the right.

1. is the positive charge.
2. is the greater charge

In 3 through 8 enter one of a, b,...g as the case may be. (Note: At c the magnitude of due to charge A is equal to the magnitude of due to charge B.

3. is the point at which the magnitude of is greatest
4. is the point at which the magnitude of is least.
5. is the point where V is likely to be positive.
6. is the point where V is most likely to be negative.
7. could be a point where V = 0.
8. is a point where an electron will feel no electric force if placed there
9. is the number of times V = 0 along a horizontal axis extending through the two charges.
10. At e draw an arrow representing the direction of
11. At f draw an arrow representing the direction of the acceleration of an e- is released at that point.

B. A circular speaker emits sound at the center of a stage in a concert hall. Describe what happens to the angular width of the central loud region of the sound diffraction pattern coming from the speaker when each of the following changes occur. Enter increases, decreases, stays the same, or cannot tell.

1. The wavelength of the sound emitted by the speaker decreases.
2. The intensity (loudness) of the emitted sound is increased.
3. The diameter of the circular speaker is increased.
4. The speaker is moved more to the rear of the stage from where it originally was.
19. Three charges $q_1$, $q_2$ and $q_3$ are located at 3 of the four corners of a square as in the figure. The origin is located at the center of the square.

\[ q_1 = -5.00 \ \mu C \text{ at (a,0)}; \ q_2 = -10.0 \ \mu C \text{ at (0,a)}; \ q_3 = 5.00 \mu C \text{ at (-a,0)} \]
\[ a = 0.150 \text{ m}; \ P \text{ is at (0,-a)} \]

A. What is the magnitude of the electric field at the origin of the coordinate system due to the charges $q_1$, $q_2$ and $q_3$?

B. What would be the magnitude of the acceleration of a 0.500 kg mass carrying a 2.00 $\mu C$ charge released at the origin? In what quadrant would the mass initially move?

C. What is the absolute electric potential at both point $P$ and at the origin due to charges $q_1$, $q_2$ and $q_3$?

D. How much work would an external force have to do to move an electron from point $P$ to the origin? (The charge on an electron is $e = -1.60 \times 10^{-19} \ \text{C}$.)

20. The drawing shows a 12.5 kg block (m) held in position on a frictionless 37.0° inclined plane by a cord whose length is 0.750 m (L) and whose mass per unit length is $1.20 \times 10^{-5} \ \text{kg/m}$. The upper end of the cord is connected to an oscillator (not shown). The frequency of the oscillator is adjusted until standing waves appear in the cord. Assume the two ends of the cord are nodes in the standing wave pattern set up in the cord.

A. What is the oscillating frequency such that the fundamental standing wave pattern appears in the cord?

B. What is the oscillator frequency such that the new standing wave patterns have two antinodes?

C. The angle of the incline is increased to 45°. Would the oscillator frequency have to increase, decrease, or remain the same to produce the fundamental standing wave pattern?

21. A standing wave pattern is set up on a 2.00 m rope as shown to the right. The individual waves travel at 183 m/s on the rope.

1. ________ The number of nodes in this standing wave.
2. ________ The number of antinodes in this standing wave.
3. ________ The wavelength of the individual traveling waves that make up this standing wave.
4. ________ The frequency of the individual waves.
5. ________ The period of oscillation of the waves on the rope.

To the right is a snapshot of the rope at $t_o = 0$. Assume that part of the rope near the fixed point on the right is moving downward at $t_o = 0$. In the empty space below, sketch the snapshots of the rope (a) at 1/4 period after $t_o = 0$ and (b) at 1/2 period after $t_o = 0$. 

(a) (b)
B. To the right is a drawing of the electric field pattern around a pair of charges.

1. On the drawing put plus signs, minus signs or both in the center of the charges.
2. At point 1 draw an arrow representing the electric field at this location.
3. At point 2 draw an arrow representing the electric force an electron placed here would feel.
4. At point 3 draw an arrow representing the instantaneous acceleration a proton would experience if placed there and released.
5. As best as you can, sketch an equipotential that passes through point 2 and enclosed the right charge.

22. Charges $q_1$, $q_2$ and $q_3$ are located as shown in the drawing.

$q_1 = 5.00 \text{ \mu C}; \quad q_2 = -5.00 \text{ \mu C}; \quad q_3 = 7.50 \text{ \mu C} \quad \text{(Note: } \mu = 1.00 \times 10^{-6})$

A. On the figure, draw the vector from $q_3$ representing the total electrostatic force $q_3$ feels from $q_1$ and $q_2$.
B. What is the total force $q_3$ feels from $q_1$ and $q_2$? Remember this force is a vector.
C. If $q_3$ is completely removed from the figure, what is the electric field at the position $q_3$ was located due to $q_1$ and $q_2$?

23. Two charges, $q_1 = 1.50 \times 10^{-9} \text{ C}$ and $q_2 = 4.00 \times 10^{-9} \text{ C}$, are located at the bottom corners of a square with side length $a = 0.180 \text{ m}$. See figure.

A. What is the electrostatic potential energy of the $q_1 - q_2$ configuration?
B. Which location, A or B, is at the higher electric potential?
C. What are the electric potentials due to $q_1$ and $q_2$ (a) at A and (b) at B?
D. How much work must be done on a charge $q_3 = -2.00 \times 10^{-9} \text{ C}$ to move it from B to A?
E. After $q_3$ gets to A, what is the electrostatic potential energy of the $q_1 - q_2 - q_3$ system?
24. A. The drawing to the right shows a snapshot at a particular instant of a standing wave pattern set up of a taut string that is fixed at both ends. The string has 3 antinodes, and the center of the string is moving upward at the time of the snapshot. On the 3 drawings below, sketch the snapshot in time of the string at 1. $t = \frac{T}{4}$, 2. $t = \frac{T}{2}$, and 3. $t = \frac{3T}{4}$ where $T$ is the period for the separate waves.

1. 
2. 
3. 

B. Examine the electric field pattern below.

1. Near each charge write “+” or “−” to indicate the sign of that charge.
2. Which charge has the greater amount of charge?
   Circle: Left   Right   They are the same
3. At point a draw an arrow showing the vector electric field.
4. At b draw an arrow to represent the electric force an electron placed there would feel.
5. At c draw an arrow representing the acceleration a proton released there would undergo.
6. At which location (a, b, or c) is the magnitude of the net electric field greatest?
7. Through point b sketch a closed loop equipotential curve that encloses the “−” charge.
25. The drawing shows 3 charges fixed in position as shown. The charges are \( q_1 = 9.00 \mu C \), \( q_2 = -6.00 \mu C \), and \( q_3 = 6.00 \mu C \).

(Note: \( \mu = \text{micro} = 1 \times 10^{-6} \))

A. What is the total electric force \( q_1 \) feels from \( q_1 \) and \( q_2 \)? Remember, force is a vector.

B. At the location of \( q_1 \) draw an arrow showing the force calculated in part A.

C. What is the value of the electric field at the location of \( q_1 \) due to charges \( q_1 \) and \( q_3 \) if \( q_3 \) were removed?

26. A. A string has a linear density of \( \rho = 8.70 \times 10^{-3} \text{ kg/m} \) and is under a tension of 285 N. The string is 1.50 m long and is fixed at both ends. It is vibrating in the standing wave pattern as shown with a fixed frequency oscillator at one end.

1. What is the speed of the individual waves that make this standing wave?
2. What are (i) the wavelength and (ii) the frequency of the separate waves?
3. What tension would the string have to be under for a new standing wave with 3 antinodes to form?

B. Determine the electric potential energy for the 3-charge configuration shown relative to its value when the charges are infinitely far away. \( q_1 = 10.0 \mu C; \quad q_2 = -15.0 \mu C; \quad q_3 = 20.0 \mu C \)