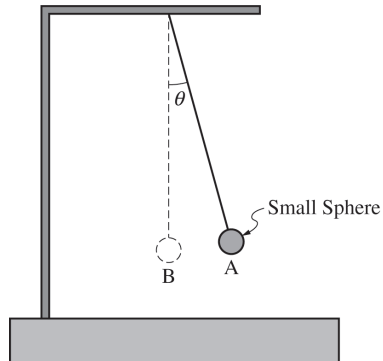


Begin your response to **QUESTION 4** on this page.



4. (7 points, suggested time 13 minutes)

A simple pendulum consists of a small sphere that hangs from a string with negligible mass. The top end of the string is fixed. The sphere is pulled to Point A so that the string makes a small angle θ with the vertical, as shown. The sphere is then released from rest and swings through its lowest point at Point B. The work done on the sphere by Earth between points A and B is W_E .

The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X .

(a) **Justify** why W_X is less than W_E .

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 4** on this page.

A new pendulum is made by hanging the same small sphere from a different string with negligible mass. The new string is slightly elastic, and the length of the string may increase or decrease depending on the tension applied to the string. On Earth, when the sphere is again displaced θ from the vertical and released from rest, the new pendulum oscillates with period T_E .

The new pendulum is then taken to a different planet, Planet Y. The radius of Planet Y is the same as the radius of Earth, but the mass of Planet Y is larger than the mass of Earth. On Planet Y, when the sphere is again displaced from the vertical and released from rest, the new pendulum oscillates with period T_Y .

(b) In a clear, coherent paragraph-length response that may also contain drawings, **explain** how T_Y could be larger than T_E but also could be smaller than T_E .

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PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.

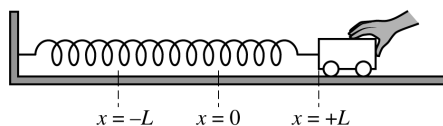


Figure 1

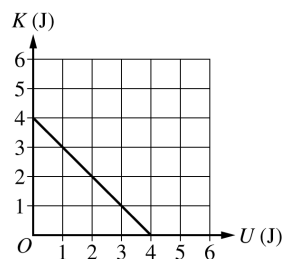


Figure 2

(7 points, suggested time 13 minutes)

A cart on a horizontal surface is attached to a spring. The other end of the spring is attached to a wall. The cart is initially held at rest, as shown in Figure 1. When the cart is released, the system consisting of the cart and spring oscillates between the positions $x = +L$ and $x = -L$. Figure 2 shows the kinetic energy of the cart-spring system as a function of the system's potential energy. Frictional forces are negligible.

- (a) On the graph of kinetic energy K versus potential energy U shown in Figure 2, the values for the x -intercept and y -intercept are the same. Briefly explain why this is true, using physics principles.

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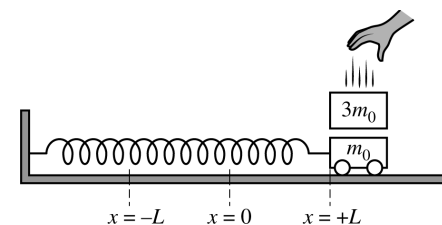
Continue your response to **QUESTION 1** on this page.

Figure 3

When the cart is at $+L$ and momentarily at rest, a block is dropped onto the cart, as shown in Figure 3. The block sticks to the cart, and the block-cart-spring system continues to oscillate between $-L$ and $+L$. The masses of the cart and the block are m_0 and $3m_0$, respectively.

- (b) The frequency of oscillation before the block is dropped onto the cart is f_1 . The frequency of oscillation after

the block is dropped onto the cart is f_2 . Calculate the numerical value of the ratio $\frac{f_2}{f_1}$.

GO ON TO THE NEXT PAGE.

- (c) The dashed line in Figure 4 shows the kinetic energy K versus potential energy U of the block-cart-spring system after the block is dropped onto the cart. This graph is identical to the graph shown in Figure 2 for the cart-spring system before the block is dropped onto the cart.

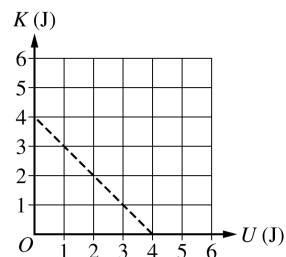
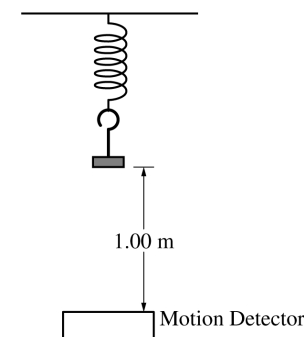


Figure 4

- i. Briefly explain why the two graphs must be the same, using physics principles.
- ii. After the block is dropped onto the cart, consider a system that consists only of the cart and the spring. On Figure 4, sketch a solid line that shows the kinetic energy of the system that consists of the cart and the spring but not the block after the block is dropped onto the cart.

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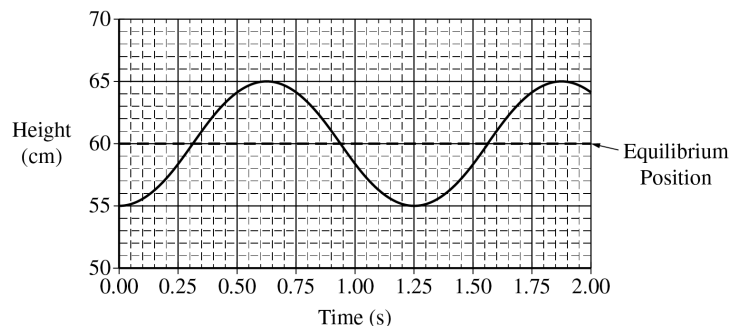


(7 points, suggested time 13 minutes)

A spring of unknown spring constant k_0 is attached to a ceiling. A lightweight hanger is attached to the lower end of the spring, and a motion detector is placed on the floor facing upward directly under the hanger, as shown in the figure above. The bottom of the hanger is 1.00 m above the motion detector.

A 0.50 kg object is placed on the hanger and allowed to come to rest at the equilibrium position. The spring is then stretched downward a distance d_0 from equilibrium and released at time $t = 0$. The motion detector records the height of the bottom of the hanger as a function of time. The output from the motion detector is shown in the graph on the following page.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 5** on this page.

(a) Using the information given and information taken from the graph, calculate the spring constant.

(b) At time 0.75 s, the object-spring-Earth system has a total kinetic energy K_0 and a total potential energy U_0 . At 1.13 s, the object-spring-Earth system again has a total kinetic energy K_0 and a total potential energy U_0 .

i. Explain how a feature of the graph indicates that the total kinetic energy of the system is the same at these two times.

ii. Briefly explain why the total potential energy of the system is the same at these two times.

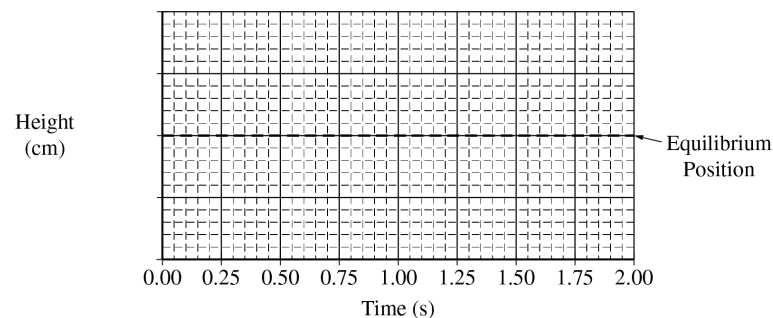
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Continue your response to **QUESTION 5** on this page.

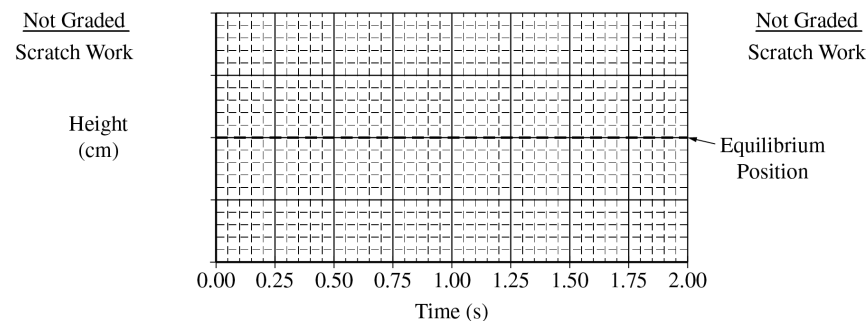
(c) The experiment is repeated with a spring of spring constant $4k_0$ and that has the same length as the original spring. The 0.50 kg object is hung from the new spring and allowed to come to rest at a new equilibrium position.

i. Determine the new equilibrium position above the motion detector.

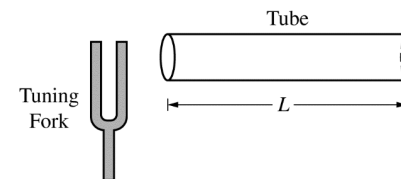
ii. The object is again pulled down the same distance d_0 from the equilibrium position and released. On the following graph, draw a curve representing the motion of the object after it is released. Label the vertical axis with an appropriate numerical scale. A grid for scratch (practice) work is also provided.



The following graph is provided for scratch work only and will not be graded.



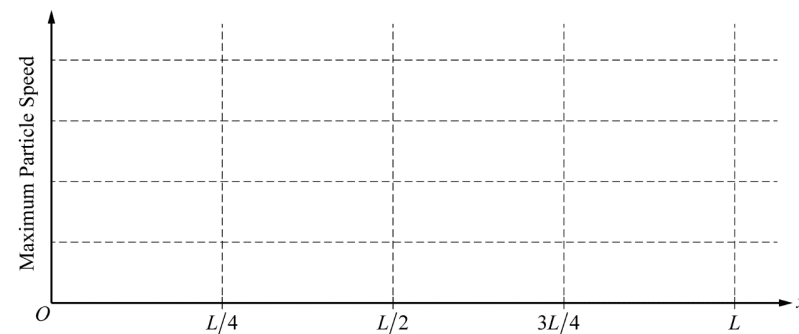
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STOP**END OF EXAM**

5. (7 points, suggested time 13 minutes)

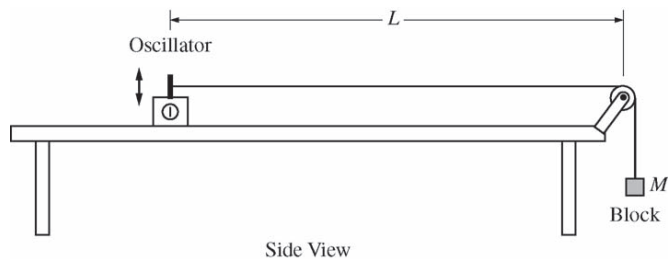
A tuning fork vibrating at 512 Hz is held near one end of a tube of length L that is open at both ends, as shown above. The column of air in the tube resonates at its fundamental frequency. The speed of sound in air is 340 m/s.

- (a) Calculate the length L of the tube.
- (b) The column of air in the tube is still resonating at its fundamental frequency. On the axes below, sketch a graph of the maximum speed of air molecules as they oscillate in the tube, as a function of position x , from $x = 0$ (left end of tube) to $x = L$ (right end of tube). (Ignore random thermal motion of the air molecules.)



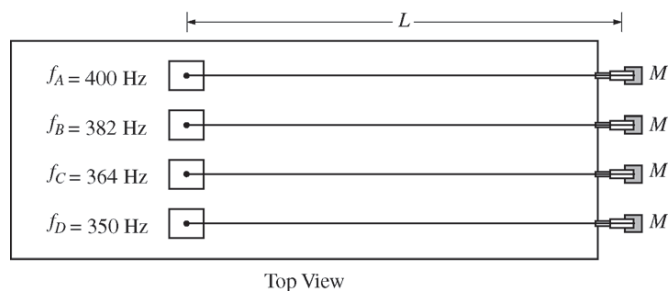
- (c) The right end of the tube is now capped shut, and the tube is placed in a chamber that is filled with another gas in which the speed of sound is 1005 m/s. Calculate the new fundamental frequency of the tube.

STOP**END OF EXAM**



5. (7 points, suggested time 13 minutes)

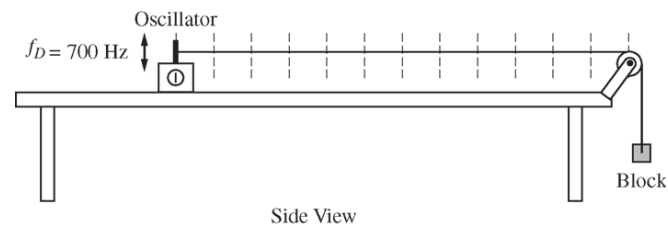
The figure above shows a string with one end attached to an oscillator and the other end attached to a block. The string passes over a massless pulley that turns with negligible friction. Four such strings, *A*, *B*, *C*, and *D*, are set up side by side, as shown in the diagram below. Each oscillator is adjusted to vibrate the string at its fundamental frequency f . The distance between each oscillator and pulley L is the same, and the mass M of each block is the same. However, the fundamental frequency of each string is different.



The equation for the velocity v of a wave on a string is $v = \sqrt{\frac{F_T}{m/L}}$, where F_T is the tension of the string and m/L is the mass per unit length (linear mass density) of the string.

- What is different about the four strings shown above that would result in their having different fundamental frequencies? Explain how you arrived at your answer.
- A student graphs frequency as a function of the inverse of the linear mass density. Will the graph be linear? Explain how you arrived at your answer.

- The frequency of the oscillator connected to string *D* is changed so that the string vibrates in its second harmonic. On the side view of string *D* below, mark and label the points on the string that have the greatest average vertical speed.



STOP
END OF EXAM