



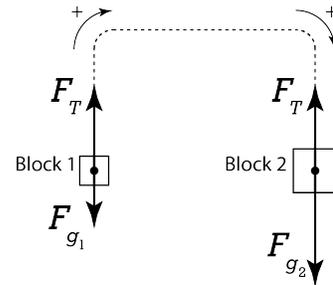
2015 FRQ #1

Flipping Physics Lecture Notes:

Free Response Question #1 - AP Physics 1 - 2015 Exam Solutions

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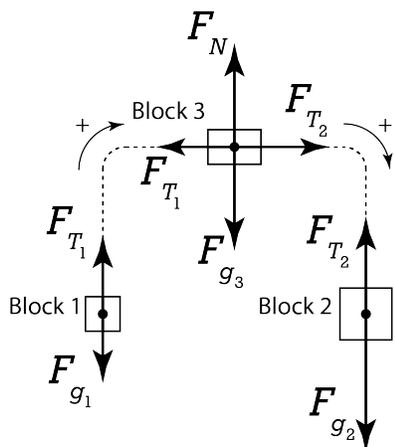
(a) First off, we know both blocks have a force of gravity acting downward on them. Let's label them F_{g_1} & F_{g_2} . We also know there is a force of tension upward on each block and, because there are no other objects attached to or pulling on the string between blocks 1 and 2, both forces of tension are the same. For the two tensions to be the same, it is also necessary that the string be massless and the pulleys be massless and frictionless, which they are. Let's label these forces of tension F_T . Now, about their magnitudes. Because block 2 has a greater mass than block 1, F_{g_2} should have a greater magnitude (or length) than F_{g_1} . This also tells us block 2 accelerates down and block 1 accelerates up. For this to happen, F_T on block 1 must be greater than F_{g_1} (to cause block 1 to accelerate upward) and F_T on block 2 must be less than F_{g_2} (to cause block 2 to accelerate downward).



Be careful with your free body diagrams! They are answers! They need to be clearly drawn and with lengths proportional to their relative magnitudes. You need to label each force. And do not break forces into components in your original free body diagram.

(b) We can sum the forces on both blocks simultaneously in the direction I have indicated in the free body diagram above (positive in the direction both blocks accelerate). Realize block 1 and 2 will have the same acceleration because they are attached to one another by the string.

$$\sum F_+ = F_{g_2} - F_T + F_T - F_{g_1} = m_t a \Rightarrow m_2 g - m_1 g = (m_1 + m_2) a \Rightarrow a = \frac{m_2 g - m_1 g}{m_1 + m_2} = \boxed{\frac{(m_2 - m_1) g}{m_1 + m_2}}$$



(c) Adding a block doesn't change the magnitude of the net force; it only increases the total mass. Therefore, using Newton's Second Law, $\sum \vec{F} = m\vec{a}$, if the net force stays the same and the mass increases, the acceleration must decrease. More specifically:

$$\begin{aligned} \sum F_+ &= F_{g_2} - F_{T_2} + F_{T_2} - F_{T_1} + F_{T_1} - F_{g_1} = m_t a \\ \Rightarrow m_2 g - m_1 g &= (m_1 + m_2 + m_3) a \Rightarrow a = \frac{m_2 g - m_1 g}{m_1 + m_2 + m_3} \end{aligned}$$

which is less than the original acceleration from part (b).

Notice there are no numbers in this problem. YOU NEED TO LET GO OF YOUR NUMBERS DEPENDENCY and be able to solve problems with variables only. This will help you answer questions with no numbers like this one, which will most certainly come up again on the AP Physics 1 exams!

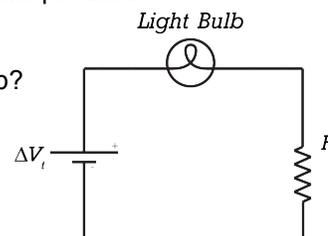
Flipping Physics Lecture Notes:

Free Response Question #2 - AP Physics 1 - 2015 Exam Solutions

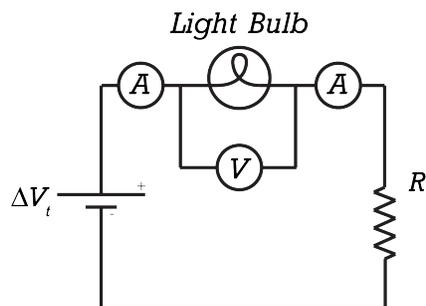
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- (1) In one second, do fewer electrons leave the bulb than enter the bulb?
- (2) Does the electric potential energy of electrons change while inside the bulb?

Note: You should already know the answers to these questions, however, the question isn't asking for the answer to these questions, but rather for you to show you know how to set up an experiment to determine the answers.



We need to start by drawing a circuit diagram of a lightbulb in series in a circuit with a power source. Then we need to add an ammeter in series with and before the lightbulb to measure the current going into the lightbulb, an ammeter in series with and after the lightbulb to measure the current leaving the lightbulb and a voltmeter in parallel with the lightbulb to measure the electric potential difference across the lightbulb.



Part (a): Place ammeters in series with the lightbulb both before and after the lightbulb. Use the ammeters to measure the current both before and after the lightbulb. Place a voltmeter in parallel with the lightbulb. Use the voltmeter to measure the electric potential difference across the lightbulb.

Part (b i): If the current in both ammeters is the same, then the number of electrons which flow into the lightbulb will be the same as the number of electrons which flow out of the lightbulb. If the two currents are not the same, then the number of electrons would not be the same.

Part (b ii): Electric potential difference equals the change in electric potential energy per unit charge. Therefore, if the electric potential difference across the lightbulb is nonzero, then the electric potential energy of the electrons will change while inside the bulb.

Part (c i): We actually don't need to adjust the setup, however, one of the ammeters is superfluous because we know the current is the same before and after the lightbulb.

Part (c ii): We need to adjust the electric potential difference across the power supply and take multiple measurements of the current through the battery and the electric potential difference across the battery.

Part (d): Because Ohm's Law is $\Delta V = IR \Rightarrow R = \frac{\Delta V}{I}$ & slope = $\frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x}$, we can create a graph

with the electric potential difference measurements across the lightbulb on the y-axis and the current measurements through the lightbulb on the x-axis. If the resistance of the lightbulb is ohmic, then we should be able to draw a best fit line which approximates all the data well. If the resistance of the lightbulb is nonohmic, then we should not be able to draw a best fit line which approximates all the data. The best fit line does not have to go perfectly through all of the measured data, it only needs to approximate the data. This is because of the uncertainties in the measured data.

Note: The answer to this problem is completely different than free response question #1. The answers to this free response question are essentially all short answer and you have to design an experiment. You can pretty much guarantee every AP Physics 1 exam will have a short answer free response question where you have to design an experiment. And again, this problem is completely devoid of numbers. So again, I ask you to Let Go of Your Numbers Dependency!!



Flipping Physics Lecture Notes:

Free Response Question #3 - AP Physics 1 - 2015 Exam Solutions

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(a i) & (a ii) At $x = -D$ the velocity of the block is zero; it starts at rest. Therefore, the Kinetic Energy at $x = -D$ is zero. The spring is compressed to its maximum magnitude; $x = -D$, therefore the Elastic Potential

Energy is at its maximum value, $PE_e = U = \frac{1}{2}kx^2 = \frac{1}{2}k(-D)^2 = \frac{1}{2}kD^2 = U_{\max}$. Because the Elastic

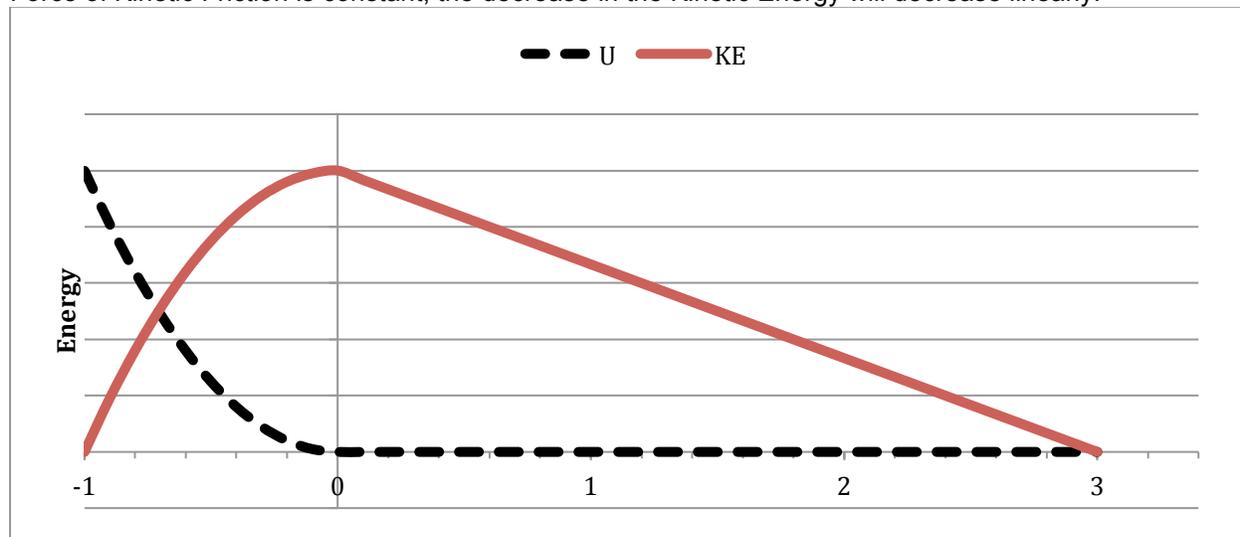
Potential Energy is proportional to x^2 , it will decrease as an x^2 function from $-D$ to 0 . There is no friction and no force applied, therefore the total mechanical energy is conserved. This means the Elastic Potential Energy will be completely converted to Kinetic Energy as the block goes from $x = -D$ to $x = 0$. Therefore Kinetic Energy will increase as an x^2 function.

At $x = 0$, the Elastic Potential Energy is zero: $PE_e = U = \frac{1}{2}kx^2 = \frac{1}{2}k(0)^2 = 0$, therefore the Kinetic Energy is now at its maximum value and has the same value as the Elastic Potential Energy at $x = -D$.

There is now friction as the block goes from $x = 0$ to $x = +3D$. The spring is no longer compressed, so

there is no Elastic Potential Energy. Because $W_{\text{friction}} = \Delta ME \Rightarrow F_{\text{kf}} d \cos \theta = ME_f - ME_i = 0 - \frac{1}{2}kD^2$,

(zero line at center of mass of block, initial point at $x = -D$ and final point at $x = 3D$) the force of kinetic friction will do work on the block to convert the Kinetic Energy completely to heat and sound. Because the Force of Kinetic Friction is constant, the decrease in the Kinetic Energy will decrease linearly.



(b i) The student is correct that, because the spring is compressed more than before, it will have more energy when it leaves the spring so it will slide farther.

(b ii) The student is incorrect that double the compression will result in double the distance. The elastic potential energy stored in the spring follows $\frac{1}{2}kx^2$, which is not a linear relationship for x .

Part (c): Use the work due to friction equation again: 1 denotes when $\Delta x = -D$ & 2 when $\Delta x = -2D$

$$F_{kf} d_1 \cos \theta = 0 - \frac{1}{2} k D^2 \Rightarrow F_{kf} d_1 \cos(180) = -\frac{1}{2} k D^2 \Rightarrow d_1 = \frac{k D^2}{2 F_{kf}}$$

$$F_{kf} d_2 \cos \theta = 0 - \frac{1}{2} k (-2D)^2 \Rightarrow F_{kf} d_2 \cos(180) = -\frac{1}{2} k (4D^2) \Rightarrow d_2 = 4 \frac{k D^2}{2 F_{kf}} = 4 d_1$$

Therefore the block will slide 4 times as far as before. $d_2 = 4 d_1 = 4(3D) = \boxed{12D}$

(d) The student is correct that the block will have more energy when compressed farther. $U_1 = \frac{1}{2} k D^2$ &

$U_2 = \frac{1}{2} k (4D^2) = 2kD^2$, therefore $U_2 > U_1$. The student is also correct that the block will slide farther

along the track before stopping because the Force of Kinetic Friction remains the same and the work done by friction to stop the block will be increased because the amount of initial potential energy is

increased. Therefore because $W_{friction} = F_{kf} d \cos \theta = 0 - ME_i$, the displacement, "d", must increase

because the initial mechanical energy increased. The student is incorrect that the stopping distance will be linearly increased because the energy is not linearly increased; the energy is increased as the square

of the distance because $PE_e = U = \frac{1}{2} k x^2$.



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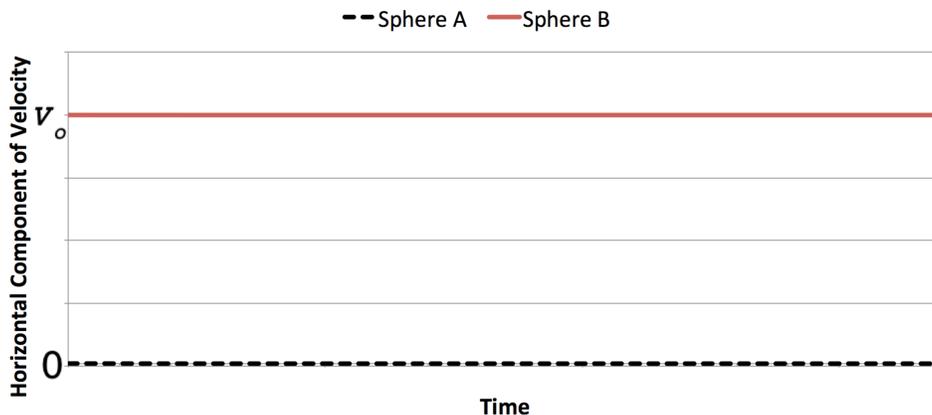
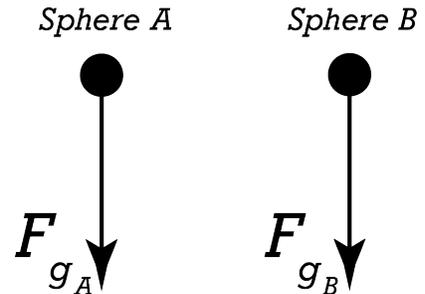
Free Response Question #4 - AP Physics 1 - 2015 Exam Solutions

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FYI: I have a video which shows and explains this demonstration:
<http://www.flippingphysics.com/bullet.html>

Part (a): Both identical spheres are in projectile motion. The only force acting on them is the force of gravity, which is straight down. Because both spheres have the same mass, the force of gravity is identical.

Part (b): Neither sphere has any forces acting on it in the x-direction, therefore neither sphere will have an acceleration in the x-direction, therefore neither sphere will have any change in its horizontal velocity. Sphere A has no initial horizontal velocity and will therefore continue with no horizontal velocity. Sphere B has an initial horizontal velocity of v_0 and will therefore continue to have a constant horizontal velocity of v_0 .



Part (c): As shown in Part (a), the only force acting on each sphere is the force of gravity. Therefore each sphere will have an acceleration in the y-direction which will equal $-g$. There is no force in the x-direction on either sphere, so, as shown in Part (b), both spheres will have zero acceleration in the x-direction. And any motion in the x-direction will not affect how long it takes the spheres to reach the ground. The initial velocity in the y-direction for both spheres is zero. The displacement in the y-direction for both spheres is $-H$. Therefore we can

use the uniformly accelerated motion equation $\Delta y = v_{iy} \Delta t + \frac{1}{2} a_y \Delta t^2$ to show that both spheres will reach the ground at the same time. We have shown that, other than the change in time, all of the variables in this equation are the same for both spheres, therefore the remaining variable, change in time, must be the same.

(the following is not a part of the solution necessary for the AP exam, however, I couldn't resist)

Knowns: $\Delta y = -H$; $a_y = -g$; $v_{iy} = 0$; $\Delta t = ?$ (all known values are the same)

$$\Delta y = v_{iy} \Delta t + \frac{1}{2} a_y \Delta t^2 \Rightarrow -H = 0(\Delta t) + \frac{1}{2}(-g)\Delta t^2 \Rightarrow H = \frac{g\Delta t^2}{2} \Rightarrow \Delta t = \sqrt{\frac{2H}{g}} \text{ (for both)}$$



Flipping Physics Lecture Notes:

Free Response Question #5 - AP Physics 1 - 2015 Exam Solutions

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Part (a): We know the velocity of a wave equals its frequency times its wavelength, $v = f\lambda$. Each of the four strings has the same length, L , and is vibrating at its fundamental frequency, therefore the wavelength for each string is the same. Each string is vibrating at a different frequency, therefore the velocity of the

wave on each string must be different. The velocity of a wave on a string is given as $v = \sqrt{\frac{F_T}{m/L}}$. Because

the mass, M , attached to the end of each string is the same, the force of tension, F_T , will also be the same.

Therefore, the mass per unit length, $\frac{m}{L}$, or linear mass density, for each string must be different.

Part (b): Frequency, f , is on the y-axis and $\frac{1}{m/L}$ is on the x-axis. Let's combine equations from part (a)

and solve for the relationship between the x and y-axis variables:

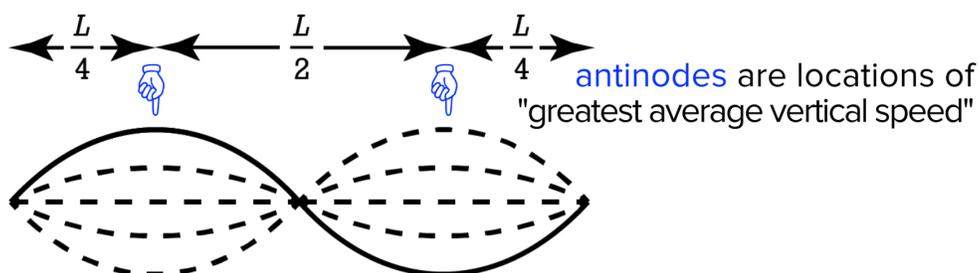
$$v = f\lambda = \sqrt{\frac{F_T}{m/L}} \Rightarrow f^2\lambda^2 = \frac{F_T}{m/L} \Rightarrow f^2 = \left(\frac{F_T}{\lambda^2}\right)\left(\frac{1}{m/L}\right)$$

In order to get a linear relationship, we would need to graph frequency squared, f^2 , as a function of

$\frac{1}{m/L}$. This is because $f^2 = \left(\frac{F_T}{\lambda^2}\right)\left(\frac{1}{m/L}\right)$ and the slope intercept form of a line is $y = mx + b$. The y-

intercept, b , would be zero and the slope, m , would be $\frac{F_T}{\lambda^2}$. So, *no* the graph would not be linear.

Part (c): Because antinodes are defined as the location on a standing wave with the greatest maximum amplitude and every point on the string takes the same amount of time to go through one full cycle, antinodes are the locations of "greatest average vertical speed". At its first harmonic or fundamental frequency, the string will have two nodes, one on either end, and one antinode in the middle, halfway between the two nodes. The second harmonic increases both of those numbers by one. So, we now have three nodes, one node on either end and one node in the middle. And two antinodes, each antinode located halfway between nodes. So the locations of "greatest average vertical speed" are at the antinodes, one fourth of L toward the middle from both ends.





Reflections on the 2015 AP Physics 1 Exam Free Response Questions

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With a few important exceptions, I am not going to repeat my suggestions from my video, "8 General Suggestions for the Free Response Questions of any AP Physics Exam".

<http://www.flippingphysics.com/8-general-suggestions.html>

1. Write legibly.
2. Graphs are answers.
 - a. Draw carefully.
 - b. Use a legend.
 - c. Use a straightedge for straight lines.
3. Beware lowercase variables vs. uppercase variables.
4. Free Body Diagrams are answers.
 - a. Draw carefully.
 - b. Lengths of arrows represent relative magnitudes.
 - c. Forces only.
 - d. Label forces.
 - e. Do not break into components on your initial diagram.
5. Be careful with your algebra.
 - a. Slow and steady.
6. Specific terms:
 - a. *Describe* means you need to show you understand the underlying physics principles in describing an event or situation.
 - b. *Explain* means you need to be able to provide evidence that clarifies what you just described.
 - c. *Justify* means an evidence based argument to support a previous answer. You will likely include equations and refer to graphs; however, you need to write in full sentences.
 - d. *Derive* means you need to *start with fundamental equations* and use algebra and/or geometry to arrive at a final answer. The final answer will most likely be an equation, however, it might be a number.
 - e. *Calculate* means you need to start with an equation, however, it doesn't need to be a fundamental equation, plug in numbers and use algebra and/or geometry to arrive at a final answer. The final answer is most likely a number, however, it might be an equation.
 - f. *"What is" and Determine* both mean no explanation necessary. They are just looking for an answer.
 - g. *Sketch* means to draw a graph with estimates the relationships.
 - i. Differences between straight lines and curves need to be clear.
 - h. *Plot* means to add specific data to a graph using a provided scale or a scale you need to create.
7. Weight and mass are not the same.
 - a. I have a video for this. <http://www.flippingphysics.com/weight-not-mass.html>
8. You will have to design an experiment.
9. There will be short answer.
 - a. You will have to write complete, legible sentences.
10. You will have to compare different situations.