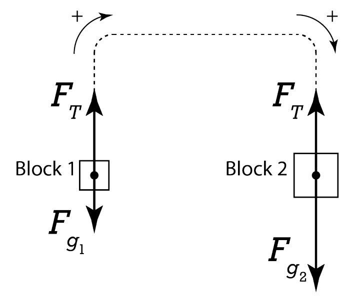
Flipping Physics Lecture Notes:

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

http://www.flippingphysics.com/ap1-2015-frq1.html

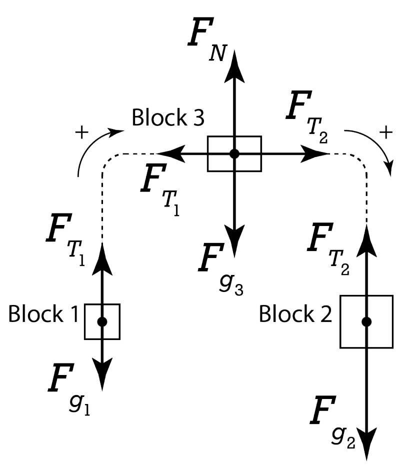
(a) First off, we know both blocks have a force of gravity acting downward on them. Let's label them F_{g_1} & F_{g_2}. We also know there is a force of tension upward on each block and, because there are no other objects attached to or pulling on the string between blocks 1 and 2, both forces of tension 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.

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



(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:

$$\sum F_+ = F_{g_2} - F_{T_2} + F_{T_2} - F_{T_1} + F_{T_1} - F_{g_1} = m_t a$$

$$\Rightarrow m_2 g - m_1 g = \left(m_1 + m_2 + m_3\right)a \Rightarrow a = \frac{m_2 g - m_1 g}{m_1 + m_2 + m_3}$$

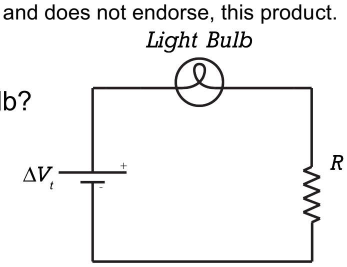
which is less than the original acceleration from part (b).

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

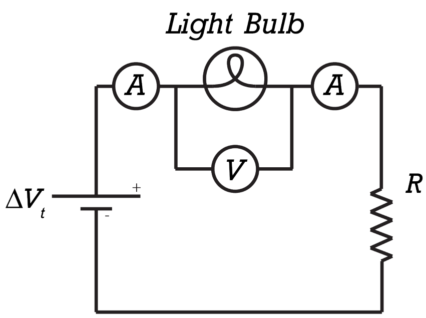
http://www.flippingphysics.com/ap1-2015-frq2.html



(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 $\Delta V = IR \Rightarrow R = \frac{\Delta V}{I}$ & $slope = \frac{rise}{run} = \frac{\Delta y}{\Delta x}$, 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!!

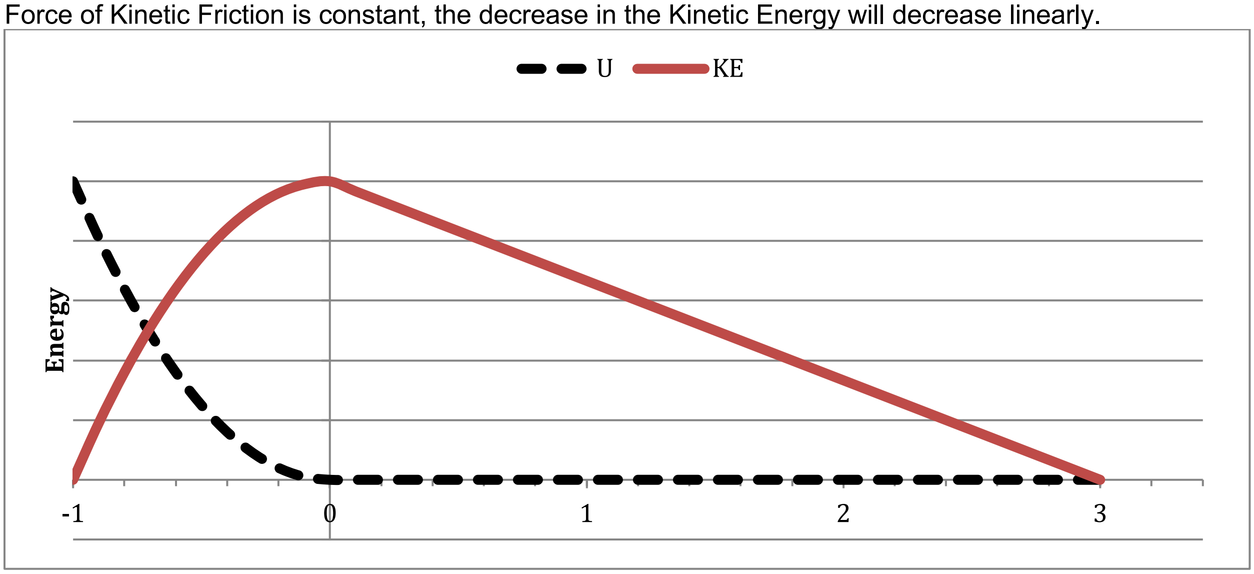
Flipping Physics Lecture Notes:

Free Response Question #3 - AP Physics 1 - 2015 Exam Solutions
http://www.flippingphysics.com/ap1-2015-frq3.html

(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, $PE_e = U = \frac{1}{2}kx^2 = \frac{1}{2}k\left(-D\right)^2 = \frac{1}{2}kD^2 = U_{max}$. 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 enery 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: $PE_e = U = \frac{1}{2}kx^2 = \frac{1}{2}k\left(0\right)^2 = 0$, therefore the Kinetic Energy is now at its maximum value and has the same value as the Elastic Potnetial 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 $W_{friction} = \Delta ME \Rightarrow F_{kf} d\cos\theta = ME_f - ME_i = 0 - \frac{1}{2}kD^2$, (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 Δx = -D & 2 when Δx = -2D

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

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

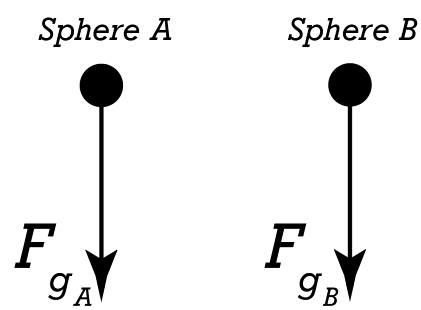
Therefore the block will slide 4 times as far as before. $d_2 = 4d_1 = 4(3D) = \boxed{12D}$

(d) The student is correct that the block will have more energy when compressed farther. $U_1 = \frac{1}{2}kD^2$ & $U_2 = \frac{1}{2}k(4D^2) = 2kD^2$, 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 $W_{friciton} = F_{kf}d\cos\theta = 0 - ME_i$, 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 $PE_e = U = \frac{1}{2}kx^2$.

Flipping Physics Lecture Notes:

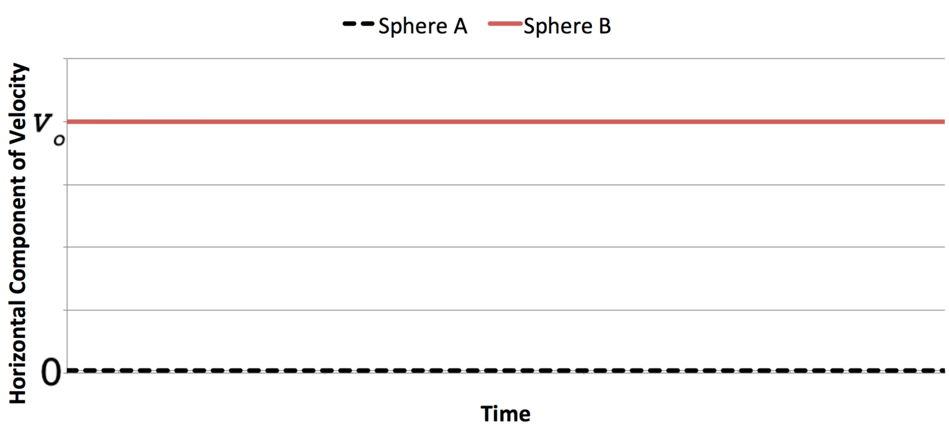
Free Response Question #4 - AP Physics 1 - 2015 Exam Solutions
http://www.flippingphysics.com/ap1-2015-frq4.html

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-direciton, therefore neither sphere will have any change in its horizontal velocity. Sphere A has no initial horiztonal velocity and will therefore continue with no horizontal velocity. Sphere B has an initial horizontal velocity of v_o and will therefore continue to have a constant horizontal velocity of v_o.



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 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
http://www.flippingphysics.com/ap1-2015-frq5.html

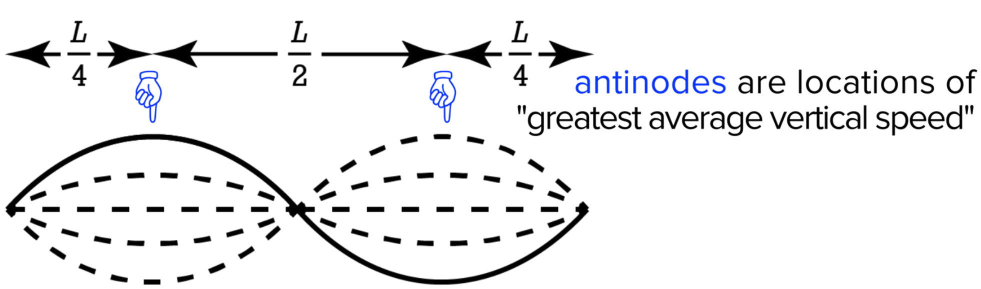
Part (a): We know the velocity of a wave equals its frequency times its wavelength, $v = f\lambda$. Each of the four strings has the same length, L, and is vibrating at its fundamental frequency, therefore the wavelength for each string is the same. Each string is vibrating at a difference frequency,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



Flipping Physics Lecture Notes:

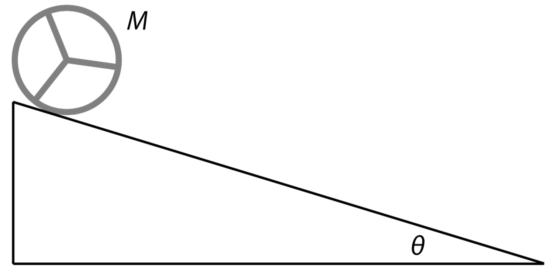
Reflections on the 2015 AP Physics 1 Exam Free Response Questions
http://www.flippingphysics.com/ap1-2015-reflections.html

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.

Flipping Physics Lecture Notes:

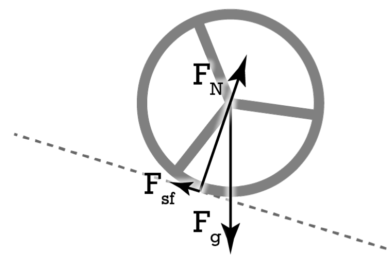
2016 #1 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2016-frq1.html



A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



- *Force of gravity, F_g, acts straight down from the center of mass of the wheel.*
- *Force Normal, F_N, acts perpendicular to the incline and up from the point of contact between the wheel and the incline.*
- *Force of Static Friction, F_{sf}, acts parallel to the incline and up from the point of contact between the wheel and the incline.*

Notes about grading:

- *This problem, problem #1, is worth 7 points. 2 of those points are just for getting this free body diagram correct. Yes, roughly 30% of the points from this problem come from this free body diagram. Hopefully this helps you to understand how important free body diagrams are.*
- *All forces need a clear indication of where they start and their direction. If you are terrible at drawing, you can always clarify force start locations and directions using words.*

ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass? Briefly explain your reasoning.

Change in angular velocity is caused by angular acceleration: $\vec{\alpha} = \frac{\Delta\vec{\omega}}{\Delta t}$

Angular acceleration is caused by net torque: $\sum\vec{\tau} = I\vec{\alpha}$

*The only force causing a torque on the wheel about its center of mass is the **force of static friction** because:* $\tau = rF\sin\theta$

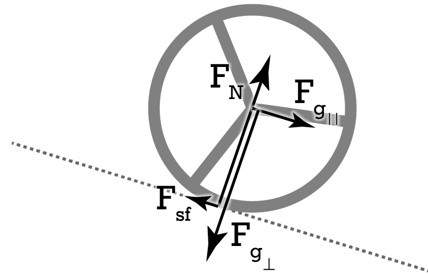
- *r for the force of gravity is zero.*
- *θ for the force normal is 180° and sin(180°) = 0.*

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

The "force component directed opposite to the force of friction" is the component of the force of gravity which acts parallel to and down the incline, $F_{g_{\parallel}}$.

Therefore, from the problem statement:

$$F_{sf} = 0.4F_{g_{\parallel}} = 0.4mg\sin\theta$$



And we can sum the forces in the parallel direction to solve for the acceleration of the center of mass of the wheel in the parallel direction. Defining down the incline as positive, we get:

$$\sum F_{\parallel} = F_{g_{\parallel}} - F_{sf} = ma_{\parallel} \Rightarrow mg\sin\theta - 0.4mg\sin\theta = ma_{\parallel}$$

$$\Rightarrow a_{\parallel} = g\sin\theta - 0.4g\sin\theta = 0.6g\sin\theta$$

Notes about grading:

- *Understand what this line means in the scoring guideline: "The expression need not be correct or consistent with the force diagram in part (a)."*
  - *This means you did not have to get part (a) correct to get points for part (b). So please, always answer every question, regardless of whether you think the rest of your solution is correct or not.*
- *Also, please make sure your answer is in terms of the variables provided.*

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel __X__ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

*The block has no force of friction acting on it, therefore, the net force in the parallel direction on the block has a larger magnitude and therefore has a larger acceleration down the incline. A larger acceleration on the block will result in a larger speed on the **block** at the bottom of the incline.*

ii. Briefly explain your answer again, now reasoning in terms of energy.

*Both the block and the wheel start with the same amount of mechanical energy and it is all gravitational potential energy. Gravitational potential energy is converted to kinetic energy as the objects go down the ramp. The block is not rotating; therefore, the block will not have any rotational kinetic energy as it slides down the incline, therefore the block will have more translational kinetic energy than the wheel and the **block** will have a larger speed at the base of the ramp.*

*Note about grading: Both (ci) and (cii) are worth one point and state "*No credit for answer without explanation*". In other words, anytime a question asks you to "*explain your answer*" you absolutely must do so! Not doing so will most likely get you zero points.*

Flipping Physics Lecture Notes:

2016 #2 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2016-frq2.html

A new kind of toy ball is advertised to "bounce perfectly elastically" off hard surfaces. A student suspects, however, that no collision can be perfectly elastic. The student hypothesizes that the collisions are very close to being perfectly elastic for low-speed collisions but that they deviate more and more from being perfectly elastic as the collision speed increases.

(a) Design an experiment to test the student's hypothesis about collisions of the ball with a hard surface. The student has equipment that would usually be found in a school physics laboratory.

i. What quantities would be measured?
ii. What equipment would be used for the measurements, and how would that equipment be used?
iii. Describe the procedure to be used to test the student's hypothesis. Give enough detail so that another student could replicate the experiment.

(b) Describe how you would represent the data in a graph or table. Explain how that representation would be used to determine whether the data are consistent with the student's hypothesis.

You should get all the way here in the problem before you begin answering any of these questions. Without knowing what will go on the x and y axes of a graph, you cannot answer the question "What quantities would be measured?". In other words, think all the way through your hypothetical lab before answering these questions. And now, on to my answers:

i. Drop the ball from various heights and measure the initial drop height, h_i, and the maximum rebound height which I will call height final, h_f.

ii. A video camera and a meter stick. Orient the meter stick vertically next to where the ball is dropped. Film the motion of the ball and use the video to measure h_i and h_f.

iii. Orient a meter stick vertically above a hard surface. Drop the toy ball 10 times from various heights such that the initial height is always measurable using the meter stick. Use the video camera to video the motion of the ball from initial drop to maximum height of the first bounce. Review the video to measure initial and final heights.

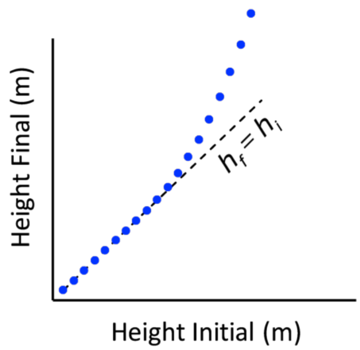
(b) On our graph plot height final as a function of height initial. If the collision is perfectly elastic, the speeds of the ball right before and after the collision will be the same. If those two speeds are the same, because mechanical energy is conserved, the initial and final heights will be the same. Therefore, if the collision is perfectly elastic, the data should show a linear relationship with a slope of 1 and a y-intercept of zero. This is because $h_f = h_i$ in an elastic collision. In order for our data to be consistent with the hypothesis, for small initial heights the data should have a best-fit line near a slope of 1, for large initial heights the data should be below the $h_f = h_i$ line.

Point about grading: One of the "sample student responses" includes measuring data which was unnecessary. For example, there is no need to measure the mass of the ball or the time the ball is in the air. The student did not gain full points because their response included extraneous measurements. So please, only include measurements you know need to be collected. This is an example where writing more simply to fill space is not helpful.

(c) A student carries out the experiment and analysis described in parts (a) and (b). The student immediately concludes that something went wrong in the experiment because the graph or table shows behavior that is elastic for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

i. Give an example of a graph or table that indicates nearly elastic behavior for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

ii. State one physics principle that appears to be violated in the graph or table given in part (c)i. Several physics principles might appear to be violated, but you only need to identify one. Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.



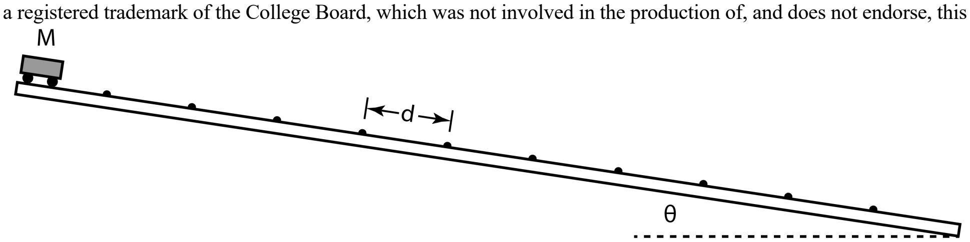
i. *The dotted line represents expected behavior if the collision is perfectly elastic. The blue dots represent data collected which appears to violate basic physics principles.*

ii. *Conservation of Energy appears to be violated because the height final appears to be greater than the height initial, therefore there appears to be more mechanical energy, in the form of gravitational potential energy, after the collision than before the collision. The final mechanical energy of the system cannot be greater than the initial mechanical energy.*

And one last comment about grading. Be aware that part (c)ii is only worth 1 point and, if you do not give any explanation to your answer, you get zero points. In other words, if you wrote only "Conservation of Energy is the physics principle which appears to be violated." You would garner zero points even though your answer is correct, however, you did not explain your answer. Always explain your answer when asked to on the exam.

2016 #3 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2016-frq3.html



Note: Figure not drawn to scale.

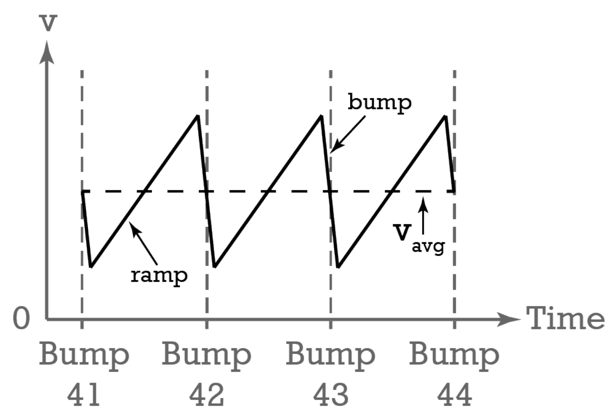
A long track, inclined at an angle θ to the horizontal, has small speed bumps on it. The bumps are evenly spaced a distance d apart, as shown in the figure above. The track is actually much longer than shown, with over 100 bumps. A cart of mass M is released from rest at the top of the track. A student notices that after reaching the 40th bump the cart's average speed between successive bumps no longer increases, reaching a maximum value v_{avg}. This means the time interval taken to move from one bump to the next bump becomes constant.

(a) Consider the cart's motion between bump 41 and bump 44.

i. In the figure below, sketch a graph of the cart's velocity v as a function of time from the moment it reaches bump 41 until the moment it reaches bump 44.

ii. Over the same time interval, draw a dashed horizontal line at v = v_{avg}. Label this line "v_{avg}".

We know the cart reaches a maximum speed value, v_{avg}, down the incline. In the absence of bumps, the cart would have a constant acceleration down the incline. Therefore, between bumps, the cart will have a constant positive acceleration down the incline, a_{ramp}. A constant positive acceleration on a velocity as a function of time graph is a straight line with a positive slope. When the cart is going over a bump, the cart must have a large acceleration up the incline, therefore, this acceleration will be negative, a_{bump}. We will assume this negative acceleration caused by each bump is constant. A large, constant negative acceleration on a velocity as a function of time graph is a straight line with a large negative slope. Therefore, as the cart goes over each bump, there will be straight line with a large negative slope and, as the cart goes between each bump, there will be a straight line with a positive slope of a smaller magnitude. Add a dotted, horizontal line in the middle of the velocity graph and label it velocity average.



Notes about grading:

- *1 point is earned for this graph for having a "minimum positive value that is the same for each bump".*
- *1 point is earned for having the "same maximum value in each cycle that occurs near the bump times".*
  - *In other words, the grader must be able to see, from your drawing, that the maximum values are equal and all the minimum values are equal. If you are not careful, you could lose points there. And if you are struggling with the drawing, you can always add a note indicating what you were trying to draw.*
- *1 point is earned for your v_{avg} line if it is "horizontal and consistent with the graph drawn, even if that graph is wrong". In other words, even if you got the other parts of the drawing completely wrong, you can still earn a point for drawing a v_{avg} line which is "horizontal and consistent with the graph drawn"!*
  - *I cannot stress this enough. Answer every question! Even if you think every other part of your answer is completely wrong.*

(b) Suppose the distance between the bumps is increased but everything else stays the same.

Is the maximum speed of the cart now greater than, less than, or the same as it was with the bumps closer together?

_X_ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

*The only thing which has changed is the distance between bumps which is the distance during which the cart accelerates. The magnitudes of both the a_{ramp} and a_{bump} are unchanged. Because there is a larger distance for the cart to accelerate between the bumps, the cart will be able to accelerate to a larger final velocity before each bump, therefore, the average maximum speed of the cart will now be **greater than** it was before.*

Grading note: "No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation." In other words, when they ask you to "briefly explain your reasoning", they mean it. This is why I do not give any points for a correct answer with an incorrect solution or no solution at all. Because, the solution shows you understand what you are doing. The answer is just, the answer.

(c) With the bumps returned to the original spacing, the track is tilted to a greater ramp angle θ. Is the maximum speed of the cart greater than, less than, or the same as it was when the ramp angle was smaller?

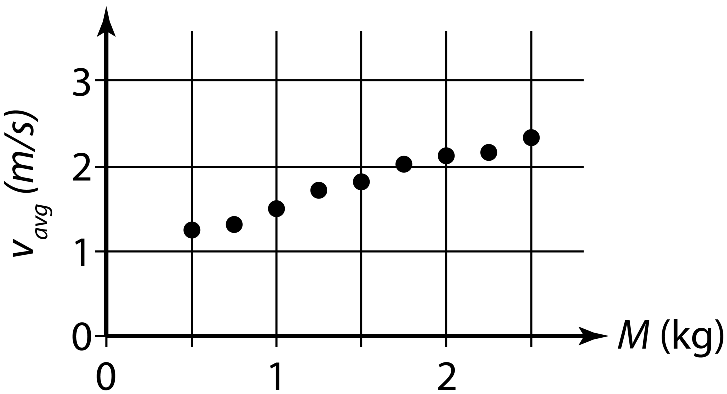
_X_ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

*Reset to the original ramp and change the ramp angle θ. This will change the magnitude of the component of the force of gravity which is parallel to and down the ramp. Because the angle is increased, the force of gravity parallel will be increased, which will increase the acceleration between the bumps, which will lead to a larger final velocity before each bump, therefore, the average maximum speed of the cart will now be **greater than** it was before.*

(d) Before deriving an equation for a quantity such as v_{avg}, it can be useful to come up with an equation that is intuitively expected to be true. That way, the derivation can be checked later to see if it makes sense physically. A student comes up with the following equation for the cart's maximum average speed: $v_{avg} = C\dfrac{Mg\sin\theta}{d}$ where C is a positive constant.

i. To test the equation, the student rolls a cart down the long track with speed bumps many times in front of a motion detector. The student varies the mass M of the cart with each trial but keeps everything else the same. The graph shown below is the student's plot of the data for v_{avg} as a function of M.



Are these data consistent with the student's equation?

____ Yes _X__ No

Briefly explain your reasoning.

The equation provided by the student predicts that, as the mass of the cart approaches zero, the average speed of the cart would approach zero, however, a best-fit line of the data has nonzero y-intercept.

Also, the equation provided by the student predicts that increasing the mass of the cart by a factor of two should increase the v_{avg} by a factor of two. The v_{avg} at 1 kg is roughly 1.5 m/s. The v_{avg} at 2 kg should then be roughly 3 m/s, however, it is only roughly 2.1 m/s.

ii. Another student suggests that whether or not the data above are consistent with the equation, the equation could be incorrect for other reasons. Does the equation make physical sense?

____ Yes _X__ No

Briefly explain your reasoning.

The equation provided by the student predicts that, as the distance between the bumps increases, the v_{avg} should decrease. We have already shown, in part (b), the reverse is true; as d increases, the average speed also increases. No, the equation does not make physical sense.

Grading note: "If 'yes' is selected, one point [out of two] can be earned for indicating that an increase in the angle increases v_{avg}." In other words, if you get the answer wrong, you can still earn a point for correctly arguing that v_{avg} increases with increasing ramp angle. Which reiterates my point that, even if you think you are wrong, answer every single question!! Because you can have the wrong answer and still earn points with a correct explanation.

Flipping Physics Lecture Notes:

2017 #2 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2017-frq2.html

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(a) Describe an experiment for determining the coefficient of static friction between the wood board and the wood block. Assume equipment usually found in a school physics laboratory is available.

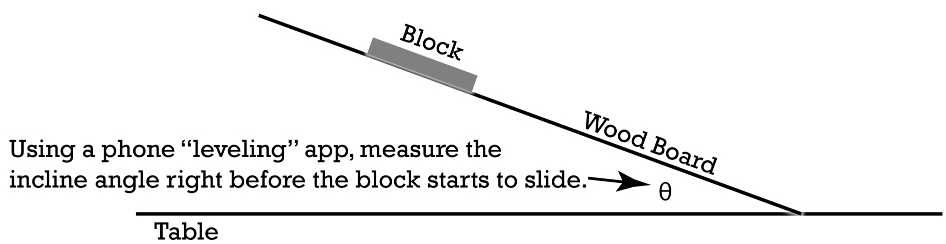
i. Draw a diagram of the experimental setup of the board and block. In your diagram, indicate each quantity that would be measured and draw or state what equipment would be used to measure each quantity.

ii. Describe the overall procedure to be used, including any steps necessary to reduce experimental uncertainty. Give enough detail so that another student could replicate the experiment.

(b) Derive an equation for the coefficient of static friction in terms of quantities measured in the procedure from part (a).

I have an entire video where I demonstrate this experiment and solve this problem. "Introductory Static Friction on an Incline Problem" https://www.flippingphysics.com/static-friction-incline.html I would suggest watching that for a more detailed solution to parts (a) and (b). I am going to do a shorter solution here.

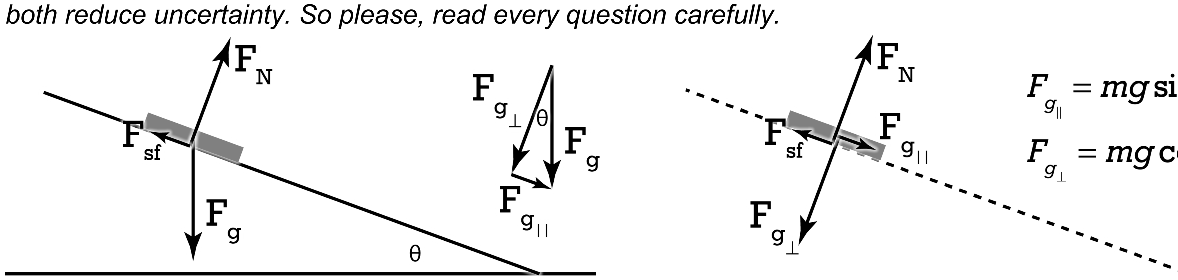
Part i:



Part ii:

- *Begin by calibrating the phone "leveling" app.*
- *Place the block on the wooden board and slowly raise one side of the board.*
- *Record the incline angle at the moment right before the board begins to slide.*
- *Repeat 10 times with the block at various locations on the board.*

*Grading note: According to the scoring guidelines, you gain one point out of three for part ii "*For including a valid method for reducing experimental error*". It might be easy to overlook the part of the question where it clearly states to include "*any steps necessary to reduce experimental uncertainty*". My statements to put the block "at various locations on the board" and to calculate the "Measures" app both reduce uncertainty. So please, read every question carefully.*



$$F_{g_{\parallel}} = mg\sin\theta$$

$$F_{g_{\perp}} = mg\cos\theta$$

Part (b): Draw the free body diagram of the forces acting on the block as the incline angle is being increased. Break the force of gravity into its components in the parallel and perpendicular directions. Then:

$$\sum F_{\perp} = F_N - F_{g_{\perp}} = ma_{\perp} = m(0) = 0 \Rightarrow F_N = F_{g_{\perp}} = mg\cos\theta$$

$$\sum F_{\parallel} = F_{g_{\parallel}} - F_{sf} = ma_{\parallel} = m(0) = 0 \Rightarrow F_{sf_{\max}} = F_{g_{\parallel}} \Rightarrow \mu_s F_N = mg\sin\theta$$

$$\Rightarrow \mu_s\left(mg\cos\theta\right) = mg\sin\theta \Rightarrow \mu_s\cos\theta = \sin\theta \Rightarrow \mu_s = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

Another grading note: "In order to earn full credit for part (b), all terms (variables) must be indicated in the diagram and/or procedure of part (a)." In other words, if θ does not appear in your diagram in part (a), you will not get full credit for part (b). *So again, read every question carefully. (No more please.) In fact, if you have the time, I suggest that, after you think you have completed each question, you should go back and read through the question one more time to make sure you answered every piece of every question.*

A physics class consisting of six lab groups wants to test the hypothesis that the coefficient of static friction between the board and the block equals the coefficient of kinetic friction between the board and the block. Each group determines the coefficients of kinetic and static friction between the board and the block. The groups' results are shown below, with the class averages indicated in the bottom row.

Lab Group Number	Coefficient of Kinetic Friction	Coefficient of Static Friction
1	0.45	0.54
2	0.46	0.52
3	0.42	0.56
4	0.43	0.55
5	0.74	0.23
6	0.44	0.54
Average	0.49	0.49

(c) Based on these data, what conclusion should the students make about the hypothesis that the coefficients of static and kinetic friction are equal?

____ The static and kinetic coefficients are equal.
__X__ The static and kinetic coefficients are not equal.
Briefly justify your reasoning.

When looking at the average values only, that seems to be true, however, lab Groups 1, 2, 3, 4, and 6 show a rather consistent relationship of $\mu_k < \mu_s$. However, Lab Group 5 shows $\mu_k >> \mu_s$, which gives an average such that $\mu_k = \mu_s$. However, it appears something went wrong during Lab Group 5's experiment; therefore, that data should either be thrown out or Lab Group 5 should repeat their experiment correcting sources of extreme error. Excluding Lab Group 5's data shows a rather consistent relationship of $\boldsymbol{\mu_k < \mu_s}$.

Another grading note: A correct answer with no reasoning or incorrect reasoning ears zero points for part (c). I've said it before, I say it again. When they ask you to justify your reasoning, you have to justify your reasoning!!

(d) A metal disk is glued to the top of the wood block. The mass of the block-disk system is twice the mass of the original block. Does the coefficient of static friction between the bottom of the block and the board increase, decrease, or remain the same when the disk is added to the block?

____ Increase ____ Decrease __X__ Remain the same   Briefly state your reasoning.

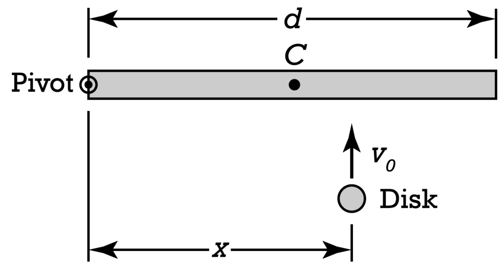
According to our answer to part (b), the coefficient of static friction equals the tangent of the incline angle right before the block starts to slide. Mass is not in that equation, so the mass of the block should have no effect on the measured coefficient of static friction. Therefore, $\boldsymbol{\mu_s}$ ***remains the same***.

*Another another another grading note: As long as the argument is valid, the The CollegeBoard accepted all three answers here. For example, "*The increased normal force will cause smoothing of the surfaces, decreasing the coefficient of friction.*" Or "*The increased normal force will cause the surfaces to become gouged, increasing the coefficient of friction.*" This, again, highlights the importance of explaining your answer carefully and thoroughly.*

Flipping Physics Lecture Notes:

2017 #3 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2017-frq3.html

The left end of a rod of length d and rotational inertia I is attached to a frictionless horizontal surface by a frictionless pivot, as shown. Point C marks the center (midpoint) of the rod. The rod is initially motionless but is free to rotate around the pivot. A student will slide a disk of mass m_{disk} toward the rod with velocity v_0 perpendicular to the rod, and the disk will stick to the rod a distance x from the pivot. The student wants the rod-disk system to end up with as much angular speed as possible.



Top View

(a) Suppose the rod is much more massive than the disk. To give the rod as much angular speed as possible, should the student make the disk hit the rod to the left of point C, at point C, or to the right of point C?

____ To the left of C ____ At C _X_ To the right of C

Briefly explain your reasoning without manipulating equations.

The angular momentum of the disk before the collision is linearly proportional to x. Therefore, a larger x value will mean a larger initial angular momentum of the system. Because angular momentum is conserved about the pivot during this collision, this will mean a larger final angular momentum of the system. Because angular momentum equals rotational inertia times angular velocity, a larger final angular momentum will mean a larger final angular speed. Therefore, a larger value of x will mean a larger final angular speed. The student should slide the disk to the right of C.

Or

A larger distance x from the axis of rotation will mean a larger net torque applied by the disk on the rod. A larger net torque will mean a larger angular acceleration of the rod during collision which will mean a larger final angular velocity of the rod after the collision. The student should slide the disk to the right of C.

(b) On the Internet, a student finds the following equation for the postcollision angular speed ω of the rod in this situation: $\omega = \frac{m_{disk} x v_0}{I}$. Regardless of whether this equation for angular speed is correct, does it agree with your qualitative reasoning in part (a)? In other words, does this equation for ω have the expected dependence as reasoned in part (a)?

_X_ Yes ____ No Briefly explain your reasoning without deriving an equation for ω.

My qualitative reasoning in part (a) states that a larger x results in a larger ω. The student's equation also shows that a larger x results in a larger ω. Therefore, Yes, the equation does have the expected dependence.

From the Scoring Guidelines: "If 'No' is selected, the explanation may still earn full credit if an incorrect selection was made in part (a)." *In other words, if you get part (a) wrong, you can still get full credit for part (b). Please, answer every part of every question.*

(c) Another student deriving an equation for the postcollision angular speed ω of the rod makes a mistake and comes up with $\omega = \frac{Ixv_0}{m_{disk}d^4}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

A larger m_{disk} will result in a larger initial angular momentum of the disk about the pivot which will result in a larger final angular momentum of the rod-disk system which will result in a larger final angular velocity of the rod. However, according to the student's equation, the mass of the disk would be inversely proportional to the final angular velocity of the rod, which is incorrect.

For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{disk}x^2$ and its angular momentum with respect to the pivot is $m_{disk}v_0x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0, and physical constants, as appropriate.

$$\vec{L}_i = \vec{L}_f \Rightarrow L_{ri} + L_{di} = L_{rf} + L_{df} \Rightarrow 0 + m_d v_o x = I_r \omega_{rf} + I_d \omega_{df} = I\omega_f + \left(m_d x^2\right)\omega_f = \left(I + m_d x^2\right)\omega_f$$

$$\omega_{rf} = \omega_{df} = \omega_f \ \& \ I_r = I \ \& \ I_d = m_d r_d^{\,2} = m_d x^2$$

$$\Rightarrow \omega_f = \frac{m_d v_o x}{I + m_d x^2}$$

*From the Scoring Guidelines: You gain one point "*For indicating that the initial angular momentum of the system is equal to $m_{disk}v_0x$.*" In other words, you can get one point for simply identifying that the initial angular momentum of the rod is zero and, therefore, the initial angular momentum of the system is the angular momentum of the disk only. Even if you did not know how to solve this problem, that is something you should be able to identify.*

(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

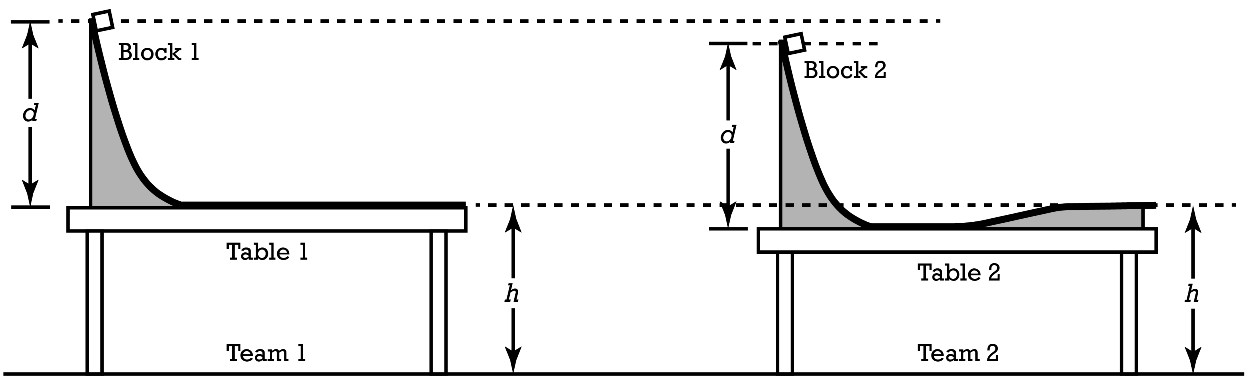
_X_ Greater than ____ Less than ____ Equal to Briefly explain your reasoning.

*Assuming the initial direction of the disk's motion is positive, when the disk bounces off the rod it will have a negative velocity and a negative angular momentum instead of a positive angular momentum when the disk sticks to the rod. Because angular momentum is conserved about the pivot during the collision, the final angular momentum of the rod will need to have a larger positive value in order to add up to the same initial angular momentum. Because the final angular momentum of the rod is larger, the final angular velocity of the rod is also **greater than** the original final angular velocity.*

Grading note: Part (e) is worth 2 points. 1 point is for describing what happens to the rod and 1 point is for describing what happens to the disk. There are two objects in this problem. You need to describe what happens to both. Keep that in mind for future problems.

Flipping Physics Lecture Notes:

2017 #4 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2017-frq4.html



A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However, team 2's table is lower than team 1's table. To compensate for the lower table, team 2 constructs the right end of the slide to rise above the tabletop so that the block leaves the slide horizontally at the same height h above the floor as does team 1's block (see figure above).

(a) Both blocks are released from rest at the top of their respective slides. Do block 1 and block 2 land the same distance from their respective tables?

___ Yes   _X_ No   Justify your answer.

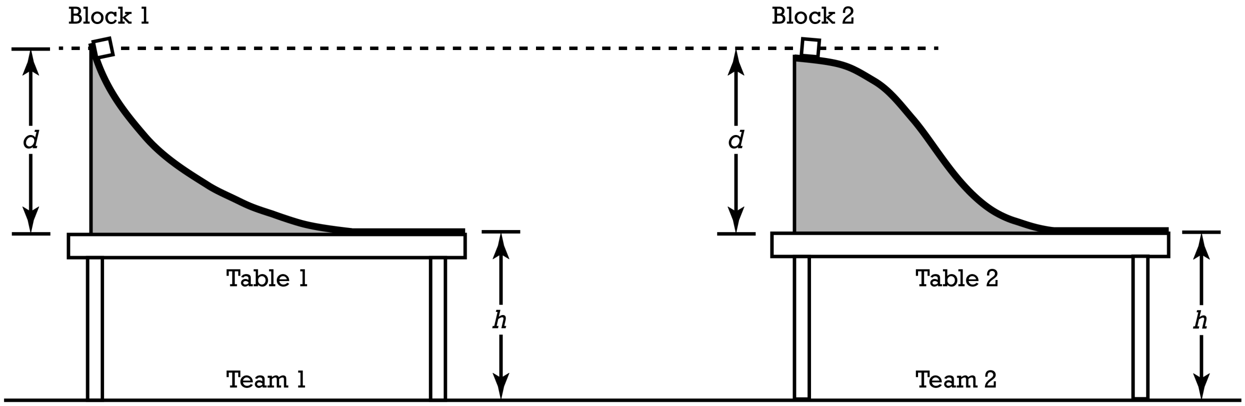
Because both slides are "low-friction", we may assume friction is negligible, therefore, there is no external work done on the system and mechanical energy is conserved. In both cases gravitational potential energy is converted to kinetic energy, however, Team 1's ramp has a larger change in gravitational potential energy because block 1 has a higher initial height above the end of the ramp. Therefore, block 1 has more kinetic energy when leaving the ramp and therefore a larger velocity in the x-direction. Because both blocks have an initial velocity off the table in the y-direction of zero, the same initial height, and the same free fall acceleration, both blocks will have the same amount of time between leaving the ramp and striking the ground. Considering they have the same time off the ramp and block 1 has a larger velocity in the x-direction, block 1 will land farther from the table than block 2. So "No", both blocks do not land the same distance from their respective tables.

Notes about grading: This problem is worth 3 points. 1 point is awarded for each of the following.

1) *"Attempting to use conservation of energy to compare the two blocks."*
    a. *Realize the word "attempt" is in there. So as long as you try to use conservation of energy, you gain 1 point.*
2) *"Explicitly or implicitly indicating that the launch velocities are different."*
    a. *Realize you do not even need to correctly identify which block has the larger launch velocity to get this point.*
3) *"Stating or implying that the time to reach the ground is the same for both blocks."*
    a. *I will be honest, when I initially did this problem, I did not mention this. So, be careful of the assumptions you are making.*

Considering "if the wrong answer is selected, partial credit can be earned for the justification" and you can get a lot wrong and still gain 2 points for this problem. Please answer every part of every problem.

In another experiment, teams 1 and 2 use tables and low-friction slides with the same height. However, the two slides have different shapes, as shown below.



(b) Both blocks are released from rest at the top of their respective slides at the same time.

i. Which block, if either, lands farther from its respective table?

____ Block 1 ____ Block 2 __X__ The two blocks land the same distance from their respective tables.
Briefly explain your reasoning without manipulating equations.

Again, mechanical energy is conserved for both blocks. Change in gravitational potential energy is the same for both blocks, so both blocks have the same kinetic energy at the base of the ramp, and therefore the same velocity in the x-direction off the table. Again, both blocks have the same velocity of zero in the y-direction off the table, the same initial height, and the same free fall acceleration, so both blocks have the same change in time in projectile motion. Because both blocks have the same velocity in the x-direction and the same change in time off the table, both blocks will have the ***same*** *displacement in the x-direction off the table.*

ii. Which block, if either, hits the floor first?

__X__ Block 1 ____ Block 2 ____ The two blocks hit the floor at the same time.
Briefly explain your reasoning without manipulating equations.

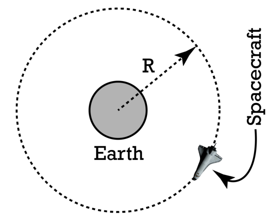
While the change in time off the table and the velocity in the x-direction may be the same for both blocks, block 1 has a steeper ramp which will result in a larger acceleration for block 1 and therefore block 1 takes less time to get to the same velocity in the x-direction at the end of the ramp. Therefore, ***block 1*** *will spend less time on the ramp and hit the floor first.*

Note about grading: It is easy to fall into the trap of rushing quickly through this problem and saying to yourself, "I remember seeing the video from Flipping Physics about this and in that video both objects hit the ground at the same time. So, that must be the answer." I mean, this is a classic physics example. However, it is typical on AP exams to see problems that expand on "typical" problems you have already seen. In other words, read carefully and apply your knowledge. Do not simply assume the problem is the same as one you have seen before.

2018 #1 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2018-frq1.html

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

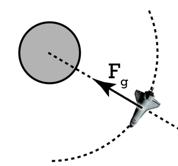


Note: Figure not drawn to scale.

(a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.

Draw the free body diagram with 1 force, the force of gravity, coming from the center of the spacecraft and pointed towards the center of the Earth.

A comment about grading. 2 out of 7 points for this problem are for this free body diagram (or force diagram) which has only one force in it. Free Body Diagrams are important!! Draw them carefully and clearly, and only include forces.



Note: Figure not drawn to scale.

(b) i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$$\sum F_{in} = F_g = ma_c \Rightarrow \frac{Gm_s m_E}{r^2} = m_s\left(\frac{v_t^{\,2}}{r}\right) \Rightarrow \frac{Gm_s m_E}{R^2} = \frac{m_s v_t^{\,2}}{R} \Rightarrow \frac{Gm_E}{R} = v_t^{\,2}$$

$$v_t = \frac{\Delta x}{\Delta t} = \frac{C}{T} = \frac{2\pi R}{T}$$

$$\Rightarrow \frac{Gm_E}{R} = \left(\frac{2\pi R}{T}\right)^2 = \frac{4\pi^2 R^2}{T^2} \Rightarrow T = \sqrt{\frac{4\pi^2 R^3}{Gm_E}}$$

More comments about grading. Do not add anything to the free body diagram answer from part (a). I know it is tempting. Do not do it! Also, make sure your answer is only in terms of the variables indicated. For example, it cannot be in terms of the speed of the spacecraft because that is not a given variable.

Alternate Solution:

$$\sum F_{in} = F_g = ma_c \Rightarrow \frac{Gm_s m_E}{r^2} = m_s r\omega^2 \;\&\; \omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T}$$

$$\Rightarrow \frac{Gm_E}{R^2} = R\left(\frac{2\pi}{T}\right)^2 \Rightarrow \frac{Gm_E}{R^3} = \frac{4\pi^2}{T^2} \Rightarrow T = \sqrt{\frac{4\pi^2 R^3}{Gm_E}}$$

(b) ii A second spacecraft of mass 2m is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than ____ Less than __X__ Equal to Briefly explain your reasoning.

The mass of the spacecraft cancelled out of our equation for the orbital period of the spacecraft derived in part (b) i, so the mass of the spacecraft does not affect period.

More, more comments about grading. As long as your explanation is consistent with your answer, you can get the full point for part (b) ii, even if you got part (b) i incorrect. Please answer every part of every question.

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure. Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than   _X__ Less than   ____ Equal to   Briefly explain your reasoning.

Going back to the middle of our solution to part (b) i: $\frac{Gm_E}{R} = v_t^2$

We have a relationship between orbital speed and orbital radius which shows that as orbital radius increases, orbital speed must decrease. So, the spacecraft's new orbital speed is less than the original speed.