Flipping Physics Lecture Notes:

Quantitative/Qualitative Translation (QQT) and Paragraph Argument Short Answer (PASA) for AP Physics Explained!

http://www.flippingphysics.com/qqt-pasa.html

Links to my solutions to the Free Response Questions from publicly released, past AP Physics 1 exams and the category for each of those Free Response Questions:
https://www.flippingphysics.com/ap-physics-1-review.html

From page 216 of the 2019 AP Physics 1 Course and Exam Description (CED)[1]:
"on the actual AP Exam, there will be one experimental design question, one quantitative/qualitative translation question, one paragraph argument short answer question, and two additional short answer questions."

In summary, every AP Physics 1 exam, except the 2020 exam, will have five questions:
1) Quantitative/Qualitative Translation or QQT (12 points)[2]
2) Paragraph Argument Short Answer or PASA (7 points)
3) Experimental Design Question or EDQ (12 points)
4) Two additional Short Answer questions or SA (7 points each)

Due to the coronavirus pandemic, the 2020 exam will only have one QQT and one PASA.

Quantitative: relating to, measuring, or measured by the quantity of something rather than its quality.
Qualitative: relating to, measuring, or measured by the quality of something rather than its quantity.

Therefore, reasoning something quantitatively will involve algebraic manipulation of variables, however, reasoning something qualitatively will involve writing out words in paragraph form.

With regards to Quantitative/Qualitative Translation, from page 46 of the 2019 CED:
"The AP Physics 1 Exam requires students to be able to re-express key elements of natural phenomena across multiple representations in the domain. This skill appears in the Qualitative/Quantitative Translation (QQT), a long free-response question that requires students to go between words and mathematics in describing and analyzing a situation. A QQT question might ask students to work with multiple representations or to evaluate another student's words or representations. Representations include mathematical equations, narrative descriptions, graphs, diagrams, and data tables.

Students who have primarily been exposed to numerical problem solving often struggle with a QQT question because it requires students to have a more conceptual understanding of both content and representations. Opportunities to translate between different representations, including equations, diagrams, graphs, and written descriptions, will help students prepare for the QQT question."

In other words, you will need to be able to go back and forth between quantitative (equations) and qualitative (words). A QQT example from the Free Response Question #3 from the 2017 AP Physics 1 exam:

In part (a), you are asked to determine where a disk should strike a rod to maximize the final angular velocity of the rod. You are asked to "Briefly explain your reasoning without manipulating equations." This is a *qualitative explanation*. This explanation requires that you write out words to explain the physics behind your reasoning.

[1] https://apstudents.collegeboard.org/ap/pdf/ap-physics-1-course-and-exam-description.pdf
[2] Point values are from page 206 of the 2019 AP Physics 1 Course and Exam Description.

In parts (b) & (c), you are given equations which *might* describe the angular speed of the rod after the collision. You are then asked to take these quantitative student answers (equations) and translate them to qualitatively reason if the equations make logical sense. Again, you are asked to “Briefly explain your reasoning without deriving an equation”.

In part (d) the described event changes slightly and you are asked to do your own quantitative analysis and derive an equation for the final angular of the rod.

In part (e) the described event is changed even further, and you are asked to qualitatively determine how the final angular velocity of the rod changes.

Hopefully you can see how this problem requires that you translate back and forth between the quantitative and the qualitative. Now, quantitative does not have to include equations. You could be given data collected by students and presented in a data table or a graph. You also could be given student qualitative arguments about physics phenomena and be expected to qualitatively explain what is correct or incorrect about the student’s qualitative argument. In other words, you have to be ready to look at data and arguments and be able to respond both quantitatively and qualitatively about the physics.

Now let’s look at Paragraph Argument Short Answer.

From page 61 of the 2019 CED:
“Students will be asked to give a paragraph-length response to demonstrate their ability to communicate their understanding of a physical situation in a reasoned, expository analysis. For full credit, the response should be a coherent, organized, and sequential description of the analysis of a situation that draws from evidence, cites physical principles, and clearly presents the student’s thinking. Full credit may not be earned if the response contains any of the following: principles not presented in a logical order, lengthy digressions within an argument, or a lack of linking prose between equations or diagrams.”

Expository: “intended to explain or describe something”

In other words, a Paragraph Argument Short Answer is not an equation derivation, it is a paragraph of sentences where you explain the physics. You are certainly going to use equations because equations are what the physics principles are based on, however, you need to not just write out equations. Instead you need to write a paragraph and use those equations to argue that your reasoning is correct. Be careful to present your argument in a logical order and, while you may include a few equations or diagrams, you need to make sure your answer is mostly words creating sentences which creates a paragraph.

A PASA example from Free Response Question #5 from the 2015 AP Physics 1 exam:

In part (a) the motion of two identical spheres is described. One is in projectile motion and one is in free fall only. After a full description of the motion, you are asked to draw free body diagrams of the force(s) acting on the spheres. No explanation is asked for.

In part (b) you are asked to draw a graph of the horizontal components of the velocities of each sphere as a function of time. Still no explanation is asked for.

Notice that this Paragraph Argument Short Answer question has yet to ask for any explanation. Please do not waste time writing out explanations when you are not asked to.

Part (c) begins with “In a clear, coherent, paragraph-length response …”

Hopefully you recognize that this is where the Paragraph Argument Short Answer goes. In every AP Physics 1 exam so far, there has been a free response question with this statement in it. So please, answer with mostly words in paragraph form.

The full question in part (c) is “In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).”

My answer to the question is “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.

Notice I did refer to my answers in parts (a) and (b), and, while I did refer to variables and an equation, I did not derive anything. Instead, I used words, to form sentences, to form a coherent paragraph argument which answers the question.

If you recall, I have been stressing that you need to let go of your numbers dependency. Hopefully you can see that because you will have to do Quantitative Qualitative Translation and Paragraph Argument Short Answer, you really do need to stop plugging in numbers so much and instead look at the equations and understand what they physically mean. When you are able to do that, you will be able to answer these questions more easily.

Flipping Physics Lecture Notes:

Experimental Design Questions for AP Physics Explained!
http://www.flippingphysics.com/experimental-design.html

Links to my solutions to the Free Response Questions from publicly released, past AP Physics 1 exams and the category for each of those Free Response Questions.[1]

Please see my previous video, "QQT and PASA for AP Physics Explained", for a discussion of the AP Physics 1 exam and all the different categories of questions.[2]

"When presented with an experimental design question, students often do not know where to start."[3]

I think it is good to begin by acknowledging that students often struggle with the experimental design question. It requires designing a hypothetical experiment and that can be intimidating. Please, heed my advice in this video and practice with as many free response questions as you can. Did I mention I have solutions for those?

"This question type assesses student ability to design and describe a scientific investigation, analyze authentic laboratory data, and identify patterns or explain phenomena."[4]

Again, you are going to design an experiment. Often you will be asked to look at raw data, determine how to rearrange that data in order to prove properties of physics, and be able to recognize relationships within the data.

"Students must be able to justify their selection of the kind of data needed to answer the question and then design a plan to collect that data."[5]

Sometimes you are not provided with data, but rather you are asked what data would need to be collected to prove physics phenomena. And then you are asked to design an experiment that will allow for collection of that data.

"Students should be prepared to offer evidence, construct reasoned arguments for their claim from the evidence, and use the claim or explanation to make predictions."[6]

You will also be asked to defend your choices using logical reasoning. When you do so, please use my suggestions about Paragraph Argument Short Answer. Let's now talk about specifics of AP Physics Experimental Design Questions (EDQs). Let's start with 2016 AP Physics 1 Free Response Question #2 part (a):

(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.**

- Notice the question asks you to "design an experiment". Clearly every one of the EDQs will ask you to "design an experiment".
  - When deciding on your lab setup and experimental design, simpler is often better.

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[1] https://www.flippingphysics.com/ap-physics-1-review.html
[2] http://www.flippingphysics.com/qqt-pasa.html
[3] From page 33 of the 2020 AP Physics 1 Course and Exam Description (CED).
https://apstudents.collegeboard.org/ap/pdf/ap-physics-1-course-and-exam-description.pdf
[4] Page 206 of the 2020 CED.
[5] Page 33 of the 2020 CED.
[6] Page 198 of the 2020 CED

- I would recommend reading all the way through part (b) of this question before beginning to answer any questions. This is typical of EDQs. When designing the experiment, you need to understand all the requirements of the experiment.
  - Think all the way through the experiment and do not rush to answer each question before answering the next question. You need to think about answering the questions in total, not individually.
    - For example, deciding how to represent the data in a graph affects what experiment you are going to perform and what data to collect.
  - When you “describe your procedure”, do not include extraneous steps like “collect all lab equipment” or “sharpen my pencil” or “meditate to clear your mind in preparation for accurate data collection”.
  - You will likely be asked to draw an experimental setup and to ***label*** the items. Please make sure you actually label the items. The AP graders should not have to guess what objects it is you have drawn.
  - You may be given a list of possible lab equipment and asked to choose which pieces to use. 2012 #2 APC: Mechanics

- Chances are very good you will be required to create a graph (see above). When you do:
  - Label both axes (include units).
  - Plot data carefully.
  - Pick axes scales such that you use more than half the graph.
  - When drawing the best fit line, a good approximation is to have half the data points above and half the data points below the best fit line.
  - Creating a graph, plotting data, adding a best fit line, and then comparing the slope to an accepted value is an effective way to “construct reasoned arguments for (your) claim from the evidence, and use the claim or explanation to make predictions.”
  - You may be asked to estimate a graph based on changes to the data. Graphs ***will*** come up on the AP Physics exams.

- Likely you will be asked what your data will look like if the experiment appears to violate a law of physics. Or the converse, what could have gone wrong in the experiment if there are errors in the given data.
  - Part (c) of 2016 AP Physics 1 FRQ #2.
  - Also 2017 #2, data table, they want you to recognize that something went wrong with data collection in Lab Group #5.

- Could be asked how the data will change if a part of the experiment is changed. For example, doubling the mass of an object.

- Please read carefully!
  - For example, “include steps necessary to reduce experimental uncertainty” or “In your diagram, indicate each quantity that would be measured”.
    - To reduce experimental uncertainty, not only do you need to perform multiple trials, you also need to make adjustments to the data you are collecting.
      - This has come up a few times.
    - Do not include extraneous measurements.
  - They may ask for “a symbol for each measurement”. AP C: Mechanics 2012 #2.
  - Be careful of the statement “in terms of the quantities measured”. AP C: Mechanics 2012 #2 part (c).
  - Always explain or justify your answer when asked to on the exam.
- If you have time, when you are done, go back and read the question carefully to make sure you have included everything they ask for.

How do we start designing an experiment?

- Start by looking at all the possible equations.
- Experiments are about relationships between variables.
- Find equations which relate the applicable variables.
- Determine which variables need to be identified and measured.
- Determine which lab equipment is necessary to measure those variables.
- Equations help visualize graphs and slopes of best-fit lines of data.

Study for exam:

- Identify physical object which represent equations.
- Look over labs/problems and identify objects which go with equations.

Best of luck on the AP Physics exams y'all!

My video: "Graphing Rotational Inertia of an Irregular Shape" is a good example of an EDQ.[7]

[7] https://www.flippingphysics.com/graphing-rotational-inertia.html

Flipping Physics Lecture Notes:

Short Answer for AP Physics Explained
http://www.flippingphysics.com/short-answer.html

I already have videos for Qualitative/Quantitative Translation, Paragraph Argument Short Answer, and Experimental Design Questions.[1] This is about the generic "Short Answer" type of question for AP Physics exams. According to the AP Physics 1 Course and Exam Description, 2 out of the 5 free response questions on the exam will be this generic "Short Answer" question. And, even though 40% of the free response questions will be "Short Answer", the Course and Exam Description only has the following to say about "Short Answer" questions:

"The two short answer questions focus on practices and learning objectives not focused on in the other question types."[2]

So, yeah. "Short Answer" questions cover everything not covered in the Qualitative/Quantitative Translation, Paragraph Argument Short Answer, and Experimental Design Questions.

In order to figure out what "Short Answer" questions are, let's look at the 10 "Short Answer" questions which are in the publicly released AP Physics 1 exams from 2015 to 2019. But, when you go through those 10 "Short Answer" questions, you will discover that a full 5 of them are about topics which, in December of 2020, were removed from the AP Physics 1 curriculum. That's right, 50% of the publicly released AP Physics 1 "Short Answer" questions are about physics topics which are no longer a part of the AP Physics 1 curriculum. So, we have 5 "Short Answer" free response questions to analyze to understand what "Short Answer" questions are. There is one from each year. While I do understand that I have detailed solution videos for each of these free response questions, I think it will be useful to look at all 5 of them in a general sense to find out what "Short Answer" questions are.

The five free response questions we are going to analyze are 2015 #1, 2016 #1, 2017 #4, 2018 #1, and 2019 #1. Each short answer question is worth 7 points. That means there are a total of 35 points represented by these free response questions.

3 out of the 5 free response questions, 2015 #1, 2016 #1, and 2018 #1, each have a free body diagram which is worth 2 points. That means, 6 out of 35 points, or roughly 17% of all the points on these 5 free response questions come from simply drawing free body diagrams correctly. And one of these free body diagrams, 2018 #1, only had 1 force in it, even though it was worth 2 points. Please take your free body diagrams seriously.

Once you have drawn a free body diagram, often you will need to use Newton's Second Law to sum the forces, manipulate equations, and solve for a variable. A total of 8 points from the same 3 free response questions require you to do that. That's roughly 23% of all the points.

But the largest category of points is where they present you with a situation, ask you to answer a multiple-choice question, and then justify or explain your answer. 15 out of 35 points, or roughly 43% of all the points fit in this category. Every one of the 5 free response questions has at least 2 out of 7 points for a multiple-choice question and answer justification. In fact, all 7 points of 2017 #4 fit in this category. Several have a 1 point question which fits in this category, which means what really matters for these is where you justify or explain your answer, not the multiple-choice answer itself. Many of these questions present you with a change to the situation presented at first, and then ask you the multiple-choice question, and ask you to justify your answer.

[1] https://www.flippingphysics.com/ap-physics-1-review.html
[2] From page 206 of the 2020 AP Physics 1 Course and Exam Description (CED).
https://apstudents.collegeboard.org/ap/pdf/ap-physics-1-course-and-exam-description.pdf

The last category is the 5 points from part (a) of 2019 #1. Here they present you with a situation of 2 objects which collide and ask you to graph the speed of the center of mass of the system as a function of time. Your entire answer, worth 5 points, is simply drawing lines on the 5 parts of the graph. No explanation necessary. 5 out of 35 points, or roughly 14% of all the points are drawing a graph with no explanation necessary. So realize, the College Board may throw something completely different at you and you need to be prepared for that.

Also, notice the complete lack of numbers in all 5 of these free response questions. Everything is free body diagrams, setting up equations, variable manipulation, graphs, and understanding and explaining how variables will be affected by changes to the physical situations presented. As I have said so many times before, you need to let go of your numbers dependency.

Free Response Question #1 from 2015.
Part (a) – 2 points – Free Body Diagram
Part (b) – 3 Points – 2 Newton's Second Law, manipulate equations to solve for variables.
Part (c) - 2 points – Situation changes. How does a variable change? Multiple-choice. Explain.

Free Response Question #1 from 2016.
Part (a i) – 2 Points – Free Body Diagram
Part (a ii) – 1 point – Pick a force (multiple-choice). Explain why something happens.

- This is the one point I did not categorize in the video.
    - Perhaps it belongs with "Multiple Choice → Explain/Justify", however, if you read it carefully, it is a *bit* different than the others.

Part (b) – 2 points – Newton's Second Law, manipulate equations, solve for variable.
Part (c i) – 1 point - Situation changes. How does a variable change? Multiple-choice. Explain.
Part (c ii) – 1 point – Explain using different physics.

Free Response Question #4 from 2017.
Part (a) – 3 points – Given 2 situations. Yes/No. Explain.
Part (b i) – 2 points – Same situations. Different multiple-choice question. Explain.
Part (b ii) – 2 points – Same situations. Different multiple-choice question. Explain.

Free Response Question #1 from 2018.
Part (a) – 2 points – Free Body Diagram (Only 1 force.)
Part (b i) – 3 points – Newton's 2econed Law, manipulate equations, solve for variable.
Part (b ii) – 1 point - Situation changes. How does a variable change? Multiple-choice. Explain.
Part (c) – 1 point - Situation changes. How does a variable change? Multiple-choice. Explain.

Free Response Question #1 from 2019.
Part (a) – 5 points – Draw lines on a graph. No explanation necessary.
Part (b) – 2 points – Situation changes. How does a variable change? Multiple-choice. Explain.

Flipping Physics Lecture Notes:
8 General Suggestions
for the
Free Response Questions
of any
AP Physics Exam

1) Pre-Read All Free Response Questions
2) Write Legibly
3) Organize Your Solutions and Label All Parts
4) SHOW ALL YOUR WORK!!
5) Do Not Break Forces in Free Body Diagrams into Components
    a. Redraw the Free Body Diagram and break into components there.
6) Answer Every Part of Every Problem
7) Dimension Your Answers
8) Leave Algebra Heavy Solutions for Later
9) Read Carefully!

I made this video called, "8 General Suggestions for the Free Response Questions of any AP Physics Exam." And then I proceeded to make video solutions to the 3 Free Response Questions of the 1998 AP Physics C Mechanics Exam and I learned a valuable lesson. I should have given 9 suggestions. I should have added a 9th suggestion: "Read Carefully."

I find it quite funny that I didn't read carefully enough because (1) for years it is something I berated my students about and (2) it is something I did not do on the third free response question. You see, I didn't answer part (a) completely. I missed the small word "magnitude". I simply drew the forces in the Free Body Diagrams, however, I didn't explicitly solve for the Magnitudes of the Forces. All the magnitudes of the forces are in my solutions because I had to find each one to solve the rest of the problem; however, I didn't quite answer part (a) correctly.

I don't know how the AP graders would grade my solution because all the physics is there, just not in the right places; however, I do feel they would not have given my solution full credit. So, please learn from my mistake and read the questions carefully. Don't have to eat humble pie, like me.

Flipping Physics Lecture Notes:

2012 #2 Free Response Question
AP Physics C: Mechanics - Exam Solution
http://www.flippingphysics.com/apcm-2012-frq2.html

This Experimental Design Question also works as a part of the AP Physics 1 curriculum.
(It does not have any calculus in it, eh!)

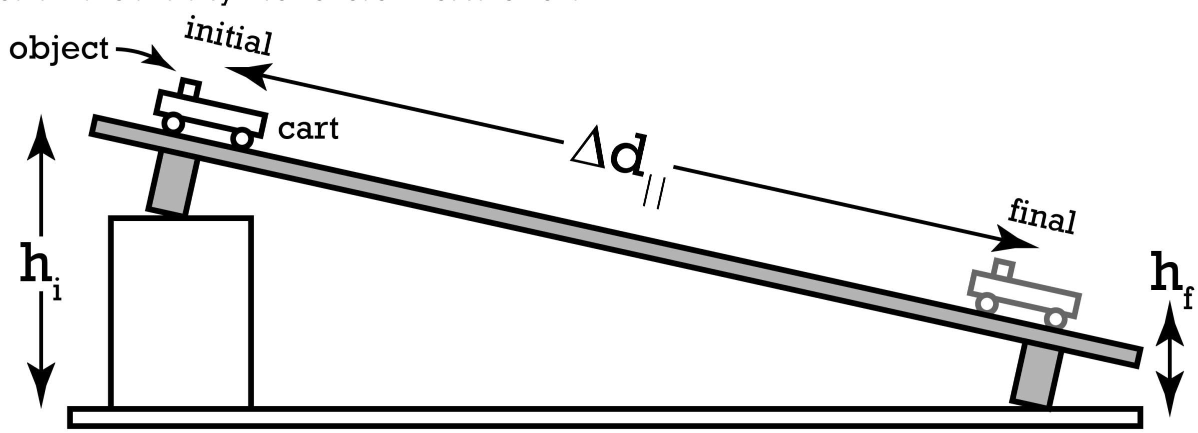
There are many correct solutions to this question. I will provide two complete, independent solutions, because, you know, why not?

You are to perform an experiment investigating the conservation of mechanical energy involving a transformation from initial gravitational potential energy to translational kinetic energy.

(a) You are given the equipment listed below, all the supports required to hold the equipment, and a lab table. On the list below, indicate each piece of equipment you would use by checking the line next to each item.

_X_ Track	_X_ Meterstick	_X_ Set of objects of different masses
_X_ Cart	_X_ Electronic balance	____ Lightweight low-friction pulley
____ String	_X_ Stopwatch	

(b) Outline a procedure for performing the experiment. Include a diagram of your experimental setup. Label the equipment in your diagram. Also include a description of the measurements you would make and a symbol for each measurement.



- *Use the electronic balance to measure the mass of the cart, m_c and the mass of the objects, m_o .*
- *Incline the track at an angle.*
- *Place the cart near the top of the track and measure the initial height of the cart above the table, h_i .*
- *Identify a location near the end of the rack as the final point for the cart. Measure the final height of the cart above the table, h_f .*
- *Measure the distance the cart will travel on the track, $\Delta d_{\parallel}$.*
- *Let go of the cart without giving it an initial velocity. Therefore, the cart has no initial velocity, $v_i = 0$.*
- *Measure the time, Δt, it takes the cart to travel the distance $\Delta d_{\parallel}$.*
- *Repeat 9 times with different known mass combinations placed in the cart.*
- *The total mass of the cart and objects in the cart is m_t .*

(c) Give a detailed account of the calculations of gravitational potential energy and translational kinetic energy both before and after the transformation, in terms of the quantities measured in part (b).

- *The horizontal zero line is at the top of the table.*
- *Gravitational Potential Energy initial:* $PE_{gi} = m_t g h_i$
- *Gravitational Potential Energy final:* $PE_{gi} = m_t g h_i$
- *Kinetic Energy initial:* $KE_i = \frac{1}{2} m_t v_i^2 = \frac{1}{2} m_t (0)^2 = 0$
- *To determine Kinetic Energy final, we need the final velocity of the cart. Use the Uniformly Acceleration Motion equation* $\Delta d_{\parallel} = \frac{1}{2}(v_i + v_f)\Delta t = \frac{1}{2}(0 + v_f)\Delta t \Rightarrow v_f = \frac{2\Delta d_{\parallel}}{\Delta t}$
- *Kinetic Energy final:* $KE_f = \frac{1}{2} m_t v_f^2 = \frac{1}{2} m_t \left(\frac{2\Delta d_{\parallel}}{\Delta t}\right)^2 = \frac{2 m_t \Delta d_{\parallel}^2}{\Delta t^2}$

(d) After your first trial, your calculations show that the energy increased during the experiment. Assuming you made no mathematical errors, give a reasonable explanation for this result.

It is difficult to let go of anything without accidentally pushing it. Perhaps you gave it an initial velocity. This would increase the initial kinetic energy above the zero assumed in our calculations.

(e) On all other trials, your calculations show that the energy decreased during the experiment. Assuming you made no mathematical errors, give a reasonable physical explanation for the fact that the average energy you determined decreased. Include references to conservative and nonconservative forces, as appropriate.

Nonconservative forces such as friction likely converted some of the mechanical energy to heat and sound, and therefore decreased the kinetic energy measured at the bottom of the track.

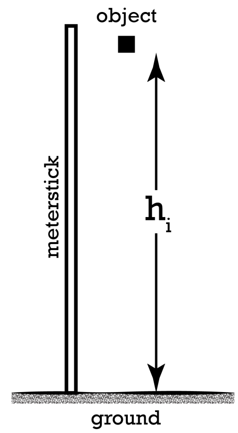
And now a completely different solution:

You are to perform an experiment investigating the conservation of mechanical energy involving a transformation from initial gravitational potential energy to translational kinetic energy.

(a) You are given the equipment listed below, all the supports required to hold the equipment, and a lab table. On the list below, indicate each piece of equipment you would use by checking the line next to each item.

____ Track	_X_ Meterstick	_X_ Set of objects of different masses
____ Cart	_X_ Electronic balance	____ Lightweight low-friction pulley
____ String	_X_ Stopwatch	

(b) Outline a procedure for performing the experiment. Include a diagram of your experimental setup. Label the equipment in your diagram. Also include a description of the measurements you would make and a symbol for each measurement.



- *Use the electronic balance to measure the mass of the objects,* m_o *.*
- *Hold one object at a height above the ground and measure that height,* h_i *.*
- *Drop the object such that it has zero initial velocity,* $v_i = 0$*.*
- *Measure the time it takes for the object to fall to the ground,* Δt*.*
- *Repeat 9 more times with different objects at different heights.*

(c) Give a detailed account of the calculations of gravitational potential energy and translational kinetic energy both before and after the transformation, in terms of the quantities measured in part (b).

- *The horizontal zero line is at the ground.*
- *Gravitational Potential Energy initial:* $PE_{gi} = m_o g h_i$
- *Gravitational Potential Energy final:* $PE_{gf} = m_o g h_f = m_o g(0) = 0$
- *Kinetic Energy initial:* $KE_i = \frac{1}{2} m_o v_i^2 = \frac{1}{2} m_o (0)^2 = 0$
- *To determine Kinetic Energy final, we need the final velocity of the object. We know the object is in free fall on planet earth and therefore has an acceleration in the y-direction of -g. Use the Uniformly Acceleration Motion equation* $v_f = v_i + a_y \Delta t = 0 + (-g)\Delta t = -g\Delta t$
- *Kinetic Energy final:* $KE_f = \frac{1}{2} m_o v_f^2 = \frac{1}{2} m_o (-g\Delta t)^2 = \frac{1}{2} m_o g^2 \Delta t^2$

(d) After your first trial, your calculations show that the energy increased during the experiment. Assuming you made no mathematical errors, give a reasonable explanation for this result.

It is difficult to drop anything without accidentally giving it an initial velocity. Perhaps you pushed the object down a bit, this would increase the final velocity and therefore the final kinetic energy of our calculations.

(e) On all other trials, your calculations show that the energy decreased during the experiment. Assuming you made no mathematical errors, give a reasonable physical explanation for the fact that the average energy you determined decreased. Include references to conservative and nonconservative forces, as appropriate.

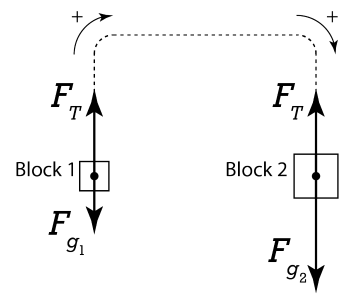
Nonconservative forces such as air friction likely converted some of the mechanical energy to heat and sound, and therefore decreased the kinetic energy measured right before the object hit the ground.

Flipping Physics Lecture Notes:

Free Response Question #1 - AP Physics 1 - 2015 Exam Solutions
http://www.flippingphysics.com/ap1-2015-frq1.html

This Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.

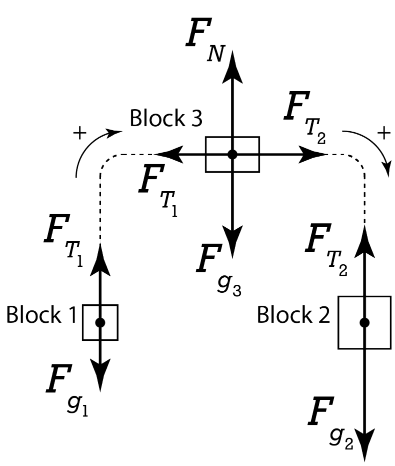
(a) First off, we know both blocks have a force of gravity acting downward on them. Let's label them F_{g_1} & F_{g_2}. We also know there is a force of tension upward on each block and, because there are no other objects attached to or pulling on the string between blocks 1 and 2, both forces of tension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

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

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

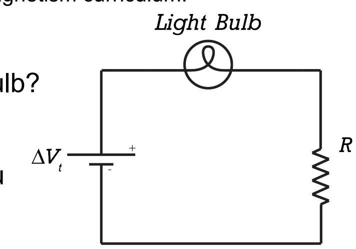
which is less than the original acceleration from part (b).

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

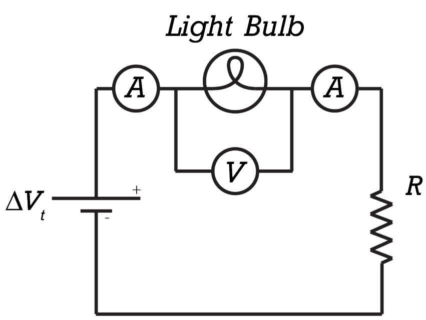
This Experimental Design question also works as a part of the AP Physics C: Electricity and Magnetism curriculum.



(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:

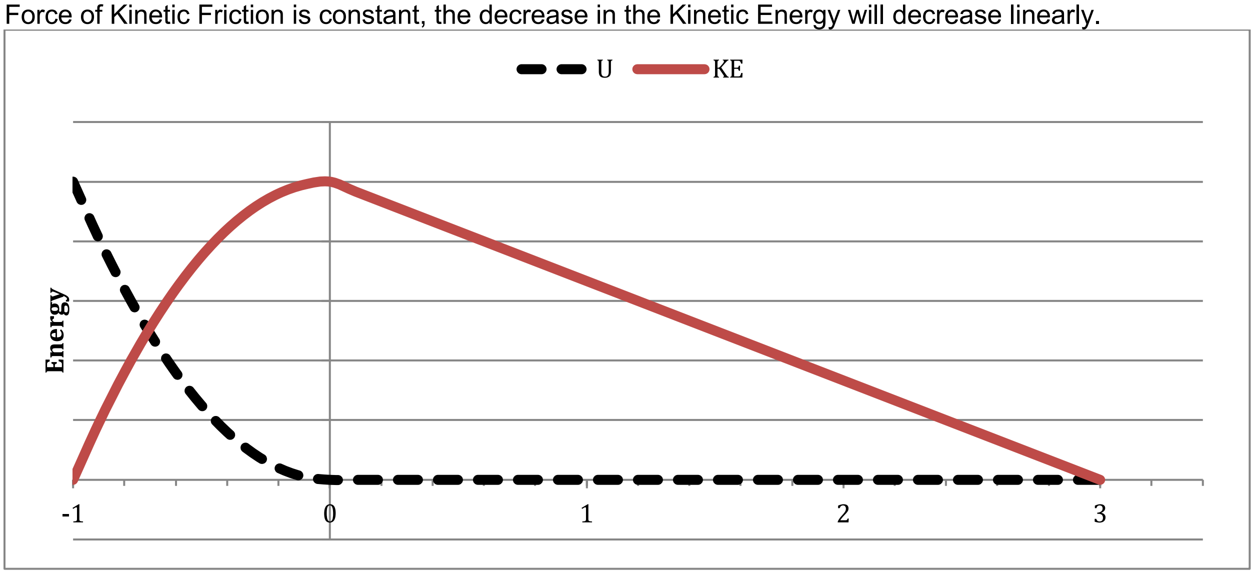
Free Response Question #3 - AP Physics 1 - 2015 Exam Solutions
http://www.flippingphysics.com/ap1-2015-frq3.html

This Quantitative/Qualitative Translation question also works as a part of the AP Physics C: Mechanics curriculum.

(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 $PE_e = U = \frac{1}{2}kx^2$.

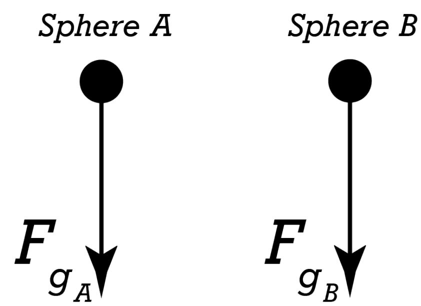
Flipping Physics Lecture Notes:

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

http://www.flippingphysics.com/ap1-2015-frq4.html

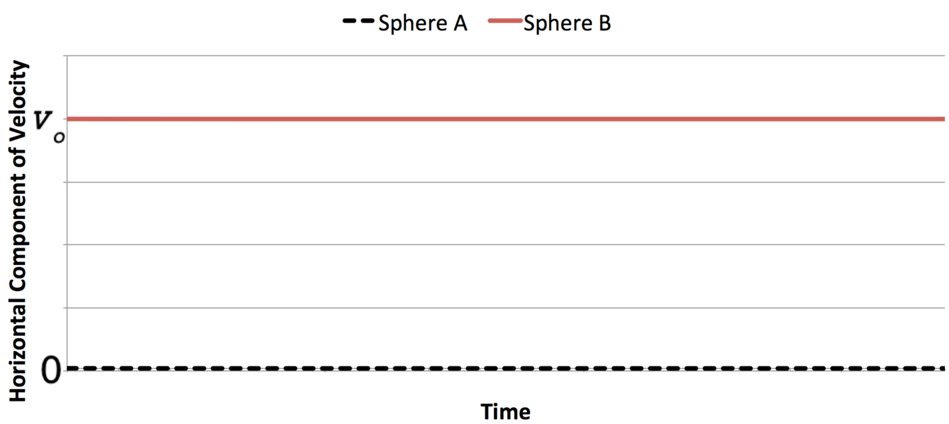
This Paragraph Argument Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.

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)

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

Flipping Physics Lecture Notes:

Free Response Question #5 - AP Physics 1 - 2015 Exam Solutions
http://www.flippingphysics.com/ap1-2015-frq5.html

This is a Short Answer question but is not included in either AP Physics C curricula.

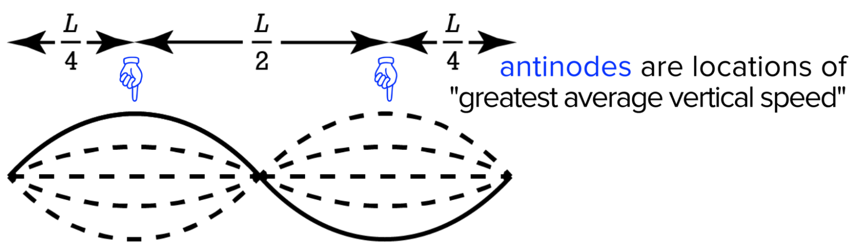
Part (a): We know the velocity of a wave equals its frequency times its wavelength, $v = f\lambda$. Each of the four strings has the same length, L, and is vibrating at its fundamental frequency, therefore the wavelength for each string is the same. Each string is vibrating at a difference frequency,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

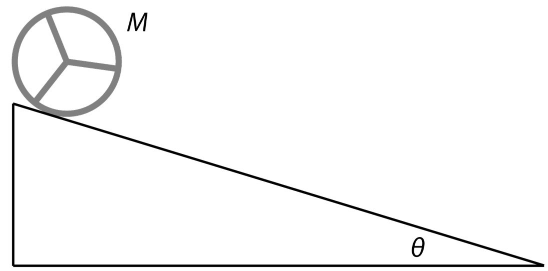
1. Write legibly.
2. Graphs are answers.
    a. Draw carefully.
    b. Use a legend.
    c. Use a straightedge for straight lines.
3. Beware lowercase variables vs. uppercase variables.
4. Free Body Diagrams are answers.
    a. Draw carefully.
    b. Lengths of arrows represent relative magnitudes.
    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

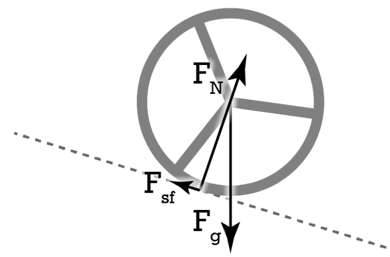
This Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.



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:* $\tau = rF\sin\theta$

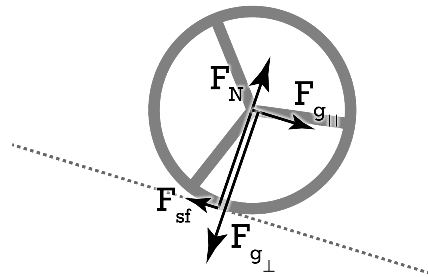
- *r for the force of gravity is zero.*
- *θ for the force normal is 180° and sin(180°) = 0.*

(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

This Experimental Design question also works as a part of the AP Physics C: Mechanics curriculum.

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:

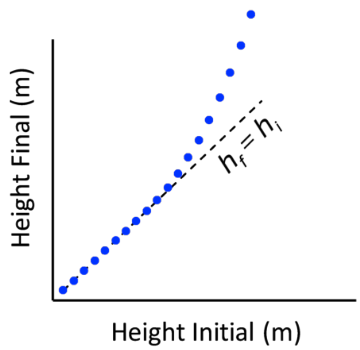
i. Drop the ball from various heights and measure the initial drop height, h_i, and the maximum rebound height which I will call height final, h_f.
ii. A video camera and a meter stick. Orient the meter stick vertically next to where the ball is dropped. Film the motion of the ball and use the video 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.

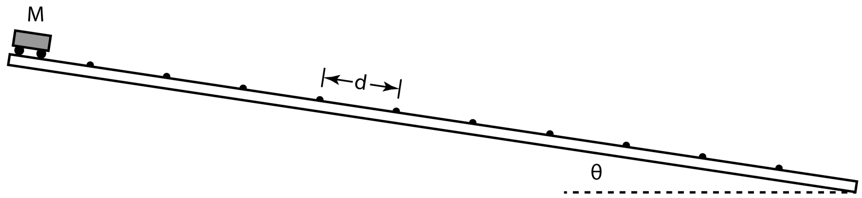
ii. Conservation of Energy appears to be violated because the height final appears to be greater than the height initial, therefore there appears to be more mechanical energy, in the form of gravitational potential energy, after the collision than before the collision. The final mechanical energy of 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.

Flipping Physics Lecture Notes:

2016 #3 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2016-frq3.html

This Quantitative/Qualitative Translation question also works as a part of the AP Physics C: Mechanics curriculum.

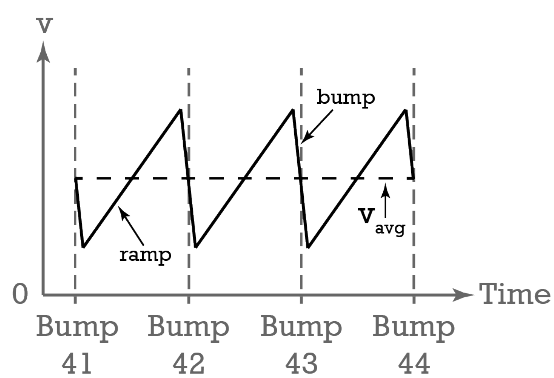


Note: Figure not drawn to scale.

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?

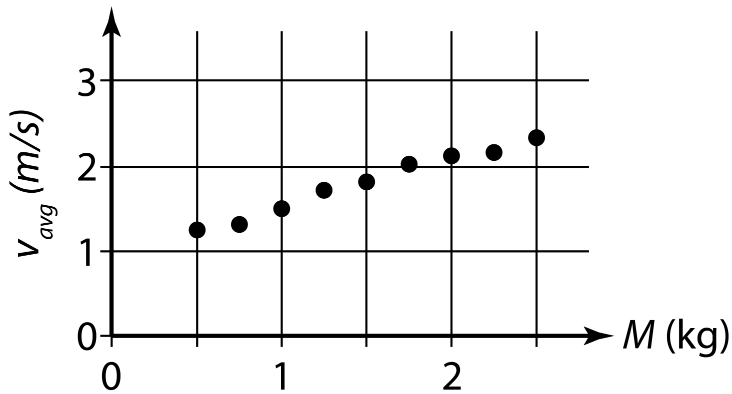
_X_ Greater than ____ Less than ____ The same as

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.

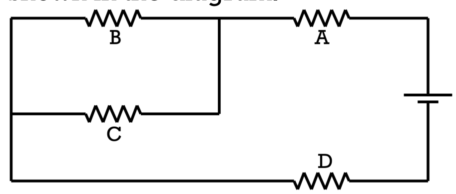
Flipping Physics Lecture Notes:

2016 #4 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2016-frq4.html

This Short Answer question also works as a part of the AP Physics C: Electricity and Magnetism Curriculum.

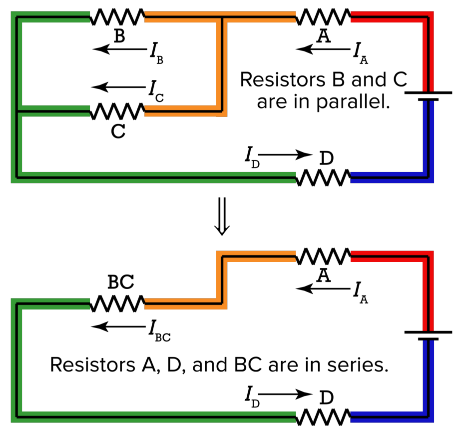
A circuit contains a battery and four identical resistors arranged as shown in the diagram.



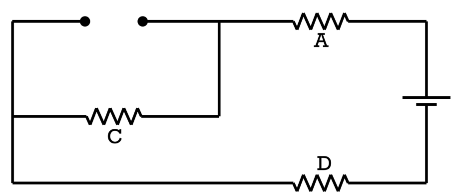
(a) Rank the magnitude of the potential difference across each resistor from greatest to least. If any resistors have potential differences with the same magnitude, state that explicitly. Briefly explain your reasoning.

Ranking: $\Delta V_A = \Delta V_D > \Delta V_B = \Delta V_C$

Brief explanation: *Because they are all in series, the currents through resistor A, resistor D, and equivalent resistor BC are all the same. Because electric potential difference equals current times resistance and the resistances of A and D are equal and the currents through A and D are equal, the electric potential differences across A and D are equal. Resistors B and C are in parallel, so they have equal electric potential differences and the current is split between those two resistors, therefore the currents through B and C are less than the current through A and D, therefore the electric potential differences across B and C are less than the electric potential differences across A and B.*



Resistor B is now removed from the circuit, and there is no connection between the wires that were attached to it. The new circuit diagram is shown.



(b) When resistor B is removed, does the current through resistor A increase, decrease, or remain the same?

____ Increase   _X_ Decrease   ____ Remain the same

Briefly explain your reasoning.

Because the equivalent resistance BC of the two resistors in parallel is less than the resistance of just resistor C, removing resistor B from the circuit increases the equivalent resistance of the circuit. Increasing the resistance of the circuit decreases the current delivered by the battery. The current delivered by the battery is the same as the current through resistor A, therefore the current through resistor A decreases.

(c) When resistor B is removed, does the current through resistor C increase, decrease, or remain the same?

_X_ Increase ____ Decrease ____ Remain the same Briefly explain your reasoning.

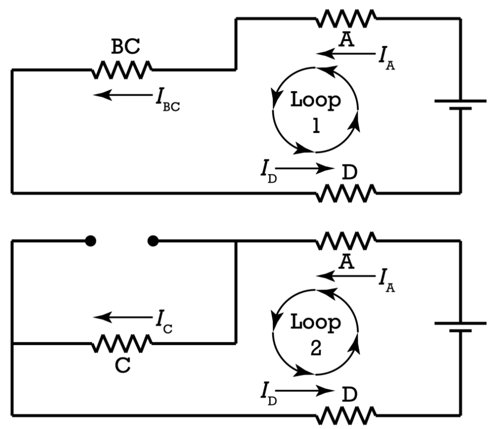
Because resistor B was removed, resistor C now receives all the current delivered by the battery, however, we have already shown in part (b) that the current delivered by the battery decreases. Use Kirchhoff's Loop Rule. Loop 1 is before B is removed from the circuit and with equivalent resistor BC.

$$\Delta V_{Loop\,1} = 0 = \Delta V_t - \Delta V_{A1} - \Delta V_{BC} - \Delta V_{D1} \Rightarrow \Delta V_{BC} = \Delta V_t - \Delta V_{A1} - \Delta V_{D1} = \Delta V_{C1}$$

Loop 2 is after resistor B is removed from the circuit.

$$\Delta V_{Loop\,2} = 0 = \Delta V_t - \Delta V_{A2} - \Delta V_{C2} - \Delta V_{D2} \Rightarrow \Delta V_{C2} = \Delta V_t - \Delta V_{A2} - \Delta V_{D2}$$

From part (b) we know the current through A and D has decreased, therefore the electric potential differences across A and D have also decreased, therefore, we can see from our two Kirchhoff's Loop Rule equations that the electric potential difference across C has increased. Because electric potential difference equals current times resistance and the resistance of C has not changed, the current through C must have increased.



Grading Note: Part (a) is worth 3 points. Parts (b) and (c) are each worth 2 points and each have this sentence in the scoring guidelines: "If the wrong answer is selected, up to one point can still be earned." In other words, you can put a mark next to the incorrect answer and still get points if your explanation has correct reasoning in it.

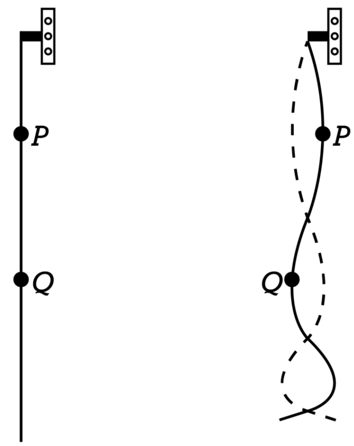
Flipping Physics Lecture Notes:

2016 #5 Free Response Question - AP Physics 1 - Exam Solution

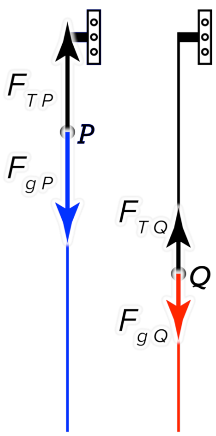
http://www.flippingphysics.com/ap1-2016-frq5.html

This is a Paragraph Argument Short Answer question.

The figure shows a uniformly thick rope hanging vertically from an oscillator that is turned off. When the oscillator is turned on and set to a certain frequency, the rope forms the standing wave as shown. P and Q are two points on the rope.



(a) The tension at point P is greater than the tension at point Q. Briefly explain why.



Every bit of rope below each point pulls downward on that point with a force of gravity equal to the total mass below the point times the acceleration due to gravity. A force of tension acts upward on each point. Because the rope is not accelerating, the force of tension and force of gravity are equal in magnitude at each point on the rope. Because P has more mass below it than Q, P has a larger force of gravity, and therefore a larger force of tension.

(b) A student hypothesizes that increasing the tension in a rope increases the speed at which waves travel along the rope. In a clear, coherent paragraph-length response that may also contain figures and/or equations, explain why the standing wave shown above supports the student's hypothesis.

As we move up the rope, the distance between nodes increases, therefore the wavelength increases. The frequency of the oscillation of the rope is constant throughout the rope. Therefore, because wave speed equals wavelength times wave frequency, the wave speed must increase as we move up the rope. From part (a) we also know that the force of tension increases as we move up the rope. Therefore, an increase in force of tension in a rope increases the speed at which waves travel along the rope.

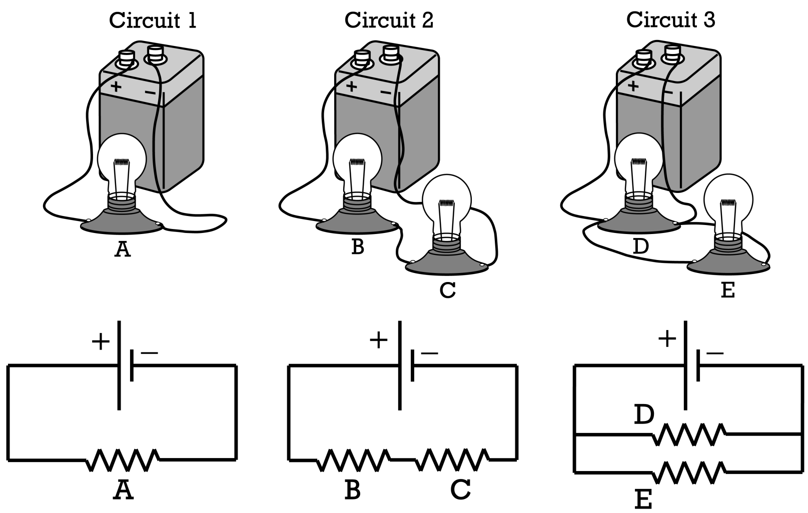
From the Scoring Guidelines, you gain 1 point out of 7 for this question for part (b):
"For a response that has sufficient paragraph structure, as described in the published requirements for the paragraph-length response."

Please make sure you have watched my video describing Qualitative/Quantitative Translation and Paragraph Argument Short Answer! https://www.flippingphysics.com/qqt-pasa.html

Flipping Physics Lecture Notes:

2017 #1 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2017-frq1.html

This Paragraph Argument Short Answer question also works as a part of the AP Physics C: Electricity & Magnetism curriculum.



In the three circuits shown above, the batteries are all identical, and the lightbulbs are all identical. In circuit 1 a single lightbulb is connected to the battery. In circuits 2 and 3, two lightbulbs are connected to the battery in different ways, as shown. The lightbulbs are labeled A–E.

(a) Rank the magnitudes of the potential differences across lightbulbs A, B, C, D, and E from largest to smallest. If any lightbulbs have the same potential difference across them, state that explicitly.

Ranking: *A = D = E > B = C*

Briefly explain how you determined your ranking: *A, D, and E are each connected across the battery, and therefore, each has the same electric potential difference as the battery. B and C are in series with the battery and therefore have an electric potential difference which is less than the electric potential difference across the battery. B and C are identical and therefore have the same electric potential difference.*

(b) The batteries all start with an identical amount of usable energy and are all connected to the lightbulbs in the circuits at the same time.

In which circuit will the battery run out of usable energy first?
____ Circuit 1   ____ Circuit 2   _X_ Circuit 3

In which circuit will the battery run out of usable energy last?
____ Circuit 1   _X_ Circuit 2   ____ Circuit 3

In a clear, coherent paragraph-length response that may also contain equations and drawings, explain your reasoning.

The rate at which the battery uses its electric potential energy is electric power. Electric power equals current times electric potential difference. The electric potential differences of all three batteries are the same, so the electric power of each battery is directly proportional to the current delivered by each battery. Considering electric potential difference equals current times resistance, current is inversely *proportional to resistance. Therefore, the circuit with the smallest equivalent resistance will have the largest current delivered by the battery and will run out of usable energy first, and the circuit with the largest equivalent resistance will have the smallest current delivered by the battery and will run out of usable energy last.*

Circuit 3 has two resistors in parallel and adding a resistor in parallel decreases the equivalent resistance. That means circuit 3 has the smallest equivalent resistance and will run out of usable energy first.

Circuit 2 has two resistors in series and adding a resistor in series increases the equivalent resistance. That means circuit 2 has the largest equivalent resistance and will run out of usable energy last.

From the Scoring Guidelines, you gain 1 point out of 7 for this question for part (b):
"For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response."

Please make sure you have watched my video describing Qualitative/Quantitative Translation and Paragraph Argument Short Answer! https://www.flippingphysics.com/qqt-pasa.html And realize, you can gain a point for "a logical, relevant, and internally consistent argument" even if your conclusions end up being incorrect.

Flipping Physics Lecture Notes:

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

This Experimental Design question also works as a part of the AP Physics C: Mechanics curriculum.

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.

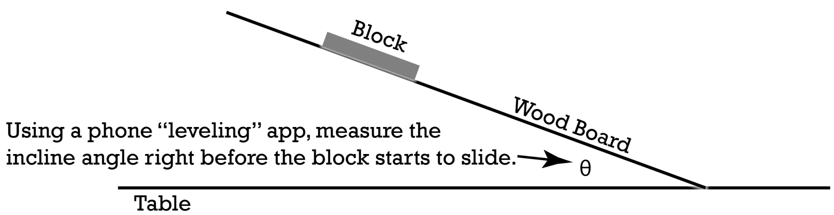
i. Draw a diagram of the experimental setup of the board and block. In your diagram, indicate each quantity that would be measured and draw or state what equipment would be used to measure each quantity.

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.

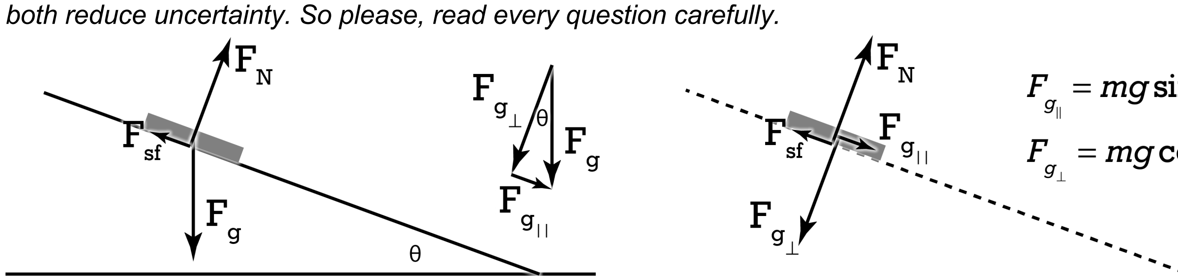
Part i:



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, ***μ_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.*

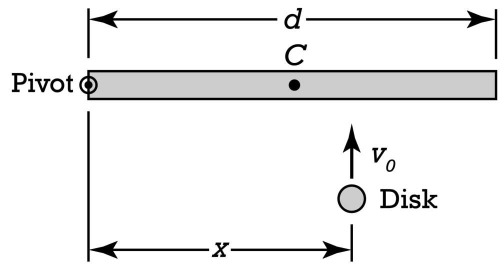
Flipping Physics Lecture Notes:

2017 #3 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2017-frq3.html

This Quantitative/Qualitative Translation question also works as a part of the AP Physics C: Mechanics curriculum.

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 $\omega = \dfrac{Ixv_0}{m_{disk}d^4}$. 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.

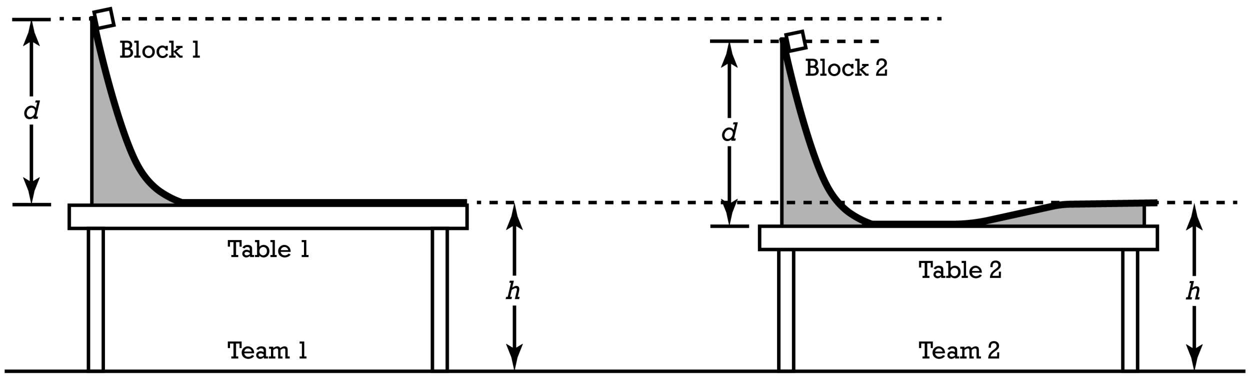
*Assuming the initial direction of the disk's motion is positive, when the disk bounces off the rod it will have a negative velocity and a negative angular momentum instead of a positive angular momentum when the disk sticks to the rod. Because angular momentum is conserved about the pivot during the 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

This Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.



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.

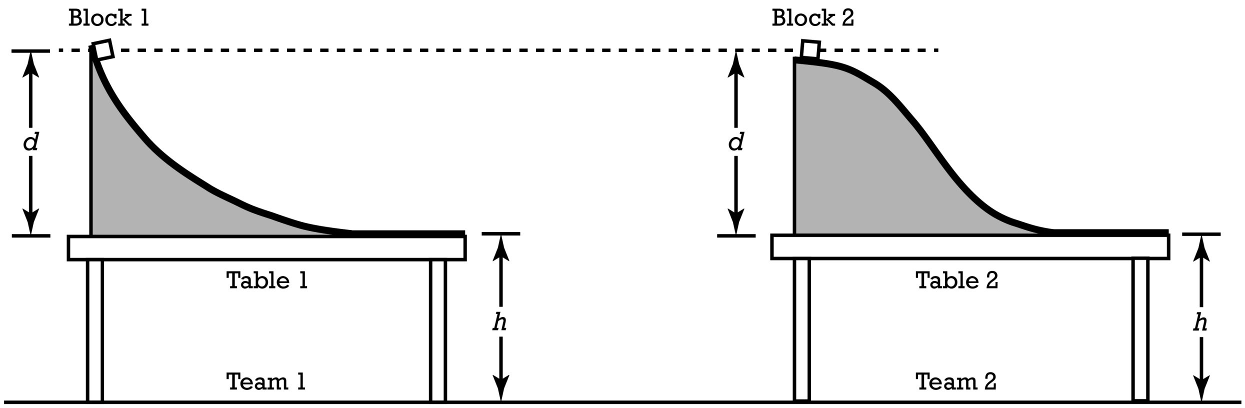
Because both slides are "low-friction", we may assume friction is negligible, therefore, there is no external work done on the system and mechanical energy is conserved. In both cases gravitational potential energy is converted to kinetic energy, however, Team 1's ramp has a larger change in gravitational 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.*

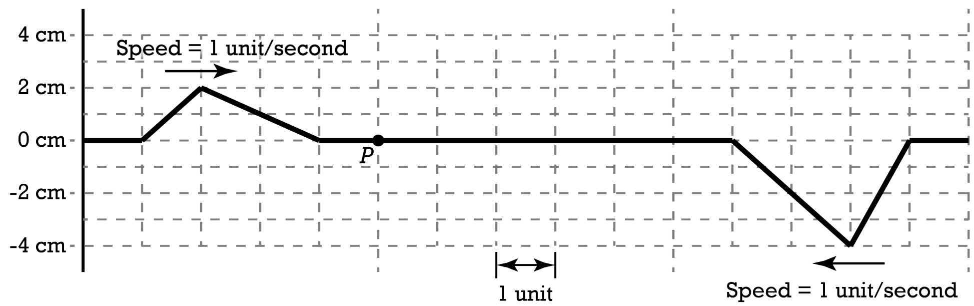
Note about grading: It is easy to fall into the trap of rushing quickly through this problem and saying to yourself, "I remember seeing the video from Flipping Physics about this and in that video both objects hit the ground at the same time. So, that must be the answer." I mean, this is a classic physics 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.

Flipping Physics Lecture Notes:

2017 #5 Free Response Question - AP Physics 1 - Exam Solution

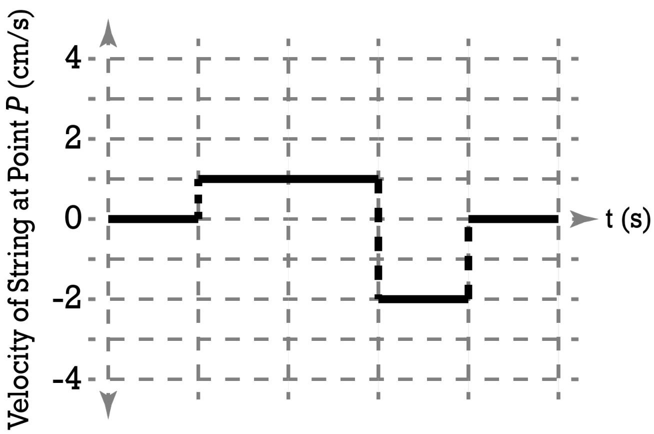
http://www.flippingphysics.com/ap1-2017-frq5.html

This is a Short Answer Question.



Two wave pulses are traveling in opposite directions on a string. The shape of the string at t = 0 is shown above. Each pulse is moving with a speed of one unit per second in the direction indicated.

(a) Between time t = 0 and t = 5 seconds, the entire left-hand pulse approaches and moves beyond point P on the string. On the coordinate axes below, plot the velocity of the piece of string located at point P as a function of time between t = 0 and t = 5 seconds.



The left-hand pulse is moving to the right at 1 unit per second, therefore, the pulse does not reach point P until t = 1 second. Therefore, the velocity of P until t = 1 second is zero. From t = 1 to 3 seconds, P moves up 2 cm. In other words, the velocity of P is:

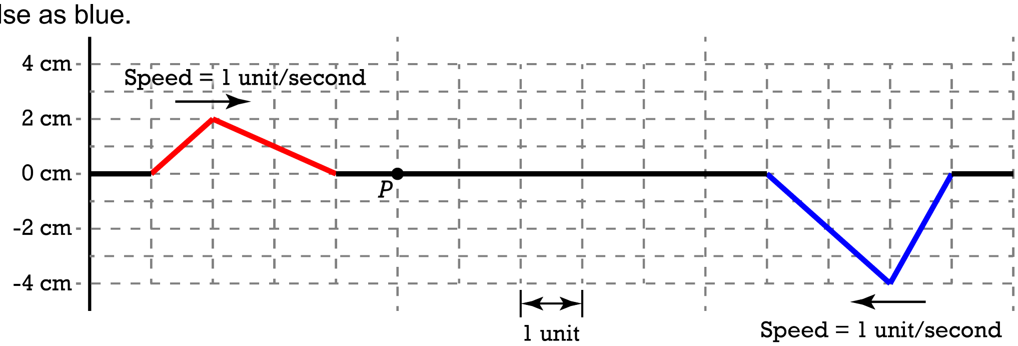
$V_{1-3} = \Delta x/\Delta t = (x_3 - x_1)/(t_3 - t_1) = (2-0)/(3-1) = 1$ *cm/sec.*

From t = 3 to 4 seconds, P moves down 2 cm: $V_{3-4} = \Delta x/\Delta t = (x_4 - x_3)/(t_4 - t_3) = (0-2)/(4-3) = -2$ *cm/sec.*

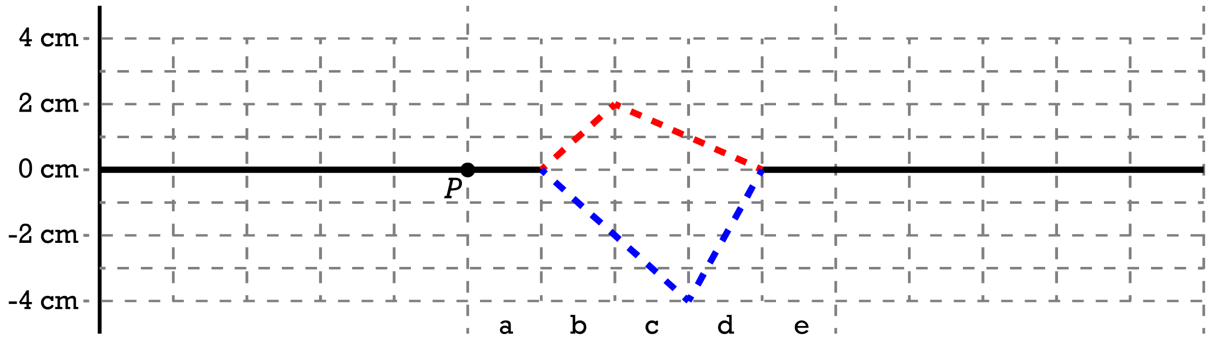
From t = 4 to 5 seconds, P does not move and velocity is zero.

(b) At t = 5 s, the pulses completely overlap. On the grid provided below, sketch the shape of the entire string at t = 5 s.

In order to better differentiate between the two pulses, let's draw the left-hand pulse as red and the right-hand pulse as blue.

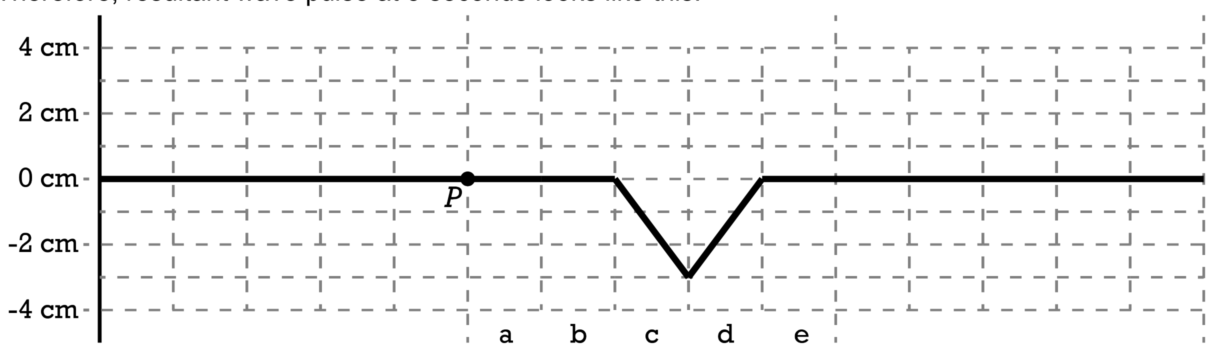


When the two pulses overlap, they will interfere with one another via wave superposition. Here is what the two original pulses look like at t = 5 seconds.



- In the two sections labeled “a” and “e”, both pulses have zero amplitude and add up to 0 cm.
- In section “b”, the red and the blue pulses are inverses of one another and therefore completely cancel one another out and the resultant wave has an amplitude of 0 cm.
- Section “c” starts with both pulses completely canceling one another out and a resultant wave of 0 cm amplitude. At the end of section “c” the red pulse is at +1 cm and the blue pulse is at -4 cm, which adds up to an amplitude of -3 cm. Both pulses are linear, so they will add up to a linear resultant pulse which, in section “c”, starts at 0 cm and ends at -3 cm.
- Section “d” will also be linear and starts at -3 cm and ends at 0 cm.

Therefore, resultant wave pulse at 5 seconds looks like this:



Please recognize that all 7 points for this problem are earned for your drawings. There is no explanation necessary. There are no equations used. Your *entire* answer is your drawings. Please, **draw carefully!!**

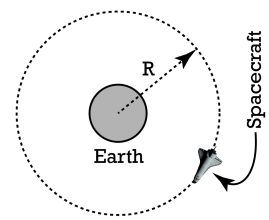
And, considering you earn 1 point in part (a) “For indicating zero velocity for 0 < t < 1 s and 4 s < t < 5 s” and 1 point in part (b) “for drawing a single pulse and zero elsewhere”, remember to draw horizontal lines at zero when necessary. … Sometimes my students do not draw lines when the value of the graph equals zero. You still have to draw horizontal lines at zero when the value is zero.

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

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

This Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.

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.

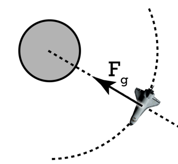


Note: Figure not drawn to scale.

(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.

Flipping Physics Lecture Notes:

2018 #2 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2018-frq2.html

This Experimental Design Question also works as a part of the AP Physics C: Electricity & Magnetism curriculum.

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas A and lengths ℓ. Each student applies a potential difference ΔV across the ends of a dough cylinder and determines the resistance R of the cylinder. The results of their experiments are shown in the table.

Dough Cylinder	A (m^2)	ℓ (m)	ΔV (V)	R (Ω)	*RA* ($\Omega \cdot m^2$)	
1	0.00049	0.030	1.02	23.6	*0.01156*	
2	0.00049	0.050	2.34	31.5	*0.01544*	
3	0.00053	0.080	3.58	61.2	*0.03244*	
4	0.00057	0.150	6.21	105	*0.05985*	

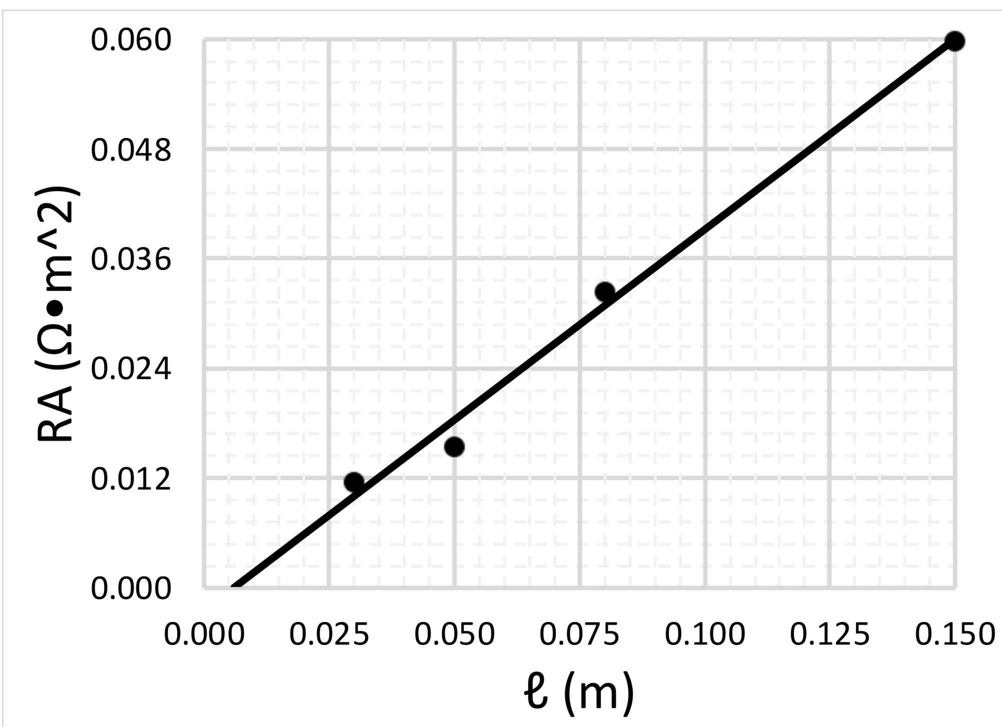
(a) The students want to determine the resistivity of the dough cylinders.

i. Indicate which quantities could be graphed to determine a value for the resistivity of the dough cylinders. You may use the remaining columns in the table above, as needed, to record any quantities (including units) that are not already in the table.

$$R = \frac{\rho \ell}{A} \Rightarrow \rho = \frac{RA}{\ell} \ \& \ slope = \frac{rise}{run} \Rightarrow Vertical\ Axis = RA \ \& \ Horizontal\ Axis = \ell$$

From the Scoring Guidelines, this question is worth 12 points. Part (a i) is worth 2 points with no explanation required. Make sure to notice when they require an explanation and also when they do not.

ii. On the grid, plot the appropriate quantities to determine the resistivity of the dough cylinders. Clearly scale and label all axes, including units as appropriate.



From the Scoring Guidelines, you gain 1 point in part (a ii):

- "For a linear scale where the plotted data uses at least half the grid"
- So, when they provide you with a grid to plot your graph, make sure you use at least half of the space provided in the grid.
- You also gain 1 point in part (a ii): "For labeling both axes, with units as appropriate"
- To me this should be obvious, because it literally tells you to do this in the problem, however, enough of my students forget to do this that I felt it necessary to point it out. Somehow y'all remember to add numbers, however, it is difficult for you to remember to label your axes and include units!

iii. Use the graph to estimate a value for the resistivity of the dough cylinders.

To solve for the units: $\rho = \frac{RA}{\ell} \Rightarrow units = \frac{\Omega \bullet m^2}{m} = \Omega \bullet m$

$$slope = \frac{rise}{run} = \frac{\Delta y}{\Delta x} = \frac{0.06 - 0}{0.15 - 0.007} = 0.41958 \approx 0.42\Omega \bullet m$$

From the Scoring Guidelines, you gain 1 point in part (a iii):
"For a correct value of the resistivity ρ = 0.42 Ω•m (± 0.03) calculated from graph or data." Notice, the slope you calculate needs to be between 0.39 and 0.45 Ω•m and has to have units. So, please, be careful plotting your data, drawing your best-fit line using your straight edge or rule, and remember units!

(b) Another group of students perform the experiment described in part (a) but shape the dough into long rectangular shapes instead of cylinders. Will this change affect the value of the resistivity determined by the second group of students?

____ Yes __X__ No Briefly justify your reasoning.

No, resistivity is a property of the material only. Material shape does not affect resistivity.

From the Scoring Guidelines, part (b) is only worth 1 point.
They mean it when they say, "***Briefly*** justify your reasoning."

(c) Describe an experimental procedure to determine whether or not the resistivity of the dough cylinders depends on the temperature of the dough. Give enough detail so that another student could replicate the experiment. As needed, include a diagram of the experimental setup. Assume equipment usually found in a school physics laboratory is available.

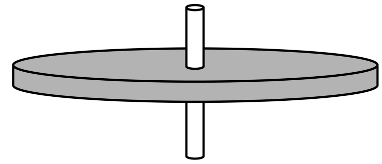
Using only one of the dough cylinders from part (a), apply a constant electric potential difference across the dough cylinder and measure the current through and temperature of the dough cylinder. Because the dough cylinder will be converting electric potential energy to internal energy, the temperature of the dough cylinder will increase over time. If the resistivity of the conductive dough changes with a change in temperature, the resistance of the dough cylinder will change, and therefore the measured current will change. Make sure to let the experiment run long enough to give the dough enough time to experience a significant temperature change.

Flipping Physics Lecture Notes:

2018 #3 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2018-frq3.html

This Quantitative/Qualitative Translation question also works as a part of the AP Physics C: Mechanics curriculum.



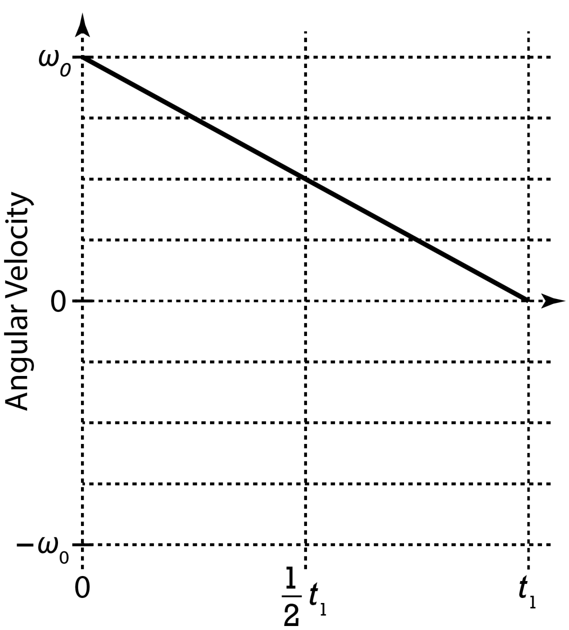
The disk shown spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

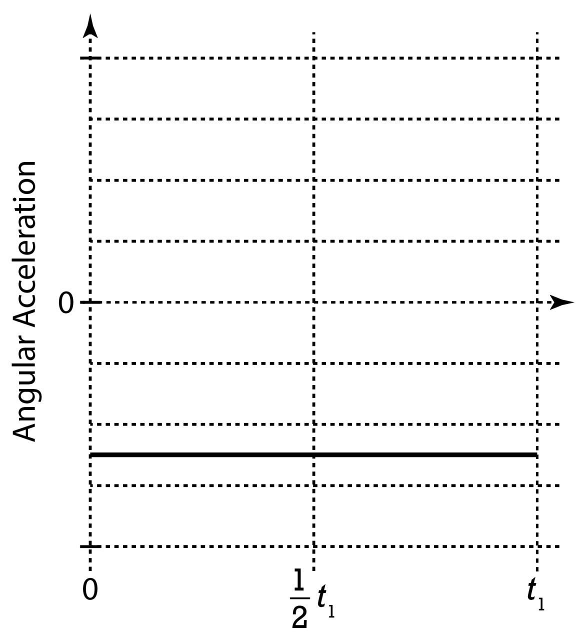
(a) At time t = 0 the disk has an initial counterclockwise (positive) angular velocity ω_0. The disk later comes to rest at time $t = t_1$.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time t from t = 0 until the disk comes to rest at time $t = t_1$.

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time t from t = 0 until the disk comes to rest at time $t = t_1$.

Friction is the only force causing a torque on the disk about its center of mass. Therefore, friction causes a constant net torque on the disk which causes the disk to have a constant clockwise (negative) angular acceleration. A constant negative angular acceleration on an angular velocity as a function of time graph is a line with a constant negative slope. The initial angular velocity is ω_0 and the final angular velocity is zero at time $t = t_1$. So, the angular velocity as a function of time graph is a straight line with a negative slope starting at ω_0 and ending at 0. A constant angular acceleration on an angular acceleration as a function of time graph is a horizontal line. Because the angular acceleration is negative, the horizontal line is below the x-axis.





Notes about grading. Part (a) is worth 4 points out of 12 for this question. One third of the points are for drawing two lines, one on each graph. No explanation is necessary at all. This should highlight the importance of the graphs they ask you to draw. Please draw carefully!

(b) The magnitude of the frictional torque exerted on the disk is τ_0. Derive an equation for the rotational inertia I of the disk in terms of τ_0, ω_0, t_1, and physical constants, as appropriate.

$$\sum \tau = -\tau_0 = I\alpha \;\&\; \alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_f - \omega_i}{t_f - t_i} = \frac{0 - \omega_0}{t_1 - 0} = -\frac{\omega_0}{t_1}$$

$$\Rightarrow I = -\frac{\tau_0}{\alpha} = -\frac{\tau_0}{-\frac{\omega_0}{t_1}} = \frac{\tau_0 t_1}{\omega_0}$$

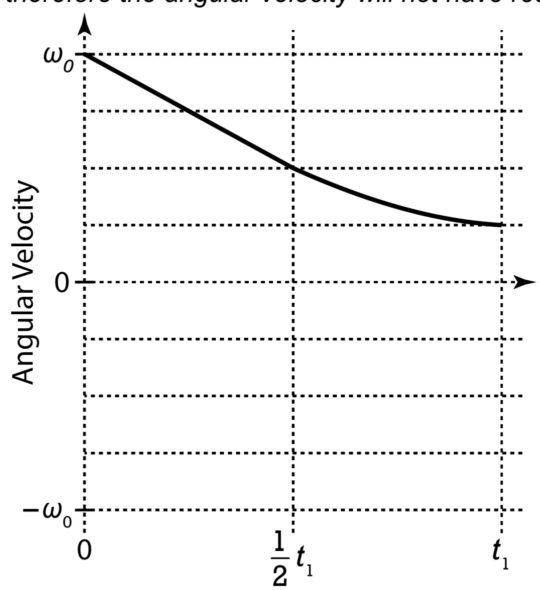
Part (b) is only worth 3 points. In other words, the graphs are worth more than the equation derivation. Remember when I said you need to be careful drawing your graphs?

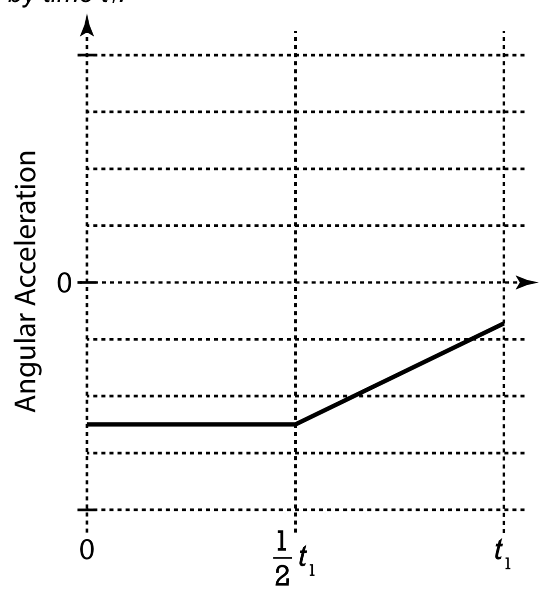
(c) In another experiment, the disk again has an initial positive angular velocity ω_0 at time t = 0. At time t = ½ t_1, the student starts dripping oil on the contact surface between the axle and the disk to reduce the friction. As time passes, more and more oil reaches that contact surface, reducing the friction even further.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from t = 0 to t = t_1, which is the time at which the disk came to rest in part (a).

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time from t = 0 to t = t_1.

First off, realize nothing has changed from time t = 0 to time t = ½ t_1, so the first half of both graphs should be the same as they were in part (a). For the second half of each graph, the oil reduces the force of friction which reduces the net torque which reduces the angular acceleration of the wheel. This means the second half of the angular acceleration graph should show a decreasing angular acceleration, in other words, the line should move towards the horizontal time axis. For the second half of the angular velocity graph, the angular acceleration is no longer constant, so the line is no longer straight, but rather is curved. The slope of an angular velocity as a function of time graph is angular acceleration, so the slope of the angular velocity graph from ½ t_1 to t_1 should slowly increase in value or get flatter and the angular velocity at time t_1 needs to be positive because the angular acceleration is less than it was in part (a) and therefore the angular velocity will not have reached zero by time t_1.





More about grading. 2 more graphs worth a total of 4 more points. 8 total points out of 12 for question #3 all for graphs with no explanation. If you did not believe me before, believe me now. Be careful when drawing your graphs!!

(d) The student is trying to mathematically model the magnitude τ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2} t_1$. The student writes down the following two equations, each of which includes a positive constant (C_1 or C_2) with appropriate units.

(1) $\tau_1(t) = C_1\left(t - \frac{1}{2}t_1\right)$ (for $t > \frac{1}{2} t_1$)   (2) $\tau_2(t) = \dfrac{C_2}{\left(t + \frac{1}{2}t_1\right)}$ (for $t > \frac{1}{2} t_1$)

Which equation better mathematically models this experiment?

____ Equation (1) __X__ Equation (2)

Briefly explain why the equation you selected is plausible and why the other equation is not plausible.

We can determine the torque for each equation at time $t = \frac{1}{2}t_1$ and $t = t_1$.

$$\tau_1(t) = C_1\left(t - \frac{1}{2}t_1\right) \Rightarrow \tau_1\left(\frac{1}{2}t_1\right) = C_1\left(\frac{1}{2}t_1 - \frac{1}{2}t_1\right) = 0 \ \& \ \tau_1(t_1) = C_1\left(t_1 - \frac{1}{2}t_1\right) = C_1\left(\frac{1}{2}t_1\right)$$

$$\tau_2(t) = \frac{C_2}{\left(t + \frac{1}{2}t_1\right)} \Rightarrow \tau_2\left(\frac{1}{2}t_1\right) = \frac{C_2}{\left(\frac{1}{2}t_1 + \frac{1}{2}t_1\right)} = \frac{C_2}{t_1} \ \& \ \tau_2(t_1) = \frac{C_2}{\left(t_1 + \frac{1}{2}t_1\right)} = \frac{C_2}{\frac{3}{2}t_1} = \frac{2}{3}\left(\frac{C_2}{t_1}\right)$$

The torque for equation 1 does not make sense because it would be zero at time ½t₁ and gets larger from there. The magnitude of the torque should start out at a positive value at time ½t₁ and decrease from there, which is what equation 2 does. So, equation 2 is the one which better mathematically models this experiment.

2018 #4 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2018-frq4.html

This is a Short Answer Question.

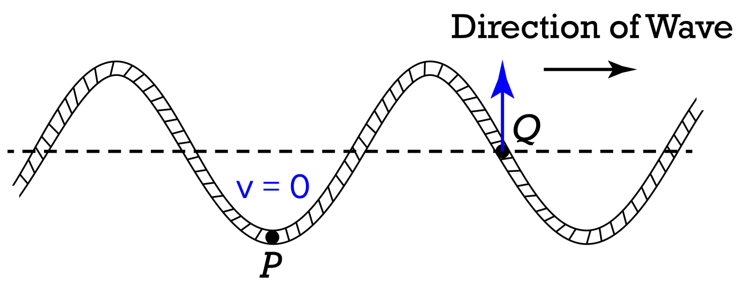
A transverse wave travels to the right along a string.

(a) Two dots have been painted on the string. In the diagrams below, those dots are labeled P and Q.

i. The figure below shows the string at an instant in time. At the instant shown, dot P has maximum displacement and dot Q has zero displacement from equilibrium. At each of the dots P and Q, draw an arrow indicating the direction of the instantaneous velocity of that dot. If either dot has zero velocity, write "v = 0" next to the dot.

Just before this instant in time P was moving downward, just after this time P will be moving up, therefore, right now point P is at rest. (Just like an object thrown upward in free fall is at rest at its maximum height.)

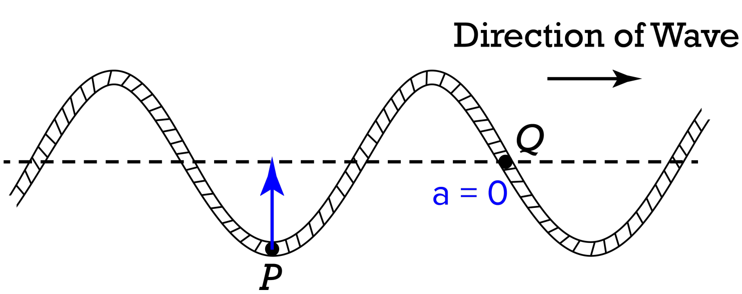
Just before this instant in time Q was moving up, just after this time A will still be moving up, therefore, right now point Q is moving up.



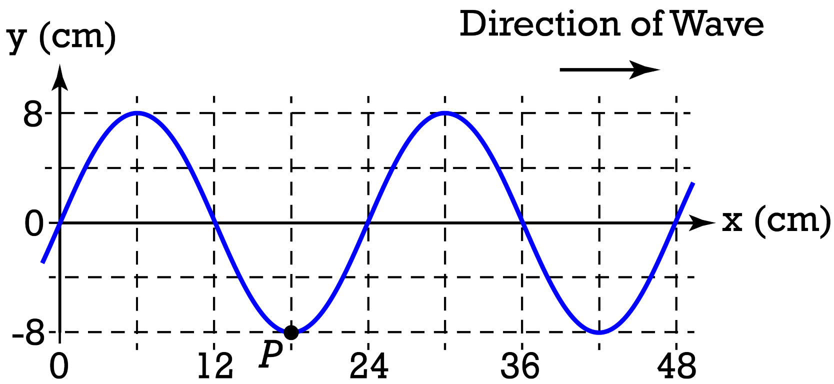
ii. The figure below shows the string at the same instant as shown in part (a)i. At each of the dots P and Q, draw an arrow indicating the direction of the instantaneous acceleration of that dot. If either dot has zero acceleration, write "a = 0" next to the dot.

Just before this time P was moving down, just after this time P will be moving up, therefore, the change in velocity of P is upward and point P has an upward acceleration. (Just like an object thrown upward in free fall has a downward acceleration at its maximum height.)

In order to fully understand point Q, remember that individual points on a mechanical wave move in simple harmonic motion. Because Q is at the equilibrium position, Q is moving at its maximum velocity and point Q has zero acceleration. Point Q's acceleration is zero at this specific instant in time because, before this time its acceleration is upward, and after this time its acceleration is downward, therefore, at this instant in time, its acceleration is zero.



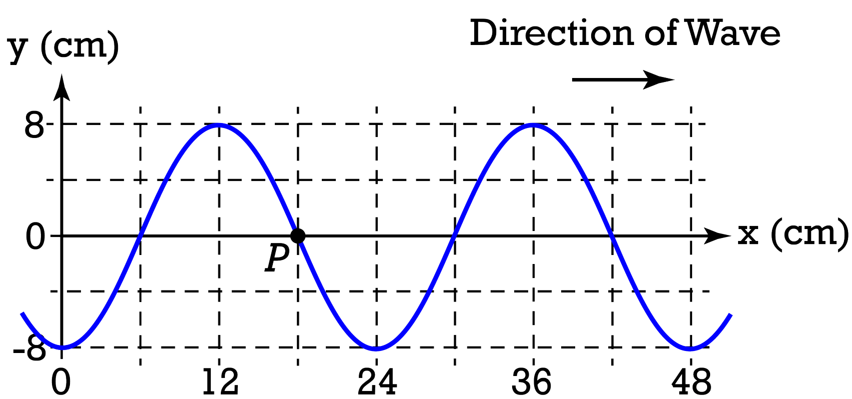
The figure below represents the string at time t = 0, the same instant as shown in part (a) when dot P is at its maximum displacement from equilibrium. For simplicity, dot Q is not shown.



(b)

i. On the grid below, draw the string at a later time t = T/4, where T is the period of the wave.

The time for a period is one full cycle. During one full cycle the wave will move one wavelength, λ, or 24 cm. Therefore, during one fourth of a full cycle the wave will have gone a distance of one fourth of a wavelength or 24cm/4 = 6 cm. The shape of the wave will not change.



ii. On your drawing above, draw a dot to indicate the position of dot P on the string at time t = T/4 and clearly label the dot with the letter P.

Point P will stay on the wave at x = 18 cm; therefore, it will move up to y = 0.

(c) Now consider the wave at time t = T. Determine the distance traveled (not the displacement) by dot P between times t = 0 and t = T.

During one full cycle, point P will start at y = -8 cm, move up to y = +8 cm, and then back down to y = -8 cm. Therefore, point P will have moved a distance equal to four times 8 cm or 32 cm.

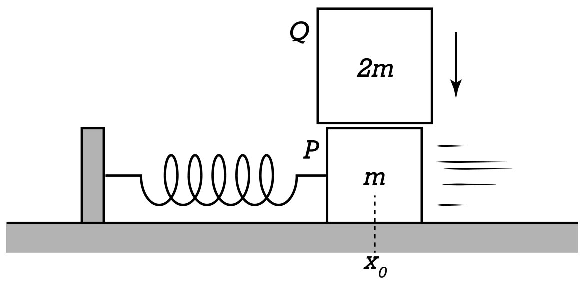
A few notes about grading:
You can gain all 7 points for this problem without writing out any calculations or explanations.

- 4 points in part (a), 1 for each item they specifically ask you for and do not require explanation.
- 2 points in part (b), 1 for each item they specifically ask you for and do not require explanation.
- 1 point in part (c) again with no explanation or calculation.
    - For part (c) you can write just 32 cm (with units) and get full credit.

Flipping Physics Lecture Notes:

2018 #5 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2018-frq5.html

This Paragraph Argument Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.



Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block Q of mass 2m is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown. Block Q immediately sticks to the top of block P, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ} .

(a) Determine the numerical value of the ratio T_{PQ}/T_P .

$$T = 2\pi\sqrt{\frac{m}{k}} \Rightarrow T_P = 2\pi\sqrt{\frac{m_P}{k}} = 2\pi\sqrt{\frac{m}{k}} \ \&\ T_{PQ} = 2\pi\sqrt{\frac{m_{PQ}}{k}} = 2\pi\sqrt{\frac{3m}{k}} = \left(\sqrt{3}\right)\left(2\pi\sqrt{\frac{m}{k}}\right) = \left(\sqrt{3}\right)T_P \Rightarrow \frac{T_{PQ}}{T_P} = \sqrt{3}$$

(b) The figure is reproduced above. How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude AP of block P alone?

__X_ $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

Part 1: Block Q colliding with Block P:
When block Q lands on block P it is a perfectly inelastic collision and linear momentum is conserved. The mass of the system is increased; therefore, the velocity of the system must be decreased.

$$\sum \vec{p}_i = \sum \vec{p}_f \Rightarrow \vec{p}_{Pi} + \vec{p}_{Qi} = \vec{p}_{Pf} + \vec{p}_{Qf} \Rightarrow m_P\vec{v}_{Pi} + m_Q\vec{v}_{Qi} = m_P\vec{v}_{Pf} + m_Q\vec{v}_{Qf}$$

$$\vec{v}_{Pf} = \vec{v}_{Qf} = \vec{v}_f \Rightarrow m\vec{v}_{Pi} = m\vec{v}_f + 2m\vec{v}_f = 3m\vec{v}_f \Rightarrow \vec{v}_f = \frac{1}{3}\vec{v}_{Pi} \Rightarrow \vec{v}_{PQ} = \frac{1}{3}\vec{v}_P$$

As you can see from the conservation of momentum equation during the collision, the velocity of both blocks after the collision is one-third the velocity of block P before the collision. To make this clear, I will identify the velocity of block P at point x_0 as v_P and the velocity of blocks PQ as v_{PQ} .

Part 2: Block(s) slide from equilibrium to amplitude:
Because the surface is frictionless and there are no other forces acting on the blocks-spring system, there is no external work done on the system, and mechanical energy is conserved. There is no change in gravitational potential energy of the blocks while they are moving horizontally, no matter where we put the horizontal zero line. Therefore, when the block is at x0, the equilibrium position, the only mechanical energy it has is kinetic energy, therefore, this is the location of maximum kinetic energy and that equals the total mechanical energy of the system. The decrease in total mechanical energy can be found by using the equation for kinetic energy.

$$KE_P = \frac{1}{2}m_p v_p^{\,2} = \frac{1}{2}mv_p^{\,2} \ \& \ KE_{PQ} = \frac{1}{2}m_{PQ}v_{PQ}^{\,2} = \frac{1}{2}(3m)\left(\frac{1}{3}v_p\right)^2 = \frac{3}{9}\left(\frac{1}{2}mv_P^{\,2}\right) = \frac{1}{3}KE_P$$

In other words, the addition of block Q decreases the total mechanical energy of the system to one-third its previous value with just block P. At maximum displacement from equilibrium position, or amplitude, all of the kinetic energy will be converted to elastic potential energy. $PE_{ef} = \frac{1}{2}kx_f^{\,2} = \frac{1}{2}kA^2$ *Because the maximum kinetic energy was decreased with the addition of block Q, the maximum elastic potential energy will also be decreased and, because the spring constant does not change, the amplitude must decrease with the addition of block Q.*

Notes about grading:
This problem is unusual in that

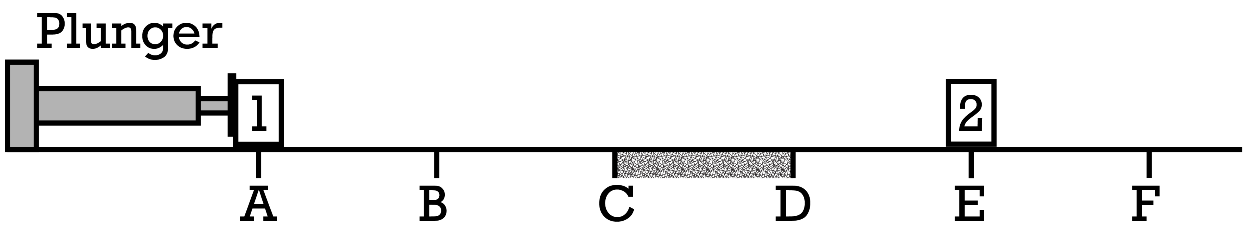
1) Part (a) is independent from part (b). Usually the Paragraph Argument Short Answer questions are one continuous problem and the parts of the problem before the “In a clear, coherent paragraph-length …” question actually end up being a part of the paragraph answer.
2) The paragraph argument ends up needing more equations than usual.

So, please be aware that clearly some of the Paragraph Argument Short Answer questions will have independent parts and may require more equations than perhaps you are used to.

2019 #1 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2019-frq1.html

This Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.



Identical blocks 1 and 2 are placed on a horizontal surface at points A and E, respectively, as shown. The surface is frictionless except for the region between points C and D, where the surface is rough. Beginning at time t_A , block 1 is pushed with a constant horizontal force from point A to point B by a mechanical plunger. Upon reaching point B, block 1 loses contact with the plunger and continues moving to the right along the horizontal surface toward block 2. Block 1 collides with and sticks to block 2 at point E, after which the two-block system continues moving across the surface, eventually passing point F.

(a) On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F . The times at which block 1 reaches points A through F are indicated on the time axis.

A to B: Block 1 experiences a constant, positive, net external force caused by the plunger which, according to Newton's Second Law, causes a constant, positive acceleration.

B to C: Block 1 experiences zero net eternal force, because there is no friction, and therefore moves at a constant velocity.

*C to D: Block 1 experiences a constant, **negative**, net external force cause by surface friction, which causes a constant, **negative** acceleration.*

D to E: Block 1 experiences zero net eternal force, because there is no friction, and therefore moves at a constant velocity.

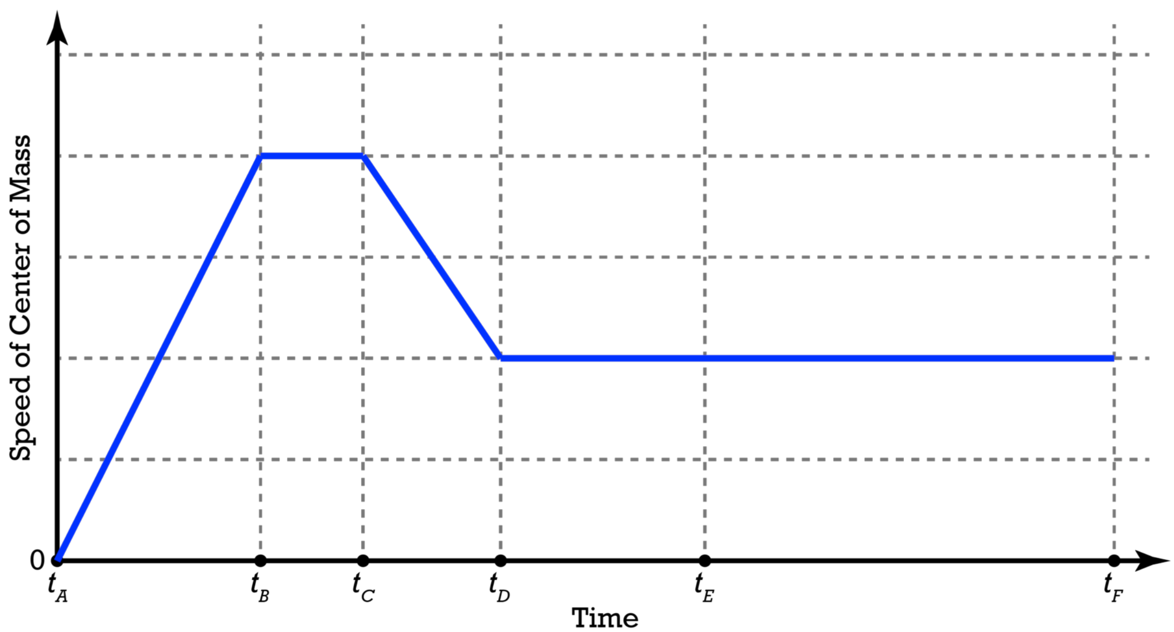
At E: Block 1 collides with block 2, linear momentum is conserved, and, because blocks 1 and 2 have identical mass, the speed of block 1 is cut in half, because the mass is doubled, and the momentum of the system stays constant. However, this collision is irrelevant because the question asks about the speed of the CENTER OF MASS OF THE TWO-BLOCK SYSTEM as a function of time. So, let's try again.

A to B: Block 1 experiences a constant, positive, net external force caused by the plunger which, according to Newton's Second Law, causes a constant, positive acceleration. Block 2 is at rest. The average of those two is a constant, positive acceleration. Yes, the magnitude of the acceleration of the center of mass of both blocks is half of what it is for just block 1, however, there is no y-axis scale given in the problem, so that does not really matter for this question. Draw a line with a constant, positive slope from t_A to t_B .

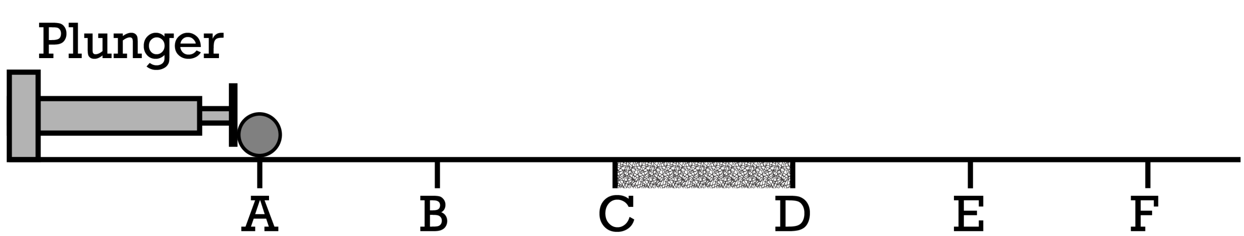
B to C: Block 1 experiences zero net eternal force and therefore moves at a constant velocity. Block 2 is at rest. The average of those two is a constant velocity. From t_B to t_C , starting where the previous line ended, draw a horizontal line.

*C to D: Block 1 experiences a constant, **negative**, net external force cause by surface friction, which causes a constant, **negative** acceleration. Block 2 is at rest. The average of those two is a constant, **negative** acceleration. From t_C to t_D , starting where the previous line ended, draw a line with a constant, **negative** slope. We know the line must not reach zero speed because the block is still moving to the right after t_D .*

*D to **F**: Block 1 experiences zero net eternal force and therefore moves at a constant velocity. Block 2 is at rest. The average of those two is a constant velocity. Yes, at E there is a collision between blocks 1 and 2, however, the net external force on the two-block system is still zero, so the center of mass of the two-block system still moves at a constant velocity! From t_D to t_F , draw a horizontal line which starts where the line from t_C to t_D ends.*



Note about grading: Part (a) is worth 5 out of 7 points for this problem. That's right, drawing lines correctly on this graph is worth 5 out of 7 points. No explanation necessary. Please draw carefully. And do not write out your explanation if you are not asked to. Also, realize you only lose one point for incorrectly showing a decrease in velocity at t_E .



(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses contact with the plunger at point B and continues moving across the horizontal surface toward point E.

In which interval(s), if any, does the sphere's angular momentum about its center of mass change? Check all that apply.

____ A to B ____ B to C __X__ C to D ____ D to E _____ None

Briefly explain your reasoning.

Angular momentum is conserved when the net torque acting on an object equals zero. Let's look at all the forces acting on the sphere and if they cause a net torque on the sphere.

Force Normal acts on the sphere from A to E. The force normal is directed toward the center of mass of the sphere and therefore will not cause zero torque on the sphere.

Force of Gravity acts on the sphere from A to E. The force of gravity acts on the center of mass of the sphere and therefore will cause zero torque on the sphere.

Force Applied by the plunger acts on the sphere from A to B. The force applied is directed toward the center of mass of the sphere and therefore will cause zero torque on the sphere.

Force of Friction by the rough surface acts on the sphere from C to D. The force of friction does not act on the center of mass of the sphere and is not directed toward the center of mass of the sphere and therefore ***will cause torque on the sphere.***

Therefore, the only interval where a net torque is acting on the sphere is from C to D. That net torque is caused by the friction force acting on the sphere.

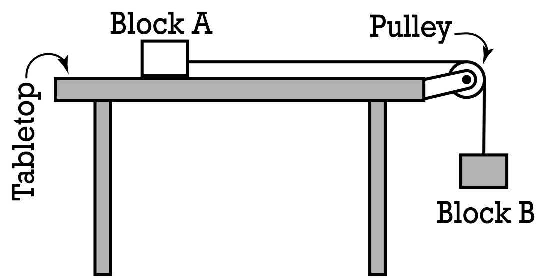
Note about grading: My explanation is a bit excessive. My goal is for you to truly understand all the physics here, which is a bit different than simply answering the question. You really only need to say change in angular momentum is caused by net torque and that the force of friction from C to D is the only force which causes a net torque and explain why.

Flipping Physics Lecture Notes:

2019 #2 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2019-frq2.html

This Quantitative/Qualitative Translation question also works as a part of the AP Physics C: Mechanics curriculum.

This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A , rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B , hangs from a light string that runs over a pulley and attaches to block A, as shown. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.



(a) i. Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

The magnitude of the acceleration of block A after release is nearly zero.

Briefly explain your reasoning without deriving or using equations.

Block A is so massive that it has enough inertia to almost completely resist the relatively small tension force in the string which is caused by the relatively small force of gravity on block B.

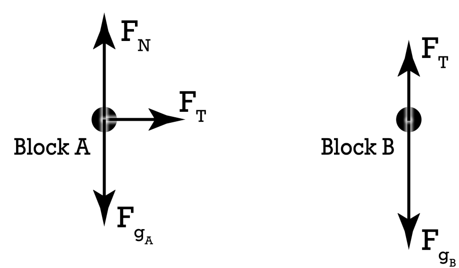
(a) ii. Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

The magnitude of the acceleration of block A after release is nearly 9.81 m/s^2.

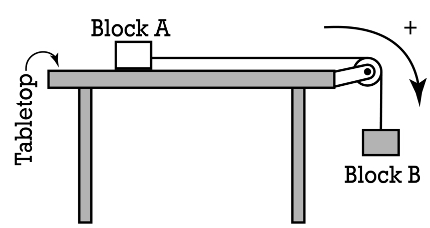
Briefly explain your reasoning without deriving or using equations.

In the absence of block A, block B would be in free fall and have an acceleration of 9.81 m/s^2 down. The relatively small mass of block A only causes a small tension force up on block B to decrease the magnitude of block B's acceleration slightly.

(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.



(c) Derive an equation for the acceleration of the blocks after release in terms of m_A , m_B , and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).



Define the positive direction as to the right on block A and down on block B. And then sum the forces on both blocks in that positive direction:

$$\sum_{\substack{\text{on both blocks}\\ \text{in+direction}}} F = F_{g_B} - F_T + F_T = m_t a \Rightarrow m_B g = \left(m_A + m_B\right)a \Rightarrow a = \left(\frac{m_B}{m_A + m_B}\right)g$$

(d) Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii) ? __X__ Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B .

If m_A is much less than m_B then the quantity $\left(\frac{m_B}{m_A + m_B}\right)$ is nearly 1 and therefore the magnitude of the acceleration of both blocks is nearly equal to g or 9.81 m/s^2.

Grading Note: Part (d) is worth 1 point and you can get that 1 point with a “no” answer, as long as you give “valid reasoning that addresses the result in part (c) and the reasoning in part (a) double i”

(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1 . Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2 . How do the two tensions compare to each other?

__X__ $T_2 > T_1$ ____ $T_2 = T_1$ ____ $T_2 < T_1$ Briefly explain your reasoning.

The addition of a pulley with non-negligible mass will increase the resistance of the system to change in velocity and therefore the new acceleration will be less than the original acceleration. We can sum the forces on block B to determine how this affects the tension force.

$$\sum_{\substack{\text{on block } B\\ \text{in + direction}}} F = F_{g_B} - F_T = m_B a \Rightarrow F_T = F_{g_B} - m_B a$$

Therefore, when acceleration is decreased the tension force is increased.

Note about grading: Part (e) is worth 2 points and you can get 1 point even if you mark the incorrect tension comparison, as long as the physics of your argument is sound. In other words, you can get the wrong answer and still get half the points. Please, answer every part of every question. You never know what will get you points, however, not answering the question is certain to get you zero points.

2019 #3 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2019-frq3.html

This Experimental Design Question also works as a part of the AP Physics C: Mechanics curriculum.

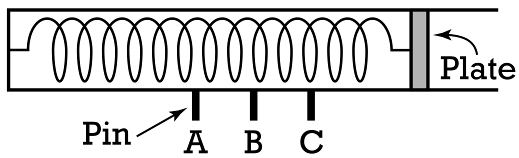


Figure 1. Uncompressed Spring

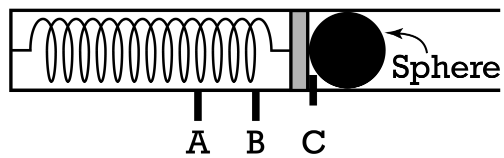


Figure 2. Compressed Spring

A projectile launcher consists of a spring with an attached plate, as shown in Figure 1. When the spring is compressed, the plate can be held in place by a pin at any of three positions A, B, or C. For example, Figure 2 shows a steel sphere placed against the plate, which is held in place by a pin at position C. The sphere is launched upon release of the pin.

A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a) The student plans to test the hypothesis by launching the sphere <u>using the launcher</u>.

i. State a basic physics principle or law the student could use in designing an experiment to test the hypothesis.

Conservation of Mechanical Energy

ii. Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory.

Set the horizontal zero line at the center of mass of the sphere. Launcher is oriented horizontally. Initial point is where the sphere is compressing the spring right before release. Final point is at the point where the sphere leaves the spring.

$$ME_i = ME_f \Rightarrow \frac{1}{2}kx_i^2 = \frac{1}{2}mv_f^2 \Rightarrow kx_i^2 = mv_f^2 \Rightarrow k = \frac{mv_f^2}{x_i^2}$$

(b) Design an experimental procedure to test the hypothesis <u>in which the student uses the launcher to launch the sphere.</u> Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities and associated symbols that would be measured in your experiment. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
mass of the sphere	m	*electronic balance*
initial displacement from equilibrium of the spring	x_i	*meterstick*
final speed of sphere	v_f	*motion sensor*

Describe the overall procedure to be used to test the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

- *Measure the mass of the sphere, m, with an electronic balance.*
- *Orient the launcher horizontally and load the sphere in the launcher.*
- *Record the initial position of the spring using the meterstick.*
- *Compress the spring to a pin position.*
- *Measure the displacement of the spring from equilibrium position, x_i, using the meterstick.*
- *Release the sphere and measure its speed, v_f, using the motion sensor.*
- *The maximum speed measured by the motion sensor is the final speed of the sphere.*
- *Conduct the experiment 12 times, 4 times at each pin location.*
    a. *Please do not miss the* "including any steps necessary to reduce experimental uncertainty" *part of the question. That is why the last step of the procedure is here.*
    b. *Also note that your procedure must* "use the launcher"! *It's even underlined, twice, in the question.*

(c) Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances.

Using our equation for the spring constant, we can create a graph of our experimental data to check our hypothesis:

$$k = \frac{mv_f^2}{x_i^2} \Rightarrow slope = \frac{rise}{run} \Rightarrow y - axis = mv_f^2 \;\&\; x - axis = x_i^2$$

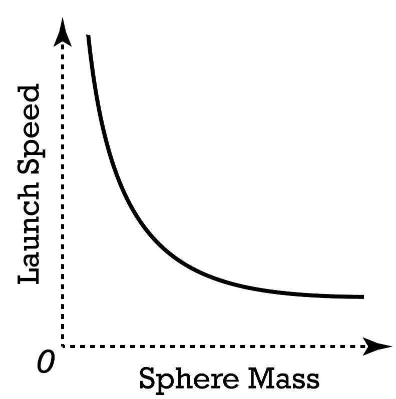
The graph of the data should show a best fit line with a slope equal to the spring constant and a y-intercept near zero. If the slope and y-intercept are within experimental error, we have confirmed the student's hypotheses.

(d) Another student uses the launcher to consecutively launch several spheres that have the same diameter but different masses, one after another. Each sphere is launched from position A. Consider each sphere's launch speed, which is the speed of the sphere at the instant it loses contact with the plate. On the axes below, sketch a graph of launch speed as a function of sphere mass.

Rearrange our equation to solve for the final speed of the sphere:

$$k = \frac{mv_f^2}{x_i^2} \Rightarrow v_f^2 = \frac{kx_i^2}{m} \Rightarrow v_f = \sqrt{\frac{kx_i^2}{m}}$$

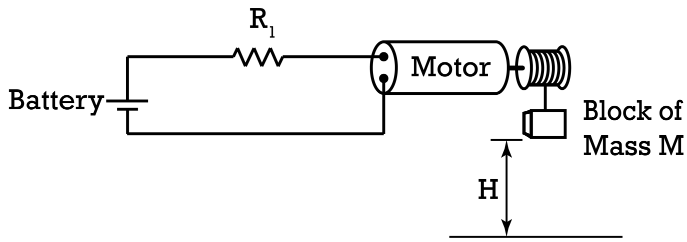
k and x_i are both constants in this situation, therefore velocity as a function of mass will be an inverse relationship. As mass increases, velocity decreases. Like this:



Flipping Physics Lecture Notes:

2019 #4 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2019-frq4.html

This Paragraph Argument Short Answer question is also good for AP Physics C: Electricity and Magnetism.



A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass M at constant speed from the ground to a height H above the ground in a time interval Δt. The motor has constant resistance and is connected in series with a resistor of resistance R_1 and a battery.

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

(a) Determine an expression for the mechanical power in terms of M, H, Δt, and physical constants, as appropriate.

At a constant velocity the force of tension and force of gravity acting on the block are equal in magnitude.

$$P_{F_T} = \frac{W_{F_T}}{\Delta t} = \frac{F_T d \cos\theta}{\Delta t} = \frac{F_g H \cos(0)}{\Delta t} = \frac{MgH}{\Delta t}$$

(b) Without M or H being changed, the time interval Δt can be decreased by adding one resistor of resistance R_2 , where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance R_2 be added to the circuit to decrease Δt?

___ In parallel with the battery _X_ In parallel with R_1 ___ In parallel with the motor ___ In series with the battery, R_1, and the motor

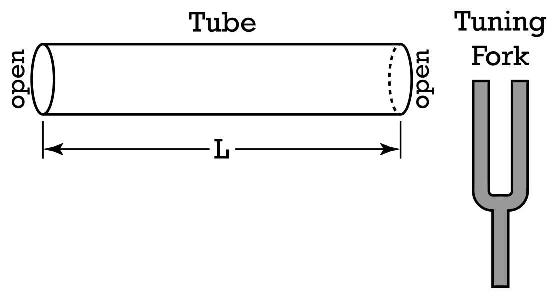
In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease Δt.

Because power equals work over change in time, Δt needs to be decreased, and the work will be constant because M, g, and H are all constants; the mechanical power needs to be increased. From the problem statement we know mechanical power increases if the electric potential difference between the two terminals of the motor increases. Therefore, we know we need to increase the electric potential difference across the motor. Because electric potential difference equals current times resistance and the resistance of the motor is constant, we need to increase the current through the motor. Placing R_2 in parallel with R_1 will decrease the equivalent resistance of the circuit and therefore increase the current in the circuit. Because the current in the circuit is also the current through the motor, the current through the motor will be increased and Δt will be decreased.

2019 #5 Free Response Question - AP Physics 1 - Exam Solution

http://www.flippingphysics.com/ap1-2019-frq5.html

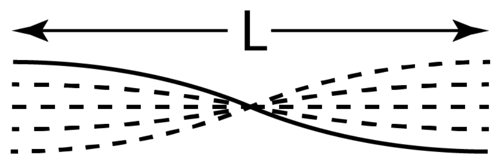
This is a Short Answer question.



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. 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.

Because the tube is open at both ends, each end will have a displacement antinode. When resonating at its fundamental frequency, the standing wave created will have the longest possible wavelength to create a standing wave pattern in this tube, therefore, there will be no other displacement antinodes in the tube, and the standing wave pattern will have a displacement antinode on each end and a displacement node in the middle.



Half a wavelength will then equal the length of the tube. We also know, for a wave, that speed equals frequency times wavelength. Therefore, we can determine the length of the tube.

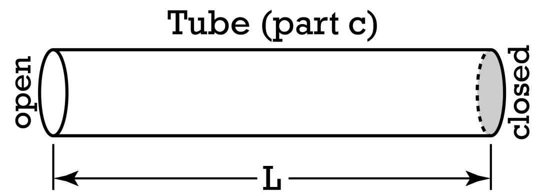
$$L = \frac{1}{2}\lambda \ \& \ v = f\lambda \Rightarrow \lambda = \frac{v}{f} \Rightarrow L = \frac{v}{2f} = \frac{340}{(2)(512)} = 0.332031 \approx 0.33\text{m}$$

(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.)

From the Scoring Guidelines: This graph is worth 3 out of 7 points for this problem. 1 point each for:

- A curve with a node (zero) at L/2.
- A curve with maxima at 0, L, and no other points.
- A nonhorizontal curve that is symmetric around L/2 and nonnegative everywhere.

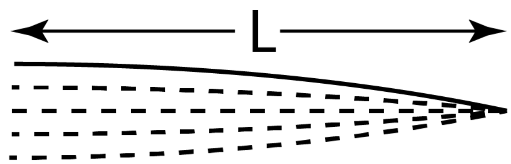
To clarify this, as long as your curve is 0 at L/2, shows a maximum value at 0 and L, is never negative, is not horizontal, and is symmetric around L/2, you get full points. In other words, the exact shape of your drawn curve is not graded and they do not expect you to know exactly what the shape of the curve should be. So, do not freak out if you do not fully understand how to draw a graph. Sometimes, you will only know specific locations and have to interpolate from there.



(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.

(d)

Now that the tube is closed on one end, the closed end is a displacement node, and the open end is still a displacement antinode. Again, when resonating at its fundamental frequency, the standing wave created will have the longest possible wavelength to create a standing wave pattern in this tube, therefore, there will be no other displacement nodes or antinodes in the tube and the standing wave pattern will look like this:



Here only one quarter of a wavelength fits in the length of the tube. And we can calculate the new fundamental frequency of the tube using the new speed of sound:

$$L=\frac{1}{4}\lambda \Rightarrow \lambda = 4L \ \& \ v = f\lambda \Rightarrow f=\frac{v}{\lambda}=\frac{v}{4L}=\frac{1005}{(4)(0.332031)}=756.706\approx 760\text{Hz}$$