LABORATORY I
FORCES AND EQUILIBRIUM

In biological systems, most objects of interest are in or almost in equilibrium, either stationary or moving with a constant velocity. This important condition of equilibrium is the result of a balance among all of the different forces interacting with the object of interest. The development of problem solving skills to analyze forces under these situations is an important first step to understanding the interactions between the objects that make up any biological system.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Determine the conditions under which an object is in equilibrium.
- Determine the interrelationships among forces that result in the equilibrium of an object or system of objects.

PREPARATION:

Read Serway & Jewett: Chapter 1 (sections 1-10), chapter 4 (sections 1, 2, 5- 7), the paragraph at equation 6-13, chapter 10 (sections 5 and 6), and chapter 15 (section 4). It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. So, it is very important that you read the text before coming to lab.

Before coming to lab you should be able to:

- Identify the forces acting on an object.
- Write down the conditions satisfied by the forces acting on an object or a system of objects in equilibrium.
- Depict forces as vectors and break these vectors into components.
- Define the concept of torque and incorporate this concept into conditions satisfied by objects in equilibrium.
- Write down the relationship between the force exerted by a spring and its elongation.

PROBLEM #1: SPRINGS AND EQUILIBRIUM I

These laboratory instructions may be unlike any you have seen before. You will not find worksheets or step-by-step instructions. Instead, each laboratory consists of a set of problems that you solve **before coming to the laboratory** by making an organized set of decisions (problem solving) based on your initial knowledge. The instructions are designed to help you examine your thoughts about physics. These labs are your opportunity to compare your ideas about what "should" happen with what really happens. The labs will have little value unless you take time to predict what will happen and know your reasons for that prediction before you do something. In particular, **before you come to the laboratory** it is important to do your best to answer the **Prediction** and **Warm-up Questions**. This will help tell you, the other members of your group, and your TA where you need to learn something.

While in the laboratory, work as rapidly as possible but <u>take your time</u> to explore both the behavior of the equipment and your own ideas. It is important to get a “feel” for how the lab equipment operates. This will help you develop the intuition about the physical world that is necessary to effectively solve problems. It is very important to use the equipment to answer the qualitative **Exploration** questions before you begin making measurements. Complete the entire laboratory problem, including all **Analysis** and **Conclusions**, before moving on to the next one. *Remember, there is no benefit in just doing the measurements for a lab problem. The benefit lies in examining your ideas and comparing them with how things behave in the real world. This is why the labs are a key to doing well in the entire course. If you don’t see how the labs are connected to the material in the textbook, the lectures, the homework, or the exams, you are missing the point. Get help immediately***.**

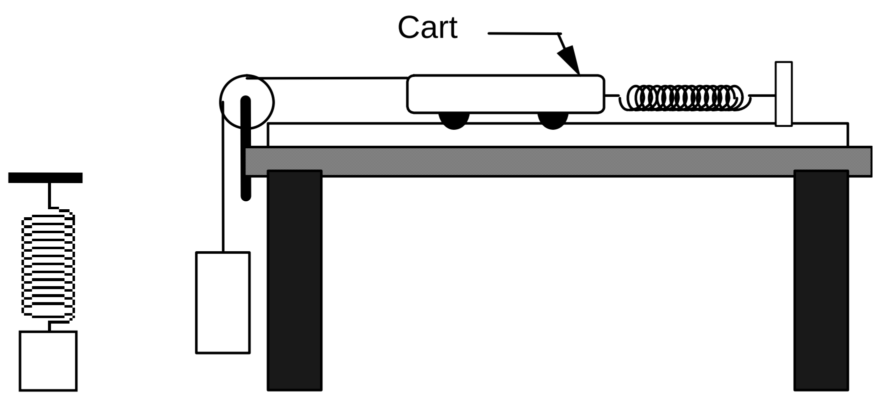
To help you become familiar with how to use the laboratory manual, this first problem contains both the instructions and an explanation of the various parts of the instructions. The explanation of the instructions is preceded by the double, vertical lines you see to the left of this paragraph. **Part of the design of these instructions is to make the laboratory problems easy to do if you understand what you are doing and very difficult to do if you do not**. If the laboratory manual is not clear to you then it is likely you do not understand some very important basic physics. That is your signal to learn what you need by reading the textbook (outside of lab), discussing your difficulties with your fellow students, and asking a TA or professor. If you ask your TA a question, it is likely that he or she will ask you questions in return to determine how you are thinking about the physics. Everyone has unique sets of experiences, learning styles, and ways of thinking. Your TA will try to help you develop yours. *Learning is not easy and no one can do it for you by just telling you the answer.*

The laboratory problem should allow you to answer the following questions that are important for meaningful learning. What is the point of doing this lab problem? How is it related to the real world? In the lab instructions, the first paragraphs describe a possible situation that raises the problem you are about to solve. This emphasizes the application of physics to situations that you might encounter.

You work for a biophysics research group studying the mechanics of DNA during cell division. One common technique involves securing one end of a DNA molecule to a surface and, with optical tweezers, measuring the force required to slightly straighten the DNA molecule from its normal coiled state. The optical tweezers exert a force on a tiny bead which has been attached to the free end of the DNA molecule. The group is concerned that the bead’s mass could affect the DNA’s response to the pulling force. The DNA molecules are expected to behave much like mechanical springs in this situation, so you decide to use a spring as a macroscopic model of DNA. You decide to calculate, and then measure, how much a spring stretches when it is subjected to external forces in two situations, which correspond to pulling on the DNA with and without a bead. In each situation, a force is exerted by a hanging object whose mass can be changed. In the first situation the object will hang directly from the spring, which will be suspended from a table. In the second situation the object will hang from a light string, which runs over a pulley and is attached to a medium-sized cart on a horizontal track. One end of the spring will be attached to the cart and the other end to an end-stop, itself attached to the track.

EQUIPMENT

To make a prediction about what you expect to happen, you need to have a general understanding of the apparatus you will use before you begin. This section contains a **brief** description of the apparatus and the kind of measurements you can make to solve the laboratory problem. The details should become clear to you as you use the equipment.



You will have a spring, a mass hanger and set of masses, a PASCO cart, cart weights, an aluminum track, an end-stop, a piece of string, and a meter stick.

PREDICTION

Everyone has "personal theories" about the way the world works. One purpose of this lab is to help you clarify your conceptions of the physical world by testing the predictions of *your personal theory* against what really happens. For this reason, you will always predict what will happen *before* collecting and analyzing the data. **Your prediction should be completed and written in your lab journal *before* you come to lab.** The purpose of the "Warm-up Questions" is to help you decide how to apply some important knowledge to build a prediction. If you cannot initially complete the prediction or are not sure if it is correct, the "Warm-up Questions" are designed to help. They should also be completed before you come to lab. **Try to answer the Prediction question first using your best understanding of the text reading. This first attempt tells you about your initial level of understanding of the material. Next answer the Warm-up Questions. These questions focus on some of the knowledge involved in making a correct prediction. After answering the Warm-up Questions, answer the Prediction question again. If you have changed your answer, determine what knowledge resulted in that change. If you cannot answer a Warm-up Question to your satisfaction, get help on that point from the textbook, lecture notes, fellow students, TAs, or the professor before going to lab.**

You will spend the first few minutes at the beginning of the lab session comparing your Prediction with those of your partners. Discuss the reasons for any differences in opinion. If you disagree, compare the answers to your Warm-up Questions. This might help pinpoint the difficulty. It is not necessary that your predictions are correct, but **it is necessary that you understand the basis of your prediction**. Your predictions represent your best determination of your own knowledge at the beginning of each lab session.

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. This equation will be a relationship between the extension of a spring (the distance it stretches) and the force exerted by an object to stretch the spring, in each situation described in the problem (when the system has reached equilibrium). Illustrate each relationship with a graph of the hanging object's *spring extension vs. weight*.

In this case, the prediction asks for a quantitative mathematical relationship. Occasionally, your prediction is a qualitative statement, drawing, or graph based on your current knowledge of the physical world. Even if no calculation is involved you still must carefully apply your knowledge and experience using systematic logical reasoning. For other problems, you will be asked to build on this knowledge of the concepts and principles of physics to calculate a mathematical relationship between quantities in the experimental problem. Always write down a logical procedure that goes from basic physics principles to your solution equation. Also make sure to write down any assumptions you need to make.

WARM-UP QUESTIONS

Warm-up Questions are intended to help you solve the experimental problem. They either help you make the prediction or help you plan how to analyze data. **The answers to the Warm-up Questions should be written in your lab journal and turned in *before* you come to lab.** If you completely understand the physics of these labs, you should find these questions simple and sometimes thought provoking. If you do not, they may appear incomprehensible. *If you get stuck or are not sure of an answer, get help. When you have finished the laboratory,* ***go back through the Warm-up Questions to see if they make more sense to you****. If not, get help.*

Read Serway & Jewett, sections 4.4 - 4.7 (through Quick Quiz 4.9), and the paragraph at equation 6-13 before attempting to answer these questions.

1. Draw a picture of a spring attached to a hanging object. On your picture, show and label the extension (distance stretched) of the spring.
2. Draw and label all the forces acting on the hanging object.
3. What condition must be satisfied by the forces acting on an object in equilibrium? Write the equation to express that for the hanging object. How do you know the object is in equilibrium?
4. Write an equation that relates the spring's stretch to the force it exerts. How does the force exerted by the spring on the hanging object relate to the force exerted by the hanging object on the spring? Use this equation and the result of the previous step to write down the relationship between the extension of the spring and the force exerted on the spring by the weight of the hanging object. Sketch a graph of *spring extension vs. weight*.
5. Draw a picture of a horizontal spring with one end connected to a cart and the other to a string which is in turn connected to a hanging object, as illustrated in the Equipment section. Identify all the forces acting on the hanging object; indicate them on the picture as vectors and label them. Repeat for the forces acting on the cart. What do you assume about the size of the force exerted by the string on the cart and the string on the hanging object? How do you justify this assumption?
6. Write an equation to express the equilibrium condition for the forces acting on (a) the hanging object and another equation for (b) the cart. Use these equations, together with the equation that gives the relationship between a spring's extension and the force it exerts, to write an equation for the relationship between the extension of the spring and the weight of the hanging object in the second situation. Sketch a graph of *spring extension vs. weight.* Is this graph the same, or different from the graph you drew in question 4?

EXPLORATION

This section is extremely important—many instructions will not make sense, or you may be led astray, if you do not take the time to carefully explore that your equipment actually works and to devise a plan for taking data before you actually take data.

In this section you practice with the equipment before you make time-consuming measurements that may not be valid. This is where you carefully observe the behavior of your physical system to see if it qualitatively matches your expectations. Remember to treat the equipment with **care and respect**. Your fellow students in the next lab section need to use the equipment after you are finished with it. If you are unsure about how anything works, ask your lab instructor.

Most equipment has a range in which its operation is simple and straightforward. This is its range of reliability. You can quickly determine the range of reliability by making **qualitative** observations at what you consider to be the extreme ranges of your measurements. Record your observations in your lab journal. If you observe that the equipment does not function as you expect for the range of quantities you were considering measuring, modify your experimental plan before you waste time taking an invalid set of measurements.

The result of the exploration should be a plan for doing the measurements that you need. **Record your measurement plan in your journal.**

Select spring(s) and a series of weights that give a usable range of displacements. The largest weight should not pull a spring past its elastic limit (about 60 cm for the large springs). Beyond that point the spring does not return to its original unstretched length is permanently damaged. Decide on a procedure to measure the extension of the spring in a consistent manner, and describe in your lab notebook why it is a reasonable procedure. Decide on how many measurements using different masses you will need to test your prediction.

MEASUREMENT

Now that you have predicted the result of your measurement and have explored how your equipment behaves, you are ready to make careful measurements. To avoid wasting time and effort, make the minimal measurements necessary to convince yourself and others that you have solved the laboratory problem.

When the spring is vertical, make a series of measurements of the mass of the hanging object and the extension in the spring in a stationary state. Repeat for the case in which the spring is horizontal and connected to a cart. To see the effect of the cart's mass, make additional measurements with mass added to the cart. As a check, make measurements with the cart removed so the string that goes over the pulley is connected directly to one end of the horizontal spring.

Estimate the uncertainty in measuring the extensions. How does friction in the pulley and in the cart affect your measurement? Is it significant?

ANALYSIS

Data alone is of very limited use. Most interesting quantities are those *inferred* from the data, not direct measurements themselves. The Analysis is where you extract the essence of your data from the measurements. This analysis may be qualitative or quantitative. The analysis also includes your evaluation of the limitations of doing the best possible measurement with the equipment you have. (For example, can you tell if two measurements are really different quantities even if you measure different numbers for them?)

Always complete your analysis before you take your next set of data. If something is going wrong, this will prevent you from wasting time taking useless data. After analyzing the first collection of data, you may need to modify your measurement plan and re-do the measurements. If you do, be sure to **record how you changed your plan in your journal**.

From your measured values of the hanging object's mass, calculate its weight. Use a spreadsheet program (such as Excel on the computer at your lab workstation) to make a graph of the extension of the spring against the weight of the hanging object for the first situation (hanging mass only). Similarly, make a graph of the spring extension versus the weight of the hanging object for the situation with the cart, string, pulley, and hanging mass. Examine the shape of the graphs. If the points in a graph seem to fall on a line, estimate the slope of that line, with appropriate units. From your predicted equation, explain the physical significance of the slope. What is the slope if you reverse the axes and plot a graph of *weight vs spring extension*? Why don't all of the data points fall exactly on your line?

CONCLUSION

After you have analyzed your data, you are ready to answer the experimental problem. State your result in the most general terms supported by your analysis. **This should all be recorded in your journal in one place before moving on to the next problem assigned by your lab instructor. Make sure you compare your result to your prediction.**

What can you say, based on your measurements, about the relationship between the extension of the spring and the weight of the hanging object each case? Compare the relationships for the two cases. Was the slope of your graphs the same for the situation without the cart and the situation with the cart? Did you find that the stretch of a horizontal spring is the same as a vertical spring? How did the mass of the cart affect the extension of the spring? Did your prediction agree with your measurements within the uncertainties of your measurement? If not, why?

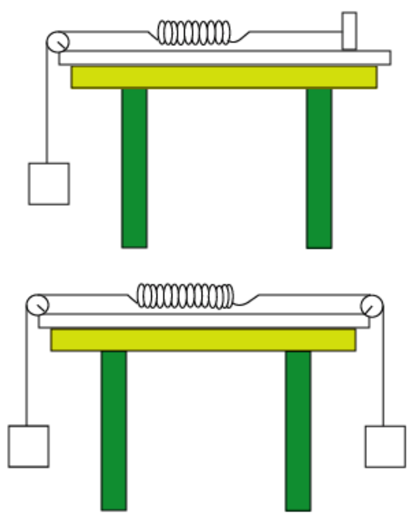
Was there a "minimum" force required to stretch your spring beyond its unstretched length? If so, write a brief justification for how you dealt with that in your measurements and analysis.

What conclusions can you draw about the corrections you will have to make for the bead's mass on the DNA measurement described in the original problem?

PROBLEM #2:
SPRINGS AND EQUILIBRIUM II

You are a cellular biologist investigating treatments for genetic diseases weakening the fibrous connective tissue that forms tendons. The cells act something like little springs, and to test their strength you are designing an experiment in which individual cells are attached to a fixed surface while a force is applied to the other end. By measuring how much the cell stretches in response to a force of a certain size you can get a measure of its elastic strength. You worry that your experiment is different what happens in the body, where a cell experiences forces exerted by neighboring cells at each end. You need to decide if a cell pulled at one end would stretch only half as much as one pulled at both ends, if all the pulling forces are equal. For that reason, you model the two possibilities using a spring in place of the cell and hanging objects to exert the pulling forces.

EQUIPMENT



You will have a spring, two mass hangers and masses, an aluminum track, two pulleys, an end-stop, string, and a meter stick.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.   What will you compare in the two situations?

WARM-UP QUESTIONS

Read Serway & Jewett, sections 4.4 - 4.7 (through Quick Quiz 4.9), and the paragraph at equation 6-13 before answering these questions.

1. Draw a picture of a spring attached to a hanging object by a string over a pulley on one end and an end stop on the other. On your picture, show and label the extension of the spring.
2. Draw and label all the forces acting on the hanging object, the spring, and the string.
3. What condition must be satisfied by the forces acting on an object in equilibrium? Write the equation to express that condition for the hanging object, another equation for the spring, and a third equation for the string.
4. Use Newton's third law to identify pairs of forces, ACTING ON DIFFERENT OBJECTS, that must have equal magnitudes.
5. Write an equation that relates the extension of a spring to the force it exerts. Use this equation and the result of the previous steps to write down the relationship between the extension of the spring and the weight of the hanging object. Sketch a graph of *spring extension vs. weight*.
6. Draw a picture of a spring connected over pulleys to two hanging objects of equal weight, as in the second illustration in the Equipment section. Repeat the above steps, this time for *both* hanging objects and strings. Write a relationship between the extension of the spring and the weight of **one** of the hanging objects in this situation, and briefly describe your reasoning. Sketch a graph of *spring extension vs. weight* for this situation. How is the displacement of each hanging mass related to the spring extension?

EXPLORATION

Select springs and a series of weights that give a usable range of displacements. The largest weight should not pull a spring past its elastic limit (about 60 cm for the large springs). Beyond that point the spring will be permanently damaged. Decide on a procedure to measure the extension of the spring in a consistent manner. Decide how many measurements using different masses and corresponding extensions you need to test your prediction. Decide how many different masses you should use in order to make a reasonable graph of the extension of the spring versus weight of the hanging object.

MEASUREMENT

For the two cases, make measurements of the weights of the hanging object(s) and the extension in the spring.

Estimate the uncertainty in measuring the spring extension. How significant is friction in the pulley?

ANALYSIS

For each case, make a graph of the extension of the spring against the weight of the hanging object. Examine the shape of each graph. If the points seem to follow a line, estimate the slope of the line. Clearly indicate the units of this slope. How is this slope related to an important property of a spring? Compare the slope for the different cases.

CONCLUSION

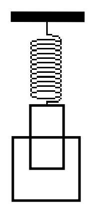
By how much does the spring in the first case stretch compared to the spring in the second case with equal weight hanging objects? Did your measurements agree with your predictions? If the measurement disagreed with your prediction, re-examine the steps that led to your prediction as well as to the analysis of your data.

How many forces acted on the spring in the first case; how many in the second case? How much a cell will stretch if only one force is acting on it?

PROBLEM #3:
FORCES AND LIQUIDS

While working with a sports medicine group, you are investigating the use of swimming pools for physical therapy. Being underwater gives a sense of "reduced weight", which can be useful for injured athletes who exercise in the pool as part of their rehabilitation. You know that the gravitational force on a person doesn't change as you stay on the surface of the earth, so the sense of reduced weight must result from a force exerted by the water. One of your co-workers believes that this force depends on the amount of a person's mass that is submerged while another claims that only the person's submerged volume is important. This is important because you need to know if the effect is the same for different people. To resolve this dispute, you calculate the size of this force as a function of the amount of the person's body that is underwater.   Your next step is to test your calculation in the laboratory. You decide to use a small object hanging on a spring and measure the extension of the spring when different fractions of the object are submerged in water. To see if the effect is due to volume or mass, you repeat the measurements using a second object of the same size but different mass.

EQUIPMENT



You will have a container of water and several cylinders that are the same size but different masses. You will also have a spring, string, meter sticks, calipers, a triple-beam balance, and a stand.

PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. This equation will be a relationship between the force of the water on the object, the spring's equilibrium extension, and the object's weight. Write another relationship that shows how that force depends on the submerged volume of the object.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 4.4 - 4.7 (through Quick Quiz 4.9), the paragraph at equation 6-13, and 15.4.

1. Draw a picture of the object hanging on a spring with no water involved. Indicate all the forces acting on the object. Write down the condition satisfied by the forces acting on the object. Write a relationship between the weight of the object and the extension of the spring in equilibrium.
2. Draw a picture of the object hanging on a spring, with a portion of the object submerged in water. Label all the forces acting on the object.
3. Calculate the force exerted by the water on the partially submerged object. To do so, it may help to imagine replacing the underwater volume of the object with water at equilibrium. What force must the rest of the water exert on this volume of water to maintain equilibrium? How is that related to the force exerted by the water on the submerged object?
4. Write down the conditions satisfied by the forces acting on the object immersed in water. What is the relationship between (a) the volume of the submerged portion of the object and (b) the extension of the spring?

EXPLORATION

Select a spring and a series of objects that give a usable range of displacements. The largest mass should not pull a spring past its elastic limit (about 60cm for the large springs). Beyond that point the spring is damaged permanently. Decide on a procedure to measure the extension of the spring in a consistent manner.

Decide on a procedure to change the submerged volume of the object in a measurable way. Decide on how many measurements using different masses and submerged volumes you will need to test your prediction. Decide how you will measure the spring constant for the spring that you use.

MEASUREMENT

Determine the spring's spring constant by taking new measurements or using the value you found in a previous lab problem with the same spring.

Make measurements of the masses of the object, the volume of the submerged portion, and the induced extension in the spring. Repeat for enough volumes (and masses) to convince others of your results.

ANALYSIS

Graph the extension of the spring versus the mass of hanging object with no water involved. For each object, graph the extension of the spring versus volume submerged. Repeat for the extension of the spring versus the submerged mass. If the graphs resemble lines, estimate their slopes and determine their physical significance, using your prediction equation as a guide. Be sure to estimate uncertainty.

CONCLUSION

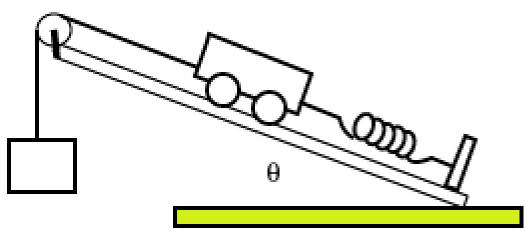
What do your measurements reveal about the relationship between volume submerged and the extension of the spring? Do your measurements agree with your predictions?

How is the stretch of the spring related to an athlete's "perceived weight"? If you wished to reduce an athlete's "perceived weight" by a particular amount, what would you need to know in order to determine the appropriate depth of the pool for that person? Explain.

PROBLEM #4:
LEG ELEVATOR

You are a consultant to a medical technology company evaluating an inexpensive traction system for exerting a predictable force at the location of a patient's leg injury. The device consists of a foot-strap connected to a weight by a rope that goes over a pulley. You are worried that the force exerted on the injury will change when the angle of the leg changes. As a first step in understanding the situation, you decide to model the portion of the patient's leg below the injury with a cart on an inclined track. You attach the cart to the bottom of the track with a spring so you can determine the force on the cart. The traction device is simply a string attached to the cart which goes over a pulley at the end of the track where it is attached to an object hanging straight down. You have been asked to calculate the force that the spring exerts and to predict how it will depend on the angle of the track. You will then test your calculation in the lab, by building the model.

EQUIPMENT



You will have a mass hanger and masses, a cart and cart masses, string, springs, an end stop, a cart track, blocks for varying the track angle, and a meter stick.

PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant?

WARM-UP QUESTIONS

Read Serway & Jewett, 1.7, 1.10, 4.4 - 4.7 (through Quick Quiz 4.9), the paragraph at equation 6-13

1. Draw a picture of the cart, spring, hanging weight and inclined track arranged as in the figure. Draw a convenient coordinate system to serve as a reference for the orientation of forces.
2. Draw and label the forces acting on the cart. Draw and label the forces acting on the hanging object (counterweight). How does the force exerted on the string by the hanging object relate to the force exerted on the cart by the string?

3. Draw a free-body diagram of the cart. Check to see that it is possible that the cart is in equilibrium. Transfer the force vectors to a coordinate system so that you can easily find the components of the forces.
4. Write down the equations that give the condition of equilibrium of the cart and the counterweight. Remember to write a separate equation for force components along each axis of your coordinate system.
5. Calculate the magnitude of the force exerted by the spring on the cart, as a function of the mass of the hanging object, the mass of the cart, and the angle of the track. For data analysis, it will be useful to calculate the amount the spring stretches, rather than the force exerted on the spring, so write an equation for the spring stretch as well.
6. Sketch a graph of *spring stretch vs. track angle*, for constant masses. Does the stretch ever equal zero? If so, under what conditions?

EXPLORATION

Select a spring and a series of weights that give a usable range of displacements. The largest weight should not pull a spring past its elastic limit (about 60cm for the large springs). Beyond that point the spring will be permanently damaged. Check the effect of removing the cart and connecting the spring directly to the hanging object via the string.

Decide which quantities you should change to test your prediction, and make a plan to change them systematically, so that you can observe the effect of changing one while the others remain constant.

Decide on a procedure to measure the extension of the spring in a consistent manner. Decide on a procedure to measure the angle or slope of the inclined track. Decide on how many measurements using different inclinations or masses you will need to test your prediction.

Decide how you will measure the spring constant.

MEASUREMENT

Make measurements of the equilibrium extension in the spring when the slope or angle of the incline is varied. Measure the effects of adding weight to the cart and to the hanging object. Don't forget to measure your spring constant.

ANALYSIS

Graph the measured extension of the spring versus the angle of the incline. On the same graph, plot the predicted relationship for the same cart and hanging object. Repeat this for the extension vs. other quantities that you systematically changed.

CONCLUSION

How does the extension of the spring vary with the angle of the track? How does the extension of the spring vary with the mass of the cart? How does the extension of the spring vary with the mass of the hanging object? How well did your prediction agree with your measurements?

In which case will a change in the leg's elevation have a greater effect on the force exerted on a patient's injury site by this device – when the injury is very near the foot, or when the injury is near the hip? In which case will the mass of the patient's leg be most important? Explain, in terms of physics and the analysis of your experiment.

PROBLEM #5:
EQUILIBRIUM ON A WALKWAY

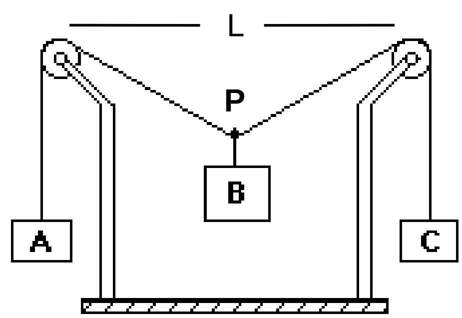
You have job with a research group studying the ecology of a rain forest in South America. To avoid walking on the delicate rain forest floor, the team members walk along a rope walkway that the local inhabitants have strung from tree to tree through the forest canopy. Your supervisor is concerned about the maximum amount of equipment each team member may carry to safely walk from tree to tree. If the walkway sags too much, the team member could be in danger, not to mention possible damage to the rain forest floor. You are assigned to set the load standards.

Each end of the rope supporting the walkway goes over a branch and then is attached to a large weight hanging down. You need to determine how the sag of the walkway is related to the mass of a team member plus equipment when they are at the center of the walkway between two trees. You know the distance between the two trees. To check your calculation, you decide to model the situation in the lab using the equipment shown below.

EQUIPMENT

The system consists of a central object, B, suspended halfway between two pulleys by a string. The whole system is in equilibrium. The picture below is similar to the situation with which you will work. The objects A and C, which have the same mass, allow you to determine the force exerted on the central object by the string.

For this investigation, you will need a meter stick, two pulley clamps, three mass hangers, string, and a mass set to vary the mass of objects.



PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant? Illustrate your calculation by graphing *distance sagged vs. the mass of the central object*, assuming other quantities remain constant.

WARM-UP QUESTIONS

Read Serway & Jewett, 1.7, 1.10, 4.5-4.7(through Quick Quiz 4.9), and the paragraph at equation 6-13.

1. Draw a free-body diagram of forces acting on object B. Do the same for objects A, C and point P. Point P may be treated as an object of zero mass.
2. Establish a coordinate system that you will use to break the forces into their components. Draw the forces on that coordinate system for object B.
3. From your force diagrams, write down the equations that describe the conditions for equilibrium of each object. Remember the components of vectors along each coordinate axis have their own equation.
4. How are the angles used in getting your force components related to the distance of sag which you want to find out and the distance between the pulleys which you know?
5. Check that the expression you obtained is reasonable by determining the largest possible value for the mass of object B. What happens if this mass is greater than or equal to that value?

EXPLORATION

Start with the string suspended between the pulleys (no central object), so that the string looks horizontal. Attach a central object and observe how the string sags. Decide how you will measure the vertical position of the object.

Try changing the mass of objects A and C (keep them equal for the measurements, but *explore* the case where they are not equal).

Do the pulleys behave in a frictionless way for the entire range of mass that you will use? How can you determine if the assumption of frictionless pulleys is a good one?

Add mass to the central object to decide what increments of mass will give a good range of values for the measurement. Decide how many measurements you will need to make.

MEASUREMENT

Measure the vertical position of the central object as you increase its mass. Record the uncertainty for each measurement. Determine what happens when object B is has its maximum mass.

ANALYSIS

Make a graph of the vertical displacement of the central object as a function of its mass, based on your measurements. On the same graph, plot the predicted relationship.

Where do the two curves match? Where do the two curves start to diverge from one another? What does this tell you about the system? What are the limitations on the precision of your measurements and analysis?

CONCLUSION

What will you report to your supervisor? How does the vertical displacement of an object suspended on a string between two pulleys depend on the mass of that object? Did your measurements of the vertical displacement of object B agree with your initial predictions? Explain any discrepancies. State your result in the most general terms supported by your analysis.

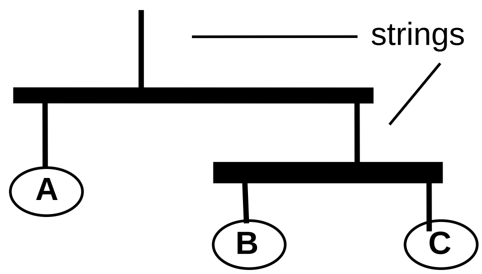
What information would you need to apply your calculation to the walkway through the rain forest?

PROBLEM #6:
DESIGNING A MOBILE

While volunteering at a hospital you are asked to design a mobile for the hospital nursery. Your design includes 5 pieces of string, two identical rods, and three objects with unknown masses. The first rod hangs from the ceiling. One object hangs from a string attached to one end of the rod; the second rod hangs from a string attached to its other end. An object hangs from a string at each end of the second rod. Your instructions are to balance the rods, but selecting the three objects is up to you. You know that the pivot point from which each rod hangs will depend on the hanging objects, and decide to prepare yourself for anything by writing an equation that relates the position of the pivot points to the masses of the rods, the length of the rods, and the masses of the three objects.

EQUIPMENT

You will have two wooden rods, some string, and three objects (A, B, and C) of different masses. Your mobile should use all these parts.



One metal rod and one table clamp will be used to hang the mobile. You will also have three mass hangers and one mass set.

PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant?

WARM-UP QUESTIONS

Read Serway & Jewett sections 10.5 and 10.6

1. Draw a mobile similar to the one in the Equipment section. Establish your coordinate system. Identify and label the masses and lengths relevant to this problem. Draw and label all the relevant forces.

2. Draw a free-body diagram for each rod showing the location of the forces acting on the rods. Identify any forces related by Newton's third law. Choose the axis of rotation for each rod (your pivot point). Identify any torques on each rod.

3. What is the net torque on an object when it is in equilibrium? What is the sum of the forces acting on an object when it is in equilibrium? For each free-body diagram, write down the conditions for equilibrium in terms of the specific quantities you have defined.
4. Identify the target quantities you wish to determine. Use the equations collected in step 3 to plan a solution for the target. If there are more unknowns than equations, reexamine the previous steps to see if there is additional information about the situation that can be expressed in an additional equation. If not, see if one of the unknowns will cancel out.

EXPLORATION

Collect the necessary parts of your mobile. Find a convenient place to hang it. Decide on the easiest way to determine the position of the center of mass of each rod.

Will the length of the strings for the hanging objects affect the balance of the mobile? Test and explain the result. Where will you put the heaviest object? The lightest?

Decide what measurements are needed to check your prediction. If any assumptions are used in your calculations, decide on the additional measurements needed to justify them. Outline your measurement plan.

MEASUREMENT

Measure and record the location of the center of mass of each rod. Also, measure and record the mass of each rod and the mass of the three hanging objects. Use your prediction to assemble the mobile, and adjust if necessary so the mobile balances. Measure (with uncertainties) the locations of the strings holding up the rods.

Is there another configuration of the three objects that also results in a stable mobile?

ANALYSIS

Calculate the differences between your measured results and the predictions. Are those differences probably due to measurement uncertainty, or are they due to some systematic error?

CONCLUSION

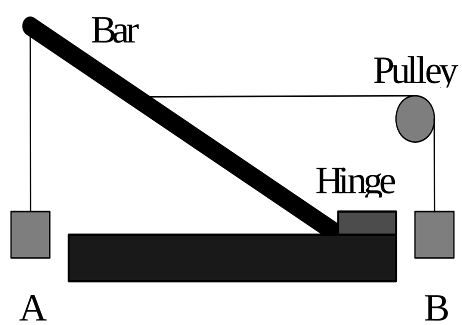
Did your mobile balance as designed? What corrections did you make to get it to balance? Were these corrections a result of measurement uncertainty, or was there a difficulty with your prediction or your measurement plan? Explain why the lengths of the strings were or were not important to the mobile design. Did your prediction work for just one design, for more than one design, or for zero designs?

PROBLEM #7:
MECHANICAL ARM

You have been hired as part of a team to design a mechanical arm as a model for future prosthetics. To begin the project you evaluate several simple designs that test specific features needed in the final device. The first is designed for lifting small objects. The arm is a steel bar of uniform thickness with one end attached to the base by a hinge (elbow) that allows it to rotate in the vertical plane. Near the other end of the arm is a cable that supports a small weight. The arm is supported at an angle to the horizontal by another cable, intended to mimic a bicep muscle. One end of the support cable is attached to the arm and the other end goes over a pulley. That other end is attached to a counterweight that hangs straight down. The pulley is supported by a mechanism that adjusts its height so the support cable is always horizontal. Your task is to determine how the angle of the arm to the horizontal changes as a function of the weight of the object being lifted. The mass of the arm, the mass of the counterweight, the attachment point of the support cable and the attachment point of the lifting cable have all been specified for your model. You will test your calculations in the laboratory, with the equipment shown below.

EQUIPMENT

You will have an aluminum bar, a pulley, a pulley clamp, two mass hangers, a mass set, and some strings.



PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant? Illustrate your calculation with a graph.

WARM-UP QUESTIONS

Read Serway & Jewett sections 10.5 and 10.6

1. Draw an arm similar to the one in the Equipment section. Establish your coordinate system. Identify and label the masses and lengths relevant to this problem. Draw and label all the relevant forces.

2. Draw a free-body diagram for the bar showing the location of the forces acting on it. Label these forces. Choose the axis of rotation. Identify any torques on the rod.

3. Write down the conditions for equilibrium (rotational and translational) using specific variables you have defined.

4. Identify the target quantities you wish to determine. Use the equations collected in step 3 to plan a solution to obtaining the target(s). If there are more unknowns than equations, reexamine the previous steps to see if there is additional information about the situation that can be expressed in an additional equation. If not, see if one of the unknowns will cancel out.

5. Use your equation to sketch a graph of the arm angle vs. the weight being lifted assuming all other quantities are constant. Is this what you expect? (If you add more weight to be lifted by the arm, do you need to increase or decrease the angle to maintain equilibrium?)

EXPLORATION

Build your device. Pay attention to the adjustments that make it stable or unstable. Decide on the easiest way to determine where the center of mass is located on the bar. How will you measure the angle?

Determine where to attach the lifting cable and the support cable so that the arm is in equilibrium for the weights you want to hang. Try several possibilities. If the bar tends to lean to one side or the other, try putting a vertical rod near the end of the bar to keep it from moving in that direction. If you do this, what effect will this vertical rod have on your calculations?

Does the length of the strings for the hanging weights affect the balance of the bar? Why or why not? Outline your measurement plan.

MEASUREMENT

Make all necessary measurements of the configuration when it is in equilibrium. Vary the mass of object A and determine the angle of the bar when the system is in equilibrium. Remember to adjust the height of the pulley to keep the support string that hangs object B horizontal for each case. Is there another configuration of the three objects that also results in a stable configuration?

ANALYSIS

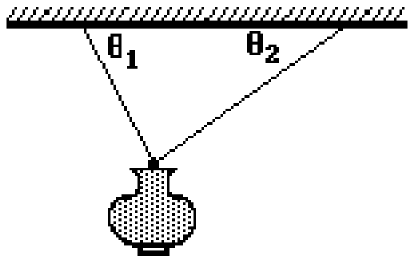
Make a graph of the bar's angle as a function of the weight of object A. What happens to that graph if you change the mass of object B? The position of the attachment of the support cable to the bar?

CONCLUSION

Did your arm balance as designed? What corrections did you need to make to get it to balance? Were these corrections a result of some measurement error, or was there a mistake in your prediction? Explain why the string lengths were (or were not) important for this experiment.

☑ CHECK YOUR UNDERSTANDING

1. A lamp is hanging from two light cords. The cords make unequal angles with the ceiling, as shown in the diagram at right.



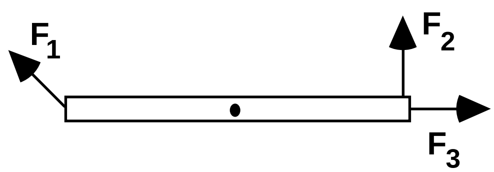
a. Draw the force diagram of the *lamp*. Clearly describe each force drawn.

b. Is the horizontal component of the pull of the left cord on the lamp greater than, less than, or equal to the horizontal component of the pull of the right cord on the lamp? Explain your reasoning.

c. Is the vertical component of the pull of the left cord on the lamp greater than, less than, or equal to the vertical component of the pull of the right cord on the lamp? Explain your reasoning.

d. Is the vertical component of the pull of the left cord on the lamp greater than, less than, or equal to half the weight of the lamp? Explain your reasoning.

2. A long stick is supported at its center and is acted on by three forces of *equal* magnitude, as shown at right. The stick is free to swing about its support. $\mathbf{F_2}$ is a vertical force and $\mathbf{F_3}$ is horizontal.



   a. Rank the magnitudes of the torques exerted by the three forces about an axis perpendicular to the drawing at the *left* end of the stick. Explain your reasoning.

   b. Rank the magnitudes of the torques about the *center* support. Explain your reasoning.

   c. Rank the magnitudes of the torques about an axis perpendicular to the drawing at the *right* end of the stick. Explain your reasoning.

   d. Can the stick be in translational equilibrium? Explain your reasoning.

   e. Can the stick be in rotational equilibrium? Explain your reasoning.

TA Name:______________________________

PHYSICS 1201 LABORATORY REPORT

Laboratory I

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ________________________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: _________

Grading Checklist	Points*
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up questions completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.