

Visual Physics 218 – Forces & Acceleration [Lab 3]

In this experiment, you will be evaluating the vector nature of forces and Newton's 2nd Law of Motion using a free-body diagram. You will accomplish this by performing experiments involving both static and dynamic forces. We will also investigate how frictional forces affect the acceleration of an object in one-dimensional motion. The goal is to calculate the coefficient of friction between two dissimilar surfaces.

Pre-Lab

Read Chapter 4 and Chapter 5 from Young & Freedman's University Physics before you arrive to perform the lab. Study Newton's Laws of Motion and learn how to draw free-body diagrams. You need to understand how to write equations of motion from your free-body diagrams and solve these equations for one of the variable parameters. In addition, you need to learn how to evaluate surface-to-surface frictional forces. You should have completed Lab 0, Lab 1, and Lab 2 and know how the position of the camera can affect your data.

Questions to be answered in your lab journal:

1. You will be using spring gauges to measure tension. These work in the same manner as a scale with a hanging tray to measure the weight of small objects at the supermarket (non-electronic). Explain how these manual weight scales work that use tension to measure weight.
2. What is meant when it is said that forces are in equilibrium? Write the most general equations of motion for forces in equilibrium in three dimensions.
3. What is the coefficient of friction μ ? What is its numerical range? Can it be greater than one? Can it be less than zero? Does it depend on surface area?

Experiment 1

In experiment 1, you will be assembling spring gauges into a specific configuration on a large square pegboard. The forces on the gauges will be recorded and used to calculate the angles between the gauges. A short video will be captured as well and the distances between the gauges will be used to calculate the angles. You will compare your results between the two different methods. To obtain the distances between the gauges, you will learn how to use a new feature in LoggerPro called *Photo Distance*. Don't forget to note all the gauge readings and dimensions in your lab journal since you will have no text files from Experiment 1 to take home with you.

Procedure:

1. You will find a large white pegboard on the end of the lab table (the end away from the computer). There will also be 3 spring gauges, a washer (or ring), 3 pegboard hooks, and a pulley/clamp and meter stick. See Figure 1.

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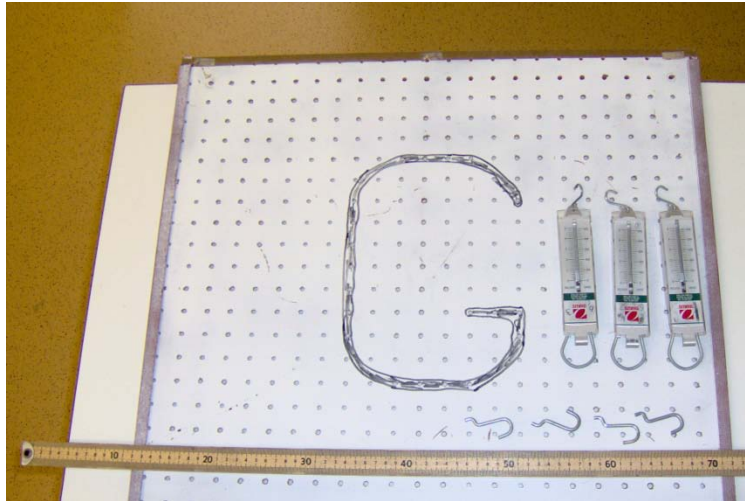


Figure 1

2. Zero out the spring gauges by sliding the front faceplate so that the zero tick mark is aligned with the lever when there is no weight hanging on the gauge.
3. Clamp the pulley to the end of the pegboard. Attach a pegboard hook and spring gauge on the pegboard and using string tied to the spring gauge, hang a 200 gram mass to the other end of the string such that the string is over the pulley and the mass hangs off the table. See Figure 2. This is to test the accuracy of the gauge. If the gauge does not read 200 grams, then adjust the faceplate of the gauge. Also ensure that the gauge reads zero with no weight hanging on it after the adjustment. Do this for all three spring gauges. If a spring gauge cannot be adjusted to read 200 grams with a 200 gram mass hanging on it and read zero with no mass on it, let your TA know so he can find a replacement.

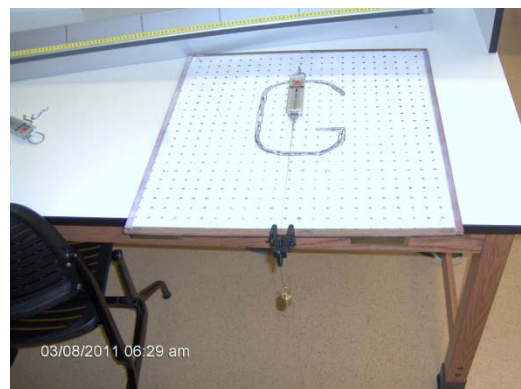


Figure 2

4. Assemble all three spring gauges into the “Y” configuration shown in Figure 3. It is highly advantageous that you ensure the angles as shown below are equal. Otherwise, the math to find the angles will be much more complicated.

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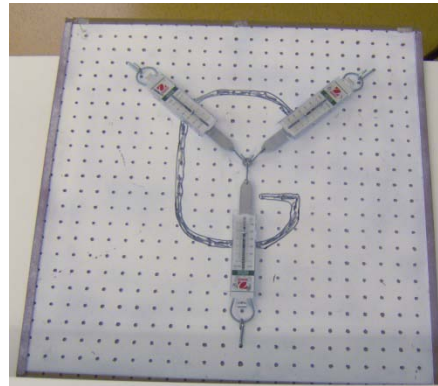
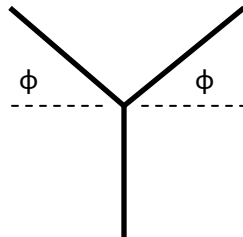


Figure 3

5. Position the camera above the pegboard. Place a meter stick in the camera image in order to accurately set the scale. Capture a quick video. Write down the spring gauge readings in your lab journal.
6. Now move the two spring gauges that are angled to two different angles. You can move each of them two holes further out and two holes further in for simplicity. See two possible configurations shown in Figure 4. Capture two more quick videos and write down the spring gauge readings in your lab journal. Be sure to associate the spring gauge readings with the correct configuration in your lab journal.

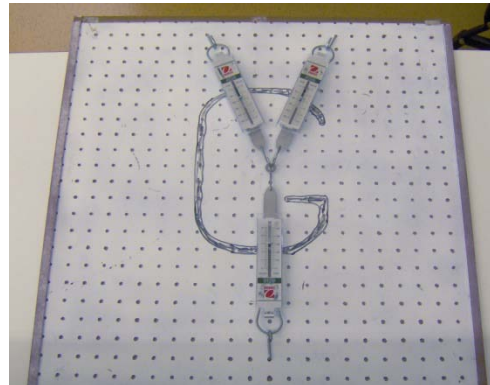
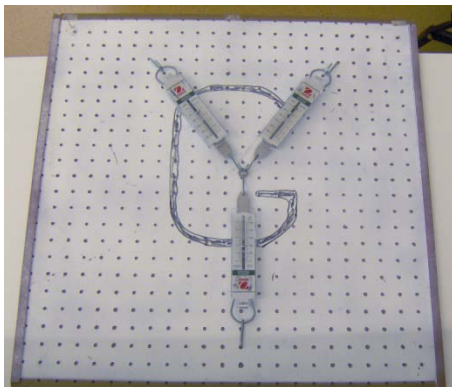
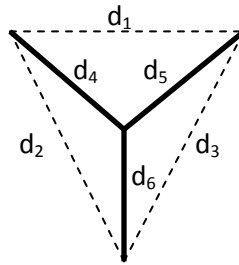


Figure 4

7. After all the movies for Lab 3 have been recorded for all three experiments, remove the memory card from the camera and insert the card into the computer. Copy the movies to your section folder under the C:\218Labs folder. Insert one of the three movies for Experiment 1 into a new LoggerPro sheet.
8. Use the *Set Scale* function and select two tick-marks on the meter stick as your distance. You need to find the distance between four points: the three end points of the "Y" and the center. This gives six separate distances you need to obtain off the video. See the diagram below:

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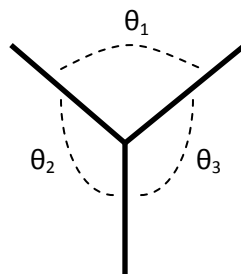


To find these six distances, select the fifth button down on the tool bar, *Photo Distance*. Click and hold down the left mouse button on the first point, then drag the cursor to the second point and release the mouse button. The distance between the points is shown in the units you set the scale. Do this for all six distances and write down the distances in your lab journal. Be sure to associate the distances with the appropriate configuration.

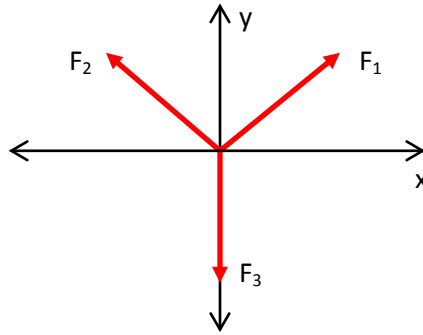
- Repeat step 8. for the remaining two videos. Place all the parts back to their appropriate locations on the lab table.

Questions to be answered in your Technical Memo:

1. You are going to calculate the angles using two different methods. First, calculate the angles θ_1 , θ_2 , and θ_3 as shown in the diagram below using the dimensions obtained from the video using the *Photo Distance* function. You will need to use some trigonometry (e.g. Law of Cosines) to find the angles. Clearly list your calculated θ_1 , θ_2 , and θ_3 in your TM. Do this for all three videos.



2. Now you are going to find the angles θ_1 , θ_2 , and θ_3 using the forces from the spring gauge readings. To do this you will need to sum the forces in the x and y directions, then solve your equations for θ_1 , θ_2 , and θ_3 . This is a static situation, so your equations will take the form:



$$\sum F_x = ma_x = m \cdot 0 = 0$$

$$\sum F_y = ma_y = m \cdot 0 = 0$$

Sum the forces in the x direction and sum the forces in the y direction. To do this you must find the x and y components of the three forces. This gives you two equations that you can solve for the angles you define and then find θ_1 , θ_2 , and θ_3 . Clearly list your calculated θ_1 , θ_2 , and θ_3 in your TM. Compare these with the angles found in 1. above using the dimensions. Do this for all three spring gauge “Y” configurations.

Experiment 2

In Experiment 2 you will study forces in dynamic situations and calculate the acceleration of an object in motion and compare this calculated acceleration with the acceleration determined directly from the video. The air cart will be set in motion on the frictionless air track by using a hanging weight and its motion captured on video. By drawing a free-body diagram of all the forces on the cart, the equations of motion can be solved for the unknown acceleration. From the movie, the acceleration can be determined directly from the velocity data as well. Videos will be captured with the air track raised at an angle but with different masses hanging and accelerating the cart, providing different accelerations.

Procedure:

1. Set up the air track, cart, 2 wood blocks and mass hanger (5g) **paper clips** as shown in Figure 5 (do not use the slotted masses). Get a length of string and secure one end to the cart and hang the paper clips(s) to the other end of the string (which goes over the pulley attached to the end of the air track). Turn the blower on and verify the control is set to maximum. Use the 2 wood blocks to elevate the track at the end where the mass is hanging. Measure or calculate this angle and the air track dimensions with a meter stick. Note this angle in your lab journal. Weigh the cart using the mass scales on the counter in the lab and note the weight in your lab journal.

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2. Place the mass hanger and three paper clips on the end of the string. Position the camera above the air track so that the velocity of the cart can be determined. Hold the mass up until you are ready to record the video, then let the mass free-fall and capture the motion of the cart to video.
3. Now place an additional two clips on the mass hanger and repeat step 2.
4. Finally, add the rest of the clips (about 3 more) on the mass hanger and repeat step 2.



Figure 5

5. After all the movies for Lab 3 have been recorded for all three experiments, remove the memory card from the camera and insert the card into the computer. Copy the movies to your section folder under the C:\218Labs folder. Insert one of the three movies for Experiment 2 into a new LoggerPro sheet.
6. Use the *Set Scale* function and select two tick-marks on the air track as your distance. Next, use the *Add Point* function and select the same point on the cart such that you have at least ten data points for the cart's motion. Now *Set Origin* and drag the origin of your coordinate axes to the first point selected. Rotate your axes so that the motion of the cart is aligned with the x-axis. Export your data to a text file and save the text file in your section folder. Remember to either save this text file to a USB flash drive or email this text file to yourself when you are finished with the lab.
7. Repeat step 6. for the remaining two movies.

Questions to be answered in your Technical Memo:

1. Determine the acceleration of the cart from your movies. Recall the acceleration between two discrete points can be determined from:

$$a = \frac{\Delta v}{\Delta t}$$

In your text file, you have data columns for the velocity v and time t , so to find the acceleration, you need to calculate the difference in the velocity and time from one data point to the next by subtracting adjacent cells in your Excel spreadsheet. Do this for all three movies and list all the accelerations for your movies in a table in your TM.

2. Now you are going to calculate the acceleration from a free-body diagram of the experiment. Draw the free-body diagram of the cart. The forces that need to be included are the weight of the cart using the mass of the cart m_c , the normal force on the cart, and the tension in the string. The cart is accelerating at the angle of the air track, which is considered frictionless. You will also need to draw a free-body diagram for the hanging weight on the mass hanger using the mass on the hanger m_w . The equations for the cart will take the form with rotated axes:

$$\sum F_x = m_c a_x = m_c a$$

$$\sum F_y = m_c a_y = m_c \cdot 0 = 0$$

The equation for the weight on the mass hanger will have the form:

$$\sum F_y = m_w a_y = m_w a$$

Solve these equations for the acceleration a , and compare this value with the values calculated from the movies.

Experiment 3

In Experiment 3, you will measure the coefficient of static friction μ_s and calculate the coefficient of kinetic friction μ_k between two similar surfaces. The experiment consists of placing wood blocks on a wood surface and finding the force that will just start the blocks in motion to determine μ_s , and then measuring the acceleration of the blocks on the video. From this data, the coefficient of kinetic friction μ_k can be calculated between wood and wood.

Procedure:

1. You will have a large wood board, pulley/clamp, masses and two wood blocks at your lab table. Weigh the wood blocks using the mass scales and note the result in your lab journal. Let the wood board hang (about 2 inches) over the edge of the lab table and clamp the pulley to the end of the wood board. Tie a length of string onto the wood blocks and tie the other end to the mass hanger. In this experiment, you will be using a mass hanger (50 grams) and adding masses to it. Run the string over the pulley. Place both blocks flat onto the wood board. Place a meter stick next to the wood board in order to set the scale. See Figure 6.

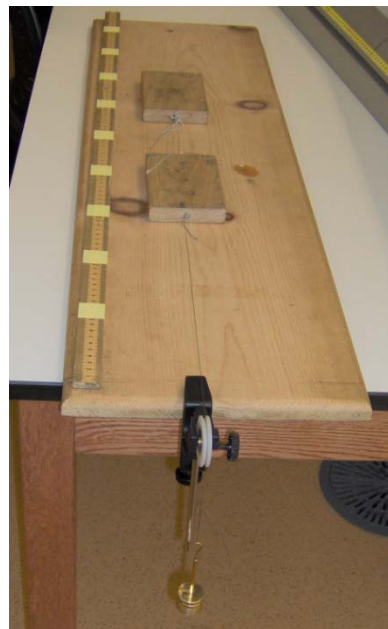


Figure 6

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2. Add mass to the mass hanger until the blocks just start to move. Note the mass on the mass hanger in your lab journal. Don't forget to include the mass of the hanger. This weight is the static frictional force f_s .
3. Flip both blocks over and repeat step 2.
4. Place one block on top of the other and repeat step 2. See Figure 7.
5. Now place both blocks onto the wood board as shown in Figure 6. Position the camera above the blocks so you can capture the motion of the blocks. Add about 20 grams more mass to the mass hanger than was required to just move the blocks. **(CAUTION – do not allow the blocks to hit the plastic pulley. This will damage and break the pulley.)** You want enough mass to accelerate the blocks. Capture the motion of the blocks to video.
6. Do the same and capture the motion of the blocks to video for the configuration of the blocks in step 3.
7. Repeat step 5. for the configuration of the blocks in step 4.
8. After all the movies for Lab 3 have been recorded for all three experiments, remove the memory card from the camera and insert the card into the computer. Copy the movies to your section folder under the C:\218Labs folder. Insert one of the three movies for Experiment 3 into a new LoggerPro sheet.
9. Use the *Set Scale* function and select two tick-marks on the meter stick as your distance. Next, use the *Add Point* function and select the same point on one of the blocks such that you have at least five data points for the block's motion. Now *Set Origin* and drag the origin of your coordinate axes to the first point selected. Rotate your axes so that the motion of the block is aligned with the x-axis. Export your data to a text file and save the text file in your section folder. Remember to either save this text file to a USB flash drive or email this text file to yourself when you are finished with the lab.
10. Repeat step 9. for the remaining two movies.

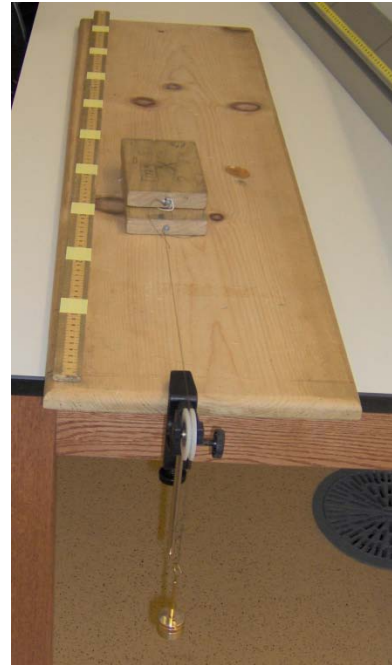


Figure 7

Questions to be answered in your Technical Memo:

1. Using your values of f_s measured for the three block configurations, calculate the coefficient of static friction μ_s . To do this, recall that the static frictional force f_s can be calculated from the

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normal force and coefficient of static friction μ_s . List the three calculated coefficients of static friction in your TM.

2. Now you are going to calculate the coefficient of kinetic friction μ_k . You need to determine the acceleration of the blocks from your movies first. Recall, the acceleration between two discrete points can be determined from:

$$a = \frac{\Delta v}{\Delta t}$$

In your text file, you have data columns for the velocity v and time t , so to find the acceleration, you need to calculate the difference in the velocity and time from one data point to the next by subtracting adjacent cells in your Excel spreadsheet. Now draw a free-body diagram of the blocks. The forces that need to be included are the weight of the blocks using the mass of the block m_b , the normal force on the blocks, the frictional force, and the tension in the string. You will also need to draw a free-body diagram for the hanging weight on the mass hanger using the mass on the hanger m_w . The equations for the blocks will take the form:

$$\sum F_x = m_b a_x = m_b a$$
$$\sum F_y = m_b a_y = m_b \cdot 0 = 0$$

The equation for the weight on the mass hanger will have the form:

$$\sum F_y = m_w a_y = m_w a$$

Substitute in your values for the acceleration a determined from the movies and solve these equations for the coefficient of kinetic friction μ_k . Do this for all three movies and list your three values for μ_k in your TM.

3. From your data, can you conclude whether the frictional force depends upon surface area? If the data in this experiment is in disagreement with what you know about the relation between friction and surface area, then what factors in this experiment can you attribute to this discrepancy between theory and experiment?

EQUIPMENT LIST FOR LAB 3:

- Camera (memory card and AC charger)
- Heavy duty stand with finger clamp
- Large white pegboard
- Three spring gauges
- Three pegboard clips
- Plastic pulley and clamp
- Mass hanger (50 gram) and masses
- Mass hanger (5 gram)
- Paper clips (5)
- Meter stick
- Air track and cart

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Large wood board

Small wood blocks (2 ea)

Mass scales (on sink table)

THINGS TO DO AT THE END OF THE LAB SESSION:

1. Replace the heavy stand, rod, clamp on the shelf of the lab table.
2. Replace the camera (with the LCD view finder window closed) on the shelf of the lab table.
3. The meter stick should be put on the shelf of the lab table.
4. The memory card should be left in the slot in the computer monitor.
5. The pegboard and wood board should be put neatly on the lab table or on the side of the table.
6. Put the spring scales, pulley, mass hangers and masses, and small wood blocks on the shelf of the lab table.