Laboratory 3
Dynamics and Free-Body Diagrams

Written October-November, 1986
by
Nancy Bronder '86, Tom Budka '89, Bob Hamwey GS, D. Mook
revised by Mook, K. Muenchinger '93 and E. Pleger '94 July-October 1991
and by Melissa Wafer '95 June 1993

You've learned about **kinematics**; you know what happens. The next logical question seems to be: why does it happen? That's where the study of **dynamics** comes in...

We know from Newton's First Law of Motion that any change in velocity, known as acceleration, is caused by an unbalanced **force**. The key to quantitatively understanding classical dynamics lies in understanding how forces act and how to represent them, Newton's Second Law states that $\mathbf{F} = m\mathbf{a}$. The forces that act on a body can be represented pictorially with a **free-body diagram**. This lab is meant to give you experience in applying Newton's Second Law and drawing and using free-body diagrams to analyze a variety of physical situations.

Overall GOAL: To use free-body diagrams to analyze and explain physical situations.

Part 1: The Elevator

GOAL: To determine the acceleration of the elevator in Fairchild.

Suggested reading: In preparation for this exercise you may want to look at pages 64 to 65 of the book The Way Things Work (on reserve in Kresge Library); some students have found these pages to be a big help.

Equipment: spring scale, 8 kilograms of masses, an elevator.

(A) Draw a free-body diagram of the mass on the scale while the whole system is at rest. Do you need to draw a different free-body diagram for the system moving at constant velocity? How about for the system while it is accelerating? Explain. (Hint: What causes acceleration?)

(B) Now draw three free-body diagrams to show the forces acting on the mass as the elevator ascends through the following stages: 1) speeding up, 2) constant velocity, and 3) slowing down. Label each as one of the following (keeping in mind that acceleration a is a **vector** quantity): a < 0, a = 0, or a > 0.

(C) Draw and label three free-body diagrams for the descending elevator, as well.

(D) Predict, based on your diagrams, what you think will happen to the reading on the scale as the elevator ascends and descends (through each of the three stages mentioned above). Explain why you think this will happen. It does not matter if your prediction is correct; what matters is the reasoning behind it.

(E) Test your predictions. Record the scale readings that you observe and calculate the acceleration of the elevator.

(F) Were your predictions correct? If not, how can you explain the discrepancy? What was wrong with the assumptions that you initially made? Here's a hint: Think of what the scale is really measuring. Explain in words what happens to the mass on the elevator. The important part is not that you guessed correctly in part D, but that you can now use the observations you made to explain what was faulty in your reasoning and to figure out what is really happening to the mass.

(G) Do you think the acceleration would be affected by the number of people inside the elevator or the distance it travels? Test this out and record your observations and conclusions.

(H) Could you figure out the speed of the elevator from the equipment provided? Explain.

Part 2: Air Table

GOAL: To analyze the circular motion of the puck on the air table.

Equipment: Air table with hole in center, puck, several lengths of string, various masses, meter stick, stopwatch.

Set-up Procedure: Attach a string to the puck. Run the string through the hole in the table and suspend a mass on the end of the string below the table. Make sure the string passes over the small pulley in the hole.

(A) Draw a free-body diagram for the puck as it moves at a constant speed in a circular path on the table, and draw another free body diagram for the mass hanging on the end of the string while the puck is moving uniformly in a circle. Indicate which of the two bodies is in force equilibrium (that is: net force = zero) and which is not. (You should be able to figure this out from your diagrams.)

(B) Turn on the air source. Play around with the puck a bit and record any observations you make. For example, qualitatively observe how fast the puck moves toward the center of the table if you let it go from rest at the edge of the table. In what direction must you start the puck so that it moves in a circle? Why does the puck accelerate inward?

(C) Use the measured value of the mass hanging on the string to calculate values of the forces on your free body diagram for the hanging mass.

(D) You have been provided with a meter stick, a stopwatch, and a balance to measure the mass of the puck. Record with these instruments whatever data you need to calculate the **centripetal force** that the string must be exerting on the puck; then do this calculation. Is this value consistent with the force values on your free-body diagram of the hanging mass?

(E) Calculate percent error against the theoretically predicted value (the value for the tension on the string calculated in part C) and give an uncertainty estimate.

(F) What is the effect of changing the length of the string or changing the value of the mass hanging below the table? Make a prediction and then test it.

Part 3: Pulleys

GOAL: To raise a mass while exerting a force equal to only a quarter of the mass's weight.

Equipment: large number of identical pulleys, string, assorted masses, laboratory stands and clamps, spring scale.

Set-up: In a pre-lab problem you were asked to devise an arrangement that allows you to raise a mass while exerting a force equal to only a quarter of the mass's weight. Turn to your analysis of this situation in your laboratory notebook and construct the device you have designed as best you can.

Assess the strengths and weaknesses of your design. Comment on anything that surprised you or any problems you had in constructing your design. Does it work?

(A) If it does, then simply explain why it works.

(B) If not, explain what is wrong with your design. Then come up with a new design to meet the necessary qualifications and explain why this one works.