

# LABORATORY VII

## TORQUE AND EQUILIBRIUM

For most of this course you treated objects as points rather than as extended objects. This assumption is useful and sometimes sufficient. However, the approximation of objects as point particles gives an incomplete picture of the real world.

This laboratory introduces a more realistic description of the interactions of real objects that can *rotate* as well as move along trajectories. You already have a lot of experience with rotating objects: doors, wheels, and balls all rotate. Also, the earth rotates about its axis. Rotations are important to consider in all cases, whether you are discussing baseball, galaxies, or subatomic particles.

Describing rotations requires little more than the application of the physics concepts you have studied -- position, velocity, acceleration, force, mass, kinetic energy, and momentum. We apply these concepts to objects that have three-dimensional shape and exhibit rotational properties.

### **OBJECTIVES:**

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

- Use the concept of torque in a system that is in static equilibrium.
- Determine the conditions under which an object is in equilibrium.

### **PREPARATION:**

Read Serway & Vuille Chapter 8, sections 8.1 and 8.2.

Before coming to lab you should be able to:

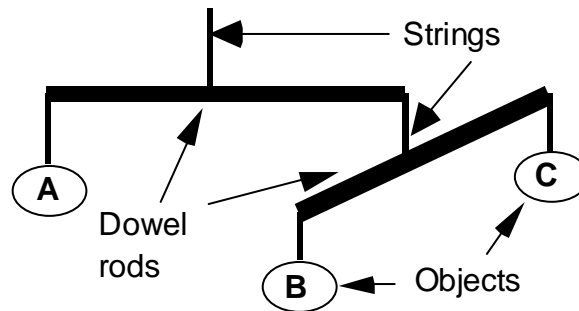
- Identify the forces acting on an object.
- Determine the net force on an object from its acceleration.
- Define the concept of torque, and determine the net torque on an object from its angular acceleration.
- Draw and use force and torque diagrams.
- Explain what is meant by a system in "equilibrium."

## PROBLEM #1: DESIGNING A MOBILE

A friend has asked you to help him make a mobile for his little sister's room. The project would be simple if your friend's sister knew what she wanted to hang from the mobile, but she cannot make up her mind. One day it is dinosaurs, another day it is planets, and another day it is famous women scientists. Frustrated, you decide to build a laboratory model to test the type of mobile you will build. Then, when she makes a decision, it can be easily assembled. To do this you must write an expression to calculate the position of the strings as a function of the masses of the objects and rods to balance a mobile consisting of two rods and three hanging objects, as shown below.

### EQUIPMENT

To test your mobile design, you will have a meter stick, some string, two wooden dowel rods, one metal rod and one table clamp will be used to hang the mobile. You will also have 3 mass hangers and one mass set to create objects A, B, and C.



### PREDICTION

Write a formula for the equilibrium position of each string that supports a dowel, in terms of equipment masses and distances.

### WARM UP

Read: Serway & Vuille Chapter 8, Sections 8.1 and 8.2.

1. Draw a picture of the mobile similar to the one in the Equipment section. Select a coordinate system. Identify and label the quantities you can measure in this problem, such masses and lengths. The unknown quantities in the problem are the locations of the two strings that are attached to the rods.
2. On your picture, identify each force on your system. Then, draw a separate 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 in the two diagrams. Label a point on each rod that you choose as the axis of rotation.

3. Write down Newton's second law for the forces on one rod. Next write down an expression for the net torque on that same rod. Repeat this procedure for the second rod. (Remember, your system will be in static equilibrium.) What are the total torque and the sum of the forces on an object when it is in equilibrium?
4. Solve these equations to find the equilibrium location of the two strings in terms of the masses and lengths along the rod. 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 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 location of the center of mass of each rod. Do you think that the length of the strings for the hanging masses will affect the balance of the mobile? Why or why not? Try it. How close to the ends of the rods can you hang the masses? Where does the heaviest object go? The lightest?

Determine the location on the top rod from which you will hang it. Determine the location for the string connecting the second and third rods. Is there a configuration for these objects (the two rods) that results in a stable mobile?

Decide what measurements you need to make to check your prediction. If any major assumptions are used in your calculations, decide on the additional measurements that you need to make to justify them.

Outline your measurement plan.

### MEASUREMENT

Measure and record the location of the center of mass of each rod, the mass of each rod, and the mass of the three hanging objects. Also, measure (a) the locations on the top rod where you will hang object A and the second rod, and (b) the locations on the bottom rod where you will hang objects B and C.

*Note: Be sure to record your measurements with the appropriate number of significant figures and with your estimated uncertainty. Otherwise, the data are nearly meaningless. If you need a review, see Appendix B for how to determine significant figures and Appendix C for how to determine uncertainties.*

### ANALYSIS

Use your prediction equations to calculate the location (with uncertainties) of the two strings attached to the rods. using the values you measured.

To test your prediction, build your mobile and then hang it up. If your mobile did not balance, adjust the strings attached to the rods until it does and determine their new positions. Is there another configuration of these three objects that also results in a stable mobile? Try it!

Repeat this process, while hanging the masses in different places.

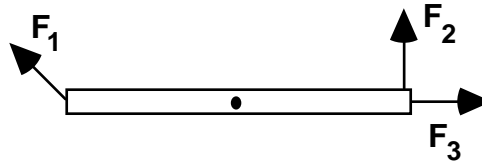
<b>CONCLUSION</b>
-------------------

Did your mobile balance as designed? What corrections did you need to make to get it to balance? Were these corrections a result of some systematic error, or was there a mistake in your prediction? Justify your answer.

Was the length of each string important in your mobile design? Explain why or why not.

CHECK YOUR UNDERSTANDING

1. 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.



- 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.
- Rank the magnitudes of the torques about the *center* support. Explain your reasoning.
- Rank the magnitudes of the torques about an axis perpendicular to the drawing at the *right* end of the stick. Explain your reasoning.
- Can the stick be in translational equilibrium? Explain your reasoning.
- Can the stick be in rotational equilibrium? Explain your reasoning.



TA Name: \_\_\_\_\_

## PHYSICS 1101 LABORATORY REPORT

### Laboratory VII

Name and ID#: \_\_\_\_\_

Date performed: \_\_\_\_\_ Day/Time section meets: \_\_\_\_\_

Lab Partners' Names: \_\_\_\_\_

\_\_\_\_\_

Problem # and Title: \_\_\_\_\_

Lab Instructor's Initials: \_\_\_\_\_

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

