LABORATORY III
POTENTIAL ENERGY

In previous problems, you have been introduced to the concepts of kinetic energy, which is associated with the motion of an object, and internal energy, which is associated with the internal structure of a system. In this section, you work with another form of energy, called potential energy, which is associated with the configuration of a system of two or more interacting objects or particles.

OBJECTIVES:

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

- Incorporate the concept of potential energy within the framework of the conservation of energy.

- Apply the concept of potential energy in problem solving.

PREPARATION:

Read Serway & Jewett chapter 7 (sections 1-4). It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. It is very important that you read the text before coming to lab.

Before coming to lab you should be able to:

- Write down the conservation of energy equation for any system of one object.

- Understand the difference between energy transfer terms and the energy of the system.

- Be able to use forces and draw a free-body diagram for any system.

- Be able to determine the components of forces.

- Know which components of forces contribute to energy transfer.

- Write down the potential energy for a spring.

- Write down the gravitational potential energy for a system of two objects.

- Use the concept of velocity.

PROBLEM #1:
ELASTIC AND GRAVITATIONAL POTENTIAL ENERGY

You are working in a research group investigating the structure of coiled proteins. These proteins behave to some extent like a spring. Your group intends to fasten one end of the protein to a stationary base while it attaches an electrically charged bead to the other end. The bead will be attracted by an electrostatic force. From the motion of the bead under the influence of this electrostatic force, your group will determine the mechanical properties of the protein. Before setting up this experiment, you decide to test the ideas using a physical model in the lab. You decide to model you system using a cart attached by a spring to the top of an inclined track. Instead of an electrostatic force, you will use the gravitational force. You can't change the gravitational force but you can change its effect on the cart by changing the angle of the track. You intend to release the cart from the top of the track where the spring is unstretched and measure its motion. To characterize the motion, you have been asked to calculate what will be the maximum extension of the spring and where the cart will have its maximum speed as a function of the properties of the cart and the spring and the angle of the track.

EQUIPMENT
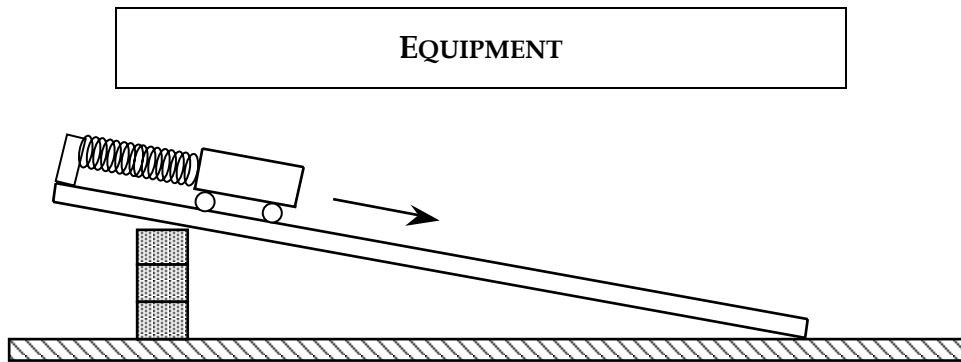
For this problem you will have an aluminum track, a cart, weights, springs, a balance, a meter stick, a video camera and a computer with a video analysis application written in LabVIEW™.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get the two equations that give the solutions to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett: sections 7.1-7.3.

1. Draw a picture of the situation at each of the three different times described in the problem. Label all relevant quantities on the diagram for each time.

2. Define a system you will use. Does the spring transfer energy into or out of your system? Write an expression for the energy transferred by the spring while the cart is moving down the ramp. This is also called the "elastic potential energy" of the spring. Does the force of gravity transfer energy into or out of your system? Write an expression for the energy transferred by gravity while the cart is in motion. . This is also called the change in "gravitational potential energy" for the system. Express this energy in terms of the distance traveled along the ramp, rather than the vertical height. Use these terms to write a energy conservation equation for the system that relates its initial energy to its energy when the cart's speed is maximum.

3. Solve your conservation of energy equation for the velocity of the cart. When the cart has reached its maximum position (maximum spring stretch), what is its velocity? Use this information to solve for the maximum extension of the spring.

4. What is the position of the cart when the velocity is at a maximum? Write down a calculus expression that you can use to find the cart displacement when the velocity is maximum. Use this calculus expression with your equation for the velocity of the cart to solve for the position when velocity is maximum. Make a graph of velocity as a function of position and verify that your calculus does give you the maximum.

5. How does the position of the cart at maximum velocity compare to the cart's position when the spring is at its maximum extension?

6. What is the maximum velocity of the cart, in terms of its mass, the angle of the incline, and the spring constant?

EXPLORATION

Choose an angle of incline for the track and a range of weights to place on the cart such that the elongations of the spring are distinct, significant and do not exceed the elastic limit of the spring which is about 60 cm. Try different track angles to get a good range of motion for the video.

Use a meter stick to get approximate values for the maximum displacement and the position when the velocity is maximum.

Decide how you will measure the spring constant and the angle of the track. Decide how you will measure the cart's maximum speed and displacement from each video, and how you will adjust the camera for maximum convenience and accuracy. Decide on how many angles and cart weights you will need to test your equations. Write down a measurement plan.

MEASUREMENT

Carry out your measurement plan. Remember to measure the dimensions necessary to determine the slope or angle of the inclined track, and the spring constant.

ANALYSIS

Analyze the video for the position and velocity of the cart as a function of time. Use both graphs to determine the position of the cart when it has maximum velocity. Also indicate how you would determine the position of maximum velocity from the just the graph of position vs. time.

CONCLUSION

Do your measurements match your predictions? Why or why not?

PROBLEM #2:
USING POTENTIAL ENERGY

Redo the calculations for one of the problems from Lab 2 problems 1 – 5 by re-defining your system so that you can use potential energy. Use the data you have already recorded in your lab journal to test your calculations.

Read Serway & Jewett: sections 7.1-7.3.

PROBLEM #3:
PENDULUM

You work in a research group trying to understand the migration patterns of mammals. One element in this investigation is the maximum speed with which different mammals can walk. One theory is that this speed is determined primarily by the length of the animal's leg. In this theory, the leg is essentially a pendulum pivoted at the hip. Then the maximum speed of the leg is related to the maximum angle that the leg can be displaced from the vertical as well as other properties of the leg. You have been asked to calculate this relationship and then test your calculation by using a model of this motion in the laboratory. As a first step, you calculate the maximum speed of the end of a pendulum as a function of the maximum angle that the pendulum is displaced from the vertical as well as the other properties of the pendulum for a model in which all of the mass is concentrated at the end of the pendulum instead of being continuously distributed as with a real leg.

EQUIPMENT

For this problem you will have a stopwatch, a protractor, string, weights, a meter stick, rods and clamp, a video camera and a computer with a video analysis application written in LabVIEW™.

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.

WARM-UP QUESTIONS

Read Serway & Jewett: sections 7.1-7.3.

1. Draw a picture of the pendulum at an initial time, with the string at an angle and an initial speed of zero. Draw a second picture to represent the time when the speed of the object at the end of the string, called the pendulum bob, is maximum. On each picture, draw and label the quantities necessary to describe the energy of your system.

2. Write down a relationship between the height of the bob and the angle of the pendulum. Label any other quantities of interest in each picture.

2. Define your system for this situation so that you can use gravitational potential energy. Are there any external forces on your system? Determine if they transfer any energy to or from your system and explain why.

3. Write the conservation of energy equation to relate the system's energy at the initial time to its energy when the bob has its maximum velocity. If energy is transferred into or out of the system, be sure to include it in your equation. State and justify any approximations or assumptions you make.

4. Solve your equation to give the maximum speed of the pendulum bob in terms of its initial angle and properties of the pendulum. At what angle does the speed reach a maximum? Sketch a graph of *maximum speed vs. release angle*. How does this maximum speed depend on the mass of the pendulum bob?

EXPLORATION

Choose a convenient length of string. Test the effects of using different pendulum bob masses when they are released from the same height. Explore a useful set of heights at which the pendulum may be released. Can you neglect air resistance?

Decide how you will determine the pendulum's maximum speed from video measurements of its horizontal and vertical velocity components. Decide how you will determine the pendulum's initial angle from video measurements of its horizontal and vertical position.

Decide how many different pendulum masses and lengths you need to use in your measurement to convince yourself and others that you calculation is correct.

Write down your measurement plan.

MEASUREMENT

Measure the length of the pendulum string. Record the necessary video for several release heights, lengths of string, and pendulum masses. Be sure to measure each initial angle and bob height with a meter stick for comparison with your video measurements.

ANALYSIS

Analyze each video to determine the pendulum bob's initial angle and maximum speed. Check to see that the maximum speed occurs at the expected position.

Make a graph of the measured *maximum speed vs. release angle* data, with estimated uncertainties. On the same graph, plot the predicted relationship. Also graph the *maximum speed vs pendulum mass* and *maximum speed vs pendulum length* for the initial release angle.

CONCLUSION

Were your predictions consistent with your measurements? Why or why not?

How would doubling the pendulum bob's mass affect its maximum speed? How would doubling the pendulum's initial height affect its maximum speed?

TA Name:

PHYSICS 1201 LABORATORY REPORT

Laboratory III

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.