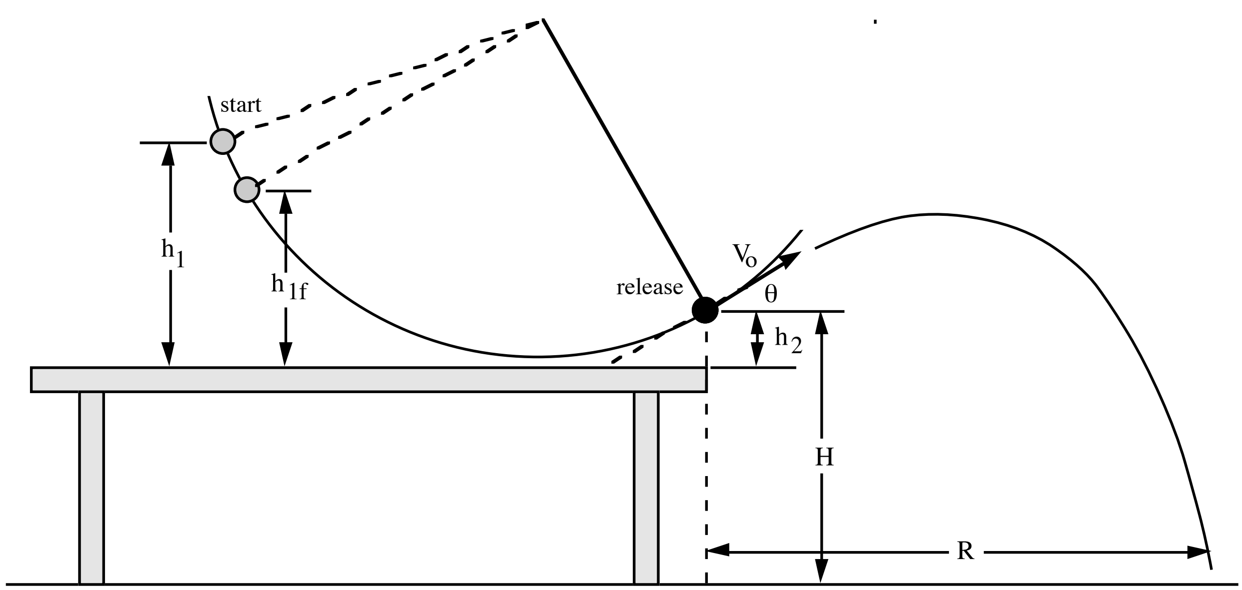
Introduction

Preparation: Before coming to lab, read this lab handout and the suggested reading in Giancoli (through Chapter 6, p. 136-160). Some of the questions that appear in this lab handout are pre-lab questions and the answers are to be handed in at the beginning of your lab — the questions are compiled (and elaborated) on a separate sheet at the end of this handout. *Be sure to bring your* ***completed Pre-Lab Questionnaire*** *to lab along with this handout, writing paper, a calculator, and your copy of the Lab Companion.*

Lab questionnaire: At the beginning of each lab section, you will also be given an *additional* handout with a series of questions to be answered and handed in at the end of the experiment. Try to answer these questions with one or two concise sentences. For this experiment you will also hand in your target. *To satisfactorily complete the* ***Lab Questionnaire*** *satisfactorily you should pay special attention to all text that appears in italics and/or bold* when you study this handout.

Experimental Setup: The apparatus shown in the figure consists of a steel ball, suspended to swing like a pendulum. At the edge of the bench a mechanism that releases the ball is mounted. The ball then becomes a free projectile, and lands on the floor a distance R from the launch point. Details are given later.



Objective: You will attempt to predict the range of the steel ball by invoking the law of conservation of energy to determine v_o and kinematics of trajectory motion to predict R.

Theory

Let us begin by assuming that the energy loss due to friction is negligible. Since the ball is at rest at h_1, by conservation of mechanical energy,

[potential energy at h_1] = [potential energy at h_2] + [kinetic energy at h_2],

or

$$mgh_1 = mgh_2 + (1/2)mV_o^2 \quad . \qquad [1]$$

Therefore

$$V_o = \sqrt{2g(h_1 - h_2)} \quad . \qquad [1a]$$

The components of velocity at the moment of release are therefore

$$V_{horiz} = \cos\theta \sqrt{2g(h_1 - h_2)} \qquad \text{and} \qquad V_{vert} = \sin\theta \sqrt{2g(h_1 - h_2)} \quad . \qquad [2]$$

If the ball is in flight for a time t, then the range R is

$$R = (V_{horiz})t \qquad [3]$$

and, for the height at the launch point H, we can write (assuming down is positive)

$$H = \frac{1}{2}gt^2 - (V_{vert})t \qquad [4]$$

Solve equation (4) for t:

$$t = \frac{V_{vert} \pm \sqrt{(V_{vert})^2 + 2gH}}{g} \qquad [4a]$$

Substitute [4a] into equation [3] and, making use of equation [2], we have the result

$$R = 2\cos\theta\,[\sin\theta\,(h_1 - h_2) + \sqrt{\sin^2\theta\,(h_1 - h_2)^2 + H(h_1 - h_2)}\;] \quad . \qquad [5]$$

Does the value of g have any effect on R? Explain.

Does the mass m have any effect on R? Explain.

If you could do this experiment on the moon, would R be >, <, or = to the value on earth?

Why should the plus sign be chosen in Eq. [4a] as the solution to Eq. [4]?

We began with Eq. [1] by assuming frictional energy losses to be negligible. However, if you let the steel ball make a complete swing (forth and back), you will notice that it does *not* return to the same height. Rather, it returns to some smaller height, h_{1f}. Air resistance and friction in the pendulum suspension contribute a small but noticeable loss in mechanical energy — designate this energy loss as E_f.

The fact that the steel ball does not return to the same height suggests a way in which we may determine E_f experimentally: The difference in height (h_1 - h_{1f}) will give us the loss in potential energy in one complete swing, which we can attribute to the frictional loss:

$$E_f = mg(h_1 - h_{1f})$$

In the actual experiment, the steel ball does not swing forth and back — it is released on the forward swing. Therefore, we shall assume that only one-half of this energy is lost.[1]

We now rewrite Eq. [1] to take into account this frictional energy loss:

[potential energy at h_1] = [potential energy at h_2] + [kinetic energy at h_2]+ [energy loss]

or

$$PE_1 = PE_2 + KE_2 + E_f$$

or

$$mgh_1 = mgh_2 + (1/2)mV_0^2 + (1/2)[mg(h_1 - h_{1f})].$$

This equation can be rearranged to read

$$mg\left(\frac{h_1 + h_{1f}}{2}\right) = mgh_2 + \frac{1}{2}mV_0^2 \qquad [1']$$

Equation [1'] is identical to Eq. [1] with the substitution of $\frac{h_1 + h_{1f}}{2}$ for h_1. Thus, one way of correcting for the frictional energy loss is to use the average value of h_1 and h_{1f} for the starting height in the range equation. This has the effect of making the initial potential energy less by an amount just equal to the frictional losses. Eq. 5, which gives the range, will now read as

$$R = 2\cos\theta\,[\sin\theta\,(h_1' - h_2) + \sqrt{\sin^2\theta(h_1' - h_2)^2 + H(h_1' - h_2)}\,], \text{ where} \qquad [5']$$

$$h_1' = \frac{h_1 + h_{1f}}{2} \qquad [5'a]$$

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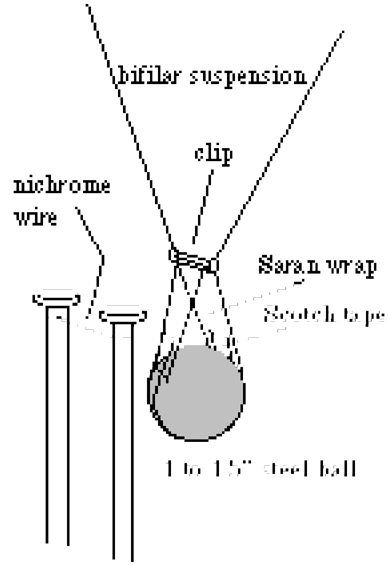
[1] Maybe a little less than one-half is lost because the ball doesn't complete even 1/2 of a swing before release. On the other hand, losses encountered in the hot-wire release, although very small, are not known and these effects seem to cancel. Therefore we shouldn't worry about estimating the frictional loss to any greater accuracy than suggested above because any greater accuracy is meaningless in light of the small, but unknown, magnitude of the release effect.

Procedure



The basic setup is simple: a steel ball is suspended with Saran™ Wrap from a clip and, as the assembly swings into a hot wire, the Saran™ Wrap is cut by the wire, allowing the ball to fly free. You will place a target (and small can) at your calculated landing spot on the floor, and if you calculated correctly, you'll get a hole in one! (And if you don't, you'll get to chase your metal ball across the floor.)

Your TF will show you all the possible parameters you can change and/or adjust on the suspension that will be set up at the lab tables. You may use any suspension length you like. The distance of the suspension assembly from the nichrome hot wire release assembly is also up to you, as well as the starting height of the ball. However, **do not disassemble the hot wire assembly**. The hot wire assembly should be centered and clamped at the edge of the table such that the plumb bob just clears the side of the table.

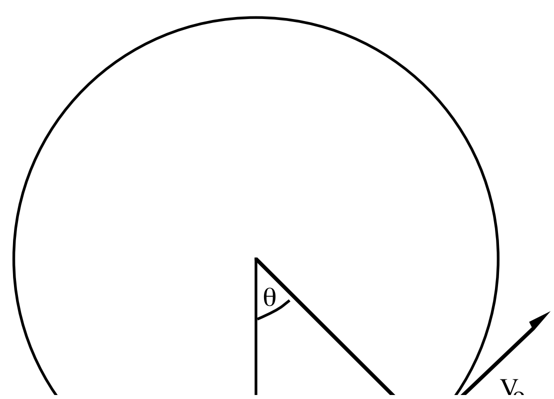
Begin by making the sling support for the steel ball projectile. Cut yourself a piece of Saran™ Wrap that is approximately 3/4" x 4". You will need several of such pieces throughout the experiment. The more consistent you are with the length of the suspension, the better your experimental results will be.

Stick a 4" long piece of Scotch™ tape onto one end of the Saran™ Wrap, pass the tape around the ball (sticky side toward ball), and fasten the other end of the tape to the Saran™ Wrap. Next open the center section of the clip and slide the Saran™ Wrap loop over the center bar and then close the clip. When suspended, the sling-like cradle should look something like the illustration. Adjust the height of the bifilar suspension support rod so that the steel ball **barely** clears the bench top at the bottom of its swing. (This will simplify your angle measurements.) Additionally, the clip holding the Saran™ Wrap should pass about _ inch above (and parallel to) the hot wire.

The hot wire ball-release mechanism consists of a nichrome wire stretched between two threaded rods. When current from a 6-volt battery is passed through the nichrome wire, it becomes red hot — hot enough so that the Saran™ Wrap suspending the ball melts through easily. **Be sure that only the Saran™ Wrap passes through the hot wire and <u>not</u> the Scotch™ tape. Do not touch the wire when it's hot — ouch!!**

Devise an experimental procedure for measuring h_1, h_2, h_{1f}, and θ as accurately as you can with a meter stick. Do not forget the radius of the steel ball in measuring the h's.

The adjacent figure illustrates the geometry — how one might measure the release angle, θ, with a meter stick may not be obvious to you. Notice that the angle of the suspension string w.r.t. the vertical is the same angle as the velocity vector w.r.t. the horizontal.



You will need to take some preliminary swings without the hot-wire assembly in place to determine h_{1f}. Simply loosen the c-clamp that holds it in place and remove the entire assembly as one. When you have finished your h_{1f} measurements, replace the hot-wire release assembly. Line it up and clamp it in place. The angle measurement will depend on the position of the hot-wire release. Be sure to mark its position (if you need to move it again for any reason) so that you can easily reposition it — otherwise you will be forced to remeasure your angle.

Calculating The Range

Calculations involving a complicated formula like Eq. [5'] must be carried out systematically to avoid confusion and wasted time. Organize the elements of these equations as follows:

$$h_1' = \frac{h_1 + h_{1f}}{2} \qquad A = (h_1' - h_2) \qquad B = (h_1' - h_2)^2 = A^2$$

$$C = \sin\theta \qquad D = \sin^2\theta = C^2 \qquad E = \cos\theta$$

Substituting these values into Eq. [5'] gives

$$R = 2E\,[CA + \sqrt{DB + HA}\,]\,. \qquad [6]$$

Now using your measurements and Eq. 6, calculate a range R_{calc} for the projectile. *From what part of the ball should the h's be measured for the most accurate determination of the range?* In this lab, we deliberately omit the error propagation requirement due to its complexity. {**optional**: for ambitious students who want to complete the error calculation, use the extreme values of your h's and θ to calculate the extreme values of R — the extreme values will give you a predicted value for ΔR.}

The Big Moment

You will check your prediction by testing if the ball goes into an empty soup can placed at the predicted landing point.

Drop a plumb line from the hot-wire position (hang the plumb bob from the hook on the underside of the board that supports the hot wire) to the floor. Then measure from the point on the floor directly below the hot-wire to the spot where you predict the ball will land. Tape the target (the last page of this write-up) to the floor at the predicted landing site. Place a sheet of carbon paper (carbon side down) on top of the paper, and a soup can in the middle.[2] The carbon paper will leave an imprint of the projectile's landing if it misses the can.

Close the brass switch that connects the battery to the hot-wire so that current passes through the wire heating it to a red glow. DO NOT TOUCH THE WIRE — IT'S HOT! ALSO, DO NOT BRINGS THE TWO BATTERY CLIP LEADS TOGETHER. (The voltage and current are safe, but you may damage the battery if the leads are shorted together).

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[2] Remember to take the height of the can's wall into consideration. For example, you may wish to tilt the can a little so that the steel ball doesn't hit the rim on the way to its mark, or you might move it a tiny bit closer to the bench to avoid a rim shot — use your judgment.

Raise the steel ball to your predetermined height and go for it! RELEASE THE SWITCH AS SOON AS YOU HAVE LAUNCHED YOUR PROJECTILE. CAUTION! THE WIRE TAKES QUITE A WHILE TO COOL DOWN AND IS STILL HOT ENOUGH TO BURN YOU LONG AFTER IT LOOSES ITS RED COLOR.

The Aftermath

Take the soup can away and test the repeatability of the experiment by launching the projectile four or more additional times. Recording the landing of each launch on your target with the carbon paper.

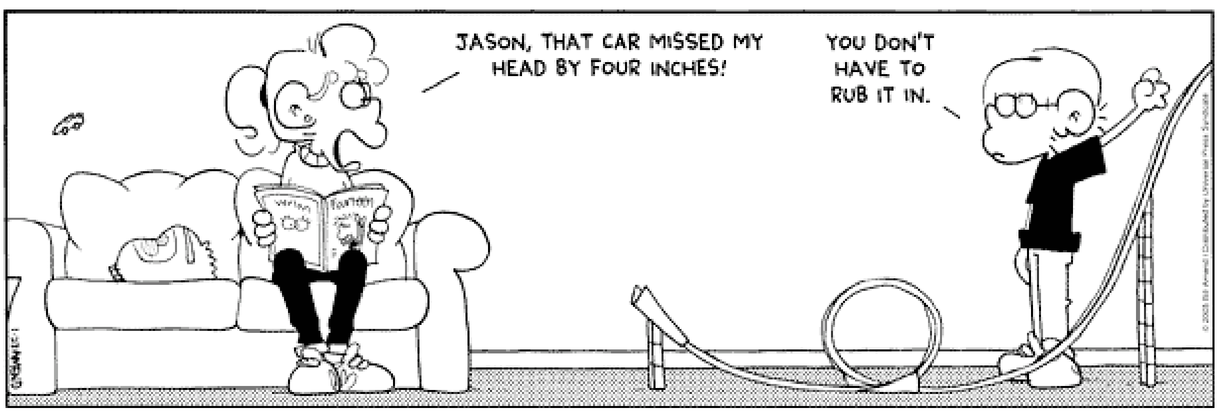
→ Hint: When repeating the experiment you should try to make the Saran™ Wrap and tape assembly the same size each time, and return carefully to the same predetermined starting height.

Before moving the target, measure the range for each trial. ***Determine the average value, R_{exp} and the experimental uncertainty (the spread in values), ΔR. Note that this is not the same as the ΔR on p.5.***

Considering Error Analysis

Characterize your data in terms of accuracy and precision. What type(s) of error do you see in your data (systematic or random)? How can you tell the difference between these two types of errors? (hint: accuracy & precision are discussed on page 6 of the Lab Companion) If you have random error(s) what do you believe to be cause of these errors? If you have systematic error(s) what do you believe to be cause of these errors?

*{**optional**: If you followed through with the propagation of errors and calculated an uncertainty in your predicted value of R, is your actual experimental range of ΔR (i.e., the scatter of landing sites) consistent with the calculated uncertainty? The answer to that question will tell you if there were random or systematic errors in your experiment.}*



Pre-Lab Checklist

1. Answer the five questions in the Pre-Lab Questionnaire. The answers will be collected at the beginning of the hour. If you feel that they will be helpful during the lab, make a copy for yourself.

Post-Lab Checklist

1. Answer and hand in the six questions in the Post-Lab questionnaire.

2. Hand in your target with the hits on it.

3. Include your data sheet and calculations

Name ________________________ **lab section ______________**

Phys E-1a Pre-Lab Questionnaire Fall 2006
Experiment 3: Conservation of Energy & Projectile Motion

Note that (for clarity) some of these questions have been rephrased from those that appear in the lab write-up. Answer the questions on both sides of this sheet of paper and hand it in to your TF when you arrive in lab.

1. Equation [5], the range equation, does not contain g. However, the equation for the range on page 60 of *Giancoli* is inversely proportional to g. How do you reconcile these two seemingly contradictory statements? Justify your answer.

2. Similarly, mass does not enter into the equation for the range. Explain why not. How does your explanation relate to Galileo's experiments on the Leaning Tower of Pisa?

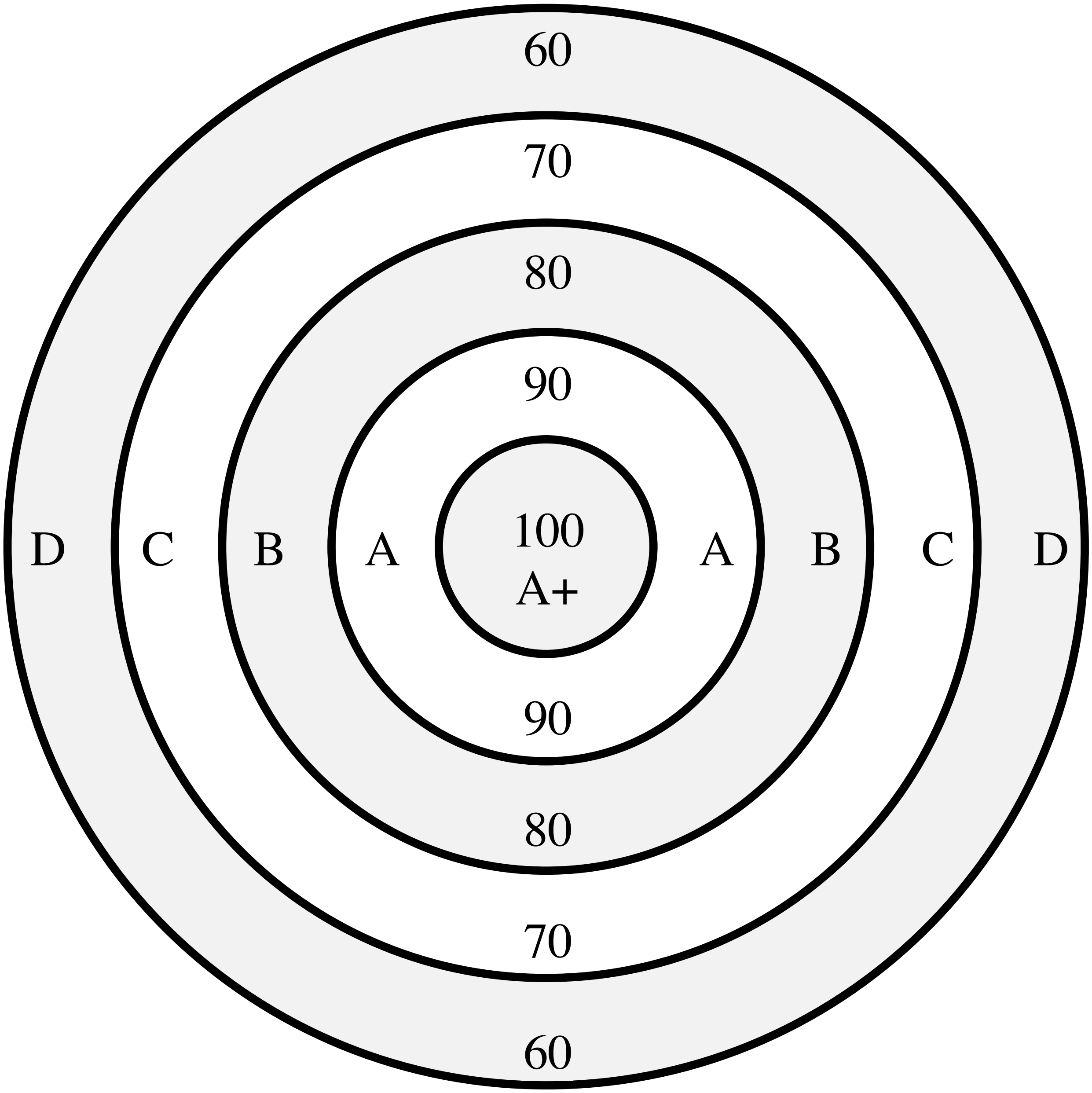
3. On the other hand, if you simultaneously drop a piece of paper and a book from the same height, the book falls faster. Why? How does this relate to the previous question?

4. Consider the following two hypothetical experiments:

(a) The apparatus in the laboratory is set up so that the ball is released from a height of 40 cm above the table top. The hot wire cuts the Saran Wrap 10 cm above the table. The table is 100 cm above the floor. The experiment is performed on the Earth and then repeated exactly on the Moon. In which case do you find the greater range? Justify your answer.

(b) A ball is released 110 cm above the ground at an angle of 45 degrees with respect to the horizontal and has an initial speed of 3 m/s. The experiment is performed on the Earth and then repeated exactly on the Moon. In which case do you find the greater range? Justify your answer.

5. What would the answer to equation [4] mean if the minus sign were chosen in equation [4a]?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