Pendulum Potential Energy to Kinetic Energy

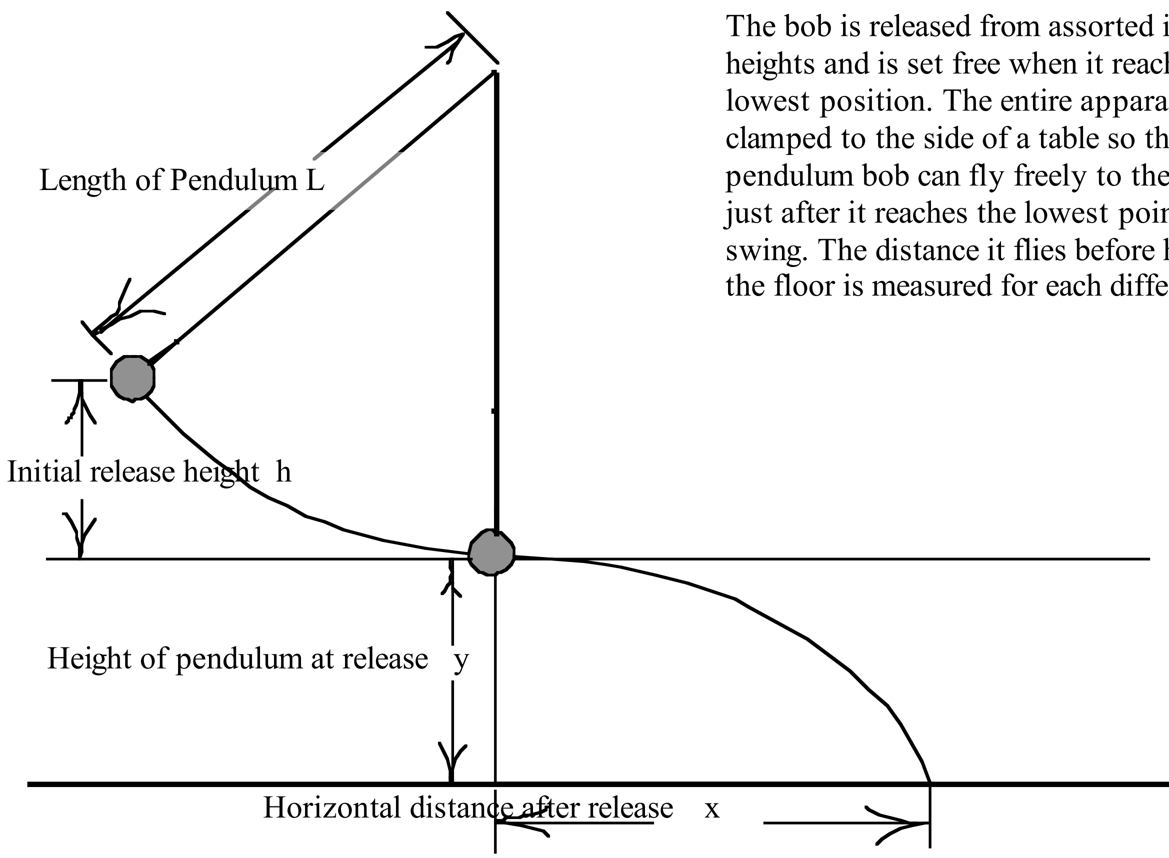
Materials:

Pendulum bob or equivalent weight, non twisting string, meter stick or measuring tape, ruler, special bent hook, ring stand support with stopping device. (Teacher's note: "Mason's string" can be purchased in hardware stores and is cheaper than fishing line. Both will not twist when loaded.)

Outline of Procedure:

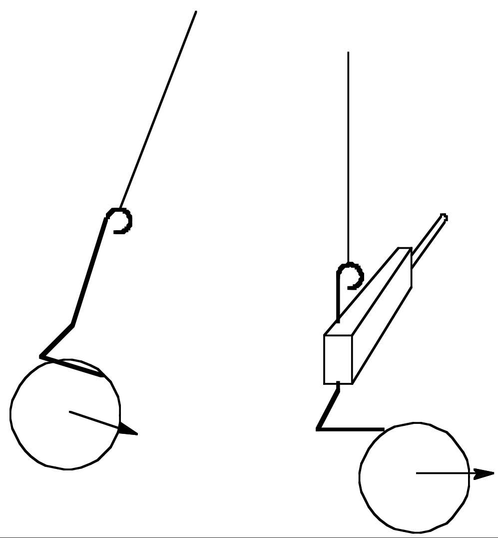
The essential idea behind this experiment is to elevate a pendulum a measured vertical height above its rest position, allow it to swing but when it reaches its lowest point the bob is released and is allowed to fly through the air until it hits the floor. By measuring the horizontal distance the bob flies and noting the vertical distance it fell, the horizontal velocity of the bob the instant it disconnected can be computed. This makes it possible to compute the kinetic energy of the bob at the bottom of the swing and to compare it with its original potential energy.

The illustration below shows the essential set-up. You should measure all of the quantities indicated but throughout the course of the experiment, L and y will probably remain constant.



The bob is released from assorted initial heights and is set free when it reaches the lowest position. The entire apparatus is clamped to the side of a table so the pendulum bob can fly freely to the floor just after it reaches the lowest point of its swing. The distance it flies before hitting the floor is measured for each different h.

The pendulum bob should not be tied to the string, rather a special support is used that will hold the pendulum while it initially swings downward, but when the bob reaches its lowest position, the support will strike a stop block releasing the ball and allowing it to fly freely through the air.



For an improved wire pendulum rather than string, see page 4 of this handout.

The equipment supplied in the New Physics Teachers Workshop includes a 1" steel sphere that has been ground at the top and an aluminum sleeve has been glued in place. The aluminum sleeve will just fit over the provided bent wire support that has been attached to one meter of non-twist mason's string. Also supplied is a special stop bar ¾" X 1" in cross-section with a 3/8" dowel inserted in one end to make it easy to attach to a support ring stand. The diagram on the left illustrates how the swinging ball swings downward, strikes the stop bar and is released. Careful initial adjustment of the pendulum is required so that the wire support just strikes the stop bar as it reaches the bottom of the swing. It is suggested that the top of the pendulum be tied with a clove hitch and this is in turn clamped in place with perhaps a binder clip to insure that the length of the pendulum does not change. **

<u>Suggested procedure:</u>

1. After setting up the apparatus using assorted ring stands, adjust the pendulum length and stop block so the bob will be released in its lowest position. Firmly clamp the stop so it will stop the string and smoothly release the bob just as it reaches its lowest point. **
2. Measure the length of the pendulum (L), the height of the bob above the floor in its lowest position, (y), and then carefully position the end of a meter stick on the floor directly below the pendulum when it is at its lowest point.
3. After making several practice runs to see if everything is working, pull the pendulum back to a measured height above the table, (h), release the bob and carefully watch where it first strikes the floor and record this distance, (x). (A teacher has suggested placing sand at the impact point on the floor will increase determination of where the sphere first strikes.)
4. Repeat the above for several different values of h and x. Repeat measurements as required and record the errors you observe in all of your measurements.

<u>Questions and Analysis:</u>

1. Using y and x it is possible to develop an expression for the horizontal velocity of the bob at the bottom of the swing just as it was set free. Knowing y, you can compute the time in the air and using this time and x you can find the horizontal velocity. Derive this expression for the horizontal velocity of the bob when it is set free. It will involve x, y, and g, the acceleration of gravity.

Teacher's Notes:

After the bob is released it will retain the same horizontal component of velocity and will fall vertically under the force of gravity. This is a typical horizontally fired projectile with the horizontal and vertical components given by:

$$x = v_x t \quad \text{and } y = 1/2(gt^2)$$

Eliminating t between these two equations and solving for v_x gives $v_x^2 = 1/2(gx^2/y)$. Taking the square root of both sides gives the desired answer. However, you will really want v_x^2 later.

2. The potential energy of the bob above the table top just before you released it, mgh, should equal the kinetic energy of the bob just as it reaches the bottom of its swing and is set free, $1/2(mv_x^2)$. In the question above you should have discovered that $v_x^2 = 1/2(gx^2/y)$. This means if you equate the potential energy in the beginning to the kinetic energy of the bob as it was released. You should be able to develop an expression relating your data in h to the corresponding values of x and y you measured for each initial value of h. See if you can find this simple relationship between h and the corresponding values of x and y.

Since the potential energy when the bob was held must equal the kinetic energy of the bob at its lowest point in the swing,

$mgh = 1/2(mv_x^2)$ and the mass of the bob drops out of the equation.

Substituting the value of v_x^2 found in question 1 gives:

$gh = 1/2(1/2gx^2/y)$ and the acceleration of gravity drops out of the equation leaving:

$h = 1/4(x^2/y)$

3. A careful solution to 2 above should reveal that h will always equal one fourth of the square of the horizontal distance the bob moves in the air divided by the vertical distance it falls after being set free of the pendulum. That is, your data for each value in h should be equal to $1/4\ (x^2/y)$. Check your data to see if this is in fact the case.
Here the students can simply operate on their data in x and y according to the above and comment on how this relates to the value of h. Hopefully they will relate this back to the fact that all of this depends upon the fact that the original potential energy is transformed into kinetic energy.

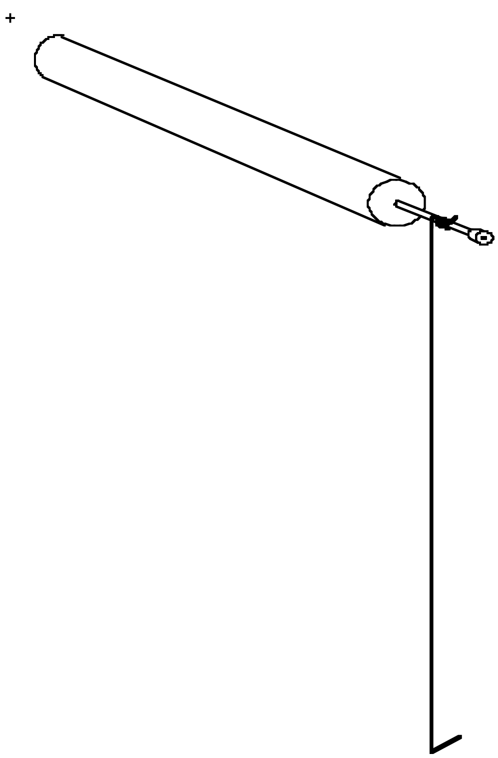
4. If you were able to make many runs involving different values of h, perhaps you could plot your values of x vs. h, or better still your values of x^2 vs. h. Using this graph, discuss how well the experiment illustrates that the original potential energy of the pendulum bob equals the kinetic energy of the bob at the lowest point of the pendulum's swing.
The graph will give the students an opportunity to comment on the consistency of their measurements. Plotting x vs. h will give a parabola but plotting x^2 vs. h should give a straight line with an intercept at the origin. Error bars and all sorts of good analysis should help to make their analysis more useful.

5. What, if any value was there in making a measurement of the length of the pendulum, L?
Students are often confused when they are asked to collect data that is never used in the analysis. However, should they need to come back and check their results at a later time, the original value of L could be very useful.

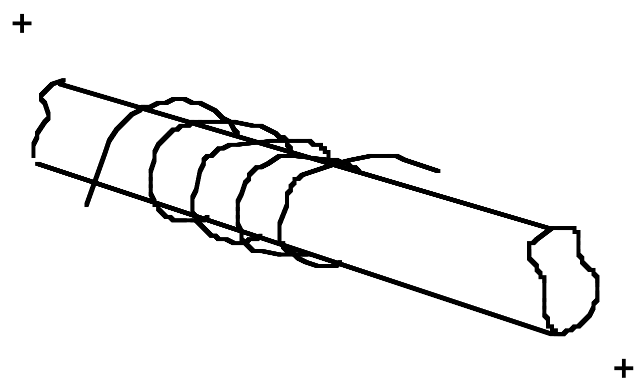
** Recent use of this release device reveals that it should be bent differently for better results. An even improved launch device will be described on the next page.

A suggested improvement for a pendulum release device for the PE to KE apparatus

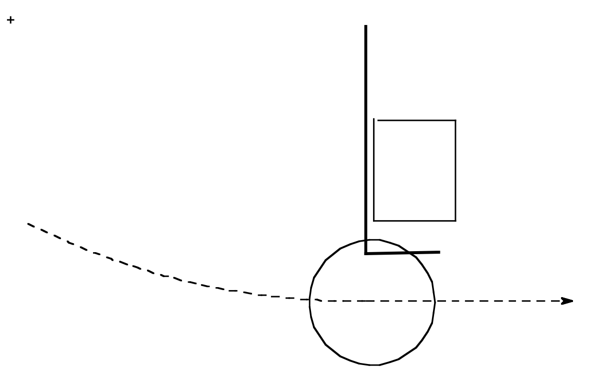
The string attached to the metal “hook” frequently does not release the ball with the required smooth horizontal velocity. When the hook slaps into the stop, it often suddenly changes direction causing an improper launch. If, however, the string and hook is replaced with a single wire support as described below, better launches will result.



Using iron or aluminum wire that can be easily bent into any desired shape, the top end of the wire will be carefully bent around a finish nail into the shape of a spring. This “spring” will allow the wire to swing freely yet constrains it to swing in a particular direction. The diagram below details the upper part of the swing.



The lower end of this wire is bent at right angles so that as it swings, the suspended sphere will be released in the forward direction. As shown on the left, the finish nail is driven into a short length of dowel that can be supported with a ring stand.



The side view of the motion of the sphere supported by the revised support is shown on the left. When the support slaps into the stop block, it will release the sphere in a level forward direction. One systematic error in this new arrangement is that now the support “string” will have a slightly larger moment of inertia about the support pin that will slightly retard the motion of the ball. A thoughtful student might come up with a way to measure how much this will slow the motion of the ball at release.

A suggested procedure to measure the additional time that might be added by the metal rather than the string pendulum would be to set two of them of the same length with a sphere on the end swinging and after several oscillations, observe and measure the change in period. (Other measurements options can be devised forming a nice student investigation.)