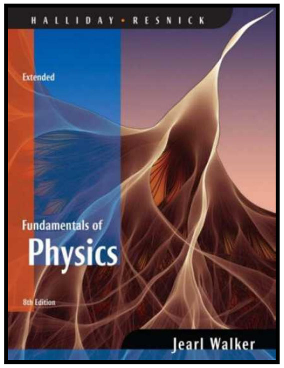
University Physics I



Week 9 : Day 3

Momentum and Energy

System analysis

- Use conservation of momentum
  - *Valid for all collisions where $F_{NET} = 0$*

$$\vec{p}_i = \vec{p}_f$$

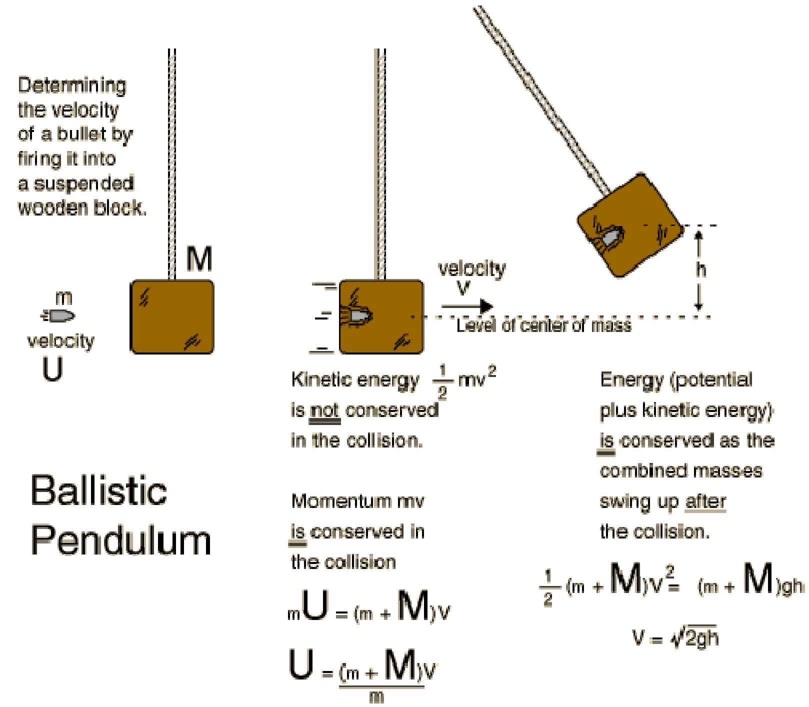
- Use conservation of mechanical energy
  - *Valid when no non-conservative forces are acting*

$$E_i = E_f$$

- Choose time of analysis wisely
  - *Principles may be applied at different times to analyze the same system*

Application – Muzzle Velocity

- **To determine muzzle velocity**
  - Shoot a bullet into a block
  - Use <u>conservation of momentum</u> at the time of impact
  - Use <u>conservation of energy</u> at a time (shortly) after the impact



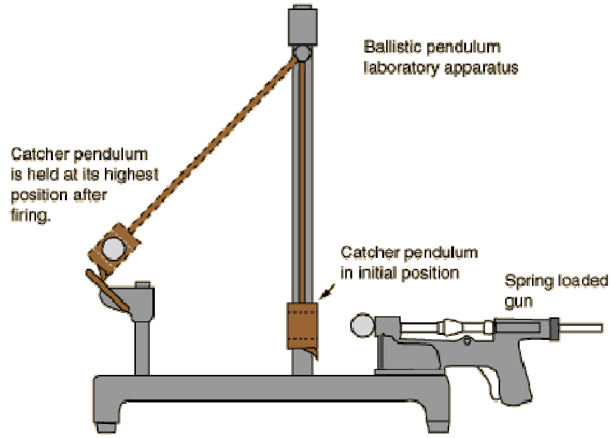
$$u_{Muzzle} = \frac{(m+M)}{m}\sqrt{2gh}$$

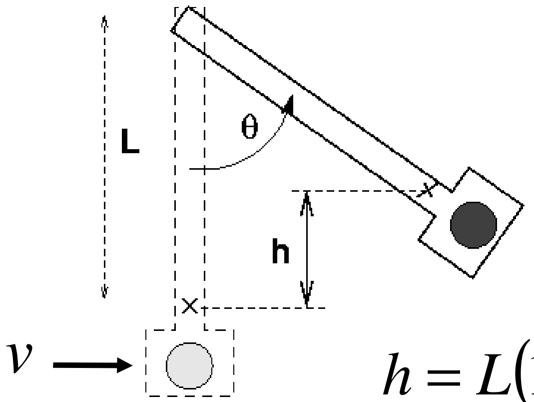
The Ballistic Pendulum

❑ System Parameters

- Record mass values
  - *Need value for ball (m)*
  - *Need value for arm (M)*
- Run several trials
  - *Record angle reached*
  - *Determine height (h)*

$$v = \frac{(m+M)}{m}\sqrt{2gh(L,\theta)}$$





$$h = L(1-\cos\theta)$$

Activity - Ballistic Pendulum – Part I

❑ Report - Part I

- A page showing your derivation of the equations relating v_1 to the measured quantities.
- Your table of measurements and estimated uncertainty.
- Your final value for v_1.
- Your calculations for the uncertainty on v_1

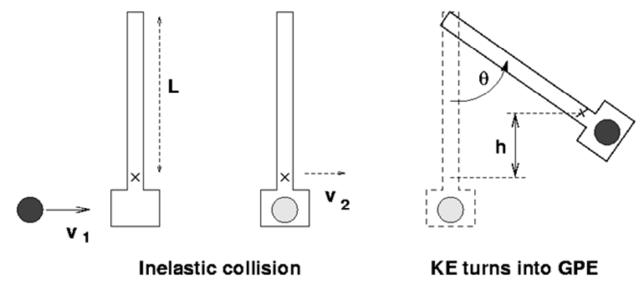
Ballistic Pendulum – Part I

In this experiment, you will use a ballistic pendulum to measure the initial velocity of a projectile fired from a spring-loaded gun.

Equipment.

Ballistic pendulum device. Rule.

Important: make a note of the serial number of your device.



Theory

Your first task is to derive an equation relating the initial speed of the ball (**v_1**) to quantities we can measure directly. Break the problem into two steps.

1 A ball of mass **m**, moving at speed **v_1** slams into the pendulum arm of mass **M**. Since the ball sticks in the cradle, this is a completely inelastic collision. Use conservation of momentum to write an equation relating **v_1** to the velocity of the arm-plus-ball, **v_2**, immediately after the collision.

2 After the collision, the pendulum arm, which has now has a mass **M+m** and an initial speed **v_2**, swings up until it reaches a high point at an angle ***θ***. Use conservation of energy to write an equation relating **v_2** to the distance **h** between the initial and final positions of the center of mass of the arm. Now use trigonometry to figure out the relationship between **h**, *θ* and the length, **L**, of the pendulum arm measured between its pivot point and its center of mass (including the ball).

When you have reached this point, get an instructor to check your equations.

Ballistic Pendulum Uncertainties

- Determine the uncertainty for the velocity
  - Need uncertainty in mass
  - Need uncertainty in height

$$v_{Ball} = \frac{(m+M)}{m}\sqrt{2gh(L,\theta)}$$

$$\Rightarrow \frac{\Delta v}{v} = \left|-1\right|\frac{\Delta m}{m} + \left|1\right|\frac{\Delta M}{M} + \left|1/2\right|\frac{\Delta h}{h}$$

Uncertainties in the ballistic pendulum experiment

Here are some tips, which may help you do the calculation. Break the problem up into a series of steps.

1. First calculate the fractional uncertainty in h ($\Delta h/h$). This will involve combining the estimated uncertainties in L and in a term that looks like ($1-\cos\theta$).

   Note 1: to convert an estimated uncertainty in θ into an uncertainty in ($1-\cos\theta$), evaluate the function for $\theta+\Delta\theta$ and $\theta-\Delta\theta$. Then $\Delta(1-\cos\theta) = \frac{1}{2}\left|(1-\cos(\theta+\Delta\theta)) - (1-\cos(\theta-\Delta\theta))\right|$

   Note 2: if $Q=Cxy$ or $Q = C(x/y)$, where C=constant, $\frac{\Delta Q}{Q} = \frac{\Delta x}{x} + \frac{\Delta y}{y}$

2. Use the fractional uncertainty in h to determine the fractional uncertainty in v_2

   Note 3: if $Q = Cx^n$, then $\frac{\Delta Q}{Q} = |n|\frac{\Delta x}{x}$

3. Determine the fractional uncertainties in the mass of the bullet and the mass of the pendulum arm plus bullet

   Note 4: if $Q=x+y$, then $\Delta Q=\Delta x+\Delta y$.

4. Combine these with the fractional uncertainty in v_2 to calculate the fractional uncertainty in v_1.

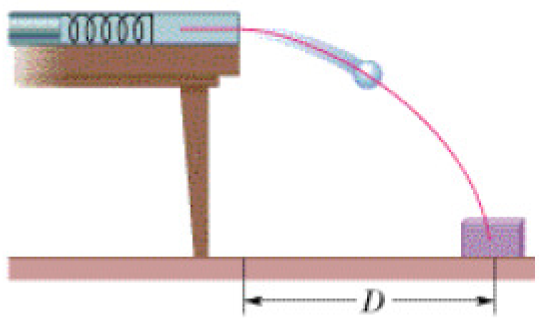
   Note 5: see *Note* 2.

5. Calculate the absolute uncertainty Δv_1.

RIT

Activity - Ballistic Pendulum – Part II

- **Predict landing site**
  - Just like WebAssign Problem 8-12…



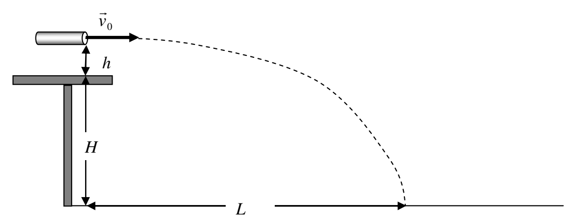
$$\frac{D}{\Delta x_s} = \sqrt{\frac{2hk}{mg}} \equiv \text{constant}$$

Ballistic Pendulum — Part II

Previously, we used a ballistic pendulum to measure the initial velocity of a projectile (steel ball) fired from a spring-loaded gun. Now we'll test that result by predicting and then measuring the range of a ball fired from the gun.

Equipment.

Ballistic pendulum device. **Make sure you use the same device that you used in Part I**. Rule. Target box, carbon paper.



Theory

First make your prediction for L, given the muzzle velocity v_0 you determined earlier, using the ballistic pendulum. You should also work out a formula for the uncertainty in L.

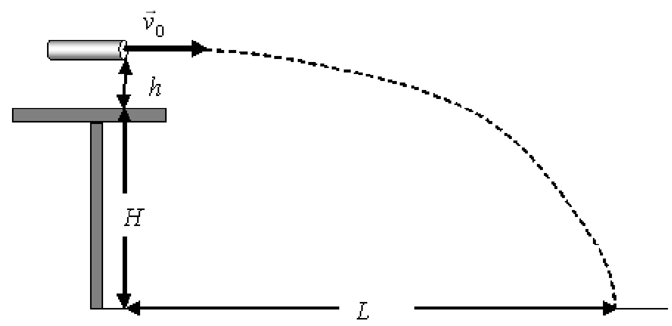
1. Use your knowledge of projectile motion to find an equation for L in terms of $(H+h)$, the initial height of the ball above the floor and the muzzle velocity v_0.
2. Given estimated uncertainties ΔH, Δh and Δv_0, find an equation for the uncertainty in L.

When you have done this, have your work checked. If it looks good, you can go ahead and set up your equipment.

Ballistic Pendulum – Part II Continued…

❑ Report – Part II

- A page showing your derivation of the equations *L* and D*L*.
- A page showing your measurements of *H*, *h*, your predicted value of *L* and the calculated uncertainty.
- Your target sheet, showing your prediction, uncertainty and the impacts of your shots.



$$L = vt\,, \quad H = \frac{1}{2}gt^2$$

$$\frac{\Delta L}{L} = ?$$