611-1410 (40-405) Projectile Launcher

Replacement Parts:
24-0405 Instructions
40-030 Aluminum ball with hole
40-069 Steel ball with hole

Congratulations on your purchase of a Science First® product. You will find Science First® products in almost every school in the world. We have been selling fine, high quality apparatus since 1960.

Warranty and Parts:
We replace all defective or missing parts free of charge. Order replacement parts by referring to part numbers above. We accept Master Card, American Express, Visa, School P.O's, checks and money orders. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse, or normal wear and tear.

Introduction:
The 40-405 Projectile Launcher can be used for experiments and demonstrations involving trajectories. It includes a built-in clamp with which fastens launcher to table tops and two balls, one each of steel and aluminum. The balls are drilled to fit a 1/8" diameter projection on the drive shaft. This prevents ball spin and permits use of other projectiles such as rubber stoppers. An attached protractor and plumb bob permit an accurate determination of angle of inclination. The range of the projectile is infinitely adjustable. The release latch adjusts to any desired setting and locks in place. The wide range of adjustment available makes it possible for each student to have a completely unique set of data. The Launcher was designed so that no matter what angle is chosen, the height of the ball at its release point from the table is constant.

Description:
The Launcher includes the base unit complete with table clamp, two drilled balls of different mass and instructions. (See Diagram 1.) Four holes in the edges of the launcher allow attachment of photogate timers. (We recommend 25- 155 from Science First®.) The holes are spaced exactly 5 cm apart. The attached protractor and plumb bob permit easy measurement of angle of inclination. Use the Launcher at any angle from -15° to 90°. Normally the ball is shot toward the left; however, by removing the protractor and installing it upside down, you may shoot toward the right as well. If you do this, the release height above the floor increases.

Always Wear Safety Glasses When Launching Balls!

Additional Materials Needed: Plumb Bob
The Launcher clamp is in line with the departure point of the ball. A plumb bob suspended from the clamp allows you to locate the departure point on the floor. A piece of string attached to a small weight will work.

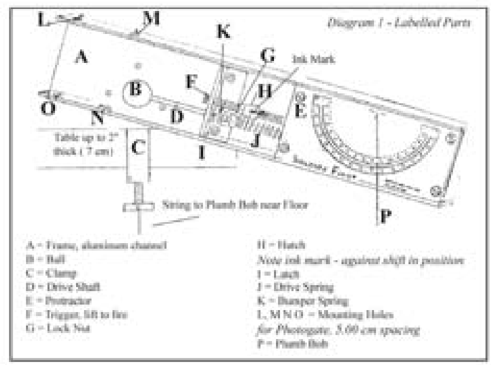
Meter Stick
A meter stick or tape is required for distance measurements (along with a target, discussed below.) To measure the horizontal distance from launcher to target, determine the points at which projectile flight begins and ends. If the launcher is on a table and the target on the floor you must locate the point on the floor directly under the launch position of the ball.

Target
Old magazines work well for a target. By placing a piece of carbon paper inside the magazine, you can locate the point of impact caused by the ball striking the magazine cover. The impact will show through many pages. If the target is placed in a shallow box, it is easier to retrieve the ball.
Photogate Timer (Optional)

Photogate Accessory
We recommend 25-155 Photogate Accessory manufactured by Science First®. These accessories clamp to the Launcher without additional equipment. Remove the photogate from the stand. Projections from rims of the photogate fasten into holes on Launcher. Tighten the photogate arms for a secure fit. (See Page 4 for detailed directions on use.)

Safety Factors:
There is potential for injury from any moving object. We recommend these safety precautions:
- **All people in the vicinity should be called to observe demonstration launches. This highlights the need to stay out of the way and shows how to avoid problems.**
- **Avoid sudden, unannounced movements. Before pursuing a rolling ball, notify those in your path. This prevents you from interfering with their experiment and keeps you out of the path of a launch.**
- **All people in the lab should always wear safety glasses when watching or experimenting.**

Operation
Setting Up:
1. Use attached clamp to clamp bracket to table edge with gun pointing at desired angle.When shooting onto the floor, use the plumb bob you attached to the clamp to position the launcher in relation to the floor. Help align launcher with a target by using a straight edge or meter stick.
2. Set angle by loosening wing nut on bracket. Rotate launcher to desired angle and tighten nut when angle is reached. (Any angle from -15° to + 90° may be selected above or below the horizontal. Use the plumb bob and protractor attachment to select angle.)
3. Position ball onto shaft. Shaft has grooved snap ring so ball is held in correct place.
4. Cock trigger mechanism. Do this by lifting trigger mechanism with one hand, using attached ball to push in shaft with the other hand. Apparatus is cocked when cone on shaft is to right of upper cone (trigger). Always cock launcher with ball in place on trigger mechanism.
5. Check vicinity for safety. Once the launcher is set up, check out your intended course before performing any experiments. Examine the direction the projectile is aimed and whatever may be within range, including people, breakable material and items that may be marred by the projectile. People in the area should be fully informed and provided with safety glasses. The teacher should perform one demonstration first.
6. Release trigger by pulling upward with thumb about 1/4". This shoots ball forward and to your left, unless you modified the launcher to shoot right, as described above. Make sure no one will be hit by the ball.
7. When shooting onto the floor, protect the floor surface from damage. Use old magazines or tablets placed at the point of impact.
8. Adjust range by adjusting latch and angle.



Experiment 1
Range vs Angle of Inclination

Equipment Needed:
Projectile Launcher
Paper
Carbon Paper
Meter Stick
Target
Photogate Timing System
(Optional)

Purpose:
The purpose of this experiment is to demonstrate the relationship between range and angle of launch. The elevation of the impact point is important. (See Diagram 2).

Theory:
The range of a projectile depends upon the horizontal component of its velocity and its time of flight. The time of flight depends upon the vertical component of its velocity. Maximum range is obtained when the product of these two components is a maximum horizontal velocity is constant. If the projectile is launched at an angle θ from the horizontal, it will have two components of velocity, vertical - $v_0 \sin\theta$ and horizontal - $v_o \cos\theta$. The projectile when

launched will rise to its acme and then fall to the floor. See Diagram 2.

We can get the acme y_{max} by first calculating the time of rise, t_r.

$$t_r = \frac{v_o \sin\theta}{g} \qquad \text{(Eqn. 1)}$$

We obtain the muzzle velocity v_o by any of the three methods described later. You can then use the kinematic equation:

$$y_{max} = v_o \sin\theta\, t_r - 1/2\, g\, t_r^2 \qquad \text{(Eqn. 2)}$$

Then the total distance, y, that the projectile falls is:

$$y = y_{max} + y_0 \qquad \text{(Eqn. 3)}$$

Where y_0 is the height of the launch point above the floor.
Then the fall time, t_f is given by

$$tf = \sqrt{\frac{2y}{g}} \qquad \text{(Eqn. 4)}$$

The time of flight, **t**, is then:

$$t = t_r + t_f \qquad \text{(Eqn. 5)}$$

Knowing the flight time, we can then calculate the range, x, by:

$$x = v_0 \cos\theta\, t \qquad \text{(Eqn. 6)}$$

Use the worksheet on page 6 to analyze your data.
You can also use the kinematic equation in the vertical mode to get the time of flight directly by using:

$$y = y_0 + v_0 \sin\theta\, t - 1/2\, g\, t^2$$

where:
y = the target height
y_0 = the launch height
v_0 = muzzle velocity

and then solving the quadratic for t by using the quadratic formula:

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Procedure:
Prepare a target consisting of a magazine and carbon paper. Set elevation at 45° and adjust the latch or target as needed. Fire 2 or 3 shots and record range and angle.
Repeat for angles 15°, 25°, 35°, 55°, 65° and 75°.

Results:
Prepare a graph of range vs product of sin θ • cos θ. Repeat this experiment with a target at a different elevation than used before.

Conclusion:
At what angle is the range a maximum? Why?

There are 3 methods of determining muzzle velocity V_0:
- **Time of flight**
- **With 1 photogate**
- **With 2 photogates**

2 photogates yield the most accurate results.

Procedure
(Time of Flight):
1 Clamp the launcher to the table in a horizontal position (zero inclination).
2 Adjust the latch as needed to fire the ball a suitable distance.
3 Tighten the lock nut finger tight and place the target at the expected point of impact. When satisfied, tape the target down and insert carbon paper.
4 Place a marker on the latch (for instance, ink, paint, a piece of tape) which would allow you to detect any rotation.
5. For extra accuracy, you may wish to tape the lock nut in place to ensure it does not move. If it moves out of position, your results will be compromised.

Data:
Measure vertical distance from lower edge of ball to upper edge of target and record on the worksheet on Page 6. Fire a practice shot and if the ball hits the target satisfactorily, fire up to 10 more. It is unlikely that all shots will hit at exactly the same spot. Record distances and calculate average velocity. (See sample worksheet on Page 5.)

Procedure
(One Photogate):
1. Clamp Science First® 25-155 Photogate Accessory against the body of the projectile apparatus, using the pair of holes labeled M and N on Diagram 1. (These are the holes closest to end of drive shaft.) Make sure that the connecting wires are not in the path of the ball.
2. Plug in your Photogate Timer.
3. Turn on the Timer and set it to Projectile Motion II (gate) mode.
4. Fire the ball. When the ball is fired, the Timer will measure the time to pass through the photogate.
5. To calculate initial vertical and horizontal velocities:
a. Divide diameter of ball (you will need to measure) by the time t.
b. This is velocity of ball in cm/sec.
c. Use this velocity and angle at which the ball was fired to work out the initial vertical and horizontal velocities.

Calculating Muzzle Velocity:
The time of flight may be determined by the time required for the ball to fall from launch point to floor. This is obtained from:

$y = 1/2\, gt^2$ or rewriting:

$$t = \sqrt{\frac{2y}{g}}$$

where **Y** is the vertical distance of fall and **g** is the gravitational acceleration.
Horizontal velocity therefore is:

$$V_x = \frac{\text{horizontal distance}}{\text{time}}$$

Procedure
(Two Photogates):
1. Clamp two Science First® 25-155 Photogates to the base of the projectile apparatus using holes L,M,N, and O.
2. Plug the photogate closest to the drive shaft (Photogate #1) into the phone jack closest to the power jack on the Timer.
3. Plug the other photogate (Photogate #2) to the other phone jack on the Timer. Make sure that no wires are in the path of the ball.
4. Set Timer to Pulse mode. When ball is fired, timer will measure the time from the first interrupt on the light beam on Photogate #1 until the first interrupt on light beam of Photogate #2.
5. Divide the time t by 5.00 cm, the distance between the photogates. This gives the initial muzzle velocity of the ball.
6. Resolve the velocity into its x and y components by using the angle at which the ball was fired.

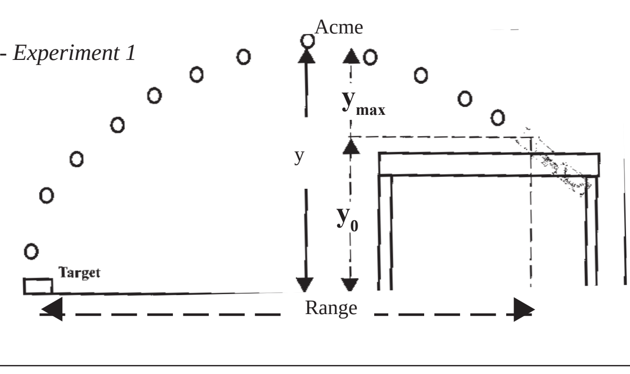
Experiment 2: Projectile Motion

Equipment Needed:
Projectile Launcher
Vertical Board on Suitable Stand
Carbon Paper
Meter Stick
Target

Purpose:
The purpose of this experiment is to verify that the trajectory of a projectile is a parabola. In order to reduce experimental error, we recommend taping the release latch in place. Mark the latch in such a way that it would be noticed if the latch turned.

Sample Procedure:
1. Set the launcher at an angle of about 35°. Make sure it is secured and does not vibrate. Measure angle using the attached protractor. Plumb bob points to angle; read off angle.
2. Set Photogate on holes M and N which are nearest launch point. (See Diagram 1.) The projectile should pass through window immediately upon leaving.
3. Set Timer on “Projectile Motion II” mode. In this mode Timer should automatically record five values of time t_{pass} of the projectile (ball) for five runs of one trial. It will also calculate average

Diagram 2 - Experiment 1



value of t_{pass}. Each value of time will be measured to one-tenth of a millisecond.
4. Find diameter of ball with vernier caliper. This is value **d**.
5. Set and lock trigger cone to set velocity.
6. Tape a small sheet of paper on floor, under the edge of the launcher. Hold plumb bob at edge of launcher such that it almost touches floor and mark point on floor. This point will be the origin of the x-axis and all x-mode distances will be measured from this point. Measure height of edge of launcher using two meter stick held in a strictly vertical position. This value is height h_0.
7. Launch projectile and let it fall on floor below to see where it falls. Tape paper in area where you expect the projectile to hit the floor. Place carbon paper on top.
8. Clear the Timer.
9. Launch projectile. As the projectile travels through its trajectory, the Timer will record the value t_{pass}. As projectile hits floor, a black mark will be registered on the paper.
10 Run through five values of t_{pass} as recorded by the Timer. If there are substantial differences, discard values and repeat. Record average value of t_{pass}.
11Remove carbon paper. You will find five spots on paper, ideally very close to each other. Find center of this "cluster' of points. Draw a line on floor from original of the x-axis to center of cluster. This line is the x-axis. Measure the distance of the "center of cluster" along the x-axis from origin; this is x_0. The corresponding value of height is $-h_0$. Record the values of x_0 and $-h_0$ for the first trial.
12 Tape long paper on vertical stand and place stand on x-axis. Tape carbon paper near lower portion of sheet. Position stand so that vertical sheet of paper is about 10 cm closer to the origin from x_0. Measure horizontal distance x_1 of vertical sheet from origin. Record value. See Diagram 3.
13 Repeat as above. The projectile will not hit floor; it will hit the vertical paper, leaving black marks close together. Draw a line around these marks and find center of "center" of point. Measure the height of this point above floor. This is h_1, a positive value.
14 Move the vertical board 10 cm closer to the origin. Repeat. Value of **h** is positive.

Calculations:
1. All values of time are expected to be the same. Find average of all values, divide by diameter of projectile d by t_{av}. This is initial velocity of projectile as it leaves launcher.
2. Add heights h_1 to h_0. All h_1 are positive.
3. Make a table of x_1 and all h_1. Plot x_1 on x-axis and h_1 on y-axis. Perform a least square second order polynomial curve fit using computer or calculator. Get r^2 value.
4. Record values of coefficient of x and x^2. The coefficient of x is tangent of theta0. By taking inverse tangent you get angle at which projectile was launched. Compare to actual angle, as set in first step. Find percentage error.
5. Coefficient of x_2 has a value of $(g/2)/v^2_x$. Solve for V_x. But V_x equals V_0 (cos q). Using value of q from step above, solve for V_0. This value of V_0 should match value of V_0 found in first step of calculations, above. Compare and find the percentage error.

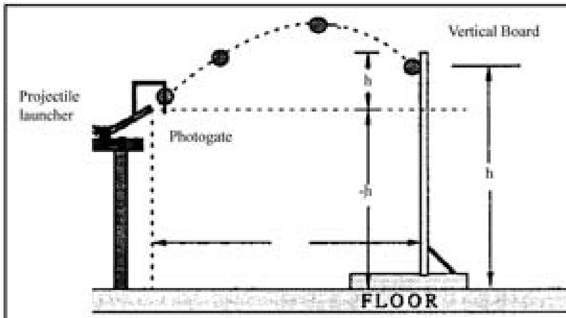


Diagram 3- Measuring trajectory of a projectile

Experiment 3: Mechanical Efficiency of a Catapult

Equipment Needed:
Projectile Launcher
Rulers, 0 to 10 cm
Objects of known weight
2 to 10 kg. We recommend books.
Ball point pen
From which writing unit is removed.

Theory:
The catapult obtains its energy input by the application of a force through a distance. Some of this energy is delivered to the projectile as kinetic energy but much of the energy is used only to provide kinetic energy to the machine itself which is wasted. Energy was also lost through friction at the latch, internal friction of the elastic components and bending of machine parts. By quantifying these loses and understanding them, better machines can be built.

Purpose:
To determine the efficiency of a simple machine - the catapult. By understanding the energy input and losses in a machine, you can design superior ones. In this experiment, you can attempt to quantify the energy input into the launcher, its effective utilization, the nature and extent of energy losses. Such information allows a designer to optimize his product by minimizing sources of waste.

Set Up:
Place the projectile launcher in a vertical direction and clamp in place. Take a ball point pen from which the writing unit has been removed. Place the hollow body of the pen on the stern of the drive shaft. This allows weights to be applied to the end of the shaft to compress the springs.

Procedure:
Find spring constants and energy output.
1. Carefully measure the distance form the holding edge of the latch on the drive shaft to the frame. Record.
2. Have one person place a load on the pen body and balance it in a manner that allows almost all of the weight to rest on the pen. The load must be steadied by hand but this can be done in such a way as to still allowalmost all the weight to be applied to the drive shaft.
3. Record the distance from latch to frame for this load.
4 Repeat with larger loads until latch to frame distance increases 2-3 cm.
5. Plot a graph of force vs distance. You should get a reasonably straight line, leading to the equation:

$F = F_0 + Cy\ Yo$
where F_0 is an initial force required to overcome spring tension; y is the distance the drive shaft is depressed and c is the spring constant.
• Energy input then is the integral of :
$(F_0 + C_y)$ dy.

Mechanical Efficiency:
1. Determine energy output by projecting the steel ball vertically upward and measuring the distance the ball rises.
2. From the weight of the ball and the distance propelled, you can obtain:
Energy = m g h
where m is mass; g is gravitational acceleration and h is the vertical distance the ball is thrown.
• At the instant the ball is released, this energy is in the form of kinetic energy:
$1/2\ mV^2$.
3. The drive shaft also has been given kinetic energy which of course is wasted.
• The kinetic energy of the drive shaft may be calculated using the departure velocity of the ball and mass of the drive shaft and latch - 49.5 grams total.
4. Some energy is given to the drive springs which weigh 13.5 grams total.
• Only the upper end of the springs have the same velocity as the ball.

Problem:
Try to predict the height to which a ball of 20 g mass might be thrown.

How to Use Photogates:

1. Place the photogate so that the object to be timed interrupts infrared beam.
• Adjust the width of the photogate by unscrewing knobs and sliding the detector and emitter along shaft. You can also rotate detector and emitter to any angle by unscrewing known at end of shaft.
• The interrupting object should be placed as close to the detector as possible. (The detector is the molded assembly with long wire attached.) The object's line of travel must be perpendicular to the photogate.
2. Attach stereo phone plug into your Photogate Timer.
3. Test operation of the photogate before your experiment. The LCD screen on your timers will indicate if photogate is working properly.
• If the beam is blocked, a filled-in box is displayed on the right side of LCD screen. The position of the box indicates when channel is active.
4. Use stereo phone plug extension cord if you require more separation between photogate and timer.

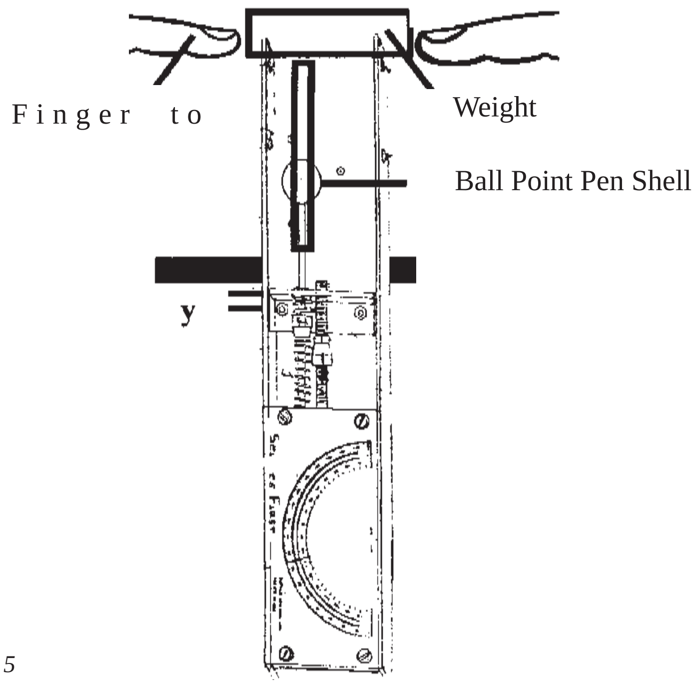


Diagram 5

Data and Data Tables

Name ______________________ Date ______________________

Instructor ______________________ Lab Section ______________________

Partner ______________________ Table # ______________________

Table - Determination of the Value of Muzzle Velocity

Shot number	Distance	Velocity
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
	Average Distance:	Average Velocity:

Data and Data Tables

Name ______________________ Date ______________________

Instructor ______________________ Lab Section ______________________

Partner ______________________ Table # ______________________

Predicting the Range

Shot Number	Muzzle Velocity V_0	Rise Time t_r (*Eqn 1*)	Rise Distance y_{max} (*Eqn 2*)	Fall Distance y (*Eqn 3*)	Time of Fall t_f sec (*Eqn 4*)	Range of Flight $t_r + t_f$ sec (*Eqn 5*)	Range Predicted (*Eqn 6*)	Range Measured
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								