Lab Manual
Accelerated Physics Version 3.2

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Good Laboratory Practices

Science labs, whether at universities or in your home, are places of adventure and discovery. One of the first things scientists learn is how exciting experiments can be. However, they must also realize science can be dangerous without some instruction on good laboratory practices.

General

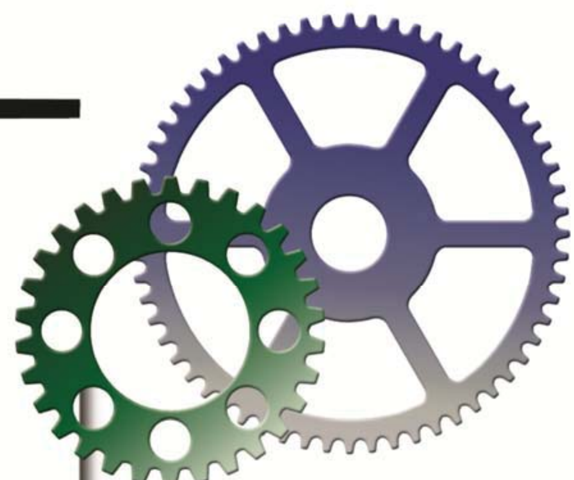
- Read the protocol thoroughly before starting any new experiment. You should be familiar with the action required every step of the way.
- Use eye protection when experimenting with chemicals, batteries, and projectiles.
- Keep all work spaces free from clutter and dirty dishes.
- Wash your hands after each experiment.
- Thoroughly rinse labware (test tubes, beakers, etc.) between chemical experiments. To do so, wash with a soap and hot water solution using a bottle brush to scrub. Rinse completely at least four times. Let air dry.
- Do not aim projectiles or other moving materials at other individuals.

Materials and Chemicals

- Use only the materials needed for each activity
- Always handle hot water carefully and with necessary hand and eye protection.
- When using knives or blades, always cut away from yourself.
- Never use more batteries than an experiment specifies. Do not create electrical circuits other than those specified by the lab manual.
- Avoid creating “short circuits” with electrical equipment. This can cause unsafe battery temperatures.
- Immediately dry any wet electronics—especially in the case of spilled liquids. Make sure materials are *completely* dry before resuming work.
- Avoid prolonged exposure of batteries and chemicals to direct sunlight and extreme temperatures.
- Immediately secure the lid or seal the package of liquids, powders, and other materials after use.

- Use test tube caps or stoppers to cover test tubes when shaking or mixing – not your fingers!
- Use a new pipette for each chemical dispensed.
- Never return excess chemical back to the original bottle. This can contaminate the chemical supply.
- Be careful not to interchange lids between different chemical bottles.
- Wipe up any chemical spills immediately. Check MSDSs for special handling instructions (provided on www.eScienceLabs.com).
- Read the labels on all chemicals, and note the chemical safety rating on each container. Read all MSDS (provided on www.eScienceLabs.com).
- Read the MSDS before disposing of a chemical to insure it does not require extra measures. (provided on www.eScienceLabs.com)

Newtonian Mechanics



Lab 5: Projectile Motion

Concepts to explore

- Scalars vs. vectors
- Projectiles
- Parabolic trajectory

As you learned in the Linear Motion Lab, a quantity that conveys information about magnitude only is called a **scalar**. However, when a quantity, such as velocity, conveys information about magnitude *and* direction, we call it a **vector**. Along with carrying that extra bit of information about the path of motion, vectors are also useful in physics because they can be separated into **components**. In fact, any vector can be resolved (broken down to) an equivalent set of horizontal (x-direction) and vertical (y-direction) components, which are at right angles to each other.

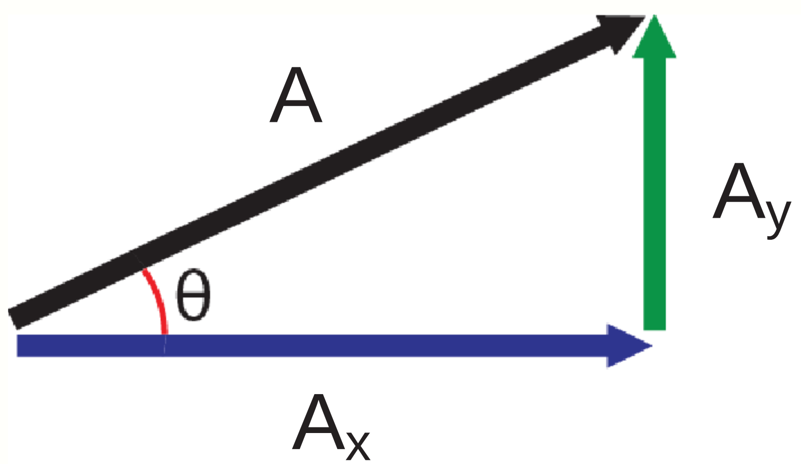


Figure 1: The vector A **can be broken up into horizontal and vertical components, A_x and A_y.**

Consider a vector arrow drawn on a rectangular coordinate plane, as vector $\mathbf{A}$ pictured in Figure 1 (For distinction, the bolded type signifies a vector). The horizontal component of a vector is the distance along the *x*-axis that the vector covers, while the vertical component is in the direction of the *y*-axis. If the angle between the horizontal component and the vector is θ, you can use trigonometry to find the magnitude of the components:

$$A_y = |\mathbf{A}|\sin\theta \qquad\qquad A_x = |\mathbf{A}|\cos\theta$$

where $|\mathbf{A}|$ is the magnitude, or length, of the original vector. Using the Pythagorean Theorem, the magnitude of any vector can be expressed in terms of its components as

$$|\mathbf{A}| = \sqrt{A_x^2 + A_y^2}$$

and the angle from the horizontal axis can be found using:

$$\tan\theta = \frac{A_x}{A_y}$$

Vector addition is done by adding horizontal and vertical components. In other words, the horizontal component of the new vector—often called the "resultant"— is simply the sum of the horizontal components of the two added vectors. Likewise, the vertical component of the resultant is the sum of the individual vertical components. You can then find the magnitude and angle of the resultant using the trigonometric equations above.

A **projectile** is any object which, once projected at an initial velocity, continues in motion by its own inertia and is influenced only by the downward force of gravity. Remember that Newton's Laws dictate that forces cause *acceleration*, not simply motion. Therefore, the only force acting on a projectile in its Free Body Diagram is the force of gravity downward. This may seem counter-intuitive since the object might initially be moving in several directions, both horizontally and vertically, but *gravity acts only on the vertical motion of the object*.

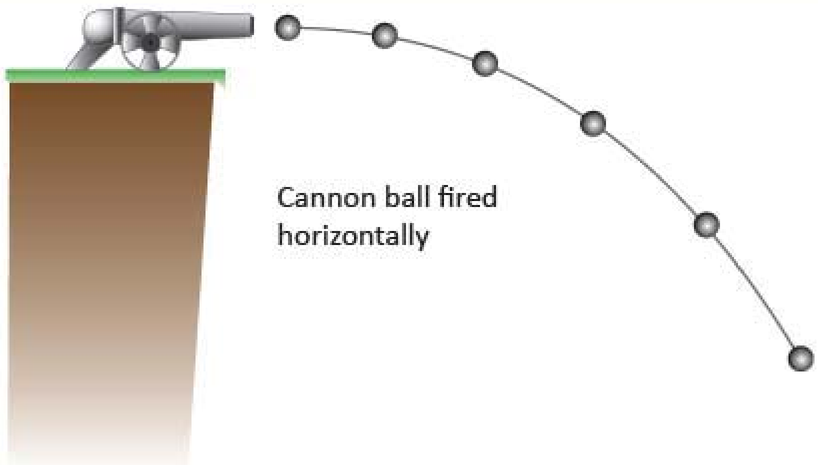
Figure 2: Some examples of projectiles are a cannonball fired from a cannon, a baseball hit by a bat, and balls being juggled in the air. All these objects follow a curved path due to the force of gravity.

Figure 3: When a projectile (water, in this case) is launched upward the vertical acceleration will reach zero at the top of the parabola. As gravity pulls the object toward the Earth the object accelerates. Horizontal velocity remains constant throughout this motion.

One convenient thing about using vectors to describe projectile motion is that we can separate the velocity of the projectile into horizontal and vertical motion. The vertical component of the velocity changes with time due to gravity, but the horizontal component remains constant because no horizontal force is acting on the object (air resistance adds quite a bit of complication at higher velocities but will be neglected in this lab). We can thus analyze each component of the projectile's velocity separately. The combination of a (constantly) changing vertical velocity and a constant horizontal velocity gives a projectile's trajectory the shape of a **parabola**.

As shown in Figure 4, the projectile with horizontal and vertical motion assumes a characteristic **parabolic trajectory** due to the effects of gravity on the vertical component of motion. The horizontal motion is the result of Newton's First Law in action (you will lean about this in Lab 7) – the object's inertia! If air resistance is neglected, there are no horizontal forces acting upon projectile, and thus no horizontal acceleration. It might seem surprising, but a projectile moves at the same horizontal speed no matter how long it falls!

The kinematic equations (Figure 5) from the previous lab can describe both components of the velocity separately. For most two-dimensional projectile motion problems, the following four equations will allow you to solve for different aspects of a projectile's flight, as long as you know the initial position and the initial velocity. In this lab you can assume that projectiles are fired either vertically or horizontally, so that the initial velocities in either case will either be $v_x = v_{ox}$ or $v_y = v_{oy}$. (The term v_{ox} can be read as "initial velocity in the x direction.")



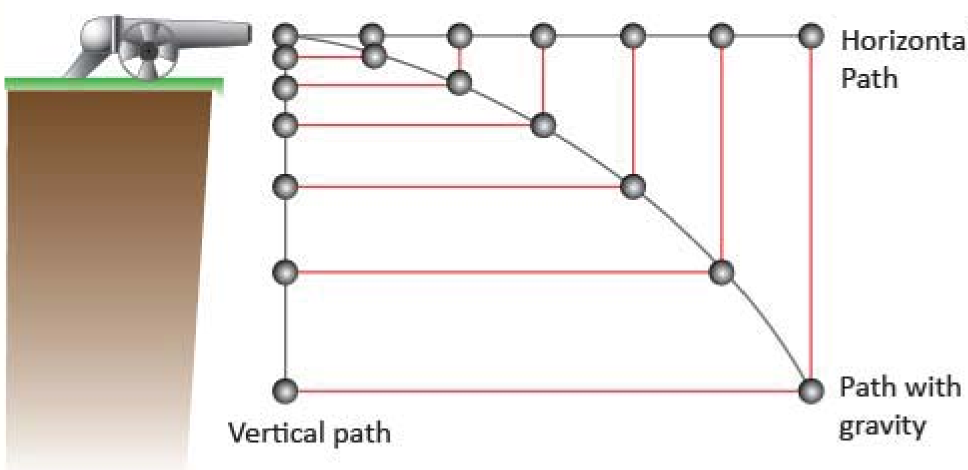


Figure 4: As the cannon ball in the upper picture travels a parabolic path, it gains velocity due to gravity. You can see that the space between successive "snapshots" of the ball gets gradually larger. Because gravity only accelerates the ball directly downward, only the vertical velocity of the ball changes. As you can see in the second figure, the vertical spacing increases according to t^2, while the horizontal spacing is constant. One surprising result of the independence of vertical and horizontal motions is that if two projectiles are launched at the same time from the same height, they will hit the ground and the same time! Their horizontal velocities do not affect the rate at which they will fall.

In the case where a projectile is not launched either vertically or horizon tally, the initial velocity components can be expressed as trigonometric functions of the total initial velocity, v_o:

$$v_{ox} = v_x = v\cos\theta \qquad v_{oy} = v\sin\theta$$

As you can see, for $\theta = 0$ (a completely horizontal launch), the horizontal velocity is equal to the total initial velocity v, while the vertical velocity is equal to zero. Meanwhile, for $\theta = 90$ (a vertical launch), the horizontal velocity is zero while the vertical velocity is equal to the total initial velocity.

Using the kinematics equations of Figure 5 you can calculate the total distance or range, R, of a projectile. If the projectile is fired at an angle, the range is a function of the initial angle θ, the initial velocity, and the force of gravity. Using a little algebra, you can derive this expression using the kinematics equations above:

$$R = \frac{v^2\sin(2\theta)}{g}$$

This range equation is useful so long as the initial height and final height of the projectile are equal. If the object ends up higher or lower than it started, you will have to use the individual kinematics equations to solve for the total range. It is important to remember that in many cases, air resistance is not negligible and affects both the horizontal and vertical components of velocity. When the effect of air resistance is significant, the range of the projectile is reduced and the path the projectile follows is not a true parabola.

Figure 5: Four useful kinematic equations for projectile motion:

$$x = x_o + v_x t$$

$$v_y = v_{oy} - gt$$

$$y = y_o + v_{oy}t - \frac{1}{2}gt^2$$

$$v_y{}^2 = v_{oy}{}^2 - 2g(y - y_o)$$

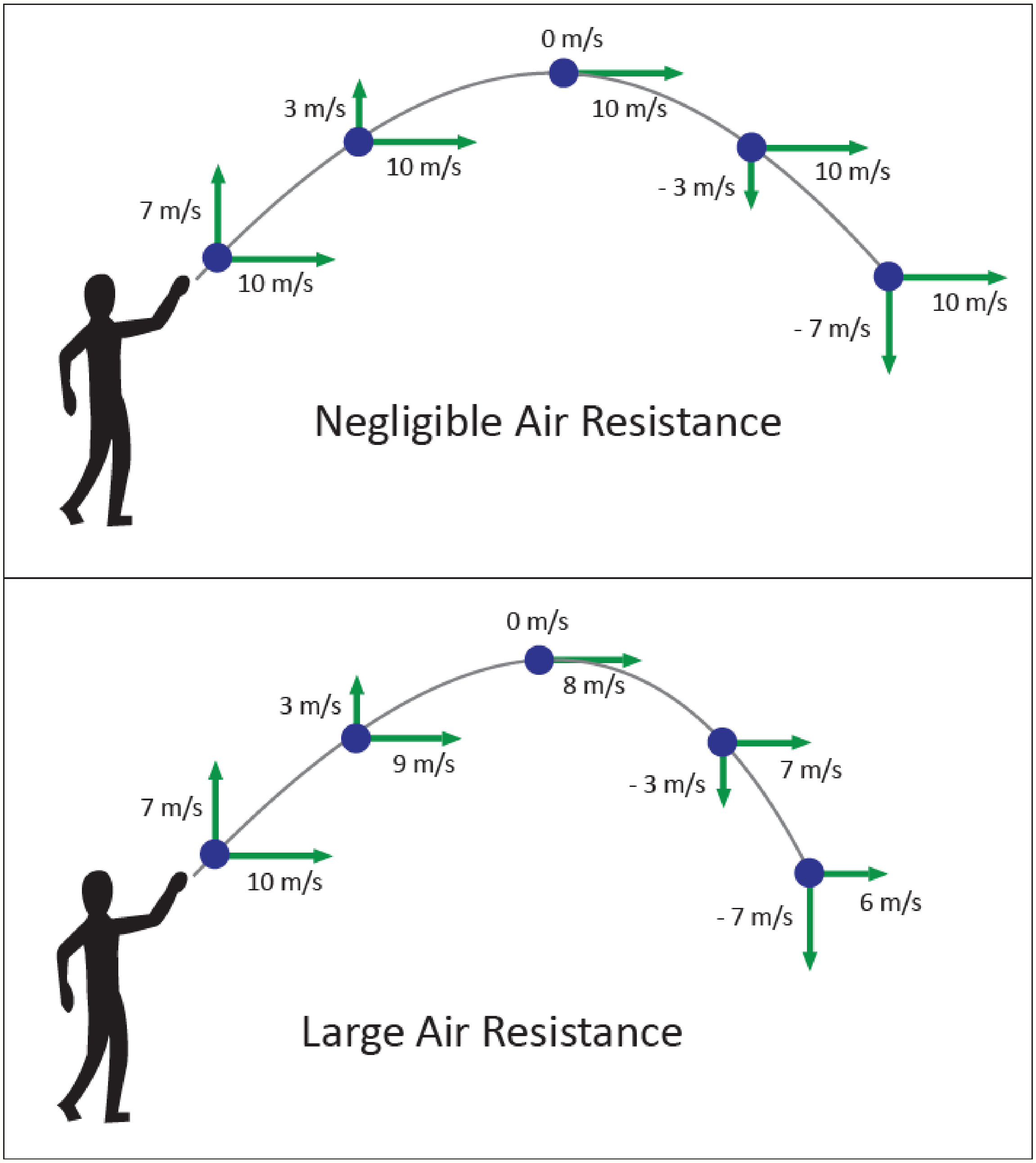


Figure 6: The path of a projectile in the absence of air resistance is a perfect parabola (top); however, with air resistance the projectile experiences a decelerating force in the opposite direction of its motion. The result is the shortened curve shown (bottom).

Experiment 1: Calculating the distance traveled by a projectile

In this experiment you will apply what you know about projectile motion and use kinematics to predict how far a projectile will travel.

Materials

- Ramp
- Marble
- Corn starch
- 4 Sheets of black construction paper
- Measuring tape
- Monofilament line
- Washer
- *Paper towel
- *Water

*You must provide

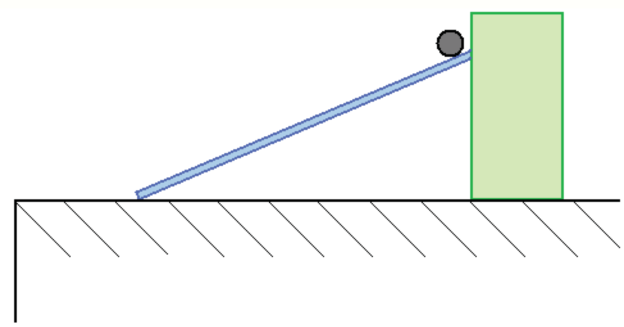


Figure 7: Ramp setup for Experiment 1

Procedure 1

1. Place the ramp on a table as shown in Figure 7 (reference the diagram at the beginning of the manual for ramp assembly instructions). Mark the location at which you will release the marble. This will ensure the marble achieves the same velocity with each trial.
2. Create a plumb line by attaching the washer to the monofilament line.
3. Hold the string to the edge of the table and mark the spot at which the weight touches the ground. (*Note: The plumb line helps to measure the exact distance from the edge of the ramp to the position where the marble "lands."*)
4. Lay down a runway of construction paper.
5. Wet the marble all over, and drop into the cornstarch bag to coat. Roll on a paper towel to achieve a smoth, even coat all over the marble (you do not want any chunks as it will affect the path of motion). When the marble hits the construction paper, the force will transfer some of the cornstarch to the paper and allow you to pinpoint where contact was first made.
5. Begin the experiment by releasing the marble at the marked point on the ramp.
6. Measure the distance traveled to the first mark made on the construction paper using the measuring tape. Record this value in Table 1 below.
7. Repeat Steps 5-6 two more times and find the average distance. Record your data in Table 1.
8. Next, use this average distance to calculate the average initial velocity of the marble when leaving the table.

Average Velocity Calculation:

Procedure 2

1. Find a higher table, or stack some books underneath the ramp to increase the height. Measure the starting height at the end of the ramp as before.
2. Using the average velocity found earlier, predict how far away the marble will land using the kinematic equations. Record this distance in Table 2. (Hint: you use one equation to find the total time in the air using the initial and final heights, and another to find the horizontal distance)
3. Measure this distance out and mark it before you release the marble. Release the marble three times and record the distance traveled in Table 2.
4. Complete the tables below using your measurements.
5. OPTIONAL Exercise: Set up the ramp to a new height, and calculate the predicted range. Place a Styrofoam cup with a small amount of water at your predicted distance. Release the marble from the ramp, testing your prediction by whether or not it lands in the cup.

Table 1: Projectile distance and velocity data

Table + Ramp Height	Distance traveled		Average Distance	Average Velocity

Table 2: Projectile distance and velocity data

Table + Ramp Height	Calculated Distance	Actual Distance		Actual Distance Average

Questions

1. If you were to throw a ball horizontally and at the same time drop an exact copy of the ball you threw, which ball would hit the ground first and why is this so?

2. What forces are acting on the marble before and after it leaves the ramp?

3. Describe the acceleration of a marble for the period after it leaves the ramp and before it hits the ground.

4. Did your prediction in Procedure 2 come close to the actual spot? Find the percent error of your predicted distance (expected) compared to the actual average distance (observed).

5. Explain some possible sources of error that could have produced the deviation above.

Experiment 2: Squeeze Rocket projectiles

The objective of this lab is to observe the distance a projectile will travel when the launch angle is changed.

Materials

- 4 Squeeze Rockets
- 1 Squeeze Rocket Bulb
- Protractor
- Measuring tape
- Stop Watch

*******Please exercise great caution when firing these rockets. Be sure the line of fire is clear of people and breakable objects prior to launching any rocket.*******

Procedure

1. NOTE: Rockets will often take unpredictable flight paths. To ensure data precision, only record trials in which the rocket travels a parabolic path and contacts the ground with the front end first.
2. Mark the spot from which the rockets will be launched.
3. Load a Squeeze Rocket onto the bulb.
4. Using a protractor, align the rocket to an angle of 90° (vertical).
5. Squeeze the bulb (you will need to replicate this force for each trial), and simultaneously start the stopwatch upon launch (alternatively, have a partner help you keep time). Measure and record the total time the rocket is in the air. Repeat this step three or more times, and average your results.

$$t_{avg} = \underline{\hspace{4cm}}$$

5. Calculate the initial velocity of the rocket ($v_{initial} = v_{oy}$) using the kinematics equations provided. Record your calculation in Table 3 below. (Hint: you can take the initial height as zero. The vertical velocity is zero at the peak of the flight, when the time is equal to t/2.)
6. Repeat this trial two more times, and record the values in Table 3 below.
7. Choose four additional angles to fire the rocket from. Before launching the rocket, calculate the predicted range using the kinematics equations and the angle of launch. Remember that you can use zero for any initial positions, and that the acceleration due to gravity, g, is – 9.8 m/s^2. Record these values in Table 3.
8. Next, align the rocket with the first angle choice and fire it with the same force you used initially. Try to record launches where the rocket travels in a parabola and does not stall or flutter at the top (this might take several repetitions). Measure the distance traveled with the measuring tape. Repeat this for two additional trials, recording the actual range in Table 3.

9. Repeat Step 7 for the remaining angles and record the data in Table 3.

Table 3: Projectile range vs. launch angle data

Initial Velocity (m/s)	Initial Angle	Predicted Range (m)	Actual Range (m)	Average	% Error
	90°	0			

Questions

1. Draw a diagram showing a rocket flying at an arbitrary angle. Indicate the force due to gravity and force due to air resistance. Why does the direction of the net force change over the course of the rocket's trajectory?

2. Explain how the launch angle affects both the trajectory and final range of the rocket. What angle (or range of angles) appears to produce the greatest range?

3. Knowing the kinematics equations, what angle *should* yield the greatest projectile range, disregarding air resistance and other factors? Show all calculations.

4. How does air resistance affect the accuracy and precision of your rocket data in this lab?

5. Calculate the percent error between your measured values and the predicted values. Given the nature of the squeeze rocket and your results, comment on any other sources of error that significantly affect your distance measurements.

6. How would a kicker on a football team use his knowledge of physics to better his game? List some other sports or instances where this information would be useful.

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