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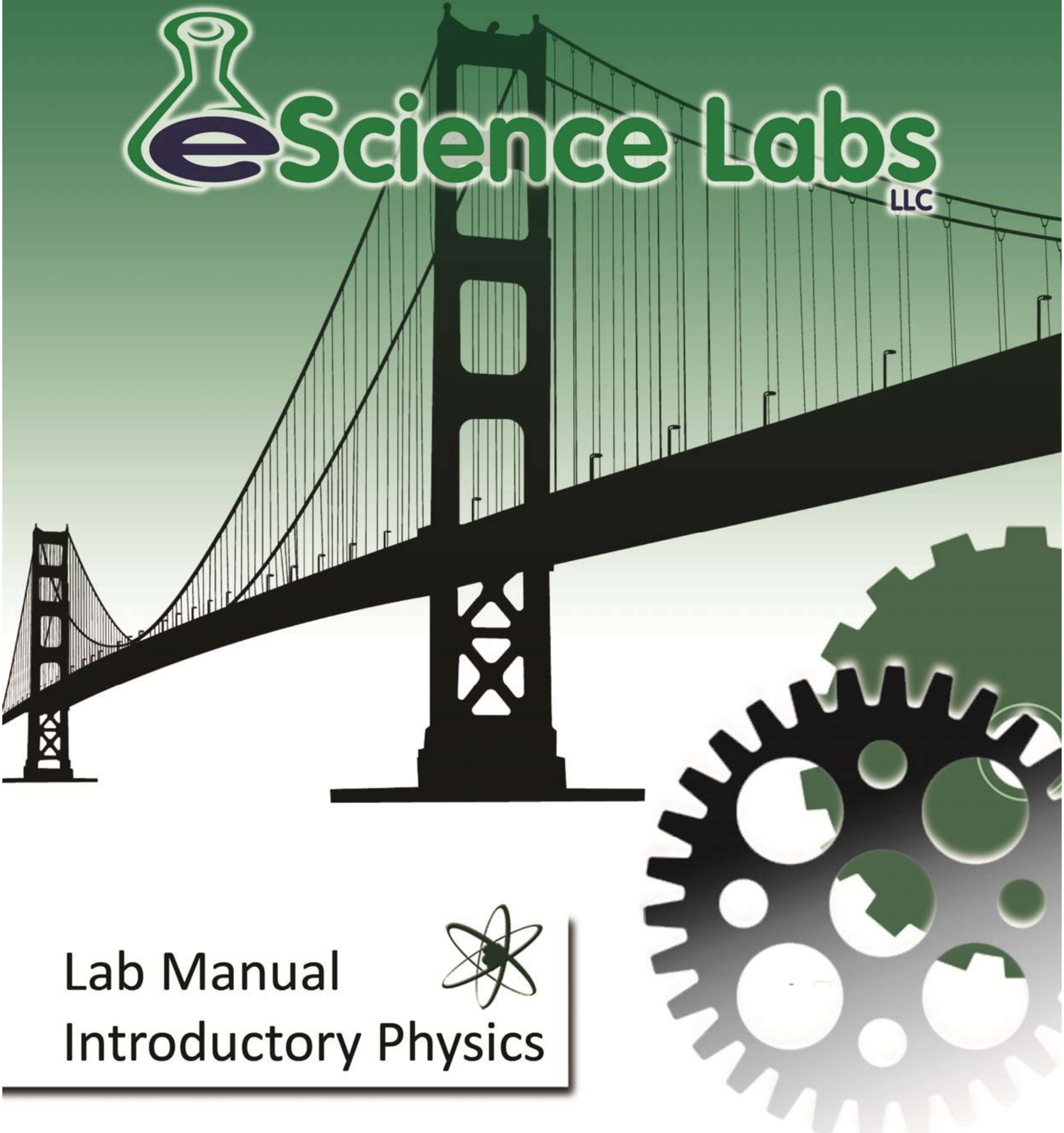

Lab Manual
Introductory Physics

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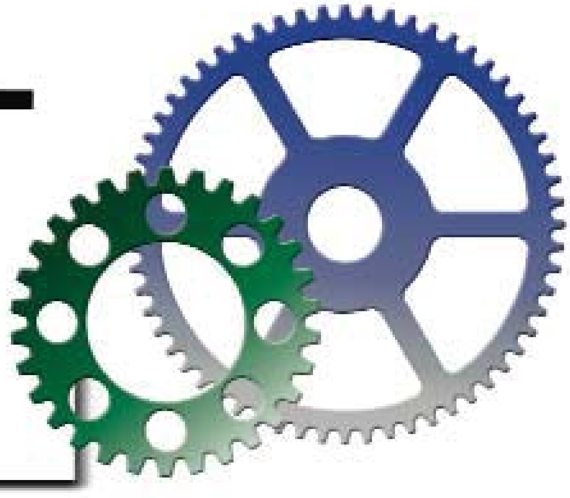
Newtonian Mechanics



Lab 7: Projectile Motion

Concepts to explore:

- Scalers vs. vectors
- Projectiles
- Parabolic trajectory

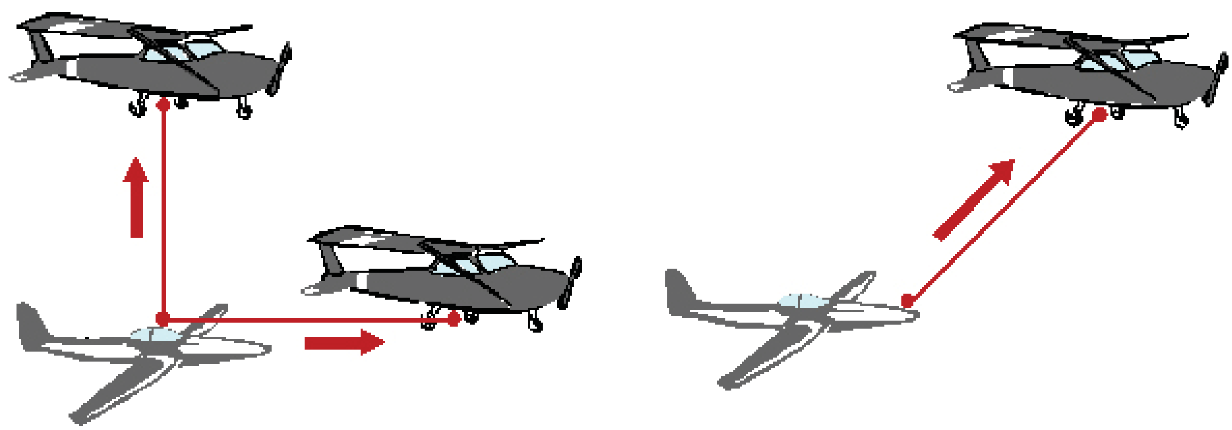


Figure 1: **The vertical and horizontal forces required to pull a glider into flight can be achieved with one tow rope.**

As you learned previously, 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) into an equivalent set of horizontal (x-direction) and vertical (y-direction) components, which are at right angles to each other.

A projectile is an object acted on by gravity alone. Typically, a projectile is any object which, once projected, 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.**

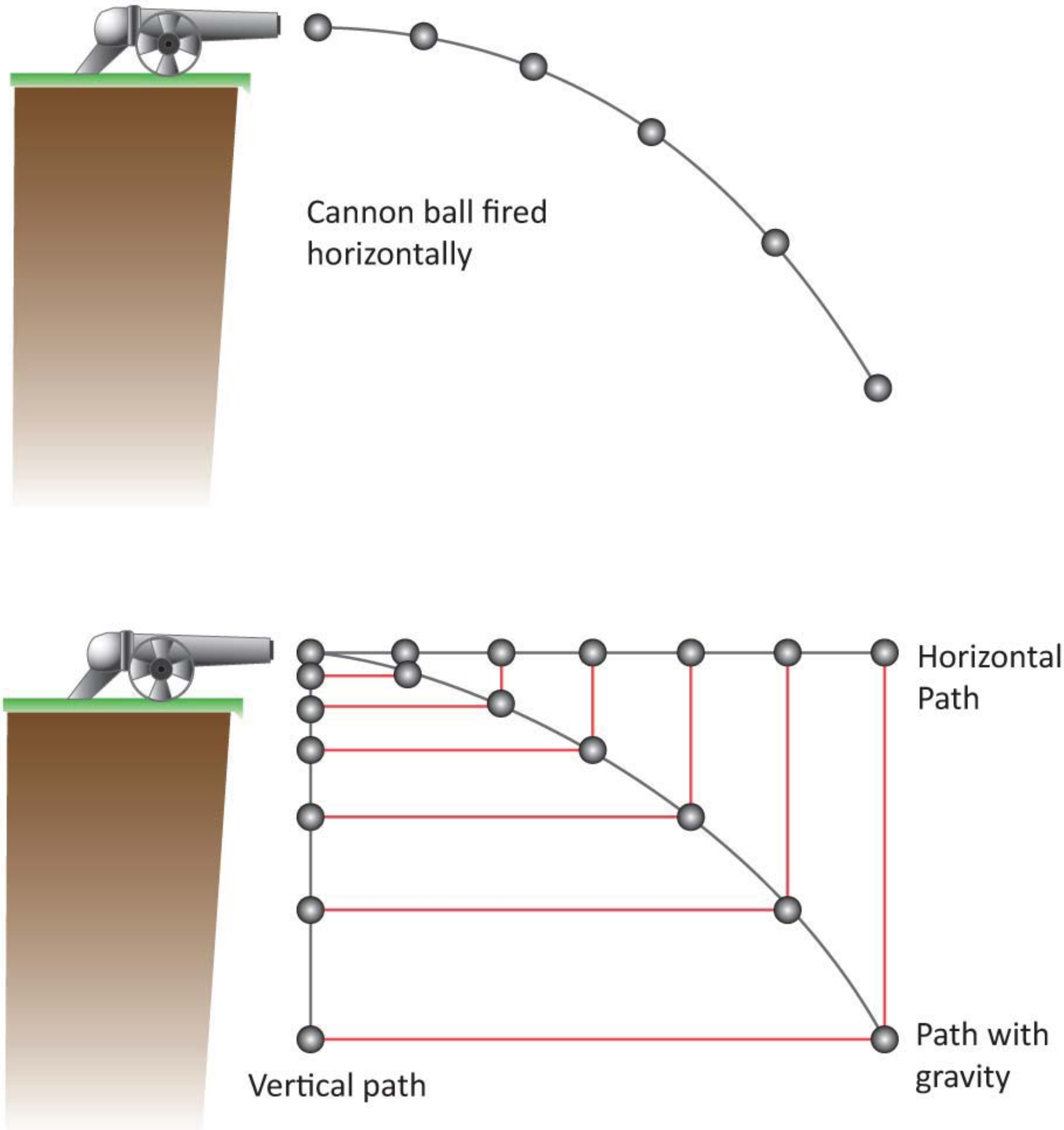


Figure 3: Notice how the horizontal distance the projectile covers is constant regardless of its vertical motion. This shows that a projectile's horizontal velocity is constant. If you fire a projectile horizontally at the same time as dropping one straight down, they will hit the ground at the same time! Even extremely fast projectiles such as bullets fall at the rate determined by gravity.

Figure 4: 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). Since projectiles move in two dimensions (vertical and horizontal), this allows for independent analysis of each component of the object's motion. 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 3, 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 – 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 kinematics 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. The two new equations can be obtained through substitution.

Figure 5: Four useful kinematic equations for projectile motion:

$$v = v_o + at$$

$$x = x_o + v_o t + \frac{1}{2}at^2$$

$$v^2 = v_o^2 + 2a(x - x_o)$$

$$x = x_o + \frac{1}{2}(v_o + v)t$$

In this lab you can assume that projectiles are fired either vertically or horizontally, so that the initial velocities in either case will be either:

$v_o = v_{yo}$

or

$v_o = v_{xo}$.

Using the equations above, 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:

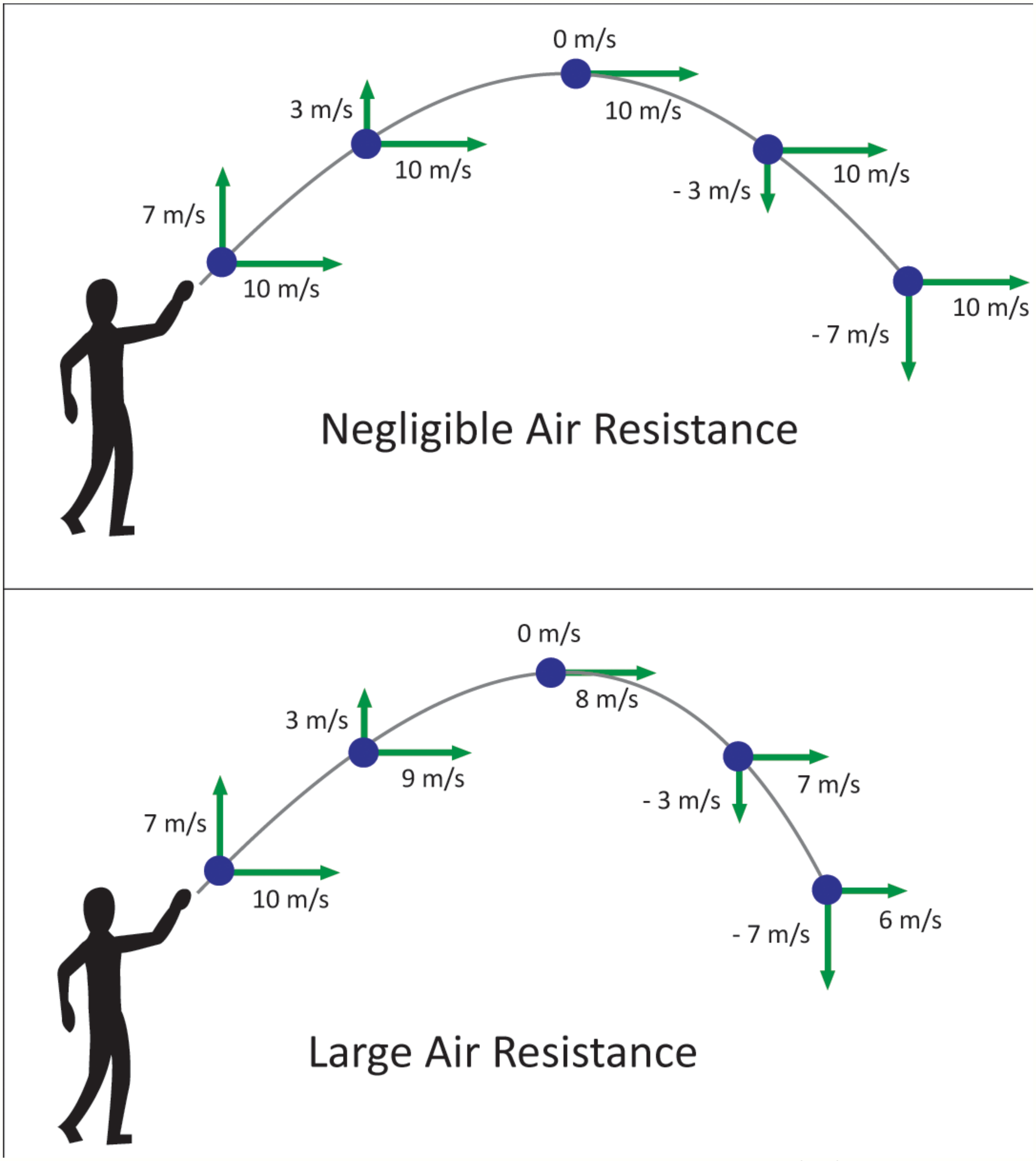


Figure 6: The path of a projectile in the absence of air resistance is a perfect parabola (top); with air resistance the trajectory looks like a "squashed" parabola, and the range of the object's flight is noticeably affected.

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

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.

Experiment 1: Calculating the distance traveled by a projectile

The objective of this lab is to predict the range of a projectile set in motion.

Materials

Ramp
Marble
Corn starch
4 sheets of black construction paper
Tape measure
Monofilament line
Fishing sinker

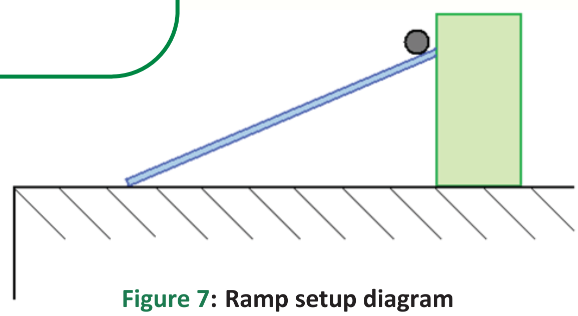


Figure 7: Ramp setup diagram

Procedure 1

1. Place the ramp on a table and 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 fishing sinker to the monofilament line.
3. Hold the string to the edge of the ramp, 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 with water, and drop into the cornstarch bag to coat. Roll on a paper towel to achieve a smooth, even coat of corn starch 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 cause some of the corn starch to come off, and leave a mark on the construction paper so you can see the point of first contact!
6. Begin the experiment by releasing the marble at the marked point on the ramp.
7. Measure the distance traveled to the first mark made on the carbon paper using the tape measure. Record this value in Table 1 on the following page.
8. Repeat steps 5-7 nine more times and record your data in Table 1.
9. Next, use your data to calculate the velocity of the marble for each trial.

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 can either use one equation to find the total time in the air using the initial and final heights, and another to find the horizontal distance, or you can use the range equation with $\theta=0$.)
3. Measure this distance out and mark it before you release the marble. Release the marble four times and record the distance traveled in Table 2.

Table 1: Range and velocity of projectile, Procedure 1

Table Height (m)	Distance Traveled		Avg Distance	Average Velocity

Table 2: Range of projectile, Procedure 2

Table Height (m)	Observed Distance		Predicted Distance	Observed D (avg)

Calculations:

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. Suppose you altered your existing ramp so that the marbles had twice their initial velocity right before leaving the ramp. How would this change the total distance traveled and the time that the marbles were in the air?

3. Draw a FBD for the marbles before and after it leaves the ramp.

4. Describe the acceleration of the marbles after it leaves the ramp.

5. 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). What are some sources of error in this experiment?

$$\% \text{ error} = \frac{\text{observed value - expected value}}{\text{expected value}} \quad X100$$

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
Tape measure
Stopwatch

NOTE: 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. 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.

Procedure

1. Mark the spot from which the rockets will be launched.
2. Load a Squeeze Rocket™ onto the bulb.
3. Using a protractor, align the rocket to an angle of 90° (vertical).
4. Squeeze the bulb (you will need to replicate the same pressure 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. Record your results in Table 3.

t_{avg}=_______________

5. Calculate the initial velocity of the rocket ($v_{initial} = v_{oy}$) using the kinematics equations.
6. Record your calculation in Table 3. (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.)
7. Repeat this trial two more times, and record the values in Table 3 .
8. Choose four additional angles to fire the rocket from. Before launching the rocket, calculate the expected range using the vertical velocity and the angle from which the rockets will be fired. 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.

9. 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. Measure the distance traveled with the tape measure. Repeat this for two additional trials, recording the actual range in Table 3.
10. Repeat Step 7 for at least 5 additional angles and record the data in Table 3.
11. Record the percent error between your calculated and actual values in the last column.

Table 3: Projectile data for Experiment 2

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

*Note: % error = $\frac{\text{observed value - expected value}}{\text{expected value}}$ x 100

Questions

1. What is the angle that gives the greatest range? The least? Based on your results, which angle should give the greatest range for projectile motion?

2. Draw a FBD for a rocket launched at an arbitrary angle (assume the rocket has just only barely left the launch tube, and neglect air resistance).

3. What role does air resistance play in affecting your data?

4. Discuss any additional sources of error, and suggest how these errors might be reduced if you were to redesign the experiment.

5. How would a kicker on a football team use his knowledge of physics to better his game? List some other examples in sports or other applications where this information would be important or useful.

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