



**GRADES**

**5-12**

# Ball Launcher

propulsion

Aeronautics  
Research  
Mission  
Directorate





## Ball Launcher

### Lesson Overview

The Ball Launcher lesson is a hands-on activity designed to introduce students to the concept of a parabolic arc by throwing a ball and how NASA flies parabolic arcs to create periods of reduced gravity with the C-9B aircraft in the Reduced Gravity Research Program. In addition, students will measure their reaction time by using a meter stick.

### Objectives

Students will:

1. Learn what a parabolic arc is and how it is used by NASA to create a microgravity environment.
2. Use a stopwatch and tape measure to gather data for each ball throw.
3. Use the equation for a falling body to calculate the highest point of the parabolic trajectory.
4. Use other equations to solve for different aspects of the ball's flight such as the angle at which the ball was released.

### Materials:

#### In the Box

Stop watch  
Chuckit ball launcher  
Tape measure or trundle wheel  
Tape  
Meter or yard sticks

#### Provided by User:

Strips of paper 1cm by 75cm)  
Graph paper

**GRADES**

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**Time Requirements:** 3 hours

## Background

### Parabola

In this lesson, students use a Chuckit Ball Launcher to throw a tennis ball and record data related to its flight. If the students were to photograph the path of the tennis ball flight, they would see that the ball goes up and comes down in an arc known as a parabola.

Students often see parabolas and may not recognize them. If the students were to draw a graph that represents the path of a projectile fired by a cannon, it would also represent a parabola. The golden arches on a favorite eating establishment are also parabolas.

Notice the drawing of the parabola in Figure 1. It looks like an upside down 'U'. Students taking a pre-calculus class learn terms associated with a parabola such as Axis of Symmetry, Vertex, Focus, Directrix, Quadratic Equation, Points, and Locus. For this lesson though, the following terms are important to understand: vertex, axis of symmetry, and range.

As shown in Figure 1, the vertex of a parabola represents the high point of the tennis ball flight. It is also the point where it crosses its axis, referred to as the axis of symmetry. The axis of symmetry is most often a vertical line that passes through the parabola's vertex. It divides the parabola into two perfect halves. Range is the horizontal distance from where the ball was tossed to where it hits the ground.

An excellent example of a parabola in action is Alan Shepard's sub-orbital Mercury Program flight aboard Freedom 7 on May 5, 1961. Shepard's flight lasted 15 minutes and 22 seconds during which time his spacecraft reached an altitude of 187.5 kilometers (116.5 miles). Freedom 7 splashed down into the Atlantic Ocean 486 kilometers (302 miles) from the launch site. If Fig. 1 represented the Shepard's flight, the distance from the vertex to the bottom of the parabola is 187.5 kilometers (116.5 miles). The range from liftoff to splashdown is 486 kilometers (302 miles). The left side of the parabola represents the ascent period, while the right side represents reentry.

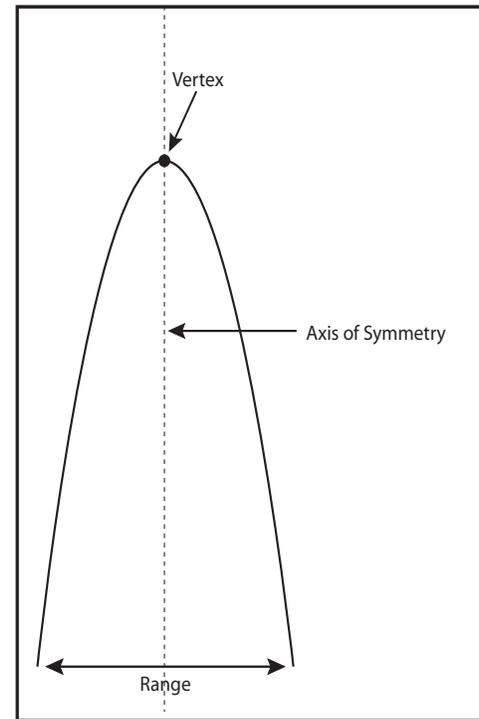


Fig. 1 Parabola



Img. 1 Mercury 3 at launch

## Galileo's Falling Bodies Equation

Galileo has been described as one of the greatest scientists that has ever lived. He was a world-renown mathematician, astronomer, physicist, and inventor. Though he really didn't invent the telescope he improved upon it by building his own with a magnification of 30X.

He was the first to use the telescope to observe the heavens and record what he saw such as craters on the moon; that Venus had phases, and that Jupiter had moons. He also built an early thermometer in the 1590s.

Among his many most significant contributions, Galileo demonstrated to us how he deduced laws to explain the results of his observations and experiments. Up until his time, most explanations were just in words. Galileo did something different. He showed the importance of mathematics in understanding natural phenomena and experimentation. It is remarkable to think that Galileo did all of his work without a reliable clock and less scientific equipment than found in today's classrooms. His observation of swaying chandeliers enabled him to better understand the nature of a pendulum which ultimately led to the development of more accurate pendulum clocks.

Galileo's study of projectile motion is one example of his work. Galileo knew that the trajectory of a projectile was a parabola. He realized for the first time that a projectile's motion is influenced by two independent motions. One of the motions is influenced by gravity. He discovered that gravity pulls down a projectile according to the equation for a falling body. The second influence demonstrated that horizontal motion is uniform and constant, according to the principle of inertia. Inertia can be considered the tendency of an object to resist any change in its motion.

Galileo realized, even during his earliest experiments, that the speed of a falling body is independent of its weight. Galileo discovered that the nature of this motion is the same for an object that falls straight down as it is for one that moves forward and down at the same time. Therefore, an arrow shot horizontally from a bow falls at the same rate as one that is simply dropped from the same height that it was shot.

Galileo was able to derive an equation for a falling body:

$$S = \frac{1}{2} at^2. \quad (S = \text{distance, } a = \text{acceleration due to gravity (9.8m[32ft]/\text{sec}^2), \text{ and } t = \text{time})$$

From the above equation, you can also solve for the following:

Instantaneous velocity of a falling object after a certain elapsed time:

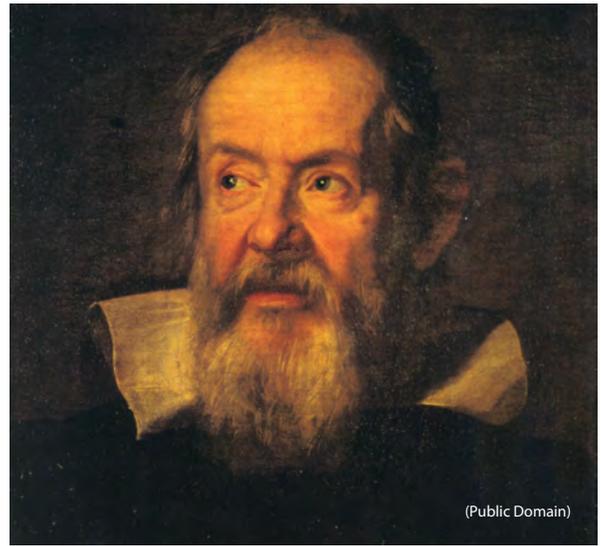
$$V_i = at$$

Average velocity of an object that has been falling for time (averaged over time):

$$V_{avg} = \frac{1}{2} at$$

**Launch Angle:** The angle that the ball was released when thrown.

**Launch Velocity:** The initial speed at which the ball was released.



Img. 2 Galileo Galilei by Justus Sustermans (1564-1642)

(Public Domain)

## Sample Problem Set:

The following is a set of problems related to throwing a tennis ball with the Chuckit Ball Launcher. Use the formulas you deem most appropriate with your students. The sample problem assumes no air resistance or the height at which the ball was released. These factors can be added later after the students gain a better understanding of a falling body. A tennis ball is thrown and its flight time is 4 seconds. It lands 25 meters from where it was thrown. Remember, in a parabola, it takes half of its flight time to reach the vertex and the other half to reach impact. So, in this case, the time to reach the vertex is 2 seconds.

Now determine the height from the vertex to the ground:

Acceleration due to gravity =  $9.8\text{m/sec}^2$ ,  $t$  = time

Use the equation:  $S = \frac{1}{2} at^2$  to solve for distance.

$$S = \text{Distance, } a = S = \frac{1}{2} 9.8\text{m/sec}^2 (2.0 \text{ sec})^2 = 4.9\text{m/sec}^2 \times (4 \text{ sec}^2) = 19.6 \text{ meters}$$

To convert meters to feet, multiply the number of meters by 3.28 feet/meter:

$$19.6\text{m} (3.28\text{ft/m}) = (64.3 \text{ feet})$$

The vertex is 19.6 meters from the ground.

What was the velocity of the tennis ball after 1.5 seconds?

$$V_i = at = 9.8\text{m/sec}^2 \times 1.5 \text{ sec} = 14.7 \text{ m/sec (48.23 feet/sec)}$$

What was the average velocity of the tennis ball?

$$Va = \frac{1}{2} at = \frac{1}{2} (9.8\text{m/sec}^2) (2.0 \text{ sec}) = (4.9\text{m/sec}^2) (2.0 \text{ sec}) = 9.8\text{m/sec (32.1ft/sec)}$$

To determine launch angle:

$$\text{Launch Angle} = \frac{S}{R} = \frac{\tan\theta}{4}$$

R = Range

S = Height of vertex in meters

$$\text{Launch Angle} = \frac{19.6\text{m}}{25\text{m}} = \frac{\tan\theta}{4}$$

$$\text{Launch Angle} = \frac{78.4\text{m}}{25\text{m}} = \frac{\tan\theta}{4}$$

$$\tan\theta \frac{78.4\text{m}}{25\text{m}} = 3.14 = 72.3^\circ$$

Launch angle was  $72.3^\circ$

To determine launch velocity:

R = Range

a = Acceleration due to gravity ( $9.8\text{m/sec}^2$ )

$$\text{Launch velocity} = Vo = \sqrt{\frac{Ra}{\sin 2\theta}}$$

From trigonometry (trig), we know that:

$$\sin 2\theta = (\text{using trig identity}) = 2\sin\theta \cos\theta$$

$$\begin{aligned} V_0 &= \sqrt{\frac{Ra}{\sin 2\theta \cos\theta}} \\ &= \sqrt{\frac{25\text{m}(9.8\text{m}/\text{sec}^2)}{2\sin(72.3^\circ)(\cos(72.3^\circ))}} = \sqrt{\frac{245 \frac{\text{m}^2}{\text{sec}^2}}{2(.952)(.304)}} = \sqrt{\frac{245 \frac{\text{m}^2}{\text{sec}^2}}{.579}} \\ &= \sqrt{423.1 \frac{\text{m}^2}{\text{sec}^2}} = 20.6\text{m}/\text{sec} \end{aligned}$$

Therefore, the launch velocity was 20.6 m/sec

## NASA's Reduced Gravity Program (RGP)

Astronauts are in a weightless condition in space, but weightlessness can be created in an aircraft that flies a free fall trajectory, which is a parabola.

The Reduced Gravity Program (RGP) managed by the Johnson Space Center is a research area at NASA that uses a specially configured aircraft to simulate a reduced gravity environment by flying parabolas over the Gulf of Mexico. The Reduced Gravity Program enables scientists, engineers, and astronauts to become accustomed to a microgravity environment. In addition, during each parabola, scientists, engineers, astronauts, or university students can test equipment or hardware that may be used on a future space flight. Each flight includes 40 parabolas and as of 2011, over 140,000 parabolas have been flown in the Program. Also, some of the scenes from the Apollo 13 movie were shot aboard the KC-135, which was used to fly parabolas. The KC-135, known as, the 'vomit comet,' was retired in 2004 and has been replaced by a Navy C-9, a twin-jet variant of the McDonnell Douglas DC-9.



**Img. 3** Astronaut Satoshi Furukawa in Space Aboard the ISS

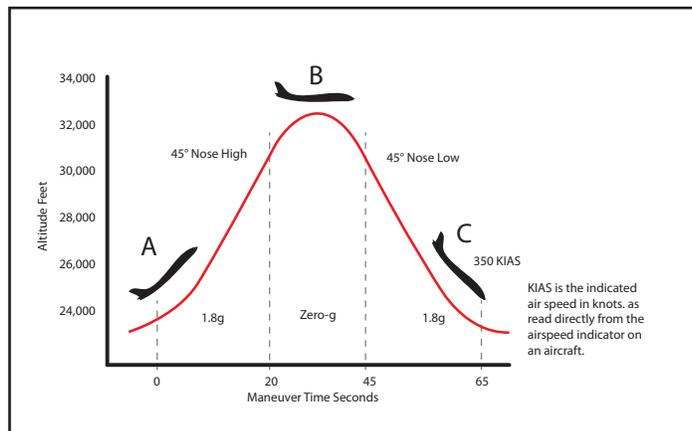


**Img. 4** "NASA 932" Weightless Wonder VI, Vomit Comet Completing a Parabola

Normally this is between 40-50 degrees nose up attitude, and at that point the yoke is pushed forward to reach a 'zero g' condition (takes about 3-4 seconds for zero g to be reached). This forward push on the yoke is matched by a reduction in the throttle position to be at idle throttle when the aircraft reaches zero g. The minimum airspeed seen is usually about 140-160 knots (161-184 mph) and the peak altitude is approximately 9449 meters (31,000 feet) (B).

Note the diagram in Figure 2. The diagram shows a typical parabola flown in The Reduced Gravity Program. The following is a description of how a parabola is created by one of the RGP pilots:

"We start at a "base" altitude of 8229.6 meters (27,000 feet) and airspeed of 250 knots (288 mph). When the test director is ready, and the autopilot is connected to the roll and yaw axes of the aircraft, the aircraft commander will push the nose over and power will be adjusted to reach 7010 meters (23,000 feet) (A) and 350 knots (403 mph) airspeed. At that point, the nose is pulled up at 1.8 g's, power is advanced to max allowable, and this condition is continued until reaching 240 knots (276 mph) airspeed.



**Fig. 2** Flying the parabola

The nose continues to fall through until approximately 35-40 degrees nose down, when the yoke is pulled back and the power advanced to max to get into another 1.8 g pull-up (C). Our lowest altitude is normally (7010 meters) 23,000 feet and highest airspeed is 350 knots (403 mph), and the process begins again."

Note in the diagram that during each parabola, there are 2 periods of more intense gravity (~1.8gs). What does 1.8gs refer to? G or g-force is the force acting on a body due to the acceleration of gravity. Under normal conditions on Earth this force is equal to one-g. If a body experiences a 1.8 g force, it is experiencing a force 1.8 times the normal force of gravity. As an example of a 1.8 g-force, a 50 kilogram person would weigh 90 kilograms (50 kilograms x 1.8gs).

Each of these periods lasts about 20 seconds. As the RGP's aircraft, a Navy C-9, goes over the top of the parabola, there is approximately 20 seconds of what is referred to as reduced gravity or zero-g during this free fall trajectory. As can be seen in *Img. 5*, during this brief period of zero-g passengers can float about the inside of the aircraft. The inside of the aircraft's walls, ceiling and floor has padding as can be seen in the photograph.

The **Background** information has referenced the importance of astronauts flying parabolas during NASA's Reduced Gravity Program to become more familiar in working with various types of equipment in a near zero-g environment. By doing this the astronauts can reduce their reaction time for completing various tasks.

The following two activities will have students measure their reaction time by dropping a meter stick or yardstick, and use a ball launcher to throw a tennis ball to determine different aspects of the trajectory of ball's flight such as the greatest height it attained during its parabolic flight.



**Img. 5** University Students Conducting an Experiment on the 'Vomit Comet'

(Photo courtesy of NASA)

# Activity 1

## Reaction Time

**GRADES** 5-12

**Time Requirement:** 1 hour 30 minutes

### Materials:

#### In the Box:

Tape  
Meter or yard sticks

#### Provided by User:

Strips of paper  
(1cm by 75cm)

#### Worksheets:

Acceleration Table Worksheet  
(Worksheet 1)  
Reaction Time Data  
Collection Worksheet  
(Worksheet 2)  
Reaction Time Bar Graph  
Worksheet  
(Worksheet 3)

#### Reference Materials:

None

### Key Terms:

Acceleration  
Reaction Time  
Bar Graph

### Objective:

Students will learn about motions and forces, specifically acceleration, by working in pairs to drop a meter stick calibrated to measure reaction time.

### Activity Overview:

In this lesson, students will learn how the speed of a falling body increases over time. The concept of acceleration will be introduced by successfully dropping a meter or yard stick over increasingly short periods of time. The students will work in pairs—one student will drop the meter/yard stick and the other person is to catch it between his/her fingers when the fingers are positioned 5 cm (2 inches) apart.

The students will use the equation for a falling body to calculate the distance that an object will fall in .01 second intervals up to .39 seconds. They will use these data to make a calibrated scale that can be pasted on a meter/yard stick.

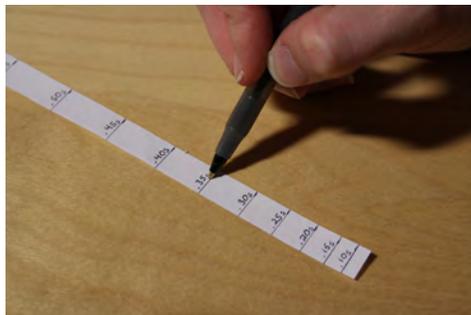
Next, students will use the calibrated meter/yard stick to determine their reaction time by dropping the meter/yard stick under varying conditions between their fingers. The students will record the results of each drop and then make bar graphs of the data.

They will read and interpret the data on the bar graph and draw conclusions. Through discussion guided by the teacher, students will learn about the importance of training to reduce reaction time.

### Activity:

1. **Provide the students with the Acceleration Table Worksheet.** Have the students work in pairs to create the calibration scale. The students are to create a reaction time scale on the long strip of paper.

To begin, have one student find the measurement for acceleration of gravity on the meter/yard stick and the other student draw the line on the strip of paper and label the time on the strip of paper. It is easier to have the 0 seconds time at the bottom of the strip and move upward from there.



2. **Once the reaction time scale has been completed, have the students tape the scale onto a meter/yard stick.** Have them place the 0 sec mark approximately 5cm (2 inches) from the end of the meter/yard stick.
3. **Now the students will work in pairs with one person dropping the meter/yard stick with the pasted reaction time scale for 4 categories of measurement.** Students will drop with eyes open right hand; drop with eyes open left hand; drop with eyes closed right hand and drop with eyes closed left hand. There are to be 3 drops for each student for each of the categories. The students are to record their times on the Reaction Time Data Collection Worksheet.
4. **For each drop of the meter/yard stick, the fingers should be 5 cm apart.** The fingers should be at the 0 second mark on the meter /yard stick. The student is not to move the fingers together until the meter/yard stick is dropped. When their eyes are closed, the fingers should not start to move together until they hear the word 'drop' by the person dropping the meter/yard stick.
5. **Once every team member has completed all of the drops, they are to calculate the average time for the four categories.**
6. **Each student should record their results on the Bar Graph Worksheet by filling in one of the boxes on the worksheet.** The first student to record must shade in the bottom box and if another student has a result that also falls in that range, he or she would shade in the box above the previous one. Students need to be sure and record their results in either the boy or girl column on the worksheet.
7. **Once all of the data has been recorded, have students share their final results with the rest of the class so that they can add them to their worksheet.** Once all the data has been entered, create the bar graphs.



## Discussion Points:

1. **Were the reaction time spaces the same width for all of the time intervals that you calculated?**

*The spaces are not the same width. The width of a space is impacted by acceleration and time. Since the acceleration rate was the same for all of the reaction times, each width is affected by the square of the time. For example, for the first tenth of a second, the meter/yard stick dropped only .49 cm. The distance traveled between .2 and .3 seconds is 24.5 cm. This result demonstrates the effect of acceleration (shorter distance in less time). If the speed was constant, the distance traveled for each tenth of a second would have been .49 cm.*

2. **Which range of the reaction time had the most number of students?**

*Answer to this question depends on student data.*

3. **Were the reaction times the same for when you had your eyes opened or closed?**

*Answer to this question depends on student data. It may be that students reacted more quickly with their eyes open since their bodies are more sensitive to visual stimuli.*

4. **What might explain the difference?**

In the case of the right or left hand, the dominate hand can react more quickly than the other hand.

5. **Were the reaction times the same for the boys and girls? If there is a difference, what might be some reasons?**

Answer depends on student data.

6. **Ask the students how training might reduce reaction time and why is this important?**

Have the students think about athletes and how practice enables them to react more quickly to tackle a runner or chase down a fly ball. Also, remind the students that astronauts are given a variety of tests to measure their reaction time. The tests are given under a variety of conditions, for example, after being spun around in a centrifuge or after taking medicine to reduce motion sickness which sometimes has side effects such as drowsiness. Astronauts also train as part of The "Reduced Gravity Program" to become more familiar with microgravity conditions. The "Reduced Gravity Program" was described in the [Background](#) section.

Also, refer to the NASA press release included in the Resources. Note how technology will help solve critical issues in situations that require quick reaction times.

## NATIONAL SCIENCE STANDARDS 5-8

### SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

### PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, speed

## NATIONAL SCIENCE STANDARDS 9-12

### SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

### PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, and speed

## Activity 2

## Thrown Ball Observation

**GRADES** 5-12**Time Requirement:** 1 hour 15 minutes**Materials:**In the Box:

Chuckit Ball Launcher  
 Stop watch  
 Tape measure or  
 trundle wheel

Provided by User:

Graph paper

Worksheets:

Thrown Ball Data  
 Collection Worksheet  
 (Worksheet 4)

Thrown Ball Data  
 Analysis Worksheet  
 (Worksheet 5)

Reference Materials

None

**Key Terms:**

Parabola  
 Trajectory  
 Range  
 Vertex

**Objective:**

Students will learn about motions and forces and transfer of energy as they learn that the trajectory of a thrown tennis ball is a parabola that can vary in shape and size from one throw to the next due to different external factors. The students will use the equation for a falling body and other equations to calculate different aspects of the parabola and trajectory of their thrown tennis ball.

**Activity Overview:**

This lesson will be conducted both in the classroom and outdoors. This activity requires the students to observe the behavior of a thrown tennis ball as it relates to time and distance the ball traveled. The students will take turns using a Chuckit Ball Launcher to throw a tennis ball. In this lesson, students will observe how different external factors influence the trajectory (parabola) of a thrown tennis ball. As the students will discover in the lesson, the trajectory of the thrown tennis ball is affected by several forces including the ball's weight, the drag caused by air resistance, the angle in which the ball was thrown, the launch velocity, and even its spin. Trajectory problems involving the force of drag or spin rate requires more advanced math and will not be included in this lesson. Also, the influence of air resistance or the height that the ball is released is disregarded so as to make the problems less complex.

Students will record the time and range for each tennis ball throw. They will use this information to solve for the highest point of the trajectory, the launch angle and the release speed of the tennis ball.

*Caution: Since students will be throwing a tennis ball during this lesson, it is important to stress the importance of safety. Remind the students not to throw the ball unless their team is ready and to be sure and alert everyone before the tennis ball is thrown.*

**Activity:*****In the Classroom***

1. Before you start the lesson, locate an open area where the students can throw the ball such as the school's baseball or football field.
2. Introduce the lesson by displaying the graphic of the parabola, Galileo and the equation for a falling body. Explain how NASA uses a parabola in their reduced gravity program described in the **Background** section.
3. Discuss the equation for a falling body and use the sample problem to highlight the math involved.
4. Explain the procedure for throwing a ball with the Chuckit Ball Launcher stressing the importance of safety, and distribute the **Ball Throw Data Collection Worksheet**. Explain that each person will make four throws—three with the Ball Launcher and one regular style (student's arm). If there is wind— students will launch one with the wind, another into the wind, and another in a direction perpendicular to which the wind is blowing. The regular throw can be in any direction. If there is no wind, students can make their throws in any direction. Also, point out to the teams that they are to enter the weather data at the time they are doing the ball throws.
5. **Divide the class into teams of seven.** Explain when they do the activity one person will be the thrower, another the timer, while another team member is the data recorder. Two of the team members are to be positioned so that they can accurately spot where the ball hits the ground, and two other team members are to measure the distance from where the ball was thrown to where it hits the ground. The stop watch is to be started when the ball is released and stopped when one of the spotters raises his or her hand to indicate the ball has hit the ground. The time should be given to the recorder and once the distance has been measured, that information is provided to the recorder. Inform the class that it might be easier for one person to complete all three throws and then rotate, and if there is a problem with the throw, redo it. REMIND THE STUDENTS THAT IF THERE IS A PROBLEM, ALERT THE TEACHER IMMEDIATELY.



- Also, remind the class that when they go outdoors, make sure they have all of the necessary equipment to complete the activity—ball launcher, stop watch, tape measure or trundle wheel, and the Ball Throw Data Collection worksheet.

### *Outside*

- Have each team use different areas of the open area where they are throwing the ball. If at a ball field, one team can throw from the first base towards right field, the second team could throw from second base to the center field area, etc.
- Have the teams assume their positions and have the first person throw the tennis ball as far as they can. Record the data for this throw.
- Have the first person rotate to the next position and have the next person throw the tennis ball, etc. Make sure that data is recorded for each throw.
- Once everyone has completed their three throws with the ball launcher, have them throw the ball without the launcher and record the measurements. As before, have a team member record their time and range for the throw.
- Make sure all data is recorded and equipment gathered before returning to the classroom.



### *Post Throw*

Provide each student with [Worksheet 5, Thrown Ball Data Analysis](#) and a sheet of graph paper. Have each student calculate the height of the parabola for each of their throws. Knowing the range and the height of the parabola, the student is to use graph paper to sketch each parabola. The teacher may want the students to determine the launch angle and launch velocity for each throw.

**Discussion Points:**

- 1. How did your results compare to the other team members' results?**  
*Results depend on student data.*
- 2. How was the trajectory the same for each of your throws? Look at the sketches to answer this question. Please account for differences.**  
*Launch angle, velocity of the launch and wind direction all have an impact.*
- 3. Which of the above type of throws most often gave the optimum or best trajectory for the longest throw for your team? What might be some reasons for this?**  
*There several reasons the students might propose, such as throwing with the wind enabled the ball to travel farther than when thrown into the wind where the air resistance was greater. In addition, under the same conditions launch angles near  $45^\circ$  will enable a ball to travel farther than a ball launched at any other angle. A ball launched at a  $55^\circ$  launch angle will travel the same distance as a ball launched at a  $35^\circ$  angle with the same launch velocity. Also, a ball launched at a  $70^\circ$  angle will travel the same distance as a ball thrown at a  $20^\circ$  angle with the same launch velocity. Notice how the two angles added together equals  $90^\circ$ .*
- 4. Compare and contrast the trajectory of the tennis ball when thrown by hand and with the Ball Launcher. Why are there differences in the two trajectories?**  
*The Ball Launcher can provide a greater launch velocity than thrown by hand. In almost every case, the Ball Launcher will have the greatest range because of that.*
- 5. Explain why the use of math in looking at a parabola provides so much more information than just observing the parabola?**  
*Most scientists before Galileo never used math to explain their observations. Galileo demonstrated how math can provide a much better explanation for events in nature than can made from just observing an event, describing it and providing an idea to explain the observation.*

## NATIONAL SCIENCE STANDARDS 5-8

### SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

### PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, speed

### SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

## NATIONAL SCIENCE STANDARDS 9-12

### SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

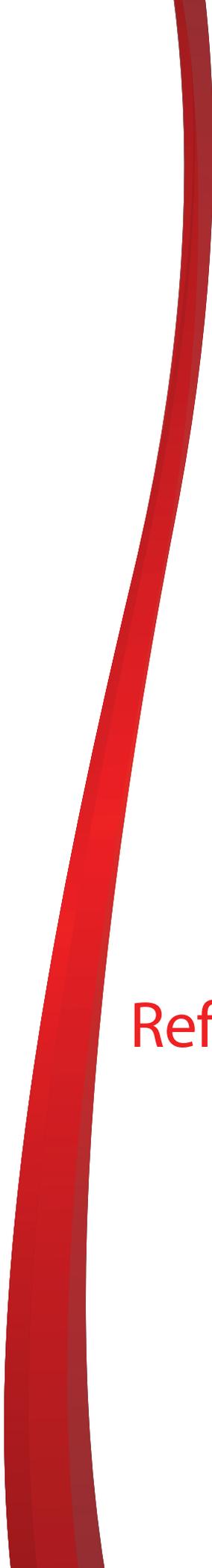
### PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, speed
- Interactions of energy and matter

### SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology





# Reference Materials

# Glossary

**Acceleration:**

The rate at which an object changes its velocity. On Earth the acceleration rate due to gravity is  $9.8 \text{ m/sec}^2$ .

**Axis of Symmetry:**

The vertical line that passes through the parabola's vertex. It divides the parabola into two perfect halves.

**Equation for a Falling Body:**

The equation for a falling body is given as  $S = \frac{1}{2} at^2$ .

$S$  = distance,  $a$  = acceleration due to gravity ( $9.8 \text{ m/sec}^2$ ), and  $t$  = time.

**G-Force:**

The force acting on a body due to the acceleration of gravity. Under normal conditions this force is equal to one  $g$ . However, a 10 kilogram object undergoing a  $g$ -force of  $2g$  experiences 20 kilograms of force.

**Galileo:**

The famous Italian scientist (1564-1642) who made great contributions to science. He was the first person to record astronomical observations with the telescope; conduct experiments with pendulums; and study the motion of objects through experimentation and the use of mathematics.

**Gravity:**

All objects in the universe, such as Earth, exert a natural force of attraction upon things at or near its surface, and tend to draw them toward its center.

**Microgravity:**

A condition that results when an object in a gravitational field (such as Earth's gravity) accelerates freely as a result of the gravitational force. Free falling objects such as a satellite on Earth orbit or a sky diver are in a condition of microgravity.

**NASA C-98 Aircraft:**

The aircraft that NASA currently uses to fly parabolas as part of NASA's Reduced Gravity Program.

This specific aircraft flies parabolic arcs to create short periods of a simulated microgravity environment so that astronauts and others can train to fly missions in a reduced gravity environment.

**Parabola:**

When an object is thrown upward and lands at a different place, or a baseball is sent over the right field fence, the type of curve that it follows is called a parabola. A parabola looks a lot like the letter U when it is drawn. You can identify an equation for a parabola when either the  $x$  or  $y$  is squared but not both.  $y = x^2 - 8$  is an equation for a parabola.

**Range:**

The distance the tennis ball travels from the spot where it was thrown to where it landed.

**Reaction Time:**

The amount of time it takes from when you receive a stimulus to the time you react to it.

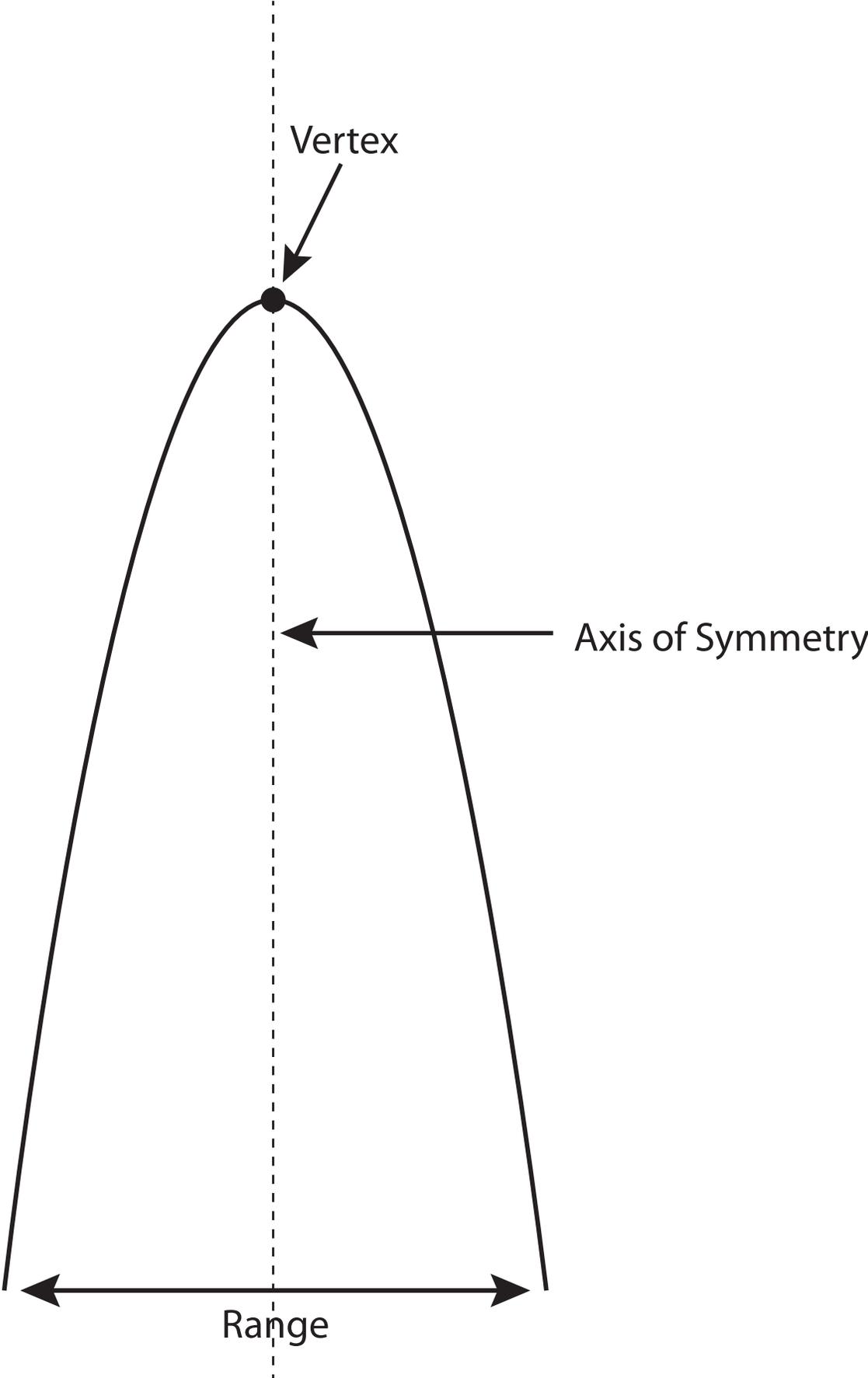
**Speed:**

The measurement of how fast something is moving. The rate of speed is given as the distance traveled per unit of time such as 5 kilometers/hour.

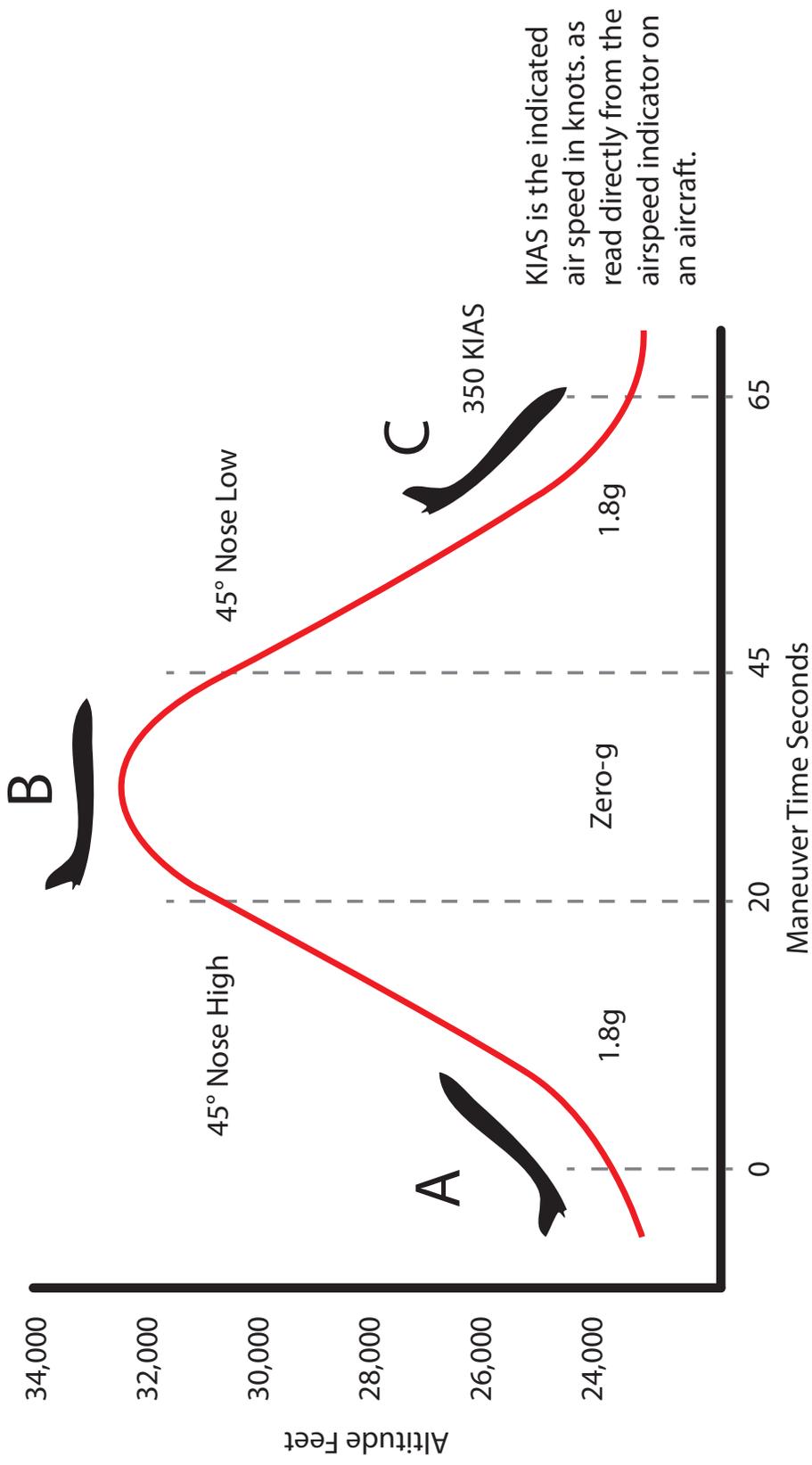
**Trajectory:**

The path that a moving body, such as a projectile, follows during its flight through space.

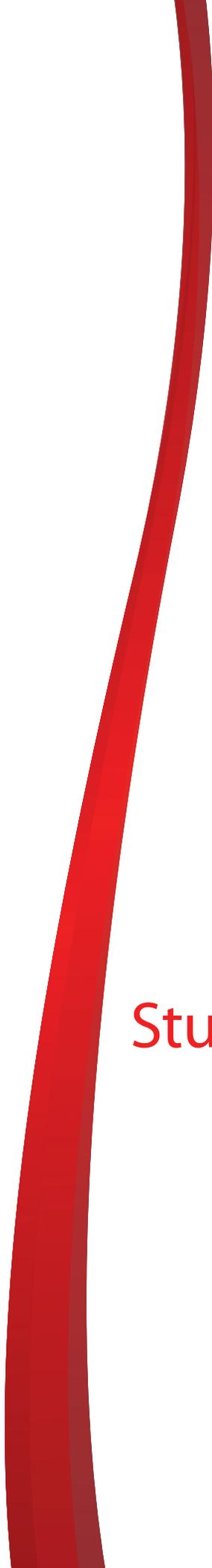
**Fig. 1** Parabola



**Fig. 2** Flying the parabola





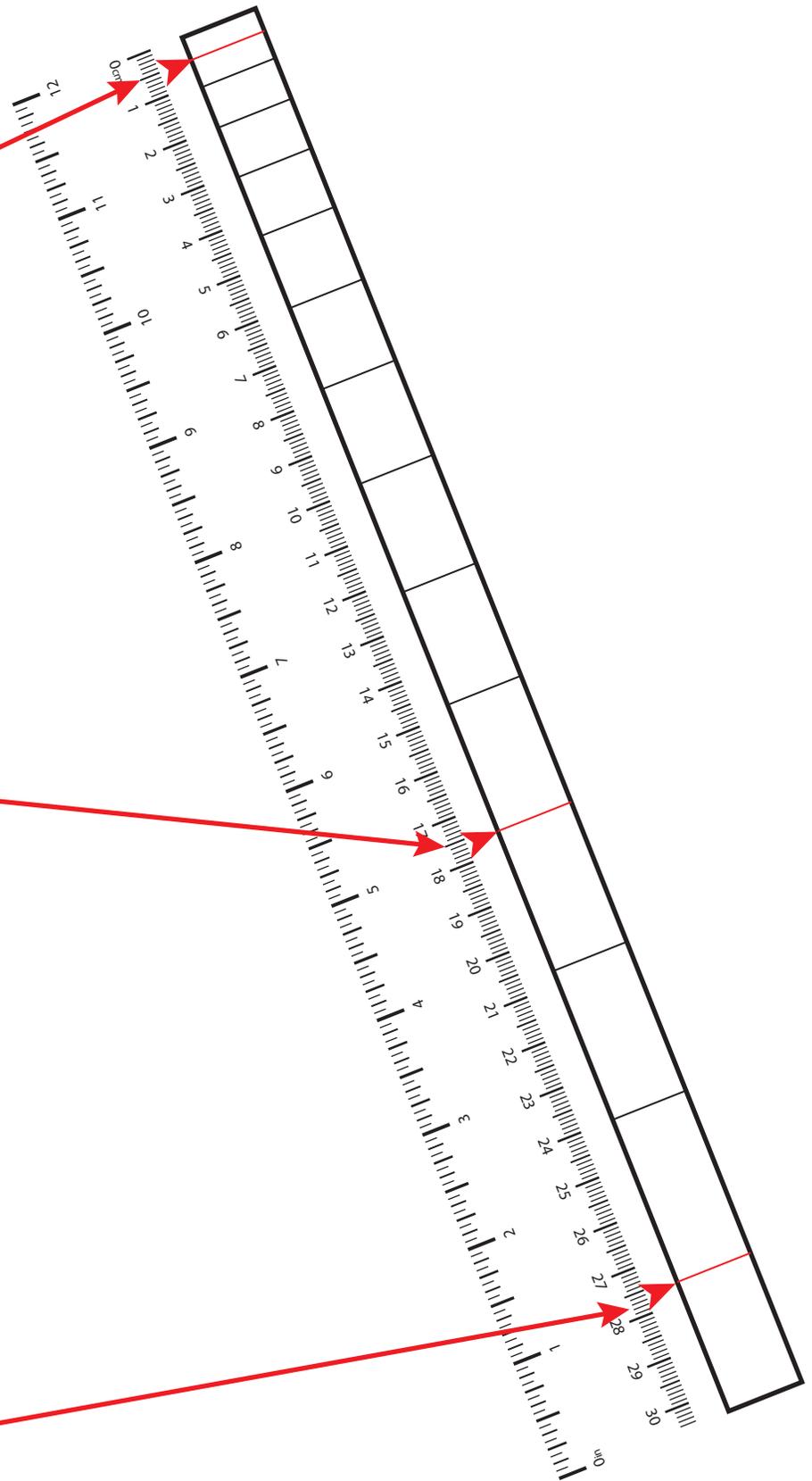


# Student Worksheets

Worksheet 1

Acceleration Table

Time in Seconds	Distance in Centimeters	Distance in Inches
.10 sec	.49 cm	2 in
.15 sec	1.1 cm	.4 in
.20 sec	2 cm	.8 in
.25 sec	3.1 cm	1.2 in
.30 sec	4.4 cm	1.7 in
.35 sec	6 cm	2.4 in
.40 sec	7.8 cm	3.1 in
.45 sec	9.9 cm	3.9 in
.50 sec	12.3 cm	4.8 in
.55 sec	14.8 cm	5.8 in
.60 sec	17.6 cm	6.9 in
.65 sec	20.7 cm	8.1 in
.70 sec	24 cm	9.4 in
.75 sec	27.6 cm	10.9 in
.80 sec	31.4 cm	12.4 in
.85 sec	35.4 cm	13.9 in
.90 sec	39.7 cm	15.6 in
.95 sec	44.2 cm	17.4 in
1 sec	49 cm	19.3 in
1.05 sec	54 cm	21.3 in
1.10 sec	59.3 cm	23.3 in
1.15 sec	64.8 cm	25.5 in
1.20 sec	70.6 cm	27.8 in



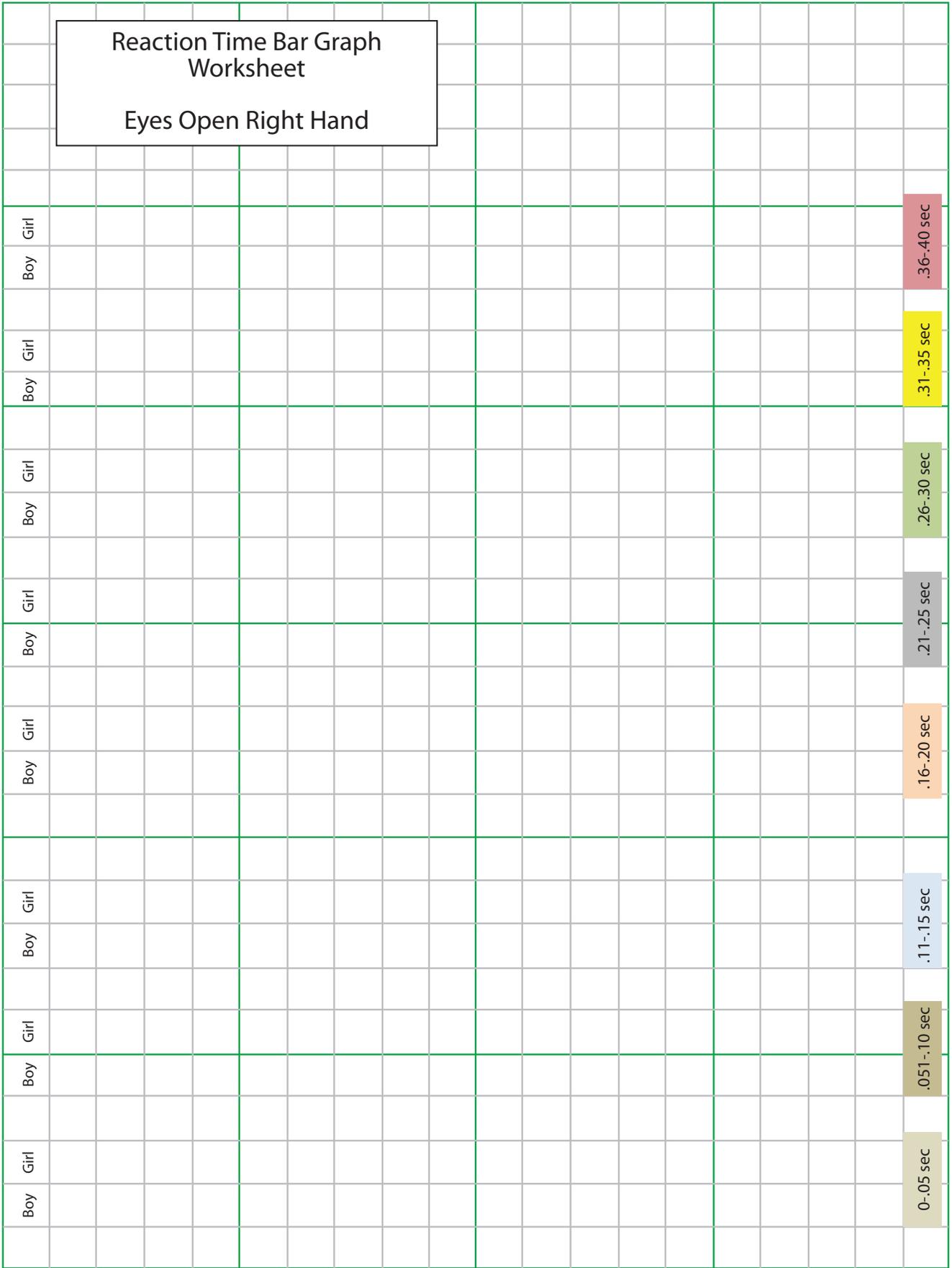
Reaction Time Data Collection Worksheet

Name of Student	Reaction Time in Seconds Right Hand Eyes Open			Reaction Time in Seconds Right Hand Eyes Closed			Reaction Time in Seconds Left Hand Eyes Open			Reaction Time in Seconds Left Hand Eyes Closed		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Student 1												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 2												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 3												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 4												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 5												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 6												
Average Time = $(T1 + T2 + T3) \div 3$												

Worksheet 3

Reaction Time Bar Graph

Reaction Time Bar Graph  
Worksheet  
Eyes Open Right Hand



20

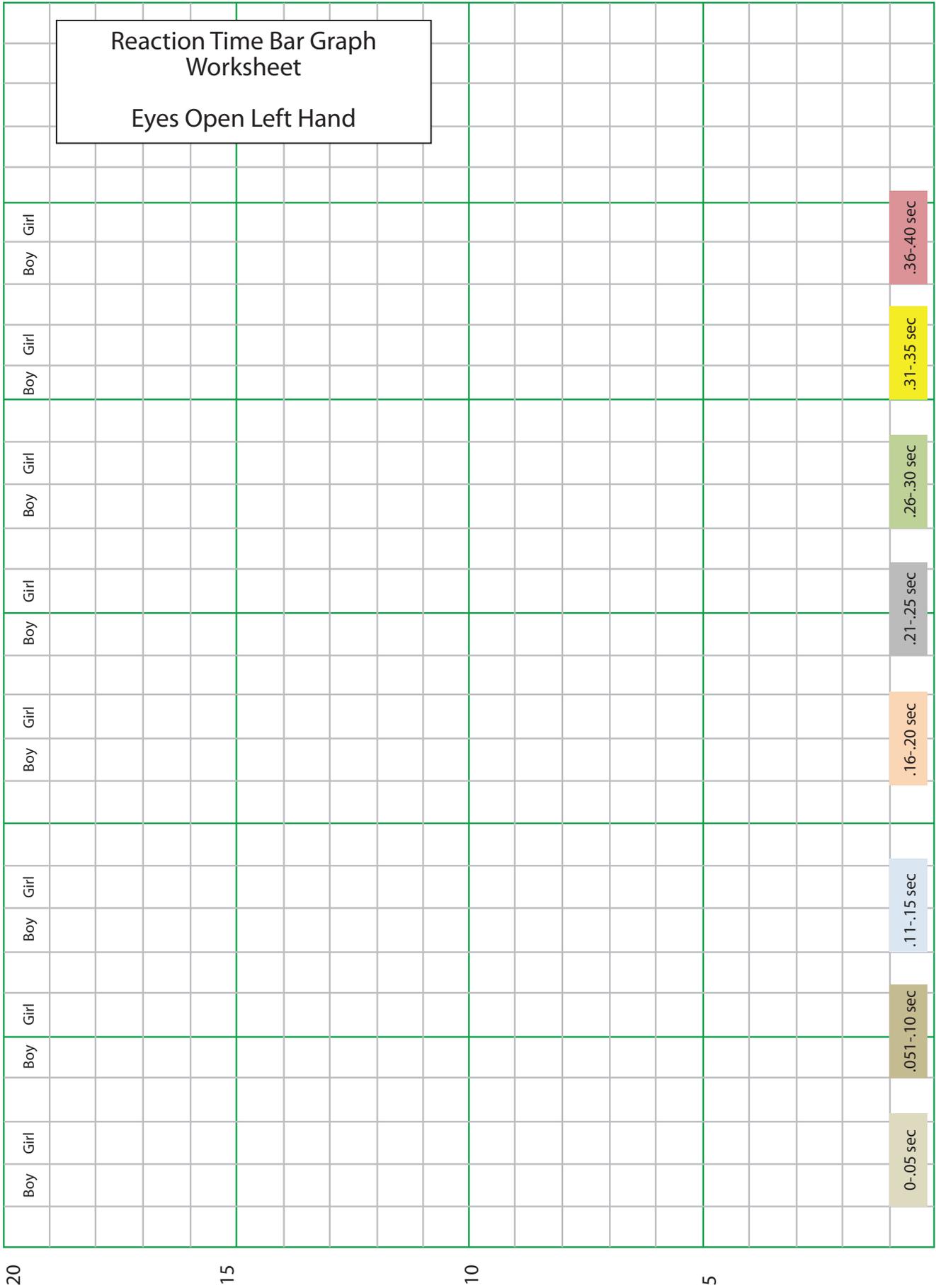
15

10

5

Number of Students

Reaction Time Bar Graph  
Worksheet  
Eyes Open Left Hand



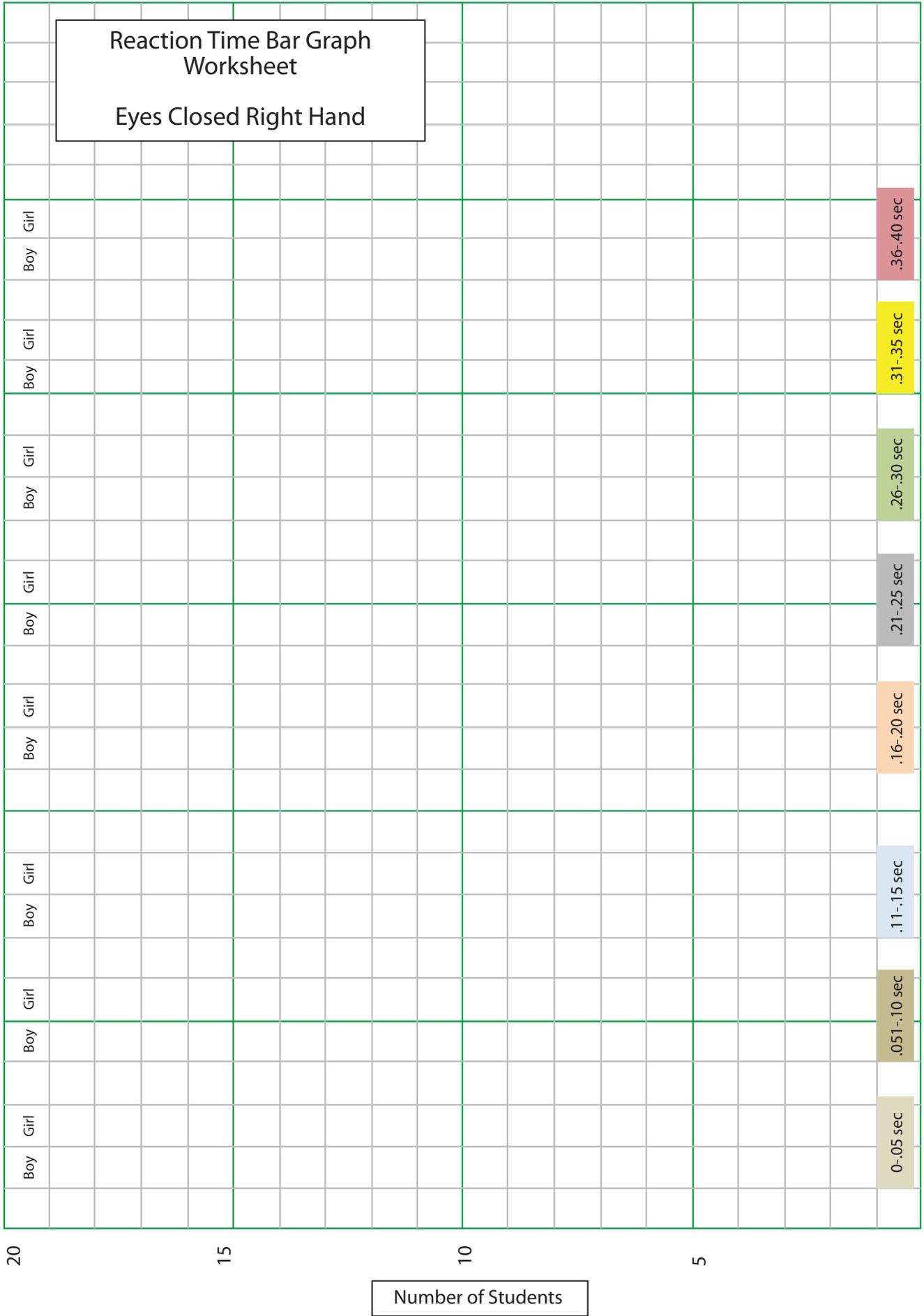
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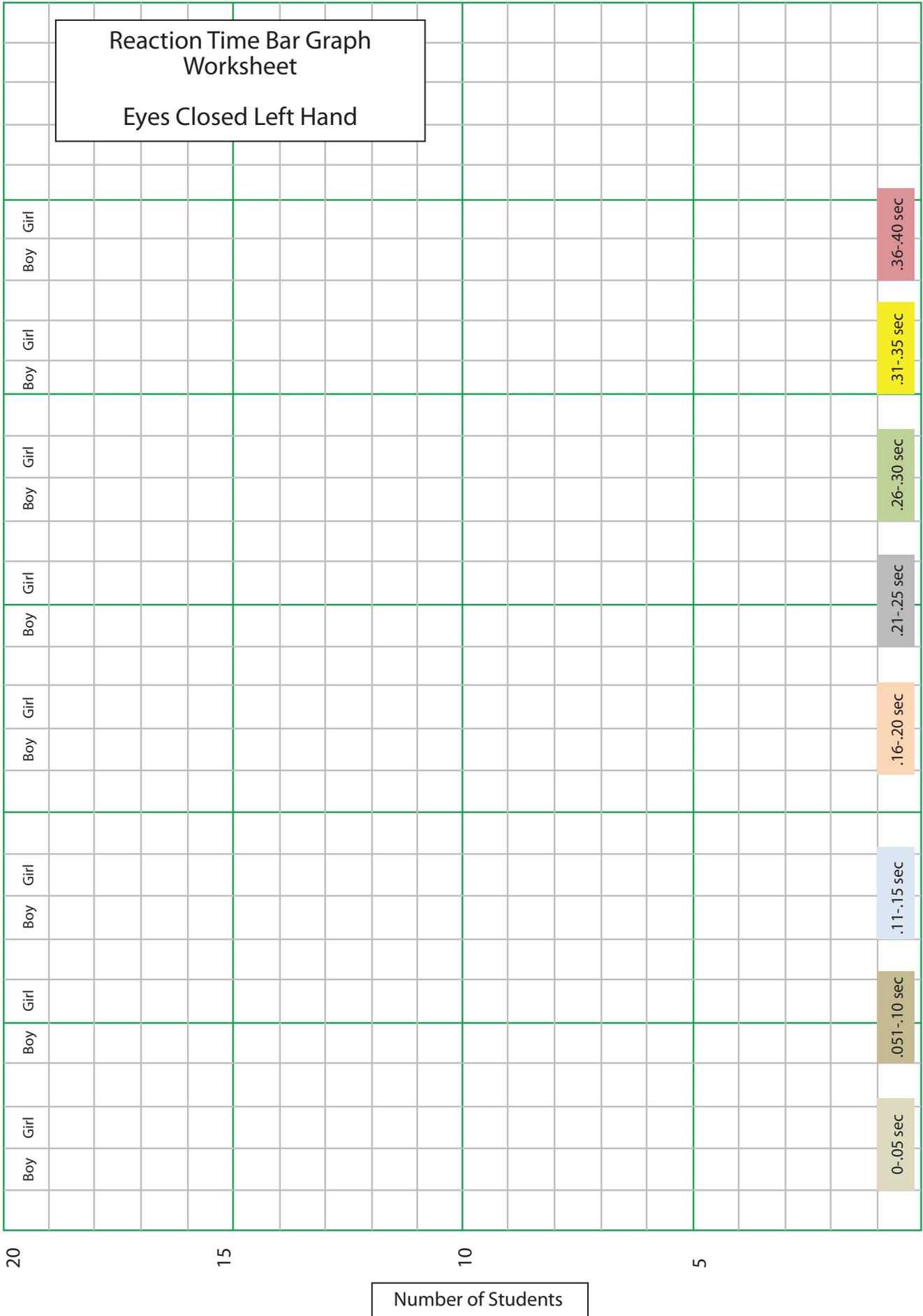
15

10

5

Number of Students





# Thrown Ball Data Recording

## Worksheet 4

Thrown Ball Data Recording Worksheet						
Name of Student	Throw 1		Throw 2		Throw 3	
	Time	Range	Time	Range	Time	Range
Student 1						
Student 2						
Student 3						
Student 4						
Student 5						
Student 6						
Indicate for each throw the direction of the throw in reference to the wind. If it is windy, do all three tosses.	With the wind Into the wind No wind If wind, throw perpendicular to the wind. If it is a north wind, throw the ball either to the east or west.		With the wind Into the wind No wind If wind, throw perpendicular to the wind. If it is a north wind, throw the ball either to the east or west.		With the wind Into the wind No wind If wind, throw perpendicular to the wind. If it is a north wind, throw the ball either to the east or west.	

# Worksheet 4 (cont.)

# Thrown Ball Data Collection

Date: \_\_\_\_\_ Time: \_\_\_\_\_

Weather:

Wind Speed: \_\_\_\_\_ Kilometers Per Hour

Wind Direction: \_\_\_\_\_

Location of Activity: \_\_\_\_\_

Name: \_\_\_\_\_

Ball Launcher Toss 1	Ball Launcher Toss 2	Ball Launcher Toss 3	No Ball Launcher Arm Toss 4
Start Time:	Start Time:	Start Time:	Start Time:
Stop Time:	Stop Time:	Stop Time:	Stop Time:
Total flight time (in seconds):			
Range: (in meters)	Range: (in meters)	Range: (in meters)	Range: (in meters)
<b>Circle wind condition related to direction of thrown ball:</b>			
Into the wind	Into the wind	Into the wind	Into the wind
With the wind	With the wind	With the wind	With the wind
Perpendicular to wind	Perpendicular to wind	Perpendicular to wind	Perpendicular to wind
No wind	No wind	No wind	No wind
Comments:	Comments:	Comments:	Comments:

# Worksheet 5

# Thrown Ball Data Analysis

Name: \_\_\_\_\_

Use the Falling Bodies Equation to determine the height of the parabola for each of the throws.

The formula is:

$$S = \frac{1}{2} at^2. \text{ (} S = \text{height of parabola, } a = \text{acceleration due to gravity (9.8m/sec}^2\text{), and } t = \text{time in seconds)}$$

Height Toss 1: \_\_\_\_\_

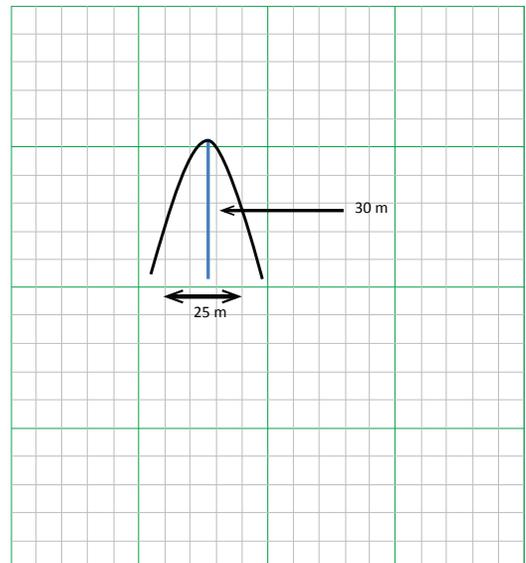
Height Toss 2: \_\_\_\_\_

Height Toss 3: \_\_\_\_\_

Height Toss 4: \_\_\_\_\_

On graph paper, sketch the parabola for each throw.

An example is given: Height 30 meters, range 25 meters.



Solve for other aspects of the ball throw. (As required by the teacher.)

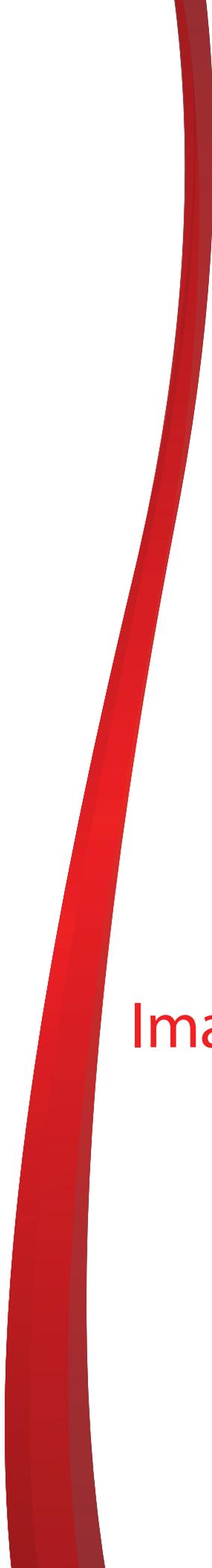
Ball Toss	Launch Angle	Launch Velocity
<b>1</b>		
<b>2</b>		
<b>3</b>		
<b>4</b>		

$$\text{Launch Angle} = \frac{S}{R} = \frac{\tan\theta}{4}$$

Use launch angle to find velocity. If the launch angle is  $60^\circ$ , then you would look up the sin and cos for the  $60^\circ$  in the Launch Velocity Equation.

$$\text{Launch velocity} = V_o = \sqrt{\frac{Ra}{\sin 2\theta}}$$





Images

**Img. 1** Mercury 3 at launch



(Photo courtesy of NASA)

**Img. 2** Galileo Galilei by Justus Sustermans (1564-1642)



(Public Domain)

**Img. 3** Astronaut Satoshi Furukawa in Space Aboard the ISS



(Image courtesy of NASA)

**Img. 4** "NASA 932" Weightless Wonder VI, Vomit Comet



(Photo courtesy of NASA)

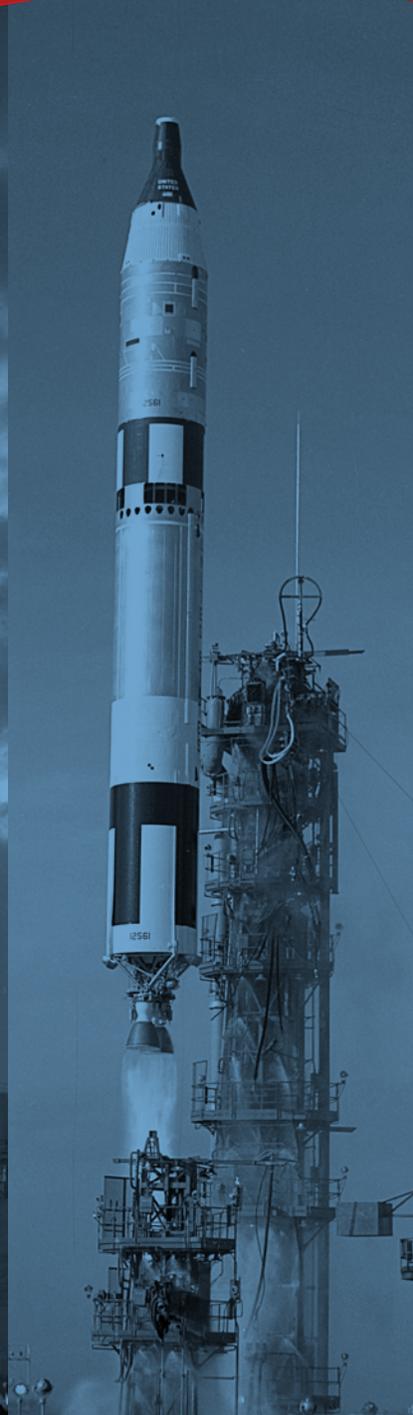
**Img. 5** University Students Conducting an Experiment on the 'Vomit Comet'



(Photo courtesy of NASA )



Aeronautics  
Research  
Mission  
Directorate



propulsion