ARBOR SCIENTIFIC

Precision Air Powered Projectile
94-2800

Teacher Guide

Contents

Precision Air Powered Projectile:

- Launch base & pressure tank assembly
- Pressure regulator & slide valve assembly
- Rocket body and nose cone
- Launch tube
- Orange tube
- T-level
- 4 metal stakes

Required for activities but not included:

- **Protective eyewear**
- **Bike Pump**
- **Stopwatch**
- **Trundle Wheel**
- **Altitude Finder (Clinometer)**

Replacements available:

- Replacement Rockets, 3/pk (94-2801)
- Replacement Nose Cone (94-2800-03)
- Replacement Launch Tube (94-2800-02)

Introduction

Launching rockets to reinforce the concepts learned in class never ceases to amaze and excite students at any level of high school physics or physical science. They are often surprised that calculations based on experimental data confirm the theory they covered in class. **There is a great sense of accomplishment and class community from this shared experience. Later periods will make sure they get to class on time once they hear other students talking about this lesson throughout the halls.**

The Arbor Scientific Precision Air Powered Projectile can be powered using any standard bike pump (using a Schrader valve). The built-in **slide valve** lets you control the exact moment when the rocket launches, making this system safe and easy to measure accurately.

The integrated protractor lets you adjust the angle of each launch without purchasing additional equipment. This system folds away for efficient storage. The setup comes with an adjustable **pressure regulator** that clearly shows the air pressure in the **holding tank** while it's pressurizing. This allows for consistent launches all at the same pressure.

The **projectile** body is very light, and brightly colored. It is still sturdy enough to bounce up from a grassy field with no damage. Since the air is not held in the launch tube, there's no need to force a seal with the projectile. In the case of a scrubbed launch, simply remove the rocket and release a harmful puff of air by pulling the **pressure release valve**. This also acts as a safety valve, automatically releasing at 130 psi. While set-up is easily accomplished by one person, this model provides more opportunities for student involvement if each group has a set. Being intentional about supporting students during group activities helps women and other marginalized groups remain involved in STEM too.

Activities

Finding the launch velocity is the first value your class will need to determine before moving on to any concepts predicting a projectile's range. This experiment is a great way to introduce the projectile launcher to your class while also determining a value they will need to use for the rest of their equations.

Measuring the maximum height can be determined by two methods: by timing a vertical launch or using a clinometer. Students will find the maximum height using the previously calculated launch velocity or by using the Altitude Finder.

Predicting the range of an angled projectile is the culmination of all these calculations. This is the moment students watch their predictions come to fruition in real time. Use the integrated protractor to accurately select the launch angle before securing it in place with the U-bolt and wingnuts. Students will either predict the range for the rocket for a known angle before you launch the rocket or compare that theoretical range with the measured range after the fact.

Background

Concepts of projectile motion have been studied alongside some of the earliest concepts in physics dating back to the ancient Greeks. However, more specific observations dealing with objects traveling through the air started to build on each other in 13th century Europe.

Theories and observations by Galileo Galilei, preceded by other Italian physicists in the 16th century Niccolo Tartaglia and Giovanni Battista Benedetti, developed the concept of projectile motion based on Aristotle's theory of motion.

The Precision Air Powered Projectile builds upon what teachers already loved about Arbor Scientific's previous design. It comes with more features that make it safer for school settings, more reliable for accurate measurements, and adjustable for endless engagement. It empowers teachers to put more of the experiment directly in the hands of their students, helping them all feel like true experimental physicists.

3 – 2 – 1 Launch!

1. **Make sure everyone is wearing eye protection!**
2. Secure the **launch base** to the ground with the **metal stakes** to minimize recoil.
3. Ensure the **safety lockout clip** is set and the launch valve is in the **"pressurize"** position.
4. Attach an **air pump** to the **pressure regulator**.
5. Adjust the angle of the launch tube by loosening the U-bolt and wingnuts attached to the launch base and adjusting the **integrated protractor** to your desired launch angle. Secure the launch angle by tightening the screws once again.
6. Make sure the regulator is fully closed by pulling up on the black knob and turning it counterclockwise. Do not over tighten. Begin pumping. Once pressure is built up, turn the regulator until the needle reaches the desired pressure. You may need to repeat this step a few times.

Note: once step 6 is completed and the regulator is set to the desired pressure, re-pressurizing the tank can be done quickly by pumping the bike pump until the regulator stops moving.

7. Slide the **projectile** onto the launch tube. It should slide easily. If it requires force, DO NOT LAUNCH. Release pressure by using the safety valve.

Final safety precautions and launching:

8. Make sure everyone is aware that a launch is about to happen and that they are wearing **eye protection**. Make sure participants are standing behind the launch area, using verbal communication if needed.
9. Remove the safety lockout clip on the slide valve.
10. Notify surrounding area one last time about launching.
11. Slide launch valve to “launch” position to launch the rocket.

You can repeat these launches by starting the process over at step 10 after resetting the safety lockout clip in the “pressurize” position. If you want to scrub a launch, you can pull the pressure release valve located at the end of the pressure tank at any point after it’s filled. If you are changing any variables before a subsequent launch, restart the process at step 6.

Things To Consider

For consistent trials, secure the launcher into the ground using the metal stakes. If you cannot use the stakes where you’re launching, secure the launcher with some additional weights like sandbags.

It is strongly recommended that you launch the projectile over a level grass surface. Despite the foam nose cone, high speed impacts to the projectile’s body can cause damage if it lands on concrete. Students should never attempt to catch the projectile before it lands.

Protective eye covering should be worn at all times. Never look directly down the launch tube.

The first few trials should be done by a teacher so an adult can explain the process to students. However, keep students engaged by having them help launch the projectile.

The pressure tank will max out at 130 psi. The pressure release valve will begin leaking air if the pressure reaches any higher than 130 psi as a safety precaution. Launches have an upper limit of 130 psi and a lower limit of 30 psi.

Consider keeping these materials close by: A stopwatch will measure the amount of time each launch spends in the air. A trundle wheel can be used to measure a launch’s distance and check results. You’ll also need your own air pump, and the system is compatible with almost any bike pump.

Finding the Launch Velocity

To find the launch velocity, you will launch the projectile completely **vertical**. The repeatability of each launch means that you can collect multiple trials of data at the same pressure level. Determine a pressure level that is easy for you to consistently reach and give a count down before you release the rocket. Have multiple students time how long the rocket is in the air total, then ask other students to record those times while you prepare the rocket again. Repeat for multiple trials.

Depending on the age level and experience of your students, you may need to guide them through the concepts to calculate the launch velocity.

While the rocket is rising up to its maximum height, **gravity** is slowing it down. We approximate the average acceleration due to gravity on Earth as **10 m/s^2**. This means that gravity is going to slow the rocket down by 10 m/s every single second on its way up and speed the rocket up by 10 m/s on its way down.

At the highest point the rocket is **momentarily stopped** then begins to speed up as it falls back to the earth. If allowed to come to the same height the rocket was launched at, ground level, it will take the same amount of time to go up as it will to come down. If the rocket takes 5 seconds to land that means it traveled up to its highest height in 2.5 seconds and took 2.5 seconds to come back down.

If you were able to consistently launch the rocket at the same amount of pressure, your students can average the time the rocket was in the air for their multiple trials. Using half of that time, and knowing that the velocity at the highest point is zero, students can calculate the launch velocity of the rocket.

$v_y = v_0 - at$ $\qquad a = 10\frac{m}{s^2}$ $\qquad t = 2.5s$

$v_y = v_0 - 10t$ $\qquad 0 = v_0 - 10t$ $\qquad 0 = v_0 - 10(2.5)$

$v_0 = 25\frac{m}{s}$

For sake of the example, we used a given time in the air of five seconds. However, you should find your own value by performing a launch with your class. Have students record the time it takes for the projectile to hit the ground after being launched completely vertically.

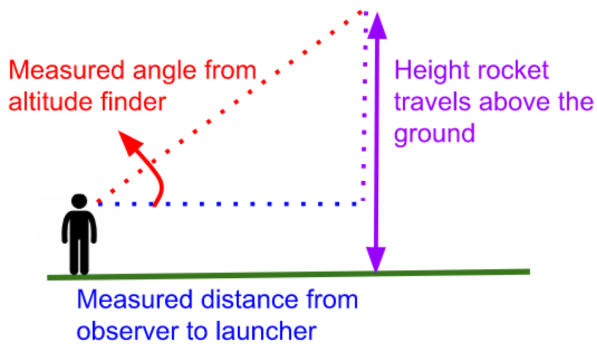
Measuring the Maximum Height

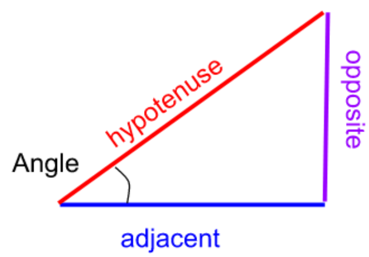
The first method of finding maximum height is to calculate use the launch velocity. Since the rocket will reach its maximum height when gravity has slowed it down to 0 ms, you can use this kinematics relationship to find the maximum height:

$$v_y^2 = v_0^2 + 2ah$$

Where $v_y = 0\,{}^{m}/_{s}$, $a = -10\,{}^{m}/_{s^2}$, v_0 is the launch velocity you found earlier and h is the maximum height.

The second option is to use an [altitude finder] and apply some trigonometry. While launching the rocket vertically, have students stand a measured distance away from the launch pad. You will also have to measure the height above the ground that the altitude finder is being held. Citing along the altitude finder, students can pull the trigger when the rocket has reached it's maximum position. This will lock in the angle on the device to be read later. It may take students some practice to recognize when the rocket has slowed down enough to reverse direction as it begins to fall.





Using tangent, students can determine the height the rocket traveled. This will be the height from level with the observer and will have to be added to the height the observer is above the ground.

<u>Here is an example:</u>
The observing student holds the altitude finder 1.8 meters above the ground and is 3.2 meters from the launcher. Once the rocket is launched, they measure an angle of 85° when the rocket reaches its maximum height.

$$\tan(85°) = \frac{opposite\ side}{adjacent\ side} = \frac{opposite}{3.2\ m}$$

Solving for the length of the opposite side results in 36.6 meters. Since this was measured by the observer at 1.8 meters above the ground, the total height is 38.4 meters.

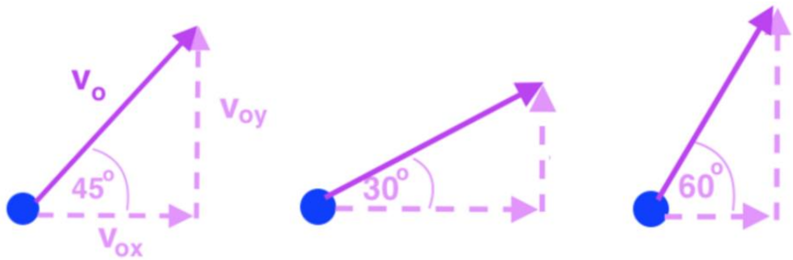
Predicting the Range of a Projectile Launched at an Angle

If you have previously found the launch velocity for your rocket for a certain amount of pressure, you can now launch the rocket at an angle. You can use the integrated protractor to accurately determine the angle of the launch tube before securing it in place.

You can either ask students to predict the range for the rocket for a known angle before you launch the rocket or compare that theoretical range with the measured range after the fact.

In either case, students will need to know the launch velocity and the angle you will launch it at. When a rocket is launched vertically, there is no horizontal velocity, and the rocket should land directly where it was launched (if there is no wind and the ground is level).

If the rocket is launched at an angle, the velocity remains the same but there is a component of that velocity in the horizontal (or x) direction and a component in the vertical (or y) direction. The larger the vertical component, the higher the rocket will go. Students may think that smaller angles, and thus larger horizontal components, would mean the rocket goes farther. However, if the vertical velocity component is too small, the rocket won't travel high enough into the air to travel very far. Theoretically the optimum angle for maximum range is 45 degrees.



Using trigonometry, students can calculate the vertical component of the launch velocity. Knowing that the rocket will land at the same height it was launched at, students can calculate the time that the rocket was in the air.

For the sake of the example, the time the projectile spent in the air going straight up and down took 5 seconds. Our launch angle will be 60 degrees.

Step one will be finding the vertical launch velocity using the equation: $v_y = v_0 - at$
After plugging in all our variables, we find the launch velocity comes out to be $25\ {}^{m}/_{s}$.

We can find the velocity in the vertical direction at the given angle by using the equation for vertical velocity:

$$v_y = v_0(\sin 60°)$$
$$v_y = 25(\sin 60°)$$
$$v_y = \mathbf{21.7}\ {}^{\boldsymbol{m}}/_{\boldsymbol{s}}$$

Our next step is solving for the horizontal velocity by swapping out the *sin* for *cos* in the same formula:

$$v_x = v_0(\cos 60°)$$
$$v_x = 25(\cos 60°)$$
$$v_x = \mathbf{12.5}\ {}^{\boldsymbol{m}}/_{\boldsymbol{s}}$$

Now we can solve for the total horizontal distance in a similar way to how we found our value for t, using the vertical velocity formula.

$$v_y = v_0 - 10t$$

We know vertical velocity, v_y, is zero at the projectile's highest point, and since we're launching from the ground, that's also the halfway point. Unlike when we were solving for t, we already know our vertical launch velocity is, $21.7\ {}^{m}/_{s}$.

$$0 = 21.7 - 10t$$
$$t = \frac{21.7}{10}$$
$$t = 2.17\ s$$

This gives us a total flight time of 4.34 s. We can finally submit our calculation for the total distance traveled using the distance formula:

$$x = v_x(t)$$
$$x = 12.5(4.34)$$
$$x = \mathbf{54.3\ m}$$