

Demonstrating internal ballistics principles using a DIY airgun: An educational laboratory experiment

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Abstract: Understanding the principles of internal ballistics is essential in forensic science education, as it provides insight into how pressure dynamics and projectile motion influence firearm performance and shooting reconstructions. This study introduces an interactive laboratory activity that demonstrates these concepts using a DIY air-powered launcher constructed from a plastic bottle, a pen barrel, and a refillable lighter mechanism. Pure alcohol vapors served as the propellant, and a 1-inch nail projectile was launched toward balloon targets to simulate projectile impact. During testing, the ignition of alcohol vapors inside the sealed chamber produced rapid combustion, generating sufficient pressure to propel the projectile through the barrel and successfully burst the balloon target. The activity enabled students to observe relationships between pressure buildup, trajectory, and projectile stability while reinforcing key physical concepts, including Newton's laws of motion, gas expansion, and energy transfer. This hands-on experiment enhances student engagement and promotes scientific inquiry by allowing learners to test variables such as propellant volume, barrel design, and projectile alignment. While the DIY airgun lacks the precision and safety features of commercial airguns, it effectively demonstrates fundamental ballistic principles in a controlled setting. The activity provides a cost-effective, safe, and engaging educational platform for teaching internal ballistics and supports the integration of practical demonstrations into forensic science curricula.

Keywords: combustion, firearms, forensic science, physics, projectiles

Introduction

Ballistics, a specialized branch of mechanics, examines the motion, behavior, and effects of projectiles in flight. Understanding these principles is fundamental across various disciplines, including engineering, physics, sports science, and forensic investigations. In forensic science education, practical demonstrations of projectile dynamics allow students to visualize complex concepts, bridging the gap between theoretical knowledge and real-world applications.

This activity introduces a hands-on approach to exploring basic ballistic principles through the construction and testing of a DIY air-powered launcher. The device uses compressed alcohol vapors to propel a 1-inch nail as a projectile, demonstrating the relationships between pressure, force, and motion. To illustrate these dynamics in an engaging and controlled setting, students used the launcher to pop a balloon target, enabling them to observe trajectory, velocity, and impact behavior firsthand. The demonstration highlights key physics concepts, including Newton's laws of motion, fluid dynamics, and energy transfer, while reinforcing the

importance of precision, control, and safety in experimental setups (1,2).

Beyond theoretical learning, this activity emphasizes practical problem-solving and critical thinking. Students are encouraged to experiment with different variables, such as air pressure, barrel length, and projectile alignment, to evaluate their effects on accuracy and projectile stability. The inclusion of a defined target by popping a balloon that provides immediate visual feedback, enhancing engagement and reinforcing cause-and-effect relationships between experimental adjustments and outcomes.

Safety remained a central consideration throughout the activity. All tests were conducted under instructor supervision in an open, well-ventilated environment, with students wearing protective goggles and gloves. The design of the experiment allowed for controlled demonstrations while minimizing risks, ensuring that students could actively participate without compromising safety.

Ultimately, simulating ballistic mechanisms through a DIY airgun activity offers an innovative, cost-effective, and engaging platform for teaching projectile dynamics.

By combining engineering, physics, and safety awareness into a single exercise, students gain valuable hands-on experience, deepen their understanding of ballistic principles, and strengthen essential scientific inquiry skills.

Methods

Materials and Equipment

- 1 plastic bottle with cap (200 mL, heat-resistant recommended) – Serves as the main pressure chamber.
- 1 refillable gas lighter – Used as the ignition source; the sparker mechanism is extracted.
- 1 pen barrel or small hollow plastic rod – Functions as the projectile barrel.
- Hot glue gun and glue sticks – Used to secure airtight seals between components.
- Pure alcohol spray (minimum 70% concentration) – Acts as the propellant to create internal pressure.
- Small electrical wire – Connects the extracted ignition mechanism for spark generation.
- 1-inch nails – Used as projectiles to strike the balloon targets.
- Balloons – Serve as visual targets for assessing projectile force and accuracy.
- Safety goggles and protective gloves – Worn by all participants during construction and testing.
- Fire extinguisher (mandatory for classroom use) – Ensures safety in case of ignition-related hazards.
- small plastic rod (used as the airgun barrel)
- Hot glue gun and glue sticks
- Pure alcohol spray (minimum 70% concentration)
- Small electrical wire (for spark connection)
- Safety goggles and protective gloves
- Fire extinguisher (mandatory for classroom use)

Assembly of the DIY Airgun

This activity utilized a DIY air-powered launcher constructed from a 500 mL plastic bottle, a refillable gas lighter, a hollow pen barrel, and hot glue, with a 1-inch nail serving as the projectile. The ignition mechanism was carefully removed from the lighter, ensuring the sparker and connecting wires remain intact. Two holes were created on the side of the bottle: a smaller hole for inserting the ignition wire and a slightly larger hole to accommodate the sparker. Both openings were secured

with hot glue to maintain an airtight chamber and prevent leakage during operation.

To form the barrel, the ink tube was removed from a pen, leaving only the hollow casing, which was inserted into a hole drilled into the bottle cap. The joint between the pen barrel and the cap was reinforced using hot glue to ensure stability and an airtight seal. Once assembled, two to three sprays of pure alcohol were introduced into the bottle chamber, after which the cap was tightly secured to contain the vapors.

For ignition, the sparker wires were connected, and pressing the ignition button generated a spark within the chamber. The alcohol vapor combusted rapidly, producing enough pressure to propel the 1-inch nail projectile through the pen barrel. The launcher was then aimed at a balloon target placed at a controlled distance of 30 cm. Successful ignition resulted in the nail striking and popping the balloon, providing students with immediate visual feedback on projectile force, accuracy, and trajectory.

Given the use of flammable vapors and sharp projectiles, strict safety measures were enforced throughout the activity. All students and instructors wore safety goggles, gloves, and lab coats, and the experiment was conducted in a well-ventilated outdoor space under direct supervision. A two-meter safety perimeter was established around the firing zone to prevent accidental injuries, and a fire extinguisher was placed nearby as a precaution.

To capture projectiles and prevent uncontrolled travel beyond the target, a rigid backstop was placed downrange behind the balloon target. The backstop consisted of a large, corrugated cardboard box (or equivalent cardboard stack) positioned directly behind the balloon target, and an additional dense backing (for example, plywood or packed sandbags) was available when higher energy trials were planned. After each trial the downrange area was approached only after the authors visually confirmed the device was safe and that there were no smoldering materials; nails and debris were then recovered and logged.

The entire session was designed to fit within a single laboratory period. Approximately 30 minutes were allocated for constructing the launcher, 20 minutes for testing and shooting demonstrations, and 15 minutes for group discussions on experimental observations, trajectory patterns, and the effects of pressure, barrel design, and projectile weight on accuracy.

Results

FIGURE 1 shows the fully assembled DIY airgun prior to testing. The capped plastic bottle with sealed holes and the inserted pen barrel are clearly visible, demonstrating the integration of components used to simulate the airgun mechanism. The setup highlights the

arrangement of materials and the readiness of the device for controlled testing involving the ignition of alcohol vapors to generate projectile motion.

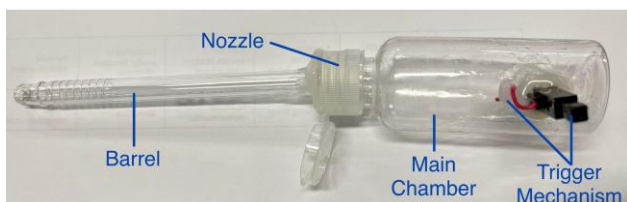


FIGURE 1 Fully assembled DIY airgun showing the capped plastic bottle, sealed openings, and integrated pen barrel.

Meanwhile, **FIGURE 2** captures the moment of testing where the combustion of alcohol vapor inside the chamber produced a visible fire burst at the point of ignition. This demonstrates the successful conversion of chemical energy into kinetic energy. The visual evidence highlights the underlying pressure dynamics and the efficiency of propulsion achieved with this simple airgun design.



FIGURE 2 High-speed capture of the ignition process inside the DIY airgun.

Next, **FIGURE 3** illustrates the results of testing the DIY airgun on a balloon target using a 1-inch nail as the projectile. In **FIGURE 3(a)**, the balloon is shown intact before the launch, while **FIGURE 3(b)** shows the balloon immediately after being punctured by the projectile. The successful burst confirms the capability of the airgun to generate sufficient force for penetration and demonstrates the practical application of ballistic principles in a controlled laboratory setting.



(a)



(b)

FIGURE 3 Results of testing the DIY airgun using a 1-inch nail projectile against a balloon target. (a) Balloon intact before testing. (b) Balloon successfully punctured and burst after impact, demonstrating the effectiveness of the projectile mechanism.

Discussion and Conclusion

The results of the DIY airgun experiment provide valuable insights into the fundamental principles of internal ballistics and their relevance to forensic science education. When pure alcohol vapors inside the sealed chamber were ignited, a rapid exothermic reaction occurred, producing a sudden increase in temperature and pressure within the confined space. According to Tipler and Mosca (3), this process follows the ideal gas law ($PV = nRT$), where the generation of hot gases raises both temperature and pressure, resulting in an outward force exerted on the projectile. As the pressure builds, it accelerates the projectile along the pen barrel, converting chemical energy into kinetic energy. Similar mechanisms occur in conventional firearms, where expanding gases from propellant combustion drive bullets forward (4). Understanding these pressure dynamics is critical in

forensic ballistics, where variations in combustion, chamber volume, and gas behavior influence projectile velocity, trajectory, and the interpretation of shooting incident reconstructions.

The pen barrel acted as a simplified projectile pathway, directing gas expansion and providing linear acceleration while preventing pressure dissipation. However, unlike rifled barrels found in conventional firearms, the pen barrel lacked spiral grooves, meaning the projectile did not spin to stabilize its flight. As highlighted by Carlucci and Jacobson (5), rifling is essential for improving accuracy and precision by imparting angular momentum. Despite this limitation, the experiment demonstrated how confinement of gases efficiently transforms stored pressure into forward motion. Minor inconsistencies in projectile speed and range observed during testing were attributed to imperfect barrel sealing and variability in combustion efficiency, reflecting real-world forensic challenges where barrel wear or irregularities affect ballistic signatures.

From a chemical perspective, using alcohol vapor as the propellant introduced variability compared to the consistent energy release of traditional gunpowder. As explained by Atkins and de Paula (6), alcohol combustion produces water vapor and carbon dioxide, generating less peak energy and resulting in lower and less stable chamber pressures. Since the alcohol spray was applied manually, the volume of vapor introduced varied between trials, affecting combustion completeness and subsequent projectile velocity. The rapid temperature increase inside the sealed chamber also aligned with Charles's and Boyle's gas laws, where pressure rises proportionally with temperature before decreasing as gases escape through the barrel (3).

When compared to commercial airguns, the DIY design shares the same underlying ballistic concept of creating chamber pressure to propel a projectile through a barrel. However, commercial systems are engineered with precision components, durable materials, and controlled propellant systems to deliver consistent performance. They also typically use compressed air or pre-regulated gas systems rather than manual alcohol combustion, resulting in higher accuracy and reproducibility. Moreover, commercial airguns incorporate multiple safety features, such as pressure relief valves and trigger mechanisms, to minimize the risk of accidental discharge. In contrast, the DIY model carries higher safety risks due to open ignition sources, variable pressures, and basic sealing techniques.

The use of a steel nail as a projectile provided a simple yet effective simulation of real-world ballistic behavior, allowing students to observe penetration, trajectory, and target response in a controlled environment. The balloon targets offered immediate visual feedback, while the downrange backstop ensured safe capture of the projectiles and enabled their recovery

for inspection. During the classroom demonstrations, a downrange backstop was used and projectiles were recovered after testing. However, precise distances travelled by projectiles after passing through the balloon target were not recorded as part of the original data collection, and therefore not reported here. This limitation highlights the importance of incorporating standardized measurements of projectile travel in future iterations of the experiment, which would provide more comprehensive data for analyzing projectile dynamics and refining safety protocols.

Despite these limitations, the experiment successfully demonstrates key concepts of internal ballistics, including pressure buildup, energy transfer, and projectile propulsion. Its simplicity provides an effective educational tool for illustrating the relationship between gas dynamics and projectile motion while engaging students in hands-on learning. By linking theoretical physics to practical application, this activity strengthens student understanding of ballistic principles, fosters critical thinking, and enhances comprehension of forensic shooting investigations and firearm performance analysis.

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