ARBOR SCIENTIFIC

Fire Syringe

P1-2020

INSTRUCTIONAL GUIDE

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Recommended for Activity:

- Heavy-Duty Air Pump with Gauge (P4-2223)

Introduction

The fire syringe provides a rather dramatic way of demonstrating the heating of a gas, in this case air, that accompanies rapid compression. With this fire syringe, the air can reach a temperature of over 260°C (500°F). As cotton fibers burn at 235°C (454°F), a small piece of cotton fiber placed at the bottom of the combustion tube will ignite.

Background

When a gas is compressed rapidly, its temperature will increase. This process is known as adiabatic compression. You've probably noticed this effect while inflating a bicycle tire. The increase in temperature results from the work being done on the gas. Pushing on the gas increases the kinetic energy of the gas molecules. This increase in internal energy manifests itself as an increase in temperature. The rapid compression reduces the amount of energy lost to the environment.

In a diesel engine, air is compressed adiabatically. This compression raises the temperature inside the cylinder to the flash point of the fuel mixture. The diesel engine differs from the gasoline engine by using adiabatic compression to ignite the fuel rather than a spark plug.

A fire syringe is a piston-and-cylinder device with a thick-walled transparent cylinder fitted with a metal piston that can travel within an inch of the bottom of the cylinder.

Operation

Note: Do NOT use ethanol or other organic solvents to clean the acrylic cylinder. Use soap and water only.

You need to have just the right amount of cotton in the apparatus for success. Experiment with larger and smaller pieces to find the right amount before using with students.

Pull the cotton apart a bit to allow air to circulate through the material to help with ignition. If the seal on the O-rings is not tight, the air will not be adequately compressed. Adjust so that O-rings form a tight seal to compress the air. The chamber must be opened and cleaned between demonstrations as the

oxygen in the tube is consumed during ignition. The chamber should be clean and dry to have success. This apparatus is constructed for use with cotton. Do not use flash paper in this device. The O-rings may need to be greased with silicone lubricant to ensure a tight seal.
Once the syringe is ready, follow these steps for proper use:

1. Put on protective eyewear.
2. Pull out the syringe and place a small piece of cotton (as little as a few fibers) at the bottom of the tube, approx. 5mm. It takes much less then you think.
3. Insert the end of the piston part way into the combustion tube and screw on the top.
4. Darken the room to increase visibility.
5. Place unit base on flat, stable surface and push syringe straight down with force and speed. You will see a flash of fire that will last as long as there is oxygen present in the tube.

ATTENTION: The downward force required along with the pressure built inside the tube can cause damage to the handle or tube if the syringe is not pushed straight down.

Activities

1. Refer to prior knowledge by discussing with students the movement of individual particles. Have students sketch and label what particles look like in a solid, liquid and gas. Students should indicate that particles in a gas are further apart and that they move freely throughout their container.
2. Tell students they will now do a small experiment with air pressure and have each group (4-6 students) pump up a partially inflated bicycle tire with a pump. Students should record observations (using all their senses except taste) before and after pumping up the tire. After they pump up the tire have them feel the temperature of the air as it exits (feels cooler). Request that students include a drawing and description of the air particles inside the tire before and after pumping. Pose these questions to the students following the activity. (If students wish, allow them time to go back and view the materials again as they may need more time to process the information)
    a. What changes did you notice before and after the tire was pumped up? (tire went from less tight to more tight-increase in pressure, tire became warmer as more air was forced inside)
    b. How do you think these changes are related to the particles inside the tire? (as you introduced more particles, they exerted more force on the inside wall of the tire)
    c. If you noticed a change in temperature, what do you think caused this? (increase in the collisions and increase in the kinetic energy of the particles. Also, as air is released through the valve, its pressure decreases and it cools rapidly, explaining the cool feeling of the air rushing out)
3. As you discuss these questions as a class, you may want to show students an online simulation of particles moving in a closed container related to its temperature. By Googling “temperature and kinetic energy” you should come up with several movies or interactive simulations that will allow students to see the particle movement more easily.
4. Now have the students view the Fire Syringe. If you are using the syringe as a demo, pass it around the room and allow students to inspect it (without the cotton inside) so they have a clear vision of the apparatus. If you are allowing the students to perform the experiment in groups, give safety instructions before beginning and do not distribute the cotton until you are ready for them to begin the ignition.

5. *It is always best to DO an experiment ahead of time to be able to best present it to the class.*
6. Have the students make predictions. What will happen when we compress the air inside the apparatus? Will the result be different if we compress slowly vs. quickly? Will the amount of cotton affect the success of ignition? Students should record their predictions on their paper, being sure to include a short explanation of WHY they think this is true.
7. Have students obtain safety glasses. Never point the fire syringe and piston at a student or towards your face. Follow instructions for setup and darken the room. Compress the handle of the fire syringe. The cotton should ignite and the spark should be visible. If doing as a demo, consider using a small camera to project the demo on a larger screen. If doing in student groups, be sure to monitor students throughout and instruct them on the correct safety and disposal procedures. Provide a fireproof container (such as a glass beaker) for the burnt cotton so that smoldering pieces of cotton do not ignite in a trash can. Remind students that it may be very hot and that they should use caution. You may choose to provide forceps for students to handle the burnt cotton.
8. After students have seen the demo or performed the demo themselves, have them record their data. Have students respond to the following:
    a. What do you think was the starting temperature of the air in the tube? (before the first time the plunger is compressed the air would be room temperature
    b. How hot do you think it would have to get to ignite the cotton? (cotton fibers ignite at 235°C, 454°F)
    c. Why doesn’t slow compression of the piston cause the cotton to ignite? (heat energy is allowed to dissipate slowly into the surrounding space, creating a temperature less that the ignition point of the cotton)
9. As you discuss the questions with the class, introduce the idea of adiabatic heating. (If the total amount of heat in a closed container of air is held constant (no heat is added or released), then when the container expands, the temperature drops. If the air is compressed, the temperature rises. This is called adiabatic heating and cooling. The term adiabatic implies a change in temperature of the air without gain or loss of heat from outside the container.
10. Summarize what the students have learned and have students revisit their predictions about the fire syringe. If they were not correct or if their explanations were incorrect, have them write a revision at the end of their lab report.

Discussion

Following are two good examples in real life that connect to the concepts covered today. As an extension you may have students investigate these for homework or write a paragraph after researching their own example

1. Diesel Engines: rather than having a spark plug, diesel engines use the same concept as you see in the fire syringe. The fuel is compressed quickly until it reaches its ignition point. It may be helpful to find an online demonstration or video clip of what is happening inside the engine.
2. Meteorology and Cloud Formation: Adiabatic processes are very important in the atmosphere. Adiabatic cooling of rising air is the dominant cause of cloud formation. Adiabatic cooling is also calling ‘lifting’ and is the most common method of humidification of air to form clouds. As air rises it expands because as altitude increases, pressure decreases. Kinetic energy is converted to potential energy and the air temperature decreases, causing the relative humidity to increase.

Student Questions

1. What changes did you notice before and after the tire was pumped up?
2. How do you think these changes are related to the particles inside the tire?
3. If you noticed a change in temperature, what do you think caused this?
4. Make Predictions: What will happen when we compress the air inside the apparatus? Will the result be different if we compress slowly vs. quickly? Will the amount of cotton affect the success of ignition?
5. What do you think was the starting temperature of the air in the tube?
6. How hot do you think it would have to get to ignite the cotton?
7. Why doesn't slow compression of the piston cause the cotton to ignite?
8. Summarize what you have learned, then revisit your predictions in question 4 about the fire syringe. If you were not correct write a revision at the end of your lab report.

Related Products

Advanced Gas Laws Demo (P1-2065) Quantitatively confirm the Combined Gas Law with one complete apparatus! Students can verify this relationship using air and this unique apparatus.

Gas Laws and Pressure Discovery Bundle (P1-2070) Don't just teach the gas laws. Let students deduce them with these exploratory activities!

Elasticity of Gases Demo (P1-2075) The perfect apparatus for verifying Boyle's Law and other properties of gases. Simply add weights to the top block and measure the volume. Students then plot pressure versus the reciprocal of the volume in search of a straight line.

Acknowledgement

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