Experiment 1 — Definition of Pressure

Topic: Definition of Pressure

Approximate duration: 15–20 minutes

Didactic objective

This introductory experiment intuitively and visually establishes the fundamental concept of pressure: **the relationship between force and contact surface**. By comparing the effect of a weight and a needle applying similar forces to a watermelon, students understand **why sharps pass through materials** with much less force.

Necessary material

- Watermelon (or similar, such as melon, zucchini, cucumber...)
- Sewing needle or thick pin
- Object with a flat base of similar size (a coin, the end of a pen with the cap on, a cap...)
- Holder for fixing watermelon, or just a stable surface

Procedure

This experiment works well as a participatory demonstration: one student can be invited to apply force while the rest observe.

1. Place the watermelon on **a stable surface** that prevents it from rolling.
2. Rest the flat-bottomed object on the shell and **push with moderate force.** Observe that the shell resists without breaking.
3. Place the needle upright on the shell and **apply a significantly lower force.** Observe how it penetrates easily.
4. Ask students to explain the difference before giving the scientific explanation.

Scientific explanation

Pressure is defined as the force applied per unit area:

$$\mathbf{P = F/A}$$

where P is the pressure (in pascals, Pa), F is the applied force (in newtons, N), and A is the contact area (in square meters, m^2).

When we apply a similar force with the flat object and with the needle, **the only thing that changes is the contact area**. The tip of a needle has a contact surface thousands of times smaller than the base of the flat object. By dividing **the same force between a much smaller surface**, the resulting pressure is **much larger**, enough to overcome the strength of the shell.

Tips for dynamization

A good starting question is: "What does more damage, being stepped on with a sneaker or a heel?" The intuitive answer is correct and leads directly to the definition of pressure. Students can even be asked to estimate how many times more pressure the heel exerts by comparing approximate areas, depending on the age of the students.

Security

The needle must be handled exclusively by the teacher, or under direct supervision. Under no circumstances should needles be left available to children unattended.

Experiment 2 — The Hydraulic Press

Topic: Pressure in fluids. Pascal's principle

Approximate duration: 20–30 minutes

Didactic objective

This experiment allows students to build and use a miniature hydraulic press with two syringes of different diameters. The result is striking: a 2 euro coin is capable of lifting an object 25 times heavier, which is known as Pascal's Principle.

Necessary material

- 1 x large ~300 mL syringe (about 5 cm plunger diameter)
- 1 small ~5 mL syringe (about 1 cm plunger diameter)
- Flexible tubing to connect both syringes
- Electrical tape or zip ties to seal the joints if there are leaks
- Water (to fill the system)
- 1 x 2 euro coin (~8.5 g)
- Object of about 300 g (a measuring beaker with 300ml of water is recommended)
- (Optional) Wooden board with two holes to hold the syringes vertically

Procedure

The success of the experiment depends on the system being watertight: any air bubble or water leak considerably reduces the effect. It is recommended to assemble and test the system in advance:

1. Assemble the system with both syringes connected by the tube **and filled with water without bubbles.**
2. Place the ~300 g object on the plunger of the large syringe and the 2 euro coin on the plunger of the small syringe.
3. Gently push **the small plunger** down and watch the large plunger rise, lifting the 300 g object with the force equivalent to the coin.
4. (Optional) Repeat the experiment in **reverse:** push the large plunger and observe that the small plunger rises much faster and with much less travel.

Image 1: *Example of the construction.*

Scientific explanation

The system works by applying pressure to any part of an enclosed, incompressible fluid, the pressure is transmitted to all points in the fluid. This is known as **Pascal's Principle.** Since the water cannot be compressed and is sealed inside the syringes and tube, the pressure generated in the small syringe is exactly the same as that which reaches the large syringe.

As we saw in the previous experiment the pressure is $P = F/A$, and the pressure is the same on both sides. Therefore, if the area of the large plunger is 25 times larger than that of the small **plunger, the force produced in the large plunger will also be 25 times greater**, since the ratio of areas is $(5/1)^2 = 25$. In return, the small plunger must travel 25 times farther than the large plunger to apply this force.

Tips for dynamization

Before the demonstration, students can be asked if they think a coin can raise the glass of water. The almost universal answer will be no, which makes the result especially shocking.

Security

The experiment does not present significant risks. Be aware that the system can disconnect and spill water if the plunger is pushed too hard. It is recommended to perform the demonstration on a waterproof tray or surface.

Experiment 3 — We create vacuum with a straw!

Topic: Vacuum and atmospheric pressure

Approximate duration: 15–20 minutes

Didactic objective

This experiment introduces the concept of vacuum and connects it to atmospheric pressure in a tangible way. Students understand that a vacuum is not "nothing," but reducing the amount of air inside a container as much as possible. The experiment is carried out in two phases: first with a commercial vacuum sealer and then replicating the same effect with a zip bag and a straw to do it yourself.

Necessary material

Demonstration 1 (packaging machine):

- Domestic vacuum sealer
- Machine-compatible vacuum packaging bag
- Any soft object for packaging (e.g., a sponge)

Show 2 (straw):

- Zip closure bag (freezer bag type)
- Drinking straw

Procedure

Demonstration 1: Vacuum Sealer

1. Place the object in the packaging bag and place **the open end of the bag on the nozzle of the machine.**
2. Close the machine and activate the packaging cycle. Observe how **the bag contracts** and sticks to the object as the air is extracted.
3. Once packaged, ask a student to try to **open the bag with only their hands, without breaking it.** Observe how the bag refuses to open.

Demonstration 2: homemade straw

4. Insert the straw through one end of the zip bag and **close the closure as much as possible around it**, leaving only the minimum gap.
5. Inhale forcefully through the straw to extract the air. When you need to breathe, **pinch the straw with your fingers to prevent air from entering**, and continue sucking.
6. When removing the straw, close the zip quickly. Observe how **the bag has been partially crushed**, with a similar (although less perfect) result to that of the packaging machine.

Scientific explanation

The air around us exerts pressure on all surfaces: this is called **atmospheric pressure**. Under normal conditions we do not notice it because the internal and external pressure of the objects is balanced.

By drawing air from inside the bag, **the pressure inside is going down** and approaching (but never reaching 0), while **the one outside the stock exchange remains the same**. As the pressure from outside is greater, it forces the bag from all sides, crushing it against the contents. After making the vacuum, you have to overcome this force to open it, and that's why it costs so much.

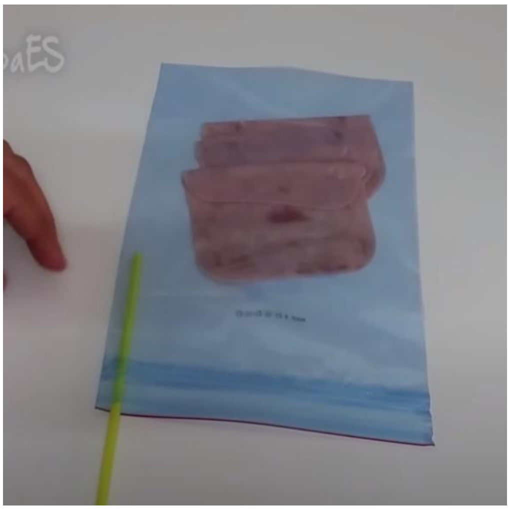

Image 1: *Example of how to perform the experiment. The bag should be as closed as possible, allowing air to enter or exit only through the straw.*

Tips for dynamization

Packaging a sponge is particularly effective: by visibly compressing under vacuum and regaining its shape when opened, it illustrates very clearly the difference in pressure between the inside and the outside.

Asking a student to try to open the packaged bag without breaking it usually generates surprise and discussion. It's the ideal time to ask what's pushing the bag inward, and discover the concept of atmospheric pressure (the very air around us!)

Security

The experiment does not present significant risks. The packaging machine must be operated by the teacher.

Experiment 4 — Paper Against Water (Unexpected Winner)

Topic: Atmospheric Pressure

Approximate duration: 10–15 minutes

Didactic objective

This experiment demonstrates the power of atmospheric pressure in a surprising and everyday way: a simple piece of paper is able to hold a glass full of water upside down without spilling a drop. The result is so counterintuitive that it generates immediate impact and opens a natural discussion about the magnitude of the pressure that the air exerts on everything around us.

Necessary material

- A glass or cup with a straight mouth
- A piece of paper covering the mouth of the glass
- Water
- Tray or sink where to perform the experiment

Procedure

It is recommended to do the experiment on a tray or near a sink. Do it first by the teacher and, if desired, repeat it with a volunteer student.

1. Fill the glass completely with water, **leaving no bubbles inside.**
2. Place the paper over the mouth of the glass and **press it with the palm of your hand** , making sure that it covers the entire opening.
3. Hold **the paper tight with your hand** and turn the cup upside down in a **single, continuous motion.**
4. Hold the whole for a moment **and slowly remove your hand from the paper**. The paper should be held in place by holding the water.

Scientific explanation

When the glass is turned upside down, **the water exerts downward pressure** on the paper equal to its weight divided by the surface of the mouth. However, the outside air exerts **the atmospheric pressure upwards** on that same surface.

For a standard 250 mL beaker, the pressure exerted by the water on the paper is **about 100 times more than the weight of the water itself**. The paper does not fall because the pressure of the outside air pushes it upwards with **a force far greater than the weight of water**. The glass must be completely filled because if there was air inside, the internal pressure would be higher, reducing the difference between the two pressures and making it easier for the water to fall.

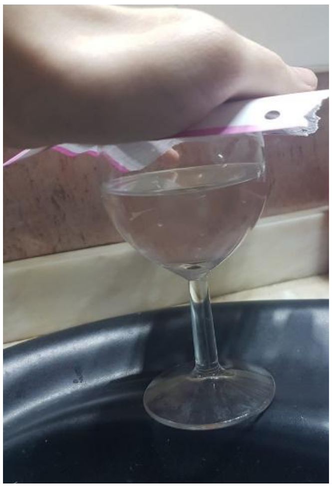

Image 1: Preparation before turning the glass. The hand makes the shape so that the water does not fall.

Image 2: The cup once turned. The paper is able to prevent water from falling.

Tips for dynamization

Before doing the experiment, ask students what they think will happen when the hand is withdrawn. Most will expect the water to fall or the paper to get wet and break, which makes the result especially shocking.

The optional step of testing with the glass half full is very helpful: if the experiment fails, it forces students to think about the role of trapped air and the difference in pressures, reinforcing the explanation.

Security

The experiment is risk-free. Do it on a tray or near the sink to avoid wetting the floor in case of failure.

Experiment 5 — The pressure is stronger than it seems!

Topic: Atmospheric Pressure

Approximate duration: 20–30 minutes

Didactic objective

This experiment replicates one of the most famous demonstrations in the history of science: Otto von Guericke's original experiment in Magdeburg (1654), where sixteen horses were unable to separate two hemispheres from which the air had been extracted. On a laboratory scale, students quantitatively check the force exerted by atmospheric pressure and verify the result using a simple calculation.

Necessary material

- Magdeburg Hemisphere Kit (available at labware stores or on Amazon)
- Manual or electric vacuum pump compatible with the kit
- Sturdy bench or anchor point from which to hang hemispheres
- Mat or mattress, for safety
- Two volunteers of about 80kg in total between the two

Procedure

1. Prepare the anchor point of the sphere (it must be solid and hold at least 100kg of weight), and **place the mat underneath** for the demonstration.
2. Fit the two hemispheres together **and connect the vacuum pump to the valve**. Extract the air following the instructions in the kit.
3. Try to separate the hemispheres manually. Observe that it is impossible or very difficult, even though **the hemispheres are not glued or screwed.**
4. Hang the hemispheres from the anchor point. Ask a first volunteer to hang from the lower sphere trying to **separate them with their own weight.**
5. If they do not succeed, add a second volunteer. If this is not enough, let **the teacher progressively pull the sphere** until, together with the weight of the volunteers, the two hemispheres separate.
6. Once the demonstration is complete, **open the valve to let the air in**. The hemispheres will separate themselves without any effort.

Scientific explanation

When the air is extracted from the inside, the pressure inside the spheres is practically zero, while outside the pressure is atmospheric pressure. It acts on the entire sphere, and generates a force that holds the two hemispheres together.

The force needed to separate them can be calculated with the formula P = F/A, where the area is the circular contact section:

$$\mathbf{F = P \times \pi \times r^2}$$

For a standard kit with radius r ≈ 5 cm (0.05 m):

$$\mathbf{F \approx 101{,}325 \times \pi \times (0.05)^2 \approx 795\ N \approx 80\ kgf}$$

In other words, it takes about 80 kg of weight to separate them, which explains why it takes the weight of two people. When the valve is opened, the inner pressure equalizes with the outer pressure **and the hemispheres separate without any effort:** it was only the pressure difference that held them together, not any closing mechanism.

The calculations have been made for spheres of radius 5cm, in case of using spheres of different sizes**, redo the calculations** to have good accuracy.

Tips for dynamization

The final opening of the valve is the most didactic moment: the hemispheres separate on their own in an instant, without any effort. Ask students to explain why before doing so.

Security

The anchor point must be well fixed and **be able to support the weight of two people more than enough** (with about 100kg, there is enough margin). **Place a mat or padded surface underneath** to cushion a possible fall if the hemispheres are abruptly separated. Volunteers must hold on only with their hands, without hooking any part of the body, so that they can be easily released.

Supplemental Resources

Example kit available on Amazon: https://www.amazon.es/Hemisferios-Magdeburgo-Instrumento-experimento-laboratorio/dp/B083GTR35L/

Experiment 6 - We launched a water-powered rocket!

Topic: Propulsion and Newton's Third Law

Approximate duration: 30-45 minutes

Didactic objective

This experiment connects concepts of pressure, fluids and dynamics in a spectacular result: a plastic bottle shoots out **powered only by water and compressed air.** It is one of the most motivating demonstrations in the series because it allows students to see real physics in action and understand the working principle of real rockets.

Necessary material

Basic (functional) version:

- 2 x 2 L plastic bottles
- **Cork stopper** that fits into the mouth of the bottle
- Pump or inflator with a metal needle **longer than the thickness of the cap**
- **Large outdoor area** for launching

Optional upgrades for a more elaborate rocket:

- Carton for making stabilizing fins and tip cone
- Water-resistant adhesive tape
- Cloth or plastic parachute for gentle retrieval
- Multiple bottles connected in series for increased water volume and more thrust

Procedure

1. Fill the bottle **with about 1/3 of its volume** with water.
2. Insert the cork stopper into the mouth of the bottle, snug**, but not too tight** (it should come out when the pressure is sufficient).
3. Thread the inflator needle through the cap, so **that it is connected to the inside of the bottle.**
4. Place the bottle upside down in the throwing area, **with the mouth pointing to the ground**. Make sure there are no people in the flight path.
5. Start pumping air. The bottle will **build up pressure until the cap gives way** and the rocket shoots upwards.

6. (Optional) Vary the amount of water between throws (1/4, 1/3, 1/2 bottle) and ask students to predict and compare heights.

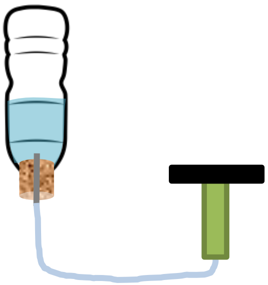

Image 1: Diagram of the assembly. The bottle is pointing downwards and the cap will be on the ground when the rocket starts flying.

Scientific explanation

When pumping air into the cylinder, **the internal pressure increases above the atmospheric pressure.** Water, being incompressible, transmits that pressure to all the walls of the bottle and in particular to the stopper.

When the pressure is sufficient to overcome the friction of the cap, it gives way and **the water is expelled at high speed downwards.** If the water exerts a downward force, the rocket **receives an equal and opposite upward force**.

Tips for dynamization

Before launch, **you can ask why they think the rocket goes up** if what comes out is water downwards. The intuitive answer is often incorrect (many think that water pushes the soil), which makes the explanation more shocking.

Vary the amount of water between casts and ask students to predict and compare heights. It is a natural introduction to the scientific method: hypothesis, experiment and observation.

Security

Always launch outdoors, in a large and clear space. Establish an exclusion zone of at least 10 meters in the direction of flight. No student should be in that area during the launch. The pitch is controlled by the teacher. Students observe at a safe distance. Do not use air compressors. With a manual bicycle pump the risk of overpressure is low. Take into account the direction of the wind before casting.

Experiment 7 – We build a homemade vacuum bell

Topic: Vacuum and Atmospheric Pressure

Approximate duration: 45-60 minutes (assembly included)

Didactic objective

This experiment is different from the rest of the series since it is not a one-off demonstration, but rather it is about **building a tool that will serve us in different experiments.** By building it as just another experiment, you will have a much better understanding of how it works and why its parts work.

Necessary material

- Thick-walled glass bowl or bell (thicker the better to prevent implosions)
- Metal griddle or metal table
- Sealing rubber (rubber or silicone strip) for the perimeter of the hood
- Manual or electric vacuum pump
- Stopcock (to be able to break the vacuum in a controlled way)
- Vacuum gauge (to measure the internal pressure)
- T-shaped or cross-shaped tube of the appropriate diameter for the plate hole
- Silicone or sealant to waterproof the joints
- Protective gloves and goggles or face shield

Assembly procedure

Given the complexity of the assembly, it is recommended to build and test the camera several days in advance.

1. Make **two holes in the metal sheet**: one inside the surface covered by the hood and one outside.
2. Install the fork (T-shaped or cross-shaped) **in the inner hole.** Connect the vacuum pump, stopcock and vacuum gauge. Seal all joints with silicone.
3. Connect **the vacuum gauge to the outer hole**.
4. Glue the rubber strip **following the entire perimeter** where the hood will rest.
5. Place the object to be studied inside the bell.
6. Place **the bell on the rubber**, making sure it is well supported and close the stopcock.
7. Activate the vacuum pump and **see how the pressure drops** (see on the vacuum gauge)
8. Finally, open the stopcock **slowly to let the air in a controlled manner** before removing the hood.

Scientific explanation

The vacuum chamber allows **the pressure inside the hood to be reduced to very low values.** By extracting the air, the molecules that generate the pressure are removed, creating a **partial vacuum** that can be measured with the vacuum gauge.

The stopcock is a critical component: it allows **the inside to be isolated from the outside once the vacuum has been reached**, so that the pump can be switched off without air entering. When we open it, the outside air enters at high speed until the pressures equalize, which generates a characteristic "pop" sound

The sealing rubber, in addition to making sure that the hood closes tightly, **distributes the force that the bell makes against the table**. This is important so that the glass does not break and the bell implodes.

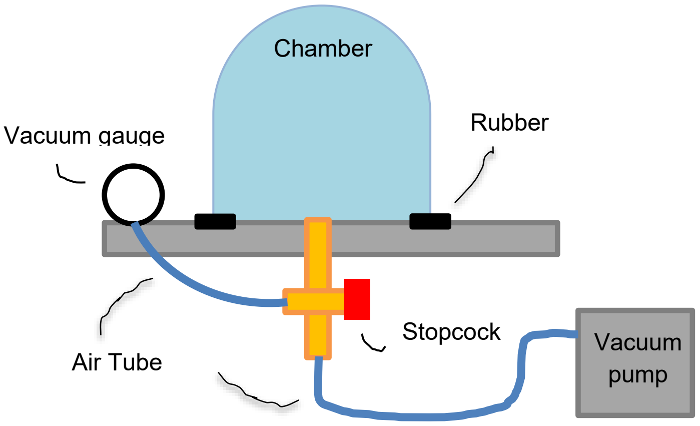

Image 1: Diagram of the assembly of the vacuum hood. Make sure that all connections are isolated from the outside to prevent air from entering.

Security

This is the most safety-demanding experiment in the series due to the risk of glass implosion. It is always necessary to wear protective gloves and a screen or face glasses during assembly and experiments.

It is very important to use good quality glass of the maximum possible thickness, in addition to inspecting the bell to detect possible cracks that compromise the safety of the experiment.

The bell should not be knocked or vibrated while in use, nor should the stopcock be opened abruptly, always slowly.

Keep students at a certain distance from the hood, and they must wear protective glasses in case the hood suffers a problem.

Supplementary Resource

Experiment reference video: https://www.youtube.com/watch?v=2opFNPDfKtw

Experiment 8 – Balloons that inflate themselves

Topic: Atmospheric Pressure

Approximate duration: 15-20 minutes

Didactic objective

This experiment takes advantage of the vacuum chamber built in experiment 7 to visually demonstrate that **the size of a balloon does not depend only on how much air it has inside**, but on the difference between the pressure inside and outside the balloon. It is a very clear demonstration of the concept of **pressure balancing** and naturally complements the explanation of why we blow balloons up.

Necessary material

- Mounted Vacuum Chamber (Experiment 7)
- 2 or 3 latex balloons inflated to different levels: one **very underinflated**, one **at half capacity** and one **almost at the limit**, to make comparisons.

Procedure

1. Inflate the balloons **to different levels** and place them inside the hood
2. Place the hood **on the base with the rubber**. Turn off the stopcock.
3. Activate the vacuum pump and slowly extract the air. Observe how **the balloons begin to expand** as the outside pressure drops.
4. Stop the bomb at different times and observe that **the balloons stop expanding**: the pressures outside and inside the balloon are equalized.
5. Continue to draw air as much as possible and **observe the differences in size between the balloons**.
6. Open the stopcock slowly to let air in. Observe how **the balloons recover their original size** when they are back at atmospheric pressure.

Scientific explanation

Image 1: Example of the experiment. There are balloons of different sizes, some of which will explode and others will not

An inflated balloon is kept at one size because **there is a balance between two opposing forces:** the air pressure inside it (which pushes out) and the pressure outside (which pushes in the balloon).

By extracting air from the chamber **the outside pressure is smaller than before,** since **there are fewer air particles** that they can push the balloon. The balloon is no longer in equilibrium: the pressure inside is stronger than the pressure outside and the latex expands **until a new balance is reached.** The lower the outside pressure, the greater the expansion.

When the stopcock is opened, **the outside pressure returns to atmospheric pressure** and the balloon returns **to its original size.** This process is completely reversible because the indoor air has not changed, **only the pressure of the environment has changed.**

The case of the highly inflated balloon is an example of **when the pressure inside the balloon is very great** and causes the latex of the balloon to rupture.

Tips for dynamization

Before activating the bomb, ask the students what they expect to happen. Most will believe that balloons will not change or that they will deflate, not that they will expand

Stop the air extraction halfway through and ask: the balloons have stopped growing, why? The response (new equilibrium of pressures) consolidates the central concept of the experiment.

Security

Maintain the same precautions as in experiment 7, gloves and face protection.

Experiment 9 - Sound and vacuum: An Impossible Marriage

Topic: Sound

Approximate duration: 15-20 minutes

Didactic objective

This experiment demonstrates in a direct and surprising way that sound needs a material medium to propagate. When we remove the air from its surroundings, the sound disappears until, when there is very little air, the sound practically disappears.

Necessary material

- Mounted Vacuum Chamber (Experiment 7)
- Continuous, self-contained sound source (e.g. a mechanical alarm clock or a mobile phone playing music constantly...)
- A piece of foam that allows the sound source to be isolated from the base

Procedure

1. Place the sound source **on a piece of foam or rubber** inside the camera, making sure that it does not directly touch the metal plate.
2. Place the hood on the base with the sealing rubber and **close the stopcock**. Confirm that **the source sounds clearly** from the outside.
3. Activate the vacuum pump and **slowly extract the air**. Ask the students to listen carefully to the sound and observe that **the sound disappears.**
4. Continue to **the maximum achievable vacuum**. The sound should be very faint or imperceptible.
5. Open the stopcock slowly. Observe how **the sound recovers its original volume** as the air enters.

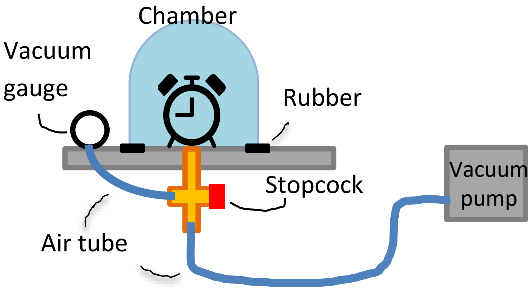

Image 1: Outline of the experiment. It is the same as the vacuum chamber, but with a sound source inside

Scientific explanation

Sound is a mechanical wave: it is **the vibrating air particles themselves**. When the sound source vibrates, it pushes the air molecules around it, which push the next ones, and these to the next ones... Different **areas are created with more and less pressure**, and this is what our ear detects.

By extracting the air from the chamber, **we are removing particles** that can vibrate to transmit sound: with fewer particles it is more difficult for the wave (the sound) to be able to propagate. If there are practically no particles (as in space), **sound cannot propagate**. That's why you can't hear anything in space! The sound source is still vibrating, that hasn't changed, but since there's no air around it we can't hear it.

Tips for dynamization

Before starting, ask the students: If we placed a speaker in the space, would we be able to hear the music?

The moment of opening the stopcock at the end is as didactic as that of extracting the air: the sound suddenly returns, which reinforces that the cause of the attenuation was the absence of air and nothing else.

Security

Maintain the same precautions as in experiment 7, gloves and face protection while the camera is in use.

Experiment 10 - Water in a vacuum

Topic: Boiling Point and Vapor Pressure

Approximate duration: 15-20 minutes

Didactic objective

This experiment **dismantles a very common idea**: that water boils at 100ºC. In reality, **water only boils at 100ºC at atmospheric pressure**, but it can boil at other temperatures if the pressure is different. It is one of the most impactful demonstrations in the series because **it directly contradicts the everyday experience of students** and introduces the concept of vapor pressure.

Necessary material

- Mounted Vacuum Chamber (Experiment 7)
- Glass of water at room temperature
- Thermometer (recommended: shows that the water is not hot)

Procedure

1. Place the glass of **room temperature water** inside the chamber. If a thermometer is used, **put the thermometer in the glass** to see in real time that the temperature does not change.
2. Place the hood on the base with the sealing rubber and close the stopcock.
3. Activate the vacuum pump and slowly extract the air. Observe the vacuum gauge.
4. As the pressure drops, **watch as the water begins to bubble** and boil visibly, without the temperature rising.
5. Open the stopcock **slowly** to let air in. Observe how the water **stops boiling immediately** when it returns to atmospheric pressure.

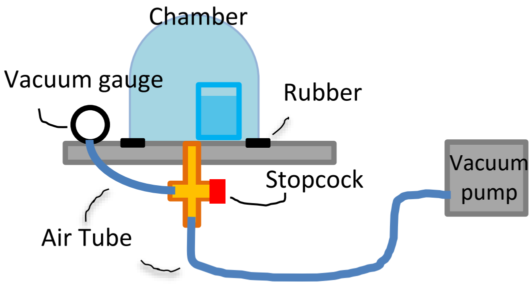

Image 1: Outline of the experiment. It's simply the vacuum chamber with a glass of water inside.

Scientific explanation

Boiling **does not occur at a fixed temperature**, but when **the vapor pressure of the liquid equals the outside pressure.** Vapor pressure is the pressure that molecules make **to escape the liquid**, that is, evaporate. The higher the temperature, the more vapor pressure the molecules in the liquid will have.

When the liquid is at atmospheric pressure, **the vapour pressure that equals the atmospheric pressure is achieved at 100ºC**. This is the temperature at which we are used to boiling water. But if the outside pressure is smaller than the atmospheric pressure, the vapor pressure that the molecules will have to make to escape **will be smaller** and, therefore, it will not have to be as hot.

When we open the stopcock, the outside pressure returns to atmospheric pressure **and the water particles do not have enough vapour pressure** to escape. The water has not heated or cooled, **only the pressure of its surroundings has changed.**

Tips for dynamization

The most effective starting question is straightforward: At what temperature does the water boil? Almost all students will respond 100ºC. Showing them immediately that it boils at room temperature without heating it is the best possible hook.

The thermometer allows students to check themselves that the temperature has not changed while the water is boiling. Without the thermometer, some might think that the hood has heated the water in some way.

Security

Maintain the same precautions as in experiment 7, gloves and face protection while the camera is in use.

Experiment 11 – What makes the pressure more or less strong?

Topic: Hydrostatic Pressure

Approximate duration: 15-20 minutes

Didactic objective

This experiment visually demonstrates that the pressure exerted by a fluid at a point depends solely on the height of the fluid above it. Not the total amount of liquid, nor the shape or anything other than the height above it.

Necessary material

- 2L plastic bottle filled with water
- Punch, nail, or fine screwdriver to make the holes
- Tape to cover the holes.
- Tray or tub to collect water
- Funnel (for refilling the bottle)
- (Optional) Irregularly shaped bottle (cone or other shape)
- (Optional) Ruler for measuring the distance jets reach

Procedure

1. With the punch make **3 holes at different heights of the bottle**. Cover the 3 holes with the electrical tape.
2. Fill the bottle **completely with water** and place it on the edge of a table, with the tray underneath.
3. Uncover **the top hole.** Observe the speed and trajectory of the jet. Cover the hole and fill the bottle to repeat with the next hole.
4. Uncover **the hole in the middle.** Compare with the previous one, cover the hole and refill the bottle again.
5. Uncover **the hole below.** Compare with the previous ones, cover the hole and refill the bottle
6. Uncover **all the holes at once** and observe the simultaneous difference between the three jets.
7. *(Optional)* Measure the distance each jet reaches from the base of the bottle

Scientific explanation

The pressure exerted by a fluid at a point **depends on the height of the fluid above that point**. This comes directly from the definition of pressure in experiment 1; The important thing is to have **the largest amount of liquid on top of a certain surface** or, in other words, the height of the water column above it. That's why it doesn't matter what the shape of the bottle is: the only important thing is **the height of the water column** above the hole.

The deeper the hole, the deeper the hole, **more water above it**, and therefore more pressure. As the pressure is stronger, **the water comes out with more force**, with more speed. The jet from below comes out with more force and reaches a greater distance than the jet from above.

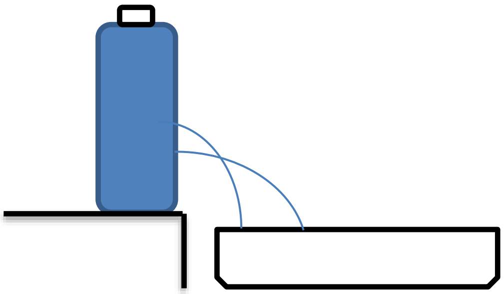

Image 1: Outline of the experiment. The trajectories are illustrative.

Tips for dynamization

Before making the holes, ask the students which way they think the water will come out with more force. Most will get it right, but it's helpful to ask them to explain why before you see the result.

The variant with irregularly shaped bottle is particularly useful to reinforce that the pressure does not depend on the shape of the container or the volume, only on the height.

Security

Use the punch carefully and, depending on the age of the students, only the teacher should do them. Use the tray (or do it outside) to prevent water from falling on the floor and avoid possible slipping.

Experiment 12 - Bernoulli's Principle

Topic: Pressure in Moving Fluids

Approximate duration: 15-20 minutes

Didactic objective

This experiment introduces Bernoulli's principle through two very simple demonstrations with paper and the breath itself. The result is counterintuitive in both cases: blowing between two pieces of paper brings them closer together instead of separating them and blowing on a piece of paper lifts it instead of knocking it over.

Necessary material

- 2 sheets of DIN-A4 paper per student
- Scissors

Procedure

Demonstration 1: The Two Roles

1. Hold **a sheet of DIN-A4 paper in each hand**, vertically and parallelly, about 20 cm apart.
2. Blow forcefully and **continuously** through the space between the two papers.
3. Notice that the papers **are moving closer towards the air current** instead of separating.

Demo 2: The Strip of Paper

4. Cut out a strip of paper **about 5 cm** wide and the length of a DIN-A4.
5. Hold the strip **by one end with two fingers**, so that it hangs freely down in front of the mouth.
6. Blow in a straight line, parallel to the top face of the strip (not downwards). Note that **The strip lifts up towards the puff** instead of falling.

Image 1: Example of conducting the experiment

Scientific explanation

Bernoulli's principle says that when a fluid is in motion, it will have **less pressure the faster it goes.** That is, the faster the air moves (for example), the **less pressure it has in that area.**

In the first demonstration, blowing between the two papers creates **a rapid air current in that area**, which **reduces the pressure between the papers**. Outside this current, where the air is still, the pressure is the atmospheric pressure and is **greater than the pressure inside the current**. Therefore, atmospheric pressure **pushes the papers inwards**, where the pressure is lower.

In the second demonstration something very similar happens. Blowing over the paper creates **a stream of air with a lower pressure than atmospheric** and the pressure under the paper remains the atmospheric pressure, which is larger. Therefore**, atmospheric pressure pushes the paper upwards**, where the air stream is with a lower pressure.

Bernoulli's principle is often mentioned as an explanation for why airplanes fly: the profile of the wing (more curved at the top than at the bottom) causes air to circulate faster through the top, creating an area of lower pressure that generates lift. This explanation is correct but incomplete, since the lift of a real plane depends mainly on Newton's 3rd Law (by pushing air down with the wings, a reaction is created in the opposite direction, upwards, lifting the plane).

Tips for dynamization

Do the experiment in a participatory way, with all the students blowing at the same time. The surprise is collective and the subsequent discussion is richer.

Before blowing, ask students what they expect to happen. Almost everyone will predict that the roles will separate, making the experiment more effective.

Security

The experiment does not present any risk.

EXTRA Experiment - Pascal's Barrel

Concept: Hydrostatic Pressure

Approximate duration: 45-60 minutes

WARNING: This experiment is listed as EXTRA because it presents significant technical and logistical difficulties. Read the preliminary considerations section carefully before trying.

Didactic objective

Pascal's barrel is one of the most spectacular experiments in the history of physics: a column of water just a few centimeters in diameter, raised to a sufficient height, generates the pressure necessary to burst a test tube. It impressively demonstrates that hydrostatic pressure depends exclusively on the height of the fluid column, not its total volume, so a relatively small amount of liquid can exert much more force than it appears.

Preliminary considerations: technical difficulties

- **Minimum height required:** at least **10 meters of water column** are needed to generate 1 atm of additional pressure In practice, to ensure that the test tube bursts, it is advisable to have **12-15 meters**. This implies access to a 3rd or 4th floor of the building.

- **Air bubbles in the tube:** the biggest technical problem. Air bubbles trapped in the tube disrupt the continuous column of water and **drastically reduce the transmitted pressure**. It can be minimized by filling the tube very slowly and using a syringe to expel the bubbles.

- **Tube diameter:** it should be large enough to **avoid capillary effects** (which retain water in very thin tubes) but not so large that it requires too much water. A useful radius of 5-10 mm is recommended.

- **Test tube strength:** it is necessary to know the breaking pressure of the material. For borosilicate 3.3 glass (standard) with walls 1.5 mm thick and radius 2 cm, **the approximate burst pressure is 1 atm**, which matches the pressure generated by 10 meters of water column. It is recommended to use plastic tube instead of glass for the long tube, reserving **the glass only for the test tube** that you want to burst.

Necessary material

- Access at a height of **12-15 meters** (3rd or 4th floor of the building)
- Long tube **(10-15 meters)** made of transparent plastic with **a useful radius of 5-10 mm**
- Borosilicate glass **test tube** with cork stopper
- Tupperware or **protective box** to house the test tube
- **Funnel** to fill the tube from above
- **Syringe** to remove air bubbles from the tube
- Insulating tape to **join and seal** the sections
- Common water
- Protective glasses
- Blue dye *(optional, to increase the visual effect)*

Procedure

1. **Prepare the test tube:** make a hole in the cork and insert the end of the long tube. Seal it with silicone or electrical tape so that there are no leaks.
2. Place the test tube **inside the protective tupperware**, with the long tube coming out of a hole in the lid. Close the tupperware.
3. With the help of several people, **extend the long tube** from the tupperware on the ground floor to the upper floor (12-15 meters high). Secure the pipe to the railing or wall so that it does not fall.
4. **Place the funnel** at the top end of the tube.
5. Fill the tube **slowly** with coloured water, checking that no bubbles form. If they appear, **use the syringe to expel them** before continuing.
6. Continue filling until the critical height (~10 meters of column) is reached. Observe the moment when **the test tube bursts** inside the tupperware.

Scientific explanation

The hydrostatic pressure at a point in a fluid **depends solely on the height** of the fluid above it. We saw this in experiment 11, but here we witness an **even more direct and visual application** than that of that experiment.

This pressure **acts on the base of the test tube** regardless of the diameter of the long tube. A 5 mm diameter tube and a 50 cm diameter tube, both with 10 meters of water column, exert **exactly the same pressure at their base.** Although in the first case there is much less water (the total weight is much lower), the pressure (force per unit area) is exactly the same as in the second case.

This result is what makes the experiment so surprising: **a minimal amount of water** (the amount that fits in a thin 10-meter tube) is capable of bursting a much more robust container, **just because of the height of the column.**

Tips for dynamization

The key question before the experiment is: How much volume of water do you think it takes to burst the test tube? When the students verify that the water contained in a thin tube of 10 meters (less than a few liters in many cases) is enough, the impact is maximum.

Security

This is the most safety-demanding experiment in the pressure series:

- The glass test tube bursts with fragments. The protective tupperware is essential, not optional.
- Everyone present must wear protective glasses during filling and the critical moment.
- Make sure that no one is under the long tube during filling: if a joint is disconnected, water falls from a considerable height.
- The long tube must be securely attached to the building structure so that it does not fall.