In the first experiment a water column is held by atmospheric pressure alone. The pressure of the water column is calculated with the formula for the hydrostatic pressure.
In the second experiment the atmospheric pressure is determined using a vacuum. The pressure needed to maintain the vacuum corresponds to the atmospheric pressure.
By comparing the hydrostatic pressure of the water column from the first experiment with the atmospheric pressure from the second experiment the difference in size becomes clear and therefore also quantitatively displayed why the first experiment works.

Material

	Experiment without board	P1423701
(1)	Fishing line, l. 0.2 m of which	02090.00
2	Gas syringe, with cock, 100 ml	02616.00
1	Plunger plate for gas syringes	02618.00
1	Microspoon, steel	33393.00
1	Glass beaker DURAN®, short, 600 ml	36015.00
1	Tray (PP), 180 x 240 mm, white	47481.00
1	Patent blue V, 25 g	48376.04
1	Vernier caliper	03010.00
1	Spring balance 100,0 N	03060.04
	sheet of paper	
	Motor oil	

	Experiment on the board	P1423702
1	Demo physics board with stand	02150.00
2	Clamp on fixing magnet	02151.01
1	Support rod “PASS”, l = 250 mm	02025.55
1	Universal clamp	37715.00
(1)	Fishing line, l. 1.3 m of which	02090.00
2	Gas syringe, with cock, 100 ml	02616.00
1	Plunger plate for gas syringes	02618.00
1	Microspoon, steel	33393.00
1	Glass beaker DURAN®, short, 600 ml	36015.00
1	Rubber tubing, vacuum, i.d = 6 mm	39286.00
2	Hose clamp for 5-12 mm diameter	40999.00
1	Tray (PP), 180 x 240 mm, white	47481.00
1	Patent blue V, 25 g	48376.04
1	Vernier caliper	03010.00
1	Spring balance 100,0 N	03060.04
1	Diaphragm pump, two stage, 220V	08163.93
	sheet of paper	
	Motor oil	

Fig. 1 shows the first experiment. Fig. 2 shows the second experiment.
This experiment can also be carried out on the board (Fig. 4). The fastening of the spring balance and the syringe onto the board can be seen in Fig. 3 and Fig. 5. The experiment without the board is described here (Fig. 2).

Fig. 1

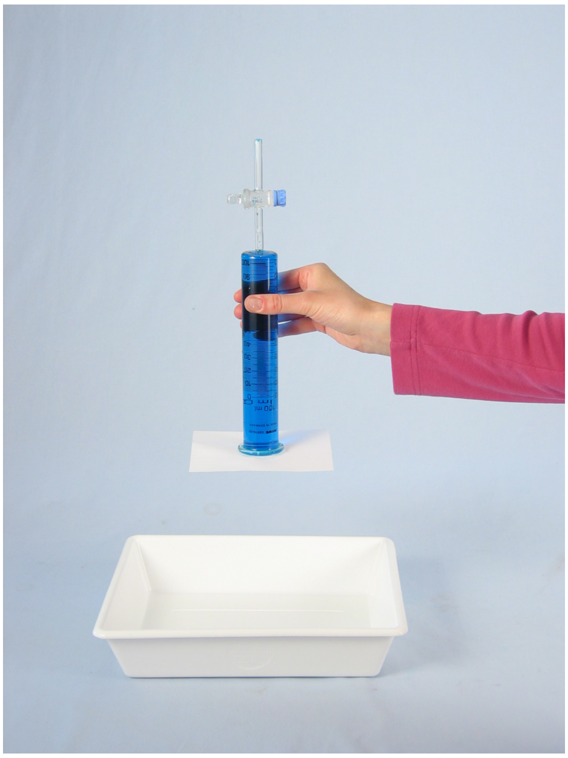

Fig. 2

Fig. 3

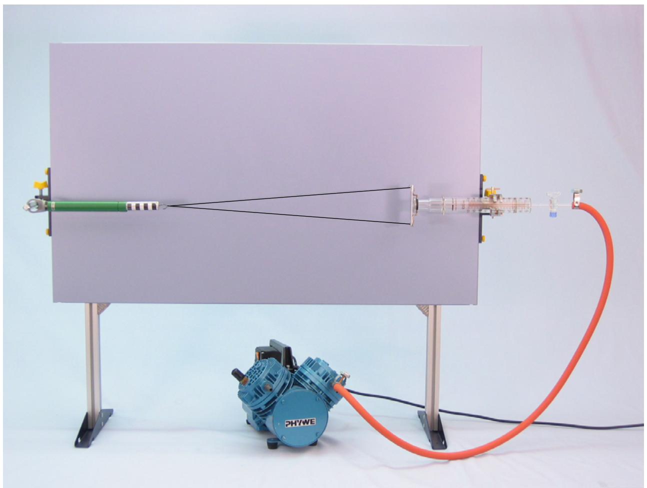

Fig. 4

Fig. 5

Setup and implementation

Experiment 1

- Use a small amount of patent blue (approx. a microspoon tip) to dye the water in the glass beaker
- Close the cock of the syringe, fill the syringe up to the rim completely with water
- Place a fourth of the sheet of paper onto the syringe and press slightly
- Turn the syringe over and turn it in any position without touching the paper, observe the water and paper (Fig. 1)
- Open the cock, observe the water and paper
- Repeat the experiment, this time fill the syringe only half way full with water

Setup

Experiment 2

- For improved sealing of the surface of the syringe glass plunger oil down completely with a small amount of motor oil, use a second syringe since the oil and water should not come into contact with each other
- Distribute the oil film evenly by moving the glass plunger back and forth in the syringe.
- Tie a piece of fishing line (approx. 20 cm) with both ends on two diagonally positioned notches of the plunger plate with very tight knots (several on top of each other)
- Fasten the plunger plate onto the gas syringe, close the mounting bracket and move so that they are pressing onto the plate

Remarks

The oiled syringe does not have to be cleaned immediately. It can be kept for several months.

Implementation

Experiment 2

- Pull the glass plunger with the cock opened once completely out of the syringe and then push it completely back into the syringe again
- Close the cock
- Hang the 100 N spring balance in the line
- Pull the glass plunger speedy as far as possible out (if possible to the 100 ml marking) (Fig. 2)
- Immediately read the force measured on the spring balance
- Open the cock, pull out the glass plunger and measure the diameter of the glass plunger with the vernier caliper

Careful!

There is a risk of injury through glass splinter, if the line tears or a knot loosens during the experiment. For this reason, do not bring the syringe near your face when carrying out the experiment and do not hold it in the direction of people.

Observation and measurement results

Experiment 1

The syringe can be turned in any direction without that the paper falls down or the water runs out.
If the cock is opened the paper falls down and the water runs out.
The paper also falls down if the syringe is not completely filled with water.

Experiment 2

With the cock open, the glass plunger can be pulled out of the syringe without any effort. If the cock is closed, however, much effort is needed to pull the glass plunger out of the syringe.
The force needed to pull the syringe out is:

$$F = 75\ \text{N}$$

The diameter of the syringe glass plunger is:

$$d = 3.1\ \text{cm}$$

Evaluation

Experiment 1

The weight force of the water is exerted on the paper which creates a pressure that pushes downward. At the same time the air exerts pressure upward. The atmospheric pressure is greater than the pressure of the water. The paper is pressed onto the syringe and closes it so that the water does not flow out.
Even if the syringe is held in another direction no water flows out. The atmospheric pressure acts in all directions.

Remarks: Without paper the water would flow out of the syringe when turned. The water forms single drops between which air moves.

If the cock is opened the outer atmospheric pressure also exerts pressure downward on the paper piece. Both together are larger than the atmospheric pressure which exerts pressure on the paper from below.
The paper also falls down if the syringe is not completely filled with water. The enclosed air that is located above the water in the upside down syringe exerts the same pressure as the outer air. The inner air pressure and the pressure of the water act on the paper. Both together are greater than the outer atmospheric pressure.

The hydrostatic pressure of a liquid depends on the density p of the liquid, the gravitational acceleration g and the depth h:

$$p_{Water} = \rho \cdot g \cdot h$$

The hydrostatic pressure on the base of the syringe filled with water is:

$$p_{\text{Water}} = 1000 \frac{\text{kg}}{\text{m}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \cdot 0.2\ \text{m} = 1962 \frac{\text{N}}{\text{m}^2} = 19.62\ \text{hPa}$$

with: p =1 g/cm³ = 1000 kg/m³, length of the syringe h = 0.2 m, g = 9.81 m/s²

Conversion of the units:

$$1\ \text{Pa} = 1\ \text{N/m}^2$$

$$1\ \text{hPa} = 100\ \text{Pa}$$

Experiment 2:
With the cock open air can flow in when the glass plunger is pulled out. This is the reason why almost no effort is needed.
When the cock is closed no air can flow back in. A vacuum is created in the syringe and the air outside of the syringe presses the glass plunger inward. The outer atmospheric pressure exerts force on the glass plunger.
In order to pull out the glass plunger or to keep it in a balanced position counter force must be exerted which is as large as the force F that the atmospheric pressure exerts. The atmospheric pressure is:

$$p_{Air} = \frac{F}{A}$$

The area A is the cross section area of the glass plunger, since this limits the volume that is enlarged. The plate is only used to fasten the string.

Glass plunger area:

$$A = \pi \cdot r^2 = \pi \cdot (1.55\ \text{cm})^2 = 7.55\ \text{cm}^2 = 7.55 \cdot 10^{-4}\ \text{m}^2$$

$$p_{Air} = \frac{75\ \text{N}}{7.55 \cdot 10^{-4}\ \text{m}^2} = 9.93 \cdot 10^4 \frac{\text{N}}{\text{m}^2} = 9.93 \cdot 10^4\ \text{Pa} = 993\ \text{hPa} \approx 1000\ \text{hPa}$$

By comparing p_{Water} und p_{Air} the great difference in pressure becomes clear. This also quantitatively shows why the first experiment works so well.
The atmospheric pressure is created like the water pressure by weight force. The air layer above the Earth is several kilometers thick and presses on the air located further below. We normally do not feel the atmospheric pressure, because our bodies have adapted to it. The air column above the Earth's surface exerts pressure that amounts to approx. 1,000 hPa at sea level. This pressure corresponds to the pressure that is created by a 10m-high water column:

$$p_{Water} = \rho \cdot g \cdot h$$

$$h = \frac{p_{\text{Water}}}{\rho \cdot g} = 10.19\ \text{m} \approx 10\ \text{m}$$

with: p_{Water} = 1000 hPa, ρ =1g/cm³ = 1000 kg/m³, g = 9.81 m/s²

The first experiment would even work with a 10m-long syringe.

Remarks

1. The first experiment can also be effectively carried out with an ungraduated cylinder (34220.00).

2. Regarding Experiment 2: At the beginning of the experiment there is still a small amount of residual air in the attachment piece to the cock. The glass plunger should therefore be pulled as far as possible out of the syringe. The greater the volume of the vacuum, the smaller the particles per volume unit are located in there and the more exact the atmospheric pressure can be measured.
   The glass plunger can be pulled completely out of the syringe under vacuum also by hand with force. The air flowing in creates a loud noise.

3. A water column can be principally used to measure the atmospheric pressure since the height of the maximum water column is a measure for the atmospheric pressure. In the empty space above the water there is a vacuum which however also consists of steam to a lesser extent. This is a liquid barometer. The mercury barometer works according to the same principle. Here mercury is used, however, that under normal conditions reaches a height of only 760 mm and which hardly dissipates.

4. The atmospheric pressure decreases with increasing altitude and is also dependent on the temperature and the weather in addition to the altitude.

5. The SI base unit for pressure is the unit Pascal.

   $$1\ \text{Pa} = 1\ \text{N/m}^2 = 1\ \text{kg/}(\text{s}^2 \cdot \text{m})$$

   In radio or on TV the atmospheric pressure values are always indicated in hPa

Room for notes