Water waves and fountains

There are some simple experiments that you can try at home with water that can be quite surprising.

Experiment 1: The magic fountain

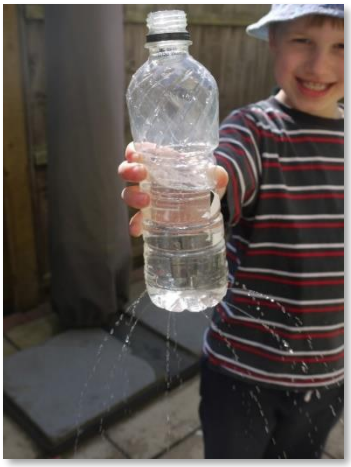
For this experiment you need:

- A plastic water bottle with lid
- A pin
- Water from the tap

Using the pin, make several small holes in the base of the bottle. Now fill the bottle with water. Not surprisingly, water pours out of the bottle through the small holes.

But now screw the lid onto the bottle tightly. What do you see?

The water now stops flowing out of the bottle. Can you explain why?

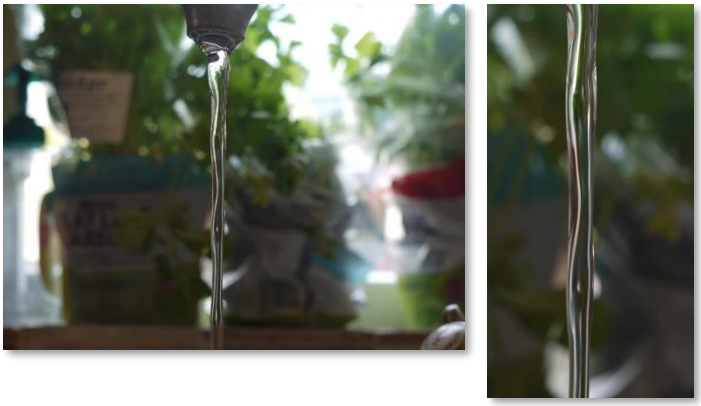


Experiment 2: Wavy water

All you need for this experiment is a kitchen or bathroom tap.

First fully open the tap, then gradually close the tap till you get a thin smooth flow of water from the tap. Now place your finger in the water and slowly move your finger upwards towards the tap. When your finger is around 3 centimetres away from the tap, you should see a stripy pattern in the water flow. The stripy pattern is caused by ripples (or waves) on the surface of the water.

Now open the tap to increase the water flow a little bit. You will no longer see the stripy pattern. Instead you might see a much longer wavy pattern



What do you think causes these wavy patterns?

Answers and follow-on experiments

Experiment 1

When the bottle is open, the air pressure in the bottle is the same as the surrounding air (atmospheric air pressure).

The water flows out of the bottle because gravity pulls on the water and there is no pressure difference between the air in the bottle and the atmospheric air.

When the bottle lid is tightly screwed on, the pressure of the air in the bottle reduces. The pressure difference between the atmospheric air pressure and the air pressure in the bottle is enough to keep the water in the bottle.

You might ask, why does the air pressure in the bottle decrease when the lid is screwed on? And why does this balance the effects of gravity?

A small amount of water leaks from the bottle while you screw on the bottle lid. This means the air in the bottle has to expand to fill the space left by the escaping water.

The expansion of the air in the bottle causes the pressure to drop. The effect of pressure dropping when air expands is sometimes known as Boyle's Law.

When the leaking water stops, the pressure difference between the air in the bottle and the air in the atmosphere, balances the effect of gravity. There is also an effect called 'surface tension' which prevents air entering the hole, which is why the hole must be small. Surface tension effects are explored in Experiment 2.

Follow-on experiments:

- What happens if you squeeze the bottle?
- What happens if you place holes closer to the top of the bottle?
- What happens if the holes are made large?

Experiment 2

These are types of water waves caused by a special property of liquids called 'surface tension' (sometimes called capillary waves). The surface molecules at the surface of the water are attracted inwardly into the water and along the surface. This force of attraction is due to the absence of strong intermolecular forces on the air-side of the surface. This gives rise to an inward force on the surface molecules.

This is similar to the surface of a balloon. When a balloon is inflated, the surface of the balloon is stretched (under 'tension'). The tension force acts inwardly, and is balanced by the air pressure in the balloon. If the forces are not balanced, the balloon will either inflate (when the pressure force is larger than the tension force) or deflate (when the pressure force is less than the tension force).

For water, the surface tension is also balanced by the pressure inside the water. The tension force depends on how smooth the surface is.

Waves form when the pressure force in the liquid and the surface tension force become unbalanced. This happens if there is a disturbance to the water surface, for instance when putting your finger in the water flow.

The shape of the outlet of the tap will tend to give rise to longer waves, especially if it is not perfectly circular. You can also obstruct the flow from the tap with your finger to see this effect.

Surface tension waves are what cause the water flow to form droplets, when the water flow is small.

Follow-on experiments:

- What happens if you put a spoon in the water flow? Try putting the spoon bowl down and bowl up- does the pattern change?
- Try different shapes of flat and curved surfaces, and observe the strange patterns which are formed. How do the patterns change when the flow is small and large?

An article which may be of interest for physics teachers can be found here: https://iopscience.iop.org/article/10.1088/0031-9120/47/4/403/pdf