Bending water

Note: This task is designed so that it can be solved with the incremental hints.
The hints are available on the media portal for printing, or the students can use them online on a tablet or smartphone via the QR code included on the worksheet.
The worksheet for the students and the hints for printing are available as separate files on the media portal of the Siemens Stiftung. General information on using tasks with incremental hints in the classroom is provided in the “Tasks with incremental hints – an introduction” document, which is also available on the media portal.

1 Topical aspects

The task addresses the dipole properties of water. Basic ideas on particles with a dipole nature should be used in the explanation of the “Bending a stream of water in an electrostatic field” experiment.

2 Learning prerequisites and level of difficulty

In order to complete the task, the students must have prior knowledge in the following areas:
Electrostatics: attraction and repulsion in the context of electrostatic fields; contingency of the involved forces on the distance (and on the strength of the charge); charge separation due to friction.
Atomic structure of matter: smallest particles/molecules can simultaneously possess opposite charge centers and be electrically neutral overall. They thus have dipole properties.
The level of difficulty of the task is medium to high, depending on the extent of the students’ prior knowledge.

3 Background on the task

Water is one of the basic elements for life on Earth. Not only is it the basis of development of the simplest life-forms, but it also plays a key role in nearly all physiological processes in highly developed life-forms – plants, animals, and people. It serves as a means to transport dissolved substances, is itself a metabolite, and supports numerous biological functions such as thermoregulation.
For most of these functions, the special properties of water are extremely important. Its dipole properties are the reason why, for example, its freezing and boiling points are so high (compared with chemically similar substances) that the heat of fusion and heat of evaporation are likewise considerably higher. The dipole properties are also the reason why water is such an excellent solvent. Thanks to water’s dipole nature, the molecules can arrange themselves around charged particles, for example, around the sodium and chloride ions in table salt. Water quickly dissolves many salts in this manner, and also electrically neutral substances like sugar that likewise have charge concentrations within the molecule. The behavior is similar with regard to water’s ability to mix with simple alcohols. The melting and boiling points form a temperature interval within which favorable conditions prevail for the existence and interaction of amino acids. That’s why astronomers are searching primarily for the presence of water when it comes to discovering planets that could possibly support life-forms.
Even if this scope of aspects cannot be fully addressed with the students from the beginning, knowledge related to water’s dipole properties and an elementary understanding of the associated mechanisms form a solid basis for being able to properly interpret additional elements of meaning at a later time.

In this elementary interpretation of the deflected stream of water, we intentionally omit the atomic chemical structure of water, namely the spatial arrangement of the hydrogen and oxygen atoms in the molecule; instead, the experimental phenomenon is interpreted at the simplest possible level of a particle with oppositely charged ends.

4 The task

In the simplest form, the task can be formulated as follows:

> Using your prior knowledge, find out what forces are at work and how the deflection ultimately comes about.

Instead of drawing on a life-world context, the task is related to the previously conducted experiment. The teacher can demonstrate the experiment, and then the students can work on the task in small groups. In addition to an easy-to-adjust tap, only a plastic object (ruler, piece of PE tubing, large comb) and a wool cloth are needed. Safety measures are not necessary.

The objective of this task is to apply a simple model for the interaction of particles with a dipole nature in an electric field to the phenomenon and to find a reason for the force that deflects the stream of water from its vertical path.

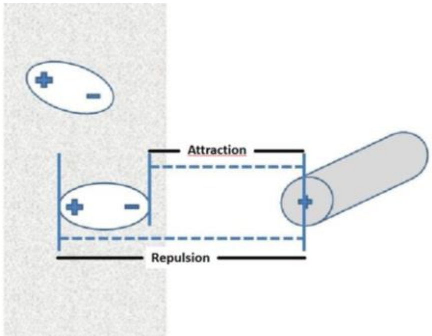
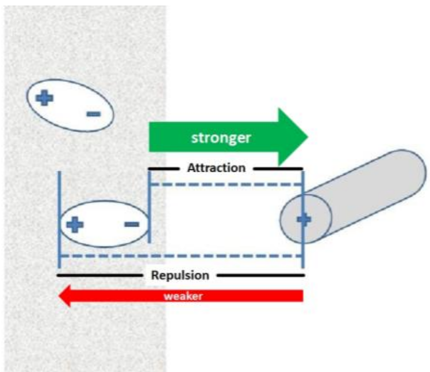
5 Variations

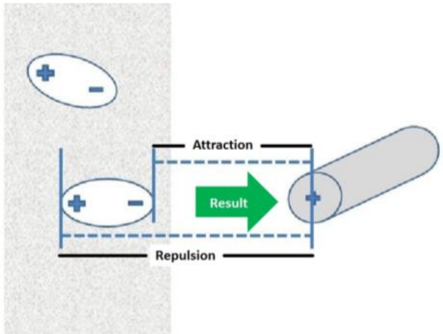
Depending on the learning group, the number of hints can be decreased or increased. Other forms can also be used in the model in grades that have already worked out the molecular structure of water.

6 Overview of the hints

Note: The hints have been prepared as a separate file for printing or can be used online via the QR codes on the worksheet. A video showing how the experiment is conducted is available on the media portal. The video is already included in the online hints.

Hint 1 Explain the task to each other again in your own words. State what you understood the task to be and what is still unclear to you.	**Answer 1** We're supposed to find out where the force that deflects the stream of water comes from and how it works.
Hint 2 The starting point for the deflection is the rubbed plastic ruler. Recall what you have learned about this in physics class.	**Answer 2** When you rub a plastic object with a cloth, charge separation occurs. The electrostatically charged ruler generates an electric field around itself.
Hint 3 You've already learned that water molecules have dipolar properties. What's the first thing that happens when a dipole enters an electric field?	**Answer 3** An electric dipole aligns itself within a field so that the opposite charge lies closer to the center of charge. Not all water molecules are aligned in this way, but a large percentage are.

Hint 4 Think about what forces occur between the aligned dipoles and the rubbed ruler. Make a sketch and assume that the ruler is positively charged.	**Answer 4** There are two forces between the electrostatically charged ruler and the water dipoles: ▪ attraction (opposite charges) and ▪ repulsion (like charges). 
Hint 5 If both attractive and repelling forces are at work between the ruler and the water molecules, how is it that the water is deflected? Recall what you know about forces between different charges and what they are contingent on!	**Answer 5** Deflection can occur only if the attractive forces are greater than the repelling forces. The negative end of the dipole is a little farther away from the negatively charged ruler than is the positive end. ▪ The shorter the distance between two charges, the stronger the acting force. ▪ The longer the distance, the weaker the acting force. This applies equally to attractive and repelling forces. 

Hint 6 Now you have all the information you need and you can answer the question of why the stream of water is deflected. Explain your answer using the sketch.	**Answer 6** The positively charged ruler generates an electric field. Some of the water dipoles align themselves in this field. The negatively charged ends are closer to the positively charged ruler than are the positively charged ends, and the forces between the charges become stronger as the distance decreases. The result: The attraction outweighs the repulsion and the stream of water is deflected toward the ruler.  (You can watch the experiment in the video named "Bending water.")

