Task of 20th IYPT – example 1

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Razor blade

A razor blade is placed gently on a water surface. A charged body brought near the razor makes it move away. Describe the motion of the razor if an external electric field is applied.

Observation

We gave and electric charge to the razor blade by the van der Graaf generator and also by the well known method of ebonite stick and the fox tail. After the approximation of the charged body to the razor blade we observed a very strong repulsion.

The observation was not carried out only with a razor blade, but also with another objects – conductors and dielectrics. We changed also a liquid; in the place of water was e.g. oil. We investigated the movement of the razor blade on the water in dependence on the temperature of the water.

The results are bewildering. At first we made a theoretic analysis of the observed phenomenon. We were not able to understand and accept the fact, that "uncharged" razor blade is repulsed by the negative charged ebonite stick. On the basis of the propositions, which we learned in the physics lessons on the grammar school we speculated, the razor blade (or another object) must be attracted to the applied charge. We carried out an easy experiment. We placed a small coin on its edge and it begins to roll or fall down with the direction to applied charge. We can suspect now, that the major role must play the liquid, on which the razor blade is placed.

Now I write some another observed phenomena. A few of more important will be explained in this article.

1. It is possible to observe the bulge on the surface near the charge. It is caused by electric force.
2. On the longer sides we observed a flexure of the surface due to surface tension.
3. The velocity of the razor blade's motion depends on the water's temperature. The temperature increase causes reduction of razor blade's motion. Surface tension is strongly dependent on the temperature. Generally surface tension decreases with increasing temperature.
4. Razor blade placed on the oil is repulsed by applied charge.

5. Polystyrene marbles are either repulsed, or repelled!
6. The razor blade is faster on the salted water.
7. A small coin moves faster than razor blade.

Bulge on the surface

An electric force, which repulses the water surface to the charge, gravity and surface tension, is applied on the water surface. In the moment, when there is equilibrium in the system, a curvature with the direction to the charge is observed on the surface. A small bulge can be observed in the video stream, there is evidently different refraction compared to the surroundings. Which electric force is applied to the water surface? I try to describe it. I will count with the method of electric mirror. I state some parameter of the electric field at first. The parameter is intensity of electric field.

$$E = \frac{1}{4\pi\varepsilon_0\varepsilon}\left(\frac{Q}{d^2} + \frac{Q}{d^2}\right) = \frac{1}{2\pi\varepsilon_0\varepsilon}\frac{Q}{d^2}$$

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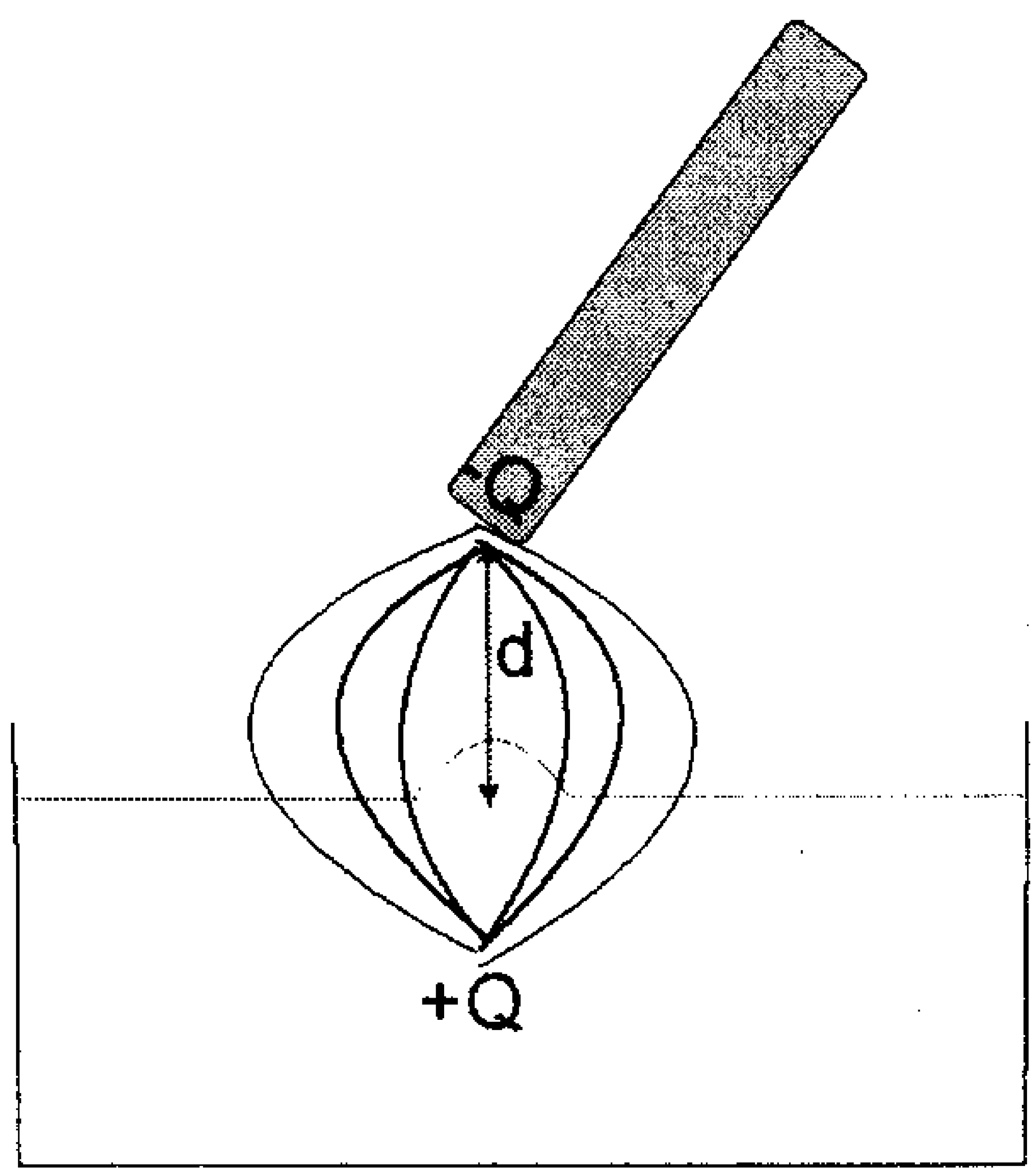
where the charges equals to each other, ε_0 is permittivity of vacuum and ε specific electric inductive capacity of the air. On the unit of the area causes force:



$$p = \frac{F}{S} = \sigma E = \varepsilon_0\varepsilon E^2 = \frac{1}{4\pi^2\varepsilon_0\varepsilon}\frac{Q^2}{d^4} \wedge$$

$$\wedge\, \sigma = \varepsilon_0\varepsilon E$$

σ is density of induced charges. The high of the water bulge can we count easy. We can give our pressure to the equation with and hydrostatic pressure.

$$\rho g h = \frac{1}{4\pi^2\varepsilon_0\varepsilon}\frac{Q^2}{d^4}$$

$$h = \frac{1}{4\pi^2\varepsilon_0\varepsilon}\frac{Q^2}{d^4\rho g}$$

This formula can state the high of our bulge. But we cannot take this formula seriously; we do not count with other parameters, which determinate the phenomenon, e.g. surface tension.

However, we tried to substitute into formula numerical values. We measured or estimated these values very carefully. But we know that the fault is not insignificant.

Estimation of the bulge's high

- $\varepsilon_0 = 8{,}854187.10^{-12}$ F.m^{-1}
- $\varepsilon = 1{,}00054$
- $Q = 10^{-9}$C
- d = 1 cm
- $\rho = 1000$ kg.m^{-3}
- g = 10 m.s^{-2}

According to this equation the bulge's high is about 3.10^{-5} m. But more important is the fact, that each little change of the distance between water surface and applied charge causes a rapid – biquadrate increment of the bulge's high.

$$h \approx \frac{1}{d^4}$$

At first we thought, that inclined plane is the reason of the razor blade's motion. But it is not the main reason. Electric force causes a bulge on the surface. How is it possible?

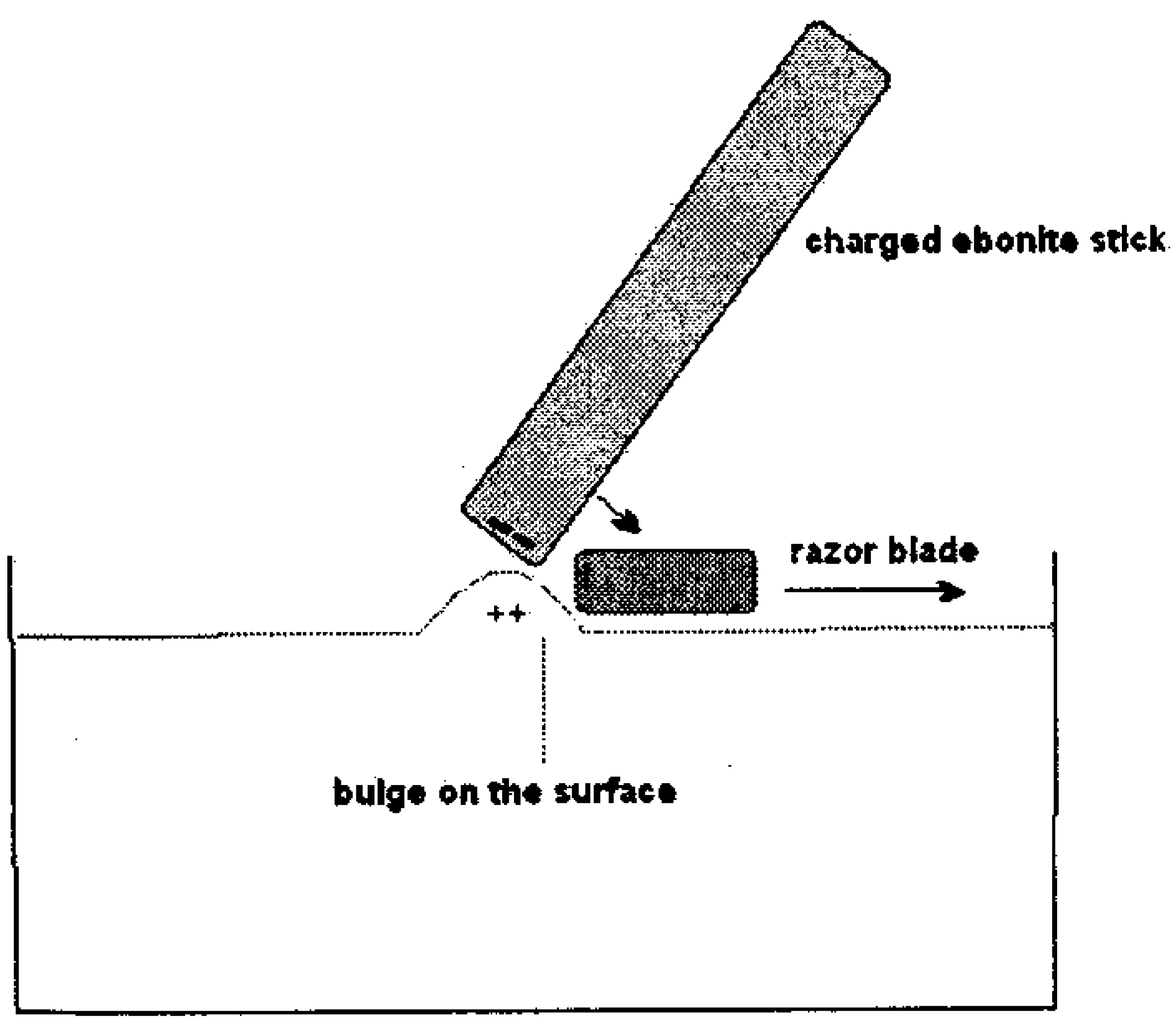
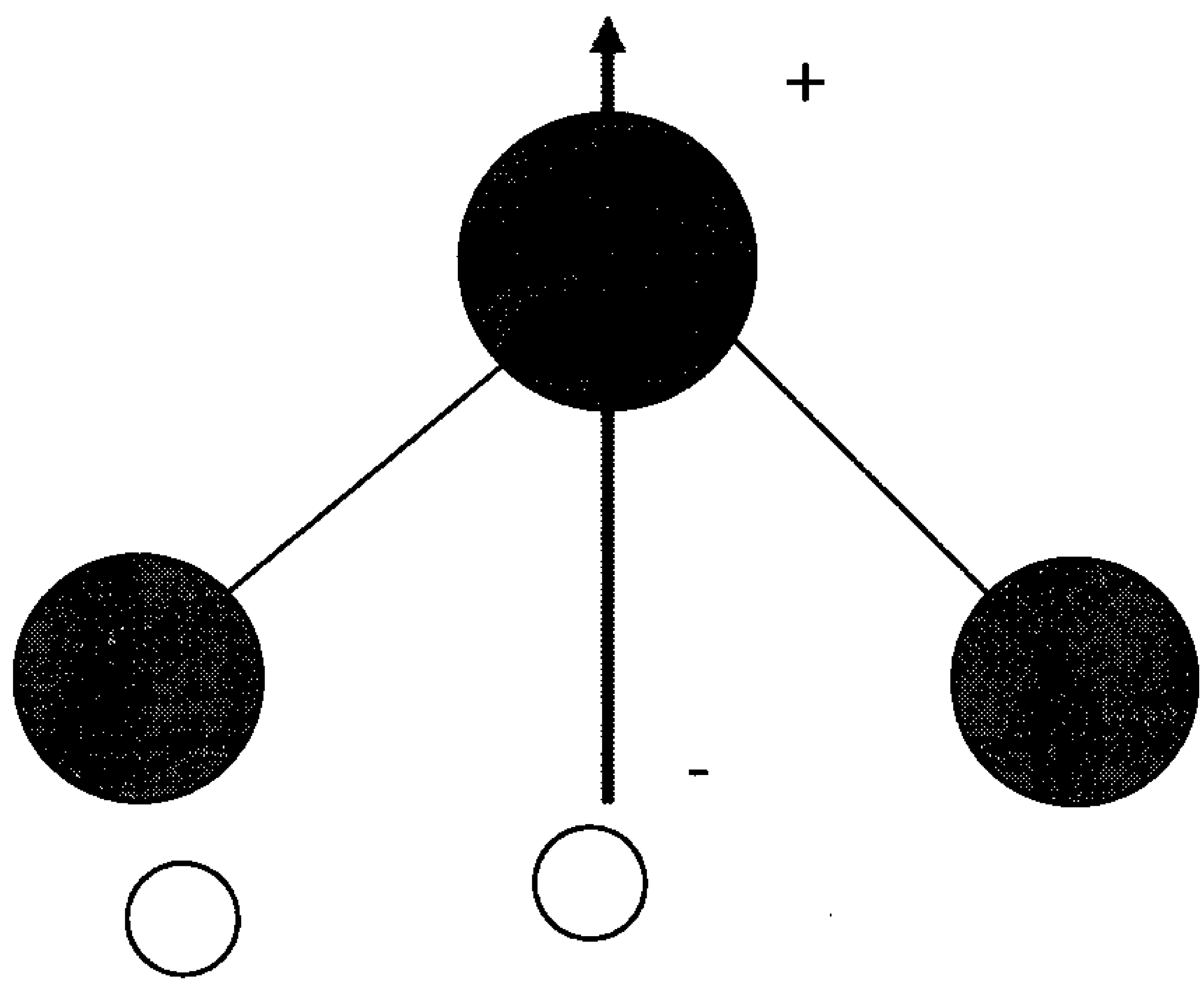


Fig. 1: simple scheme of observed phenomenon – sign of the charge is only an example. If we apply to the system a positive charge, the polarity will be changed, but the result would stay the same.

Electric force causes to the dielectric, dielectric is polarized. Water contains electric dipoles. When the external electric field is applied, the molecules of water order themselves organized, as you can see in the picture. We can also simply state, that when we apply an external negative electric charge, Fig. 1, the water surface behaves like it would be positive charged.

Now we are in the merits of the case. If the surface of the bulge is positive charged, the razor blade has to be charged in the negative charge. The razor blade is a conductor, it means, that the end, which touch the positive charged water surface repulses the free electrons. Electron, the particle with negative charge, are repelled with the applied external negative charge.. We state, that this fact is a main factor and reason of the razor blade's motion in the direction out of the charge.

Note: If the external electric field is positive, a bulge on the surface is charged positive, free electrons move to another end of the razor blade. Razor blade is also repelled by the external electric field.



Some another conclusion from our investigation

- Temperature of the liquid – the razor blade or other object moves faster at the warmer water. The surface tension is dependent on the temperature and decreases with increasing temperature. In general surface tension is the force, which keeps the smallest surface of the liquid. We can understand a surface tension as a resistance force. The smaller surface tension, the faster motion of the object on the water surface. But we have to accept the fact, that surface tension is the force, which holds the object on the surface. When the surface tension is too small, the object sinks.

- Oil – Why is repulsed the razor blade placed on the oil to the applied external electric field? We were very confused by this fact. But the explanation is simple. A molecule of the oil much complicated than the molecule of water. Oil is a liquid, which has molecules, which contain hydrophobic hydrocarbon chain. We cannot suspect the creation of electric dipole. The surface is not charged; the conductor on the surface isn't also charged. We can understand it as an object without any charge and uncharged object is repulsed by applied external electric field.
- Polystyrene marbles – We placed a few polystyrene marbles on the water surface and then applied an external electric field. Observed phenomena shocked us in first moments. Each marble moves to the different way. Some marbles were repulsed, other was repelled. Why? Marbles were charged before dropping in the water.
- Small coin – Small coin behaves like a razor blade, but only with a difference, that small coin moves much faster. We used a small coin in our experiments very oft.