THE DREAM OF TRANSMUTATION OF COMMON MATERIAL TO SILVER: AN EXAMPLE OF AN HANDS-ON-SCIENCE EXPERIMENT

Description

In the sequence of pictures in Fig. 1, you see first a cork stopper (a), which then is held in a flame (b), thus covered with a layer of soot (c) and put under water (d): Surprise! It´s covered all over with a shiny, silvery layer, as if the soot would have changed in to silver. Is this the age-old dream of "transmutation" of common metals into noble ones? Or what could be a scientifically more plausible explanation?

	
Fig. 1a) a cork stopper	b) put in flame
	
c) covered with soot	d) turned to silver??

Explanation

In the following, understanding of the experiment will be addressed by a series of 4 questions (and their answers) through which pupils can proceed by their on inquiry (the degree of classroom guidance can be adapted by giving the questions and related hints more or less explicitly).

1) *What is the reason for the silvery layer?*

It is of course not produced by transmutation, but by an entirely non-mythical, though interesting phenomenon of ordinary ray optics, viz. total internal reflection (TIR). The latter requires light passing through an interface from high to low refractive index, e.g. from water to air. While the silvery shining of the experiment is quite typical for TIR (and thus the latter put forward as key idea by quite a few people with good physics knowledge), the next question is not so obvious:

2) *Where does the necessary interface (high-to-low refractive index) come from?*
Soot is a material of large internal surface, a bit like activated carbon (see Fig. 2). This is a material specially processed to make it very porous, thus obtaining a large internal surface area (up to 1500 m^2/g, see [1.] an). Air can enter into and is absorbed in these pores.

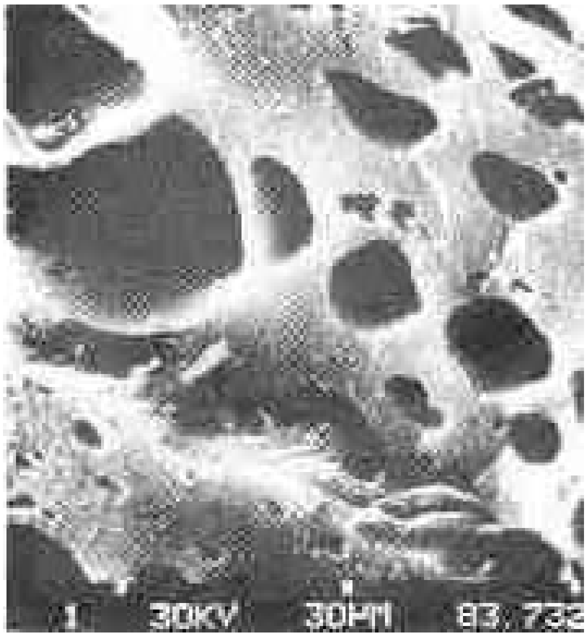	
Fig. 2. Active carbon electron micrograph [2.]	Fig. 3. Water kept outside a „pore“ due to its surface tension

3) *Why does the water not enter the pores (and the air not bubble out)?*
Water is kept outside the pores due to its surface tension, which is (as well-known) large enough to prevent it from entering holes up to some millimeters (see Fig. 3); the pores in soot are orders of magnitude smaller than this.

4) *How could we check our hypothesis?*
If the above reasoning is correct, we must look for a way of lowering surface tension. How to do this, of course, is a child´s play, viz. by adding some dishwashing liquid (for proper mixing, you will have to stir it a bit). Reasoning backwards, with the diminished surface tension, water should enter the pores, air bubble out, and the “silver” should disappear.
Curious, whether this really happens (see Fig. 4)? Try yourself!

Commentary
Physics experts usually quite rapidly put forward the key idea of total internal reflection, but for pupils this is rather not be expected even after classroom treatment of the subject. (The author has used this example for some time in his optics course for teacher education students, and even there suggestion of the idea was rather seldom). Moreover, the whole chain of reasoning is quite a challenge for the majority of pupils.
There are some features which make the experiment possibly interesting for teaching purposes: First, this very circumstance that the explanation of a phenomenon which can be produced and observed with almost extremely simple means in daily life might yet have an explanation far from being that simple: simplicity of observation (and production) does not imply simplicity of explanation. Second, that the explanation of this “simple” phenomenon of ray optics might involve several bits of knowledge from chemistry, again about well-known substances (water, soot, liquid soap) and their well-known and not-so-well-known properties (surface tension and its lowering, and internal surface, respectively): “simple” phenomena of daily life thus might require several sciences for a proper understanding, and insight might

require a broader perspective (this holds true, of course, for many scientific issues in general, and increasingly for the science(s) of today).

Fig. 4: „Re-transmutation“ of the silvery layer?

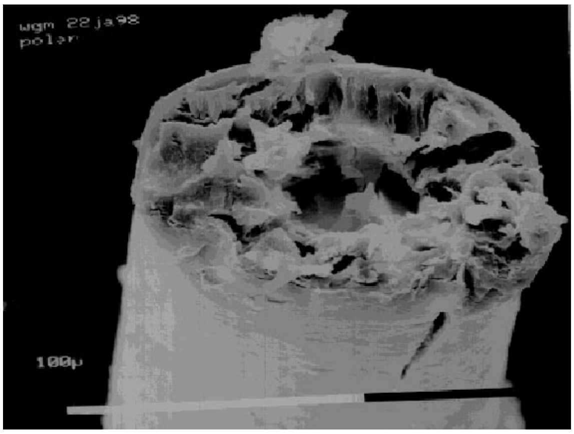

Fig. 5: Hollow, air-filled polar bear hair [5.]

Third, still connected to the “simplicity” of the necessary means: it might invite to use this science activity as a make-at-home experiment, possibly as a homework-experiment, and perhaps even involving families in a sort of mini-research.
Forth, developing the above issue of perspective still further, at least two elements of the story can be put in broader context, either by the teacher, through homework, and in other ways:
(i) For the optics side, there are many well-known cross-links for TIR, as light guiding fibers [3.] and windscreen rain sensors [4.], to mention but a few from physics itself, and from cross-disciplinary areas of course the mirage (or fata morgana, [5.]) and the hollow, air filled hairs of polar bears (see Fig. 5 leading to their white colour (the functioning of these hairs as optical fibres, however, has turned out to be a myth [7.]). (ii) For the chemistry (substance) side, there are interesting cross-links to other consequences of the large surface tension of water (lots of them, see e.g. [8.]) and to the structural and functional properties of soot, from applications of activated charcoal [9.] eventually even leading to current breakthrough developments as Fullerenes and their discovery in soot [10.]].
In sum, the experiment and the series of questions related to it appear as a feasible and motivating example of an inquiry-based learning activity with some additional benefits (possible use as make-at-home experiment, cross-disciplinary links, specific insights in interplay of (deceptive) simplicity and complexity in scientific phenomena).

References

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