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Can Sunlit Leaves With Liquid Drops On Their Surface Be Burnt?

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Abstract

My students learn elementary optics in their 11th school year, including the use of light rays in understanding the effect of focusing. In a problem of one of their physics books the task is to search for the causes why leaves can be burnt in hot summer after being watered. As a solution, the book indicates the convex-lens-like behaviour of water drops focusing sunlight on the leaf surface and thus burning them this way. After reading some publications [1-4] of Gábor Horváth and his colleagues on this topic, listening to his lecture and watching a short film about this subject broadcast by the Hungarian Television [5], I recognised how exciting this issue could be for secondary grammar school students, who could make an experiment with sunlit plant leaves covered by liquid drops. I had a few more ideas with which the problem could be approached and examined from a different physical point of view [6].

Antecedents

Figure 1. Glycerine balls (A-C) and oildrops (D) were used in the experiments

I have read a bipartite article [1, 2] in Fizikai Szemle (Physical Review), the journal of the Hungarian Physical Association, and the relating literature [3, 4], furthermore listened to a short film on this theme broadcast by the Hungarian Television [5]. Then I recognised how exciting it could be to inspire secondary grammar school students to make an experiment with leaves covered with liquid drops and to study whether these leaves are or are not burnt by the focused sunlight. I had a few more ideas with which the problem could be approached and examined from a different point of view [6].

The basic experiment

„It is a widely accepted view in gardening and plant protection that plants mustn't be watered in the blazing sun at noon as the waterdrops sticking to the leaves can burn them by focusing the sunlight on its surface. A similar opinion in dermatology and cosmetics states that the waterdrops sticking to the skin can also mean danger during sunbath as they focus the sunlight on the skin. In forestry literature one can also come along a belief saying that the sunshine focused on the dried plants by the waterdrops can cause forestfire " – you can read it in the article mentioned above.

The details about the waterdrops sitting on the surface of the plants and focusing the sunlight were examined by Gábor Horváth and his colleagues in 2010. The authors made computer models and experiments with the waterdrops sticking to the sunlit leaves. They took photos of waterdrops sitting on the horizontal leaves of different species of plants and they determined their shape. After that they calculated the dispersion of the light-intensity made by the rotation-symmetric waterdrops on the horizontal leaf surface. The result depended on the shape of the drop and the angle of incidence of the sunlight.

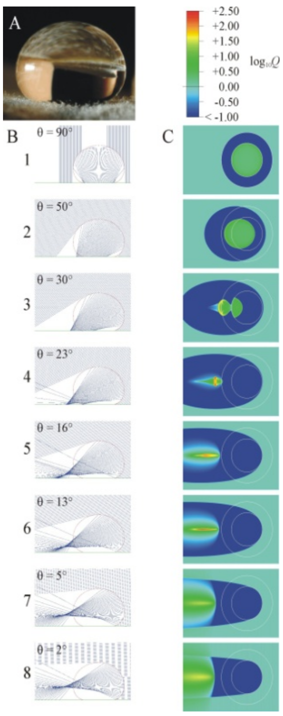

Figure 2. One example from the many simulations. (A) Side-view photograph of a spheroid water drop on a horizontal rowan (Sorbus aucuparia) leaf. (B) Ray tracing through the vertical main cross-section of the water drop (the contour of which is shown by the red curve) versus solar elevation angle θ. (C) Two-dimensional distribution of the light-collecting efficiency Q of the water drop on the leaf. The area where the water drop contacts the leaf is shown by the inner circle, while the contour of the drop as seen from above is indicated by the outer circle. (Figure 4 on page 984 of Egri et al., 2010 [4])

The lesson taught at school

My students learned the basic terms of optics in their 11th form including the image-making and noteworthy beamstream of convex lenses.


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Minden jog fenntartva. A kiadó írásbeli hozzájárulása nélkül sem a teljes mű, sem annak része, sem a feladatok megoldásai semmiféle formában nem sokszorosíthatók, nem terjeszthetők, és elektronikus formában nem tárolhatók.

Figure 3. Students often use the book titled 'Unified collection of tasks for the school-leaving exam' in the lessons and for their homework, too.

The task: 2152: In summer it is not advisable to water the plants at midday because the leaves of the plants get 'burnt'. From the following explanations only one can be accepted. Which is that?

A) The damage to the plants is caused by the steam evaporating from the water.

B) The waterdrops behave as convex lenses and they focus the sunlight on the surface of the leaves.

C) The warmed parts of the plant get cool after the sudden effect of the cold water, which causes the plant to get burnt.

The key of the book chose B) as the correct answer. Together with my students we decided to examine with physical experiments whether the raindrops can really focus the sunlight in such a way that they cause sunburn on the surface of the leaves.

Our ideas and experiments

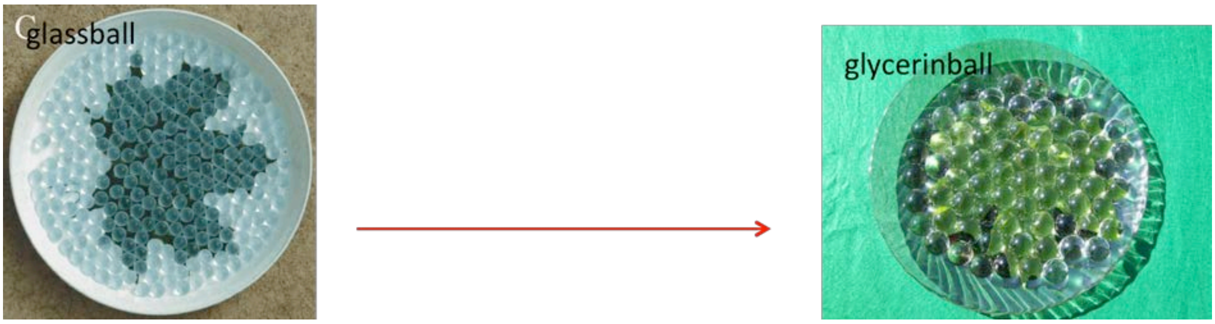


Figure 4. The authors put glassballs on the leaves: instead of the glassballs we used glycerine balls that can be bought at florists' as the refraction index of the glycerine ball soaked in water is closer to that of the water.

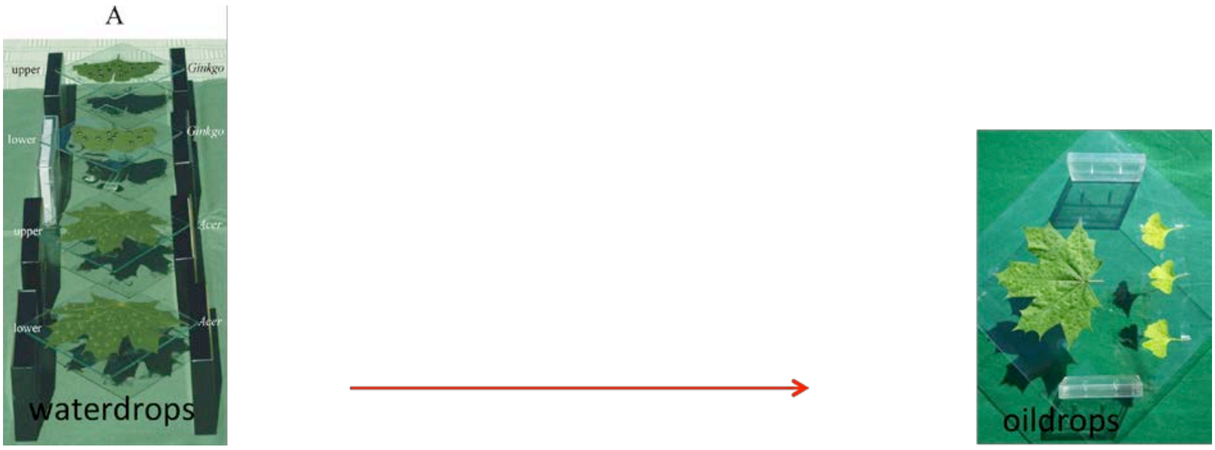


Figure 5. The authors put waterdrops on the leaves but due to the quick evaporation it had to be repeated several times during the experiment. We replaced the waterdrops with oildrops as it can evaporate more slowly than the water.

Fattening the glycerine balls

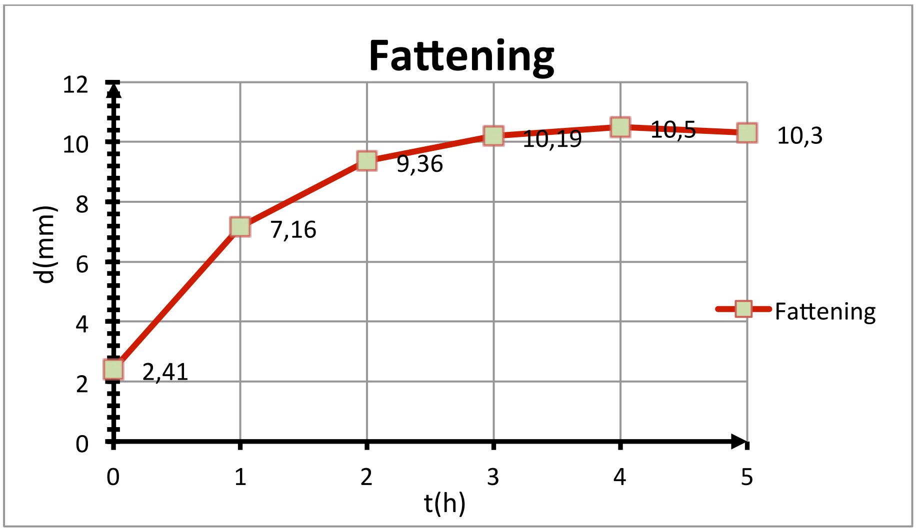


Figure 6. The changes in the size of the glycerine balls put into water in the function of time

The starting volume of the glycerine ball was:

$$V_1 = \frac{4r^3\pi}{3} = \frac{4 \cdot (1{,}205mm)^3\pi}{3} = 7{,}33mm^3$$

And its final volume was:

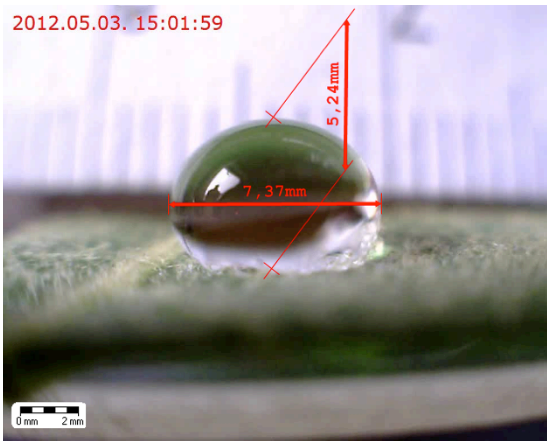
$$V_2 = \frac{4R^3\pi}{3} = \frac{4 \cdot (5{,}15mm)^3\pi}{3} = 572{,}15mm^3$$

It can be stated that at the end of soaking 98,72% of the glycerine ball there was water. Such a ball put in water becomes almost invisible because its refractive index is very close to that of the water. So with the glycerine balls the waterdrops can be modelled well. The volume reduction of the glycerine ball in the air is not significant within 6 hours, whereas the same size waterdrop - depending on the temperature and the strength of the sunshine - evaporates in 25 minutes.

Average evaporation time (min)	in shade	in sunlight
Acer platanoides	192	24
Ginkgo biloba	172	23

Table 1. Evaporation time of waterdrops on leaves in shade and in sunlight

In our experiments the evaporation time of the waterdrops put on leaves in the shade and in sunlight were compared.



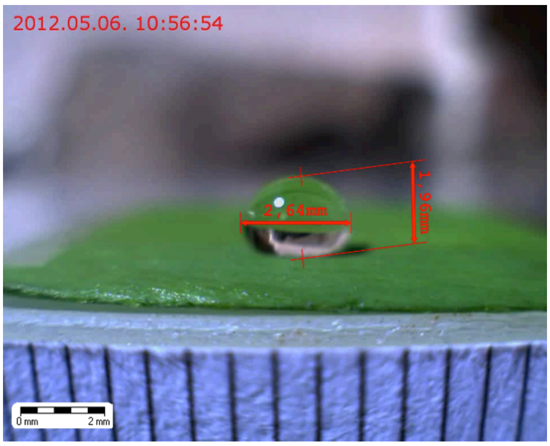
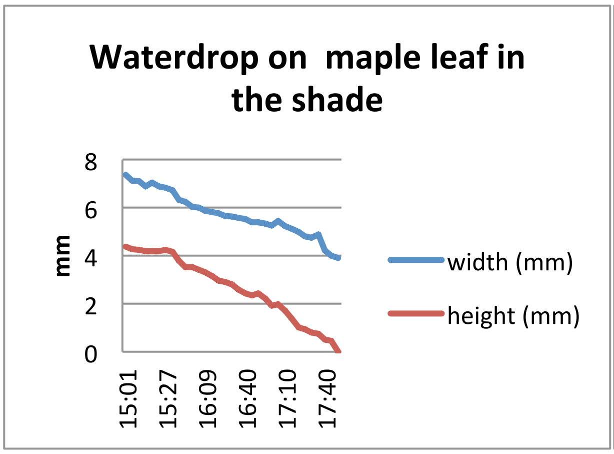


Figure 7. With the help of a computer software the size-changes of the waterdrops could be followed.



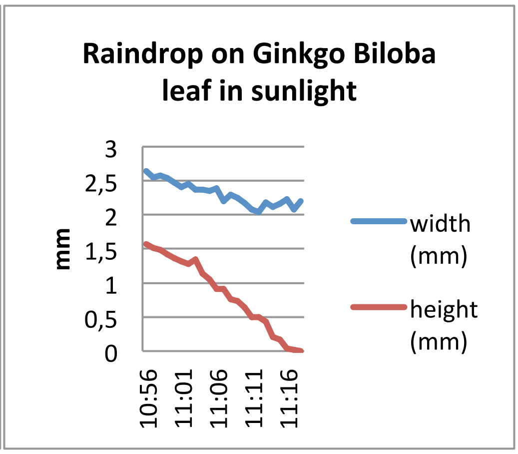


Figure 8.The changes in the size of the waterdrops in the function of time

In general on the basis of the experiments it can be stated that the waterdrops evaporate from the surface of the leaf in half an hour while their shape changes. The parameters of the width to a smaller extent. while the height of the waterdrops decreases to a greater extent, as a result of which the drops become flatter. It means the waterdrops have half an hour to burn the sunrays into the surface of the leaves and in addition the flatter drops are less and less able to do so as it turns out from the basic experiment.

Methods of experimenting

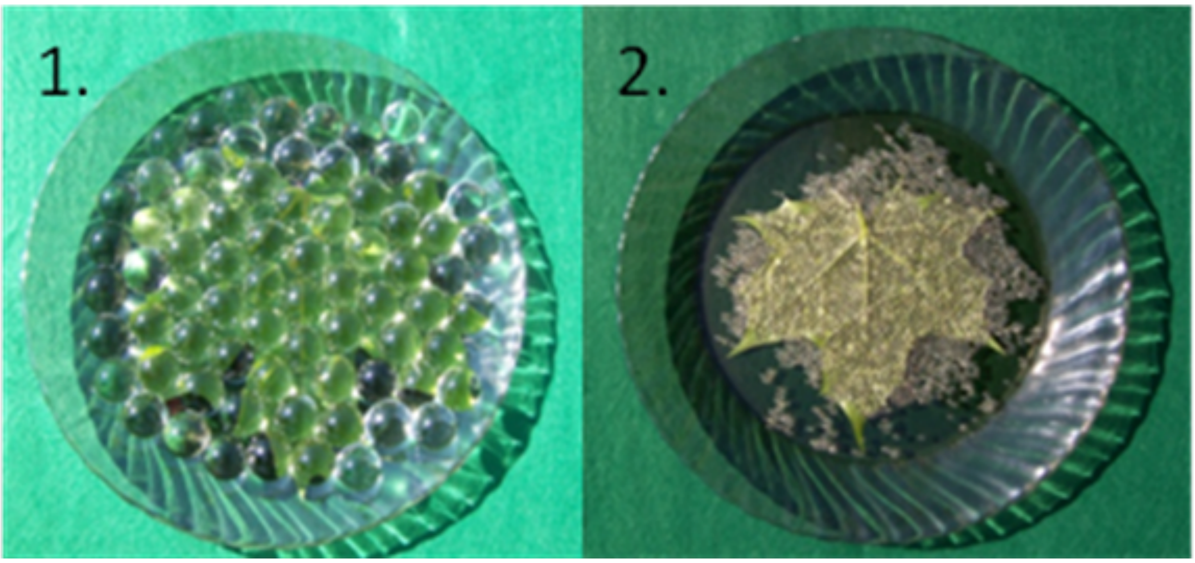


Figure 9. 1-st Experiment: The leaves from the same maple tree were placed in two glass-plates: in plate a) the leaves were put with the right side upwards whereas on plate b) they were put with their back upwards. In plates a) and b) the leaves were covered with balls soaked in water (20mm and 2mm).

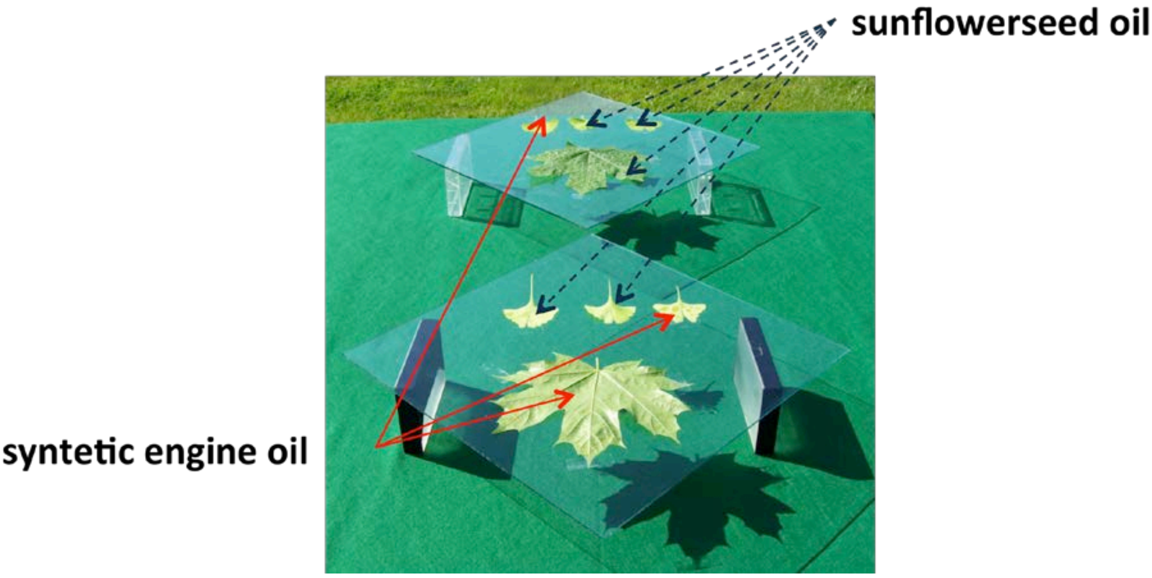


Figure 10. 2-nd experiment

In the 2nd experiment we tried to provide natural conditions: from above, the leaves got natural light, from beneath diffused green light was provided with the help of the green felt material. One of them received the light on its back side, whereas the other one received it on the right side. Because of the movement of the sun it was important to fix the points of the compasses. Two different types of oil were dropped on the leaves from a pipette: on the maple tree leaves 174-182 drops, on the fernpine tree leaves 15-20 drops.

Control experiments

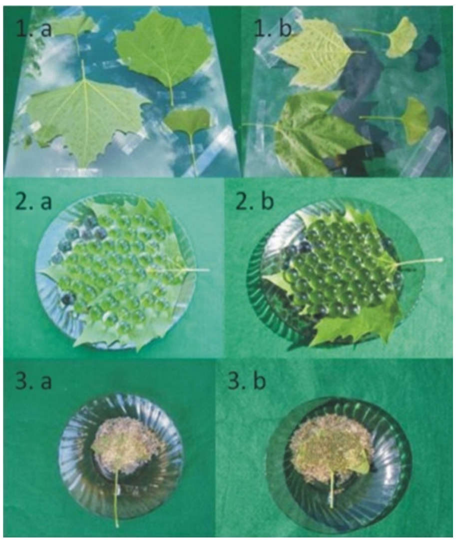


Figure 11. In the pictures on the left the leaves were put in the shade, while in the pictures on the right they were exposed to direct sunlight. In the upper line oil drops were put on the leaves, in the middle one 20mm glycerine balls and in the bottom one 2mm balls were placed.

The results of the author's experiment

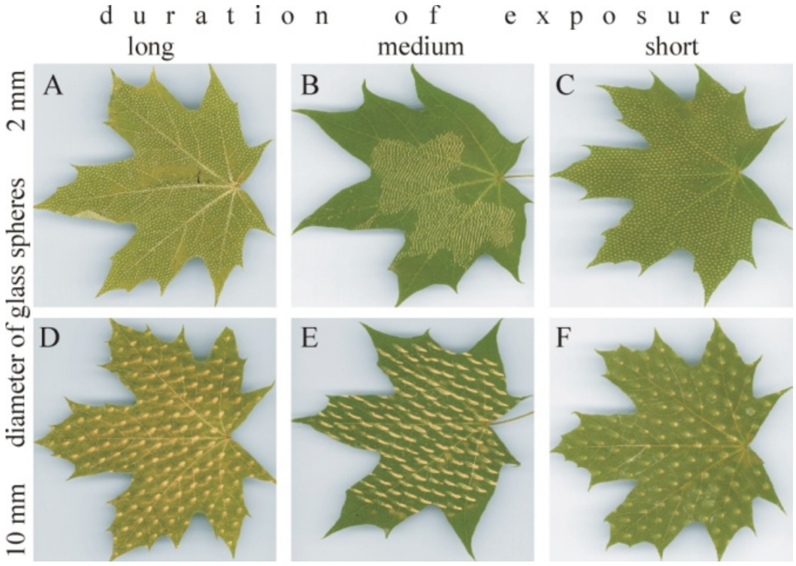


Figure 12. (A-F) Sunburnt maple (Acer platanoides) leaves exposed to direct sunlight for long (left column), medium (middle column), and short (right column) periods covered by glass spheres with 2 and 10 mm diameter in the 1st experiment. The grid pattern of sunburnt brown patches caused by intense focused sunlight is clearly visible on the green leaves. (Figure 1 on page 981 of Egri et al., 2010 [4])

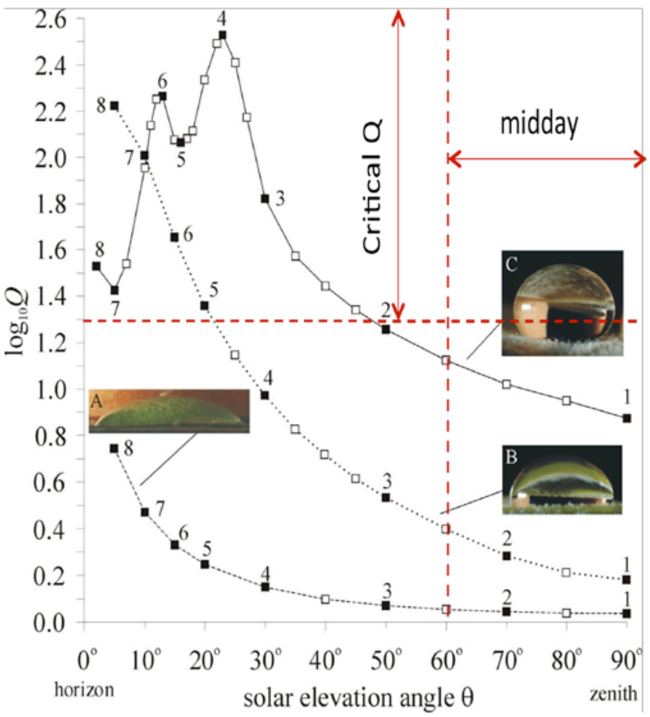


Figure 13. $\log_{10}Q$ versus solar elevation angle θ computed for a water drop on a horizontal maple (A), plane tree (B) and rowan (C) leaf with decreasing wettability from A to C. $Q(n_{water}=1.33,\theta)$ is the maximum light-collecting efficiency of water drops in the focal region. Insets show the side-view photograph of water drops. Data corresponding to rows 1, 2, … 7, 8 in Figs. 4-6 are marked by filled squares. (Figure 7 on page 985 of Egri et al., 2010 [4])

The final conclusion

The waterdrops from the pipette did not cause traces of burn (except for the Salvinia Natans). Only after about half an hour exposure to sunlight were the glassballs able to burn the leaves (the raindrops would evaporate in 25 minutes). The final conclusion of the authors is that the sunlit waterdrops never cause sunburn either on hydrophobic or hairless, plain leaves. On the other hand, if the leaves are covered with hydrophobic waxhair, which are able to hold the waterdrops above the surface of the leaves, the tissue of the leaf may be burned in the blazing sun.

The results of our experiment

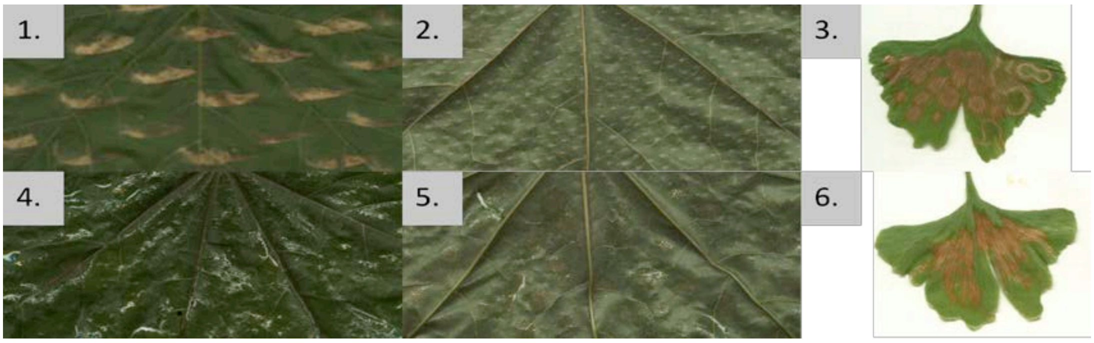


Figure 14. In picture 1) the maple leave covered with the soaked 20 mm glycerine balls can be seen, whereas in picture 2) the maple leave covered with 2 mm soaked glycerine balls is shown after being exposed to the sunlight for 6 hours. The traces of burn can be recognized and their stretching is due to the relative movement of the sun. In pictures 4) and 5) the maple leaves covered with oildrops can be seen. They spent 6 hours being exposed to the sunlight. No traces of burn can be seen. In pictures 3) and 6) traces of burn can be recognized on the fernpine leaves covered with oil drops.

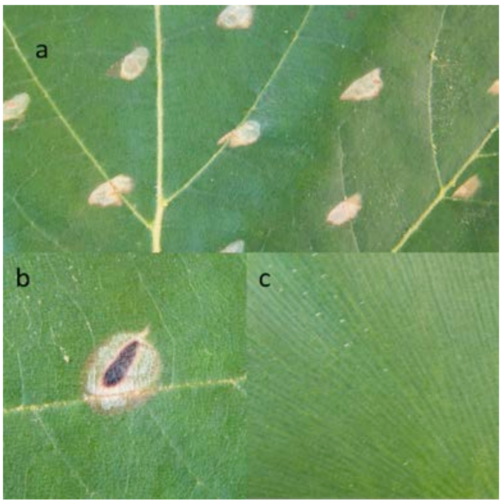


Figure 15. The results of an experiment from 3 pm till 5 pm. Figure a) shows the traces of burn on the maple leave covered with 20 mm soaked glycerine balls after being in the sun. In figure b) one of the traces of burn can be seen in a magnified view. In figure c) the tiny traces of burn on the fernpine leaf covered with 2 mm soaked glycerine balls is shown.

As the control-experiment was made late in the afternoon, the angle of incidince of the sunlight was smaller measured from the horizontal plane, so the mappings of the sunlight passing through the glycerine balls also modified. During the control there was a much more intensive burning effect, in some places there were completely dark stains. According to these results it can be stated that the burning effect of the sun is much stronger late in the afternoon - which also follows from the theoretical prediction - than at midday (as it was claimed in the text of the book). Late in the afternoon the burning effects of the sunshine focused by the soaked glycerine balls is stronger.

Our conclusions

The oildrops did not cause traces of burn on the maple leaves although they focused the sunlight on the leaves for several hours. The traces of burn on the leaves of ginkgo biloba did not show the dispersion of the computer-model. As the oils used in the experiment were not transparent, they got warm due to the absorption of the light. The chemical reaction was not possible as no traces appeared on the leaves covered with oildrops in the shade. For further examination the experiment is going to be made with transparent paraffin oil this year and also hot oil is going to be dropped on the ginkgo leaves in the shade.

To summarize our results, the waterdrops as flat convex lenses are not able to burn the smooth-surfaced leaves in the blazing sun. One consequence of this is that indicating the possible causes of forest fires with such an explanation in forestry literature and saying the strong focusing effect of the waterdrops can cause fire proves to be a false thought. As for task 2152,. in the solution book (Unified collection of tasks for the School-leaving exam) the correct answer is not given, i.e. the possible alternatives do not include this explanation, so the publisher of the book is kindly requested to correct the mistake.

I wish to express my thanks to my tutors dr. Horváth Gábor and dr. Juhász András, my students, Murguly Alexandra, Pátyay Richárd and Czérna László, the “Webcam-laboratory” for the free software use, and also to Kürti Anetta.

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