CLXIV. THE PHOTOCAPILLARY REACTION OF PLANT SAP.

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EXPERIMENTS have been carried out on the phenomenon which can be observed when the sap expressed from etiolated seedlings is suddenly illuminated. The surface tension of the sap increases until an equilibrium is attained. This depends on various factors and is destroyed in the dark so that the surface tension decreases.

It cannot be *a priori* stated whether this phenomenon belongs to the photochemical reactions as commonly understood; on the other hand, it is not entirely excluded that the changes of surface tension are brought about by physical forces, so that it is advisable to call the phenomenon a *photocapillary reaction of plant sap*.

The photocapillary reaction was first preliminarily described by the author in a paper on the influence of light on plants in relation to the surface tension of their sap [Herčík, 1926]. It was there stated that etiolated plants give a sap which has low surface tension and which is therefore rich in capillary-active substances. After illumination the amount of capillary-active substances in a plant is more and more reduced so that the plant gives a sap with a higher surface tension. Light therefore increases the surface tension in the plant so that the plant carries out a photocapillary reaction which can be observed more easily *in vitro* if only the expressed sap of etiolated plants is used instead of the plant itself. The sap is found to have a reactivity of the same order as that of the intact plant itself.

METHODS.

Photocapillary reaction was observed in the sap expressed from young etiolated seedlings of *Pisum*, *Vicia*, *Pharbitis* and *Sinapis*. The reaction of *Sinapis* sap being the most intense, young *Sinapis* seedlings were chosen for experimentation.

Seedlings of *Sinapis alba* were cultivated on thick layers of filter-paper in the dark at 20°. Before the experiment they were cut into small pieces and ground in a porcelain mortar with fine sand to a dense pulp. This pulp was pressed out and the sap collected in small watch-glasses with a diameter of 5 cm. The

surface tension was measured with the Du Noüy tensiometer, 2 cc. of the sap being used for each measurement. The sap was then illuminated with a strong Osram-Nitra lamp, 500 w., 110 v., from different distances.

The static surface tension of the sap was very soon attained, the sap therefore was illuminated directly after squeezing. The diluted sap also very soon attains its static surface tension which, however, can be very easily disturbed. Therefore several watch-glasses (ten or more according to the number of measurements) were exposed to the light, each glass being used for only one single measurement, so that the surface of the sap was not disturbed by repeated measurements.

EXPERIMENTS.

The experiments were made with sap alone and with sap which had been diluted to various extents with distilled water. The intensity of illumination amounted to 1356 lux.

Table I gives the photocapillary reaction of undiluted sap after illumination with 1356 lux. t' represents time in minutes after exposure to the light and σ surface tension in dynes per cm.

Table I.

Exp. no.	Age of the plants (days)	Changes of surface tension after illumination with 1356 lux											
		t'	0	3	5	7	9	12	17	22	32	52	62
79	7	σ	40.8	43.2	44.4	45.3	46.0	47.1	48.5	47.4	48.0	47.4	47.1
		t'	0	12	19	27	46	60					
99 a	9	σ	46.4	46.1	46.8	46.5	46.2	46.1					
		t'	0	5	10	20	25	30	45	60	85		
93	12	σ	38.4	44.3	45.4	45.8	46.3	46.4	47.0	46.4	46.4		
		t'	0	5	10	16	22	34	45	60	121		
101	16	σ	37.2	37.2	39.0	40.3	41.5	42.5	44.1	44.1	44.8		
		t'											

On Fig. 1 is plotted the reaction curve of Exp. 79. It can be seen that equilibrium is reached after a number of small oscillations. The whole rise of surface tension which the light induces amounts here to 7.7 dynes per cm., in Exp. 99 a 0.4 dynes per cm., in Exp. 93 8.3 dynes per cm., and in Exp. 101 7.6 dynes per cm.; the effect which light brings about is therefore comparatively large. The deviation in the case of Exp. 99 a is due to the fact that here the initial surface tension of the sap differs greatly from that in the other experiments. It follows that a certain minimum surface tension is necessary for the reaction to begin at all. From other experiments which are referred to in another place [Herčík, 1927, 2] it can be deduced that this minimal surface tension corresponds to about 44.2 dynes per cm.

Control experiments were also made to find out if the sap does not change its surface tension spontaneously in the dark. Table II, in which are recorded some of these experiments, shows that in the dark no change which could be taken into consideration occurs.

Table II.

Age of the plants (days)	Changes of surface tension in the dark				
	t'	0	20	30	50
5	σ	47.0	47.7	47.7	48.3
	t'	0	42	102	132
10	σ	40.5	40.8	41.5	41.9

The photicapillary reaction of diluted sap is different from that of undiluted sap. The surface tension decreases instead of increasing (Table III).

Table III.

Exp. no.	Age of the plants (days)	Concen- tration of the sap	Changes of surface tension after illumination with 1356 lux						
			t'	0	11	17	26	45	59
99 b	9	80%	σ	46.2	45.4	48.9	47.2	45.3	45.1
99 c	9	60%	t'	0	9	10	25	44	58
			σ	46.8	45.6	47.8	45.0	43.4	43.3
99 e	9	20%	t'	0	6	14	23	42	56
			σ	51.8	48.6	48.3	48.6	47.5	47.8
99 f	8	10%	t'	0	5	13	22	41	55
			σ	51.1	48.1	47.1	46.4	45.6	44.9

Fig. 1.

From the table it can be seen firstly, that the photicapillary reaction of diluted sap is *in nuce* a reversed photicapillary reaction of concentrated sap, i.e. the surface tension decreases; and secondly, that the mode and extent of this decrease depend on the degree of dilution.

In 80 % dilution the surface tension at first decreases a little, then strongly increases and again decreases. In 60 % dilution the first increase is smaller and on the contrary the second decrease is more intense. The 20 % sap shows practically no increase, the surface tension decreasing here after illumination

almost regularly. The 10 % sap finally gives a typical negative photocapillary reaction: the surface tension here decreases in a smooth parabolic curve (Fig. 2).

The reaction of slightly diluted sap is therefore composed of both types of photocapillary reaction, of a positive and negative type, indicated by rise and fall of surface tension. The predominance of one of these two types is given by the degree of the dilution. At higher dilutions the negative reaction takes place, at lower dilutions the positive reaction occurs. For other types of the reactions of the diluted sap see the previously mentioned paper of the author [Herčík, 1927, 2].

Fig. 2.

In Table IV control experiments are recorded from which we see that the surface tension of diluted sap does not change when the sap remains in the dark.

Table IV. *Sinapis alba*, 10 days old etiolated seedlings. Changes of surface tension of sap, diluted to various degrees, in the dark.

t'	50 %	25 %	12.5 %
0	49.3	51.8	53.7
53	49.7	51.4	53.5

The question naturally arises whether the photocapillary reaction depends in any way on the intensity of the light used. Three different illuminations were taken into consideration, namely of 11,720 lux, 5,420 lux and 13.19 lux. The experiment with the illumination of 11,720 lux is given in Table V.

Table V. *Sinapis alba*, 12 days old etiolated seedlings.

Conc. of the sap	1	1/2	1/4	1/8	1/16	1/32	1/64	1/128	1/256
Darkness	44.5	47.4	51.9	51.8	53.8	56.4	63.0	65.3	70.2
Light 60'	48.6	45.8	48.7	50.0	52.2	54.3	58.1	58.3	60.2
Darkness 7½ hours	45.8	45.8	46.3	48.6	50.8	56.3	55.5	60.8	65.0

In this experiment the surface tension of the sap in the dark was first measured. Then the sap was illuminated with 11,720 lux for 1 hour. The surface tension of the undiluted sap increased (only a little because the initial surface tension of the sap was high); that of the diluted sap decreased (in the dilution 1/32 there was no change). After this illumination, the samples were kept in the dark for $7\frac{1}{2}$ hours altogether. This caused a decrease of surface tension of undiluted sap and of the diluted sap in the lower dilutions. In the higher dilutions the surface tension increased.

This shows that with negligible deviations the photocapillary reaction has a reversible character.

On the other hand, a quantitative effect of the higher illumination on the amount of the reaction cannot be observed. The same was established when illuminations of 5420 and 13·19 lux were used. The amount of the reaction in both cases was nearly the same. [See for further detail Herčík, 1927, 2.]

DISCUSSION.

It cannot be maintained that this photocapillary reaction is a photochemical reaction as is generally understood. It is quite independent of the intensity of the light used, it has no induction period and only two decisive factors, namely, the initial surface tension of the sap and the degree of dilution.

The fact that the photocapillary reaction cannot be brought about when the initial surface tension of the sap is relatively high, points to the conclusion that the photoactive substances are highly capillary-active, *i.e.* they determine the lowest limit of the surface tension of the sap.

The degree of dilution strikingly changes the character of the reaction, the positive reaction being converted into a negative one bringing about a decrease of surface tension.

It is reasonable to suppose that the photocapillary reaction is governed by the Hallwachs photoelectrical effect. This suggestion is supported by the following facts. The living substance is known to carry a negative charge. The particles of the sap are undoubtedly also negatively charged. As is known every charge diminishes the surface tension, so that the surface tension of the living substance and also of the sap is reduced according to the amount of the charge present on single particles.

Zwaardemaker and Hogewind [1919] state that the Hallwachs phenomenon can be largely applied for colloidal solutions and therefore also for living substance. This means that the living substance and the sap probably lose their negative charge after illumination and the surface tension rises until an equilibrium is attained. The negative photocapillary reaction can also be explained on the basis of the photoelectrical effect, supposing that the particles lose their charge when the sap is diluted. They are therefore made electro-neutral and may be again charged by the action of the light [see Righi, 1888]. The surface tension in this case decreases.

The positive photocapillary reaction which is also carried out by green plants appears to be one of the most important factors in the growth-response of the plants to light. The growth-retarding action of the light can be more easily understood in the following way: by means of photocapillary reaction light increases the surface tension on interfacial surfaces of the cell, and this increased surface tension retards the growth. In the dark the process occurs in the reverse way, the surface tension is reduced and growth is thereby favoured [see Kříženecký, 1927; Bauer, 1924; Kopaczewski, 1924; Herčík, 1926, 1927, 1].

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