

On contact angles and the spread of liquids on solid bodies.

By Agnes Pockels.

Introduction

The observations to be reported here date mainly from the years 1897 and 1898 and were not published at that time, because the measurements of the contact angle made at different times did not agree satisfactorily. I have not yet been able to clarify the cause of these contradictions, and the observations still lack the desired completeness. However, since little work seems to have been done in this field since Quincke's observations of 1877 and since even now there can be such different views on the wettability of glass by water as those of Lord Rayleigh (1) and J. Aitken (2), it should not be superfluous to summarize the results I have obtained so far.

The basic condition for the usefulness of such investigations is the production of completely pure surfaces, and this was therefore more important than precise angle measurement. Before proceeding with the latter, it is first necessary to establish whether a boundary angle exists at all between the pair of substances in question or whether the liquid spreads out on the solid body. In order to keep the surface of a solid body clean, there are two ways of achieving this, apart from the cleaning with strong acids used by Quincke and Lord Rayleigh: either new formation of the surface by splitting, shattering or filing, or strong heating up to red heat. The latter method was used on glass and platina and will be described first.

Production of clean surfaces, control procedure and observation method

The most suitable microscope coverslips for glass were found to be 1/5 mm thick, which were moved vertically back and forth in a spirit flame for about 4 seconds so that they just began to melt at the lower edge (3). If the glass remained in the flame for too long, it was very easy for it to bend. Only glass that was already completely clean and clear in appearance was used for annealing, which was achieved by repeatedly rubbing it firmly between two fingers with water and soap or gruel and then rubbing it dry with a fine linen cloth.

Previously, fairly satisfactory results had also been achieved with pieces of window glass, but due to their greater thickness, much longer heating was necessary to destroy the organic contamination on the surface, and in most cases the plates shattered.

Whether the surface of a metallic or mineral body is completely pure or contaminated by greasy or resinous substances is most easily and reliably recognized by immersing the body in a freshly formed water surface which has been dusted with lycopodium, coal powder or, according to the method of H. Devaux (4), with talc.

If the body is only the slightest bit contaminated, the floating dust is repelled on immersion. A dust-free circle forms around the solid body, a phenomenon which I have previously referred to as "solution flow" (5), as I attribute it to the solution of the contaminating substance in the surface layer of the water. The absence of the solution current, on the other hand, proves the absolute purity of the solid surface of fat or similarly acting substances.

The glass plates washed in the above manner and dried with linen, as well as the platinum sheet rubbed with soft leather, now always gave a strong stream of solution; after annealing in the flame, however, this was completely absent.

(1) Nature **86**, 416 and **90**, 436.

(2) Nature **86**, 516 and **90**, 619.

(3) A. Pockels, Naturw. Rundschau **13**, 190 and Winkelmanns Handbuch der Physik I, p. 1186.

(4) H. Devaux, Journ. d. Phys. 11, 699.

(5) A. Pockels, Nature **43**, 437; Ann. d. Phys. (4) **8**, 854.

The contact angles were measured as follows. The glass or platinum plate was placed on an initially horizontal bar, which could be rotated around the axis of a quadrant divided into degrees (a finer division would have been pointless, as the successive observations usually differed by one degree or more). A candle flame with a horizontal slit in front of it served as the light source. A drop of the liquid to be examined was then placed on the plate using a wire that had been cleaned by annealing and left in a horizontal position until the spread of the drop appeared to have ended. Unfortunately, it is difficult to determine the correct point in time for water, as the contact angle is not only reduced by the spread but also by evaporation; I observed the water droplets after about half a minute.

The eye and light source were first adjusted so that the image of the latter appeared in the drop just at the rear edge of the latter, and then the bar was raised at the front until the slit image in the plate coincided with the same edge of the drop, the eye being maintained in an unchanged position during the rotation with the aid of a sighting device. What is measured in this way is the contact angle at which the liquid in question stops when it penetrates the plate. In addition, however, the contact angle to which the drop retracts when it is forcibly spread out (by means of a wire) to form a flat layer was always examined.

With some liquids, such as benzene, both angles coincide completely or very closely. The drop then slides easily onto the solid surface, similar to mercury on glass. With other liquids, such as water or glycerine, the behaviour when advancing and retreating shows a remarkable difference; they stick or adhere, as it were, to the solid body. One can only speak of an actual contact angle in those cases where such an angle also emerges during retraction and thus sliding takes place, even if only slowly.

Observations on glass and platinum

1. Water

The contact angle of the water when penetrating annealed and cooled glass was never more than 2° , usually 1° , often it seemed to be zero. However, the spread is limited with a somewhat irregular edge. The contact angle during retraction is $= 0$, i.e. pure glass can be wetted by water.

As examples, here are some measurements of the contact angle on glass. θ_a , means the contact angle when advancing, θ_r that when retreating.

Window glass

	Unannealed	Annealed
θ_a	$27^\circ, 25^\circ, 22^\circ, 27^\circ$	$3-4^\circ, 1-2^\circ, 0^\circ, 1^\circ$
θ_r	not observed	$0^\circ, 0^\circ, 0^\circ, 0^\circ$

Coverslip

	Unannealed	Annealed
θ_a	$33^\circ, 25^\circ, 29^\circ, 24^\circ$	$1^\circ, 1^\circ, 2^\circ, 1\frac{1}{2}^\circ, 0^\circ$
θ_r	$13^\circ, 10^\circ, 19^\circ, 12^\circ$	$0^\circ, 0^\circ, 0^\circ, 0^\circ, 0^\circ$

Here and for most other liquids, the angles obtained on unheated plates are also given in order to show the influence of the contamination of the solid surfaces.

One might now expect that the anomaly of the surface tension of water (reduction of the surface tension due to contamination) would have a considerable influence on the contact angle, in so far as a reduction

of the surface tension should promote the spread. Care was therefore taken to ensure that the drops placed on the plate were only taken from vessels in which the water surface had been freshly cleaned.

However, experiments carried out on this in particular showed hardly any noticeable effect with a moderate anomaly; only heavy contamination of the drop surface with oleic acid, palmitic acid, soap or mastic produced such an effect, namely an increase in the rim angle. Purified Provence oil had no noticeable effect as long as the water surface was not saturated with oil; however, if there were small oil droplets on the surface, a completely different phenomenon occurred. The water droplet first spread out strongly, only to immediately contract again, or it spread in branches. The areas of the glass surface that had been covered by the droplet proved to be contaminated with oil after it had been withdrawn; the oil had therefore displaced the water from the glass.

When exposed to the flame, a transparent precipitate always appeared on annealed glass plates and an opaque one on unannealed ones, corresponding to the different contact angles, and the fact that in the former case the solution flow was absent, while in the latter it was present, proves that Aitken's puff-picture experiment is actually a matter of cleaning the glass by passing the flame over it, as Lord Rayleigh assumes (1). A further proof against Aitken's view is that with the same duration of exposure to the flame, the contact angle disappears much more easily with thin plates than with the thicker window glass, which is not heated to such a high temperature, whereas gases and dust particles should produce the same effect in both cases.

On freshly annealed platinum sheet, immediately after cooling, the contact angle θ_a of the water was also $< 2^\circ$, usually immeasurably small, and on retraction = 0, whereas on unannealed sheet, which was rubbed with soft leather, $\theta_a = 53 - 60^\circ$ and also θ_r was considerable.

One difference compared to the behaviour on glass, however, is that on glass, when it is exposed to air after annealing, the contact angle reappears only slowly, whereas it increases much more quickly on platinum. After 5-10 minutes, θ_a , was already noticeably larger, after half an hour it was already considerable - θ_a , however, still 0 - without the metal plate having given a solution current when immersed in the water surface. Some observations on the influence of the time elapsed after annealing on the contact angle when penetrating glass are also given here.

Time	θ_a
After ½ minute	at most 1° , irregularly jagged edge
After 10 minutes	same
After 3 hours	$3^\circ, 4^\circ$
After 24 hours	$3 \frac{1}{2}^\circ, 5^\circ$

2. Glycerine

It behaves similarly to water with glass and platinum; clean surfaces can be wetted by it, but it withdraws from contaminated surfaces. However, the angles are generally larger than with water and the adjustment to the definitive value is slower due to the high viscosity, so that at least 1/4 hour must elapse between placing the drop and taking the reading.

	Glass		Platinum
	Unannealed	Annealed	Annealed
θ_a	$27^\circ, 26^\circ$	$6^\circ, 5^\circ, 4^\circ$	$21^\circ, 18^\circ, 18^\circ$
θ_r	$8^\circ, 9^\circ$	$0^\circ, 0^\circ, 0^\circ$	$0^\circ, 0^\circ, 0^\circ$

(1) Nature **86**, 416.

3. Ethanol, turpentine oil, petroleum (1)

These liquids spread indefinitely on pure glass and platinum surfaces until thin flakes of colour are produced. There was also no retraction on unannealed plates; however, the following was observed during penetration.

Unannealed glass, θ_a

Ethanol	0°, irregular spreading
Turpentine oil	0°, irregular spreading
Petroleum	5°, 4°, 8°, 10°

Unannealed platinum, θ_a

Ethanol	13°, 20°
Turpentine oil	limited spreading with irregular edge
Petroleum	15°, 20°

4. Benzene, ethyl ether, carbon disulphide

The contact angle of these liquids adjusts very quickly to its definitive value, it is therefore as large or almost as large when retreating as when advancing, and the droplets slide along the solid surface without wetting it.

Glass

Liquid		Unannealed	Annealed
Benzene	θ_a	10 – 15°	6° const.
	θ_r	9 – 11°	6° const.
Ether	θ_a		5 – 8°
	θ_r		5 – 8°
CS ₂	θ_a	20°	11 – 14°
	θ_r	11°	11° const.

In the case of the ether, a thin layer still spread around the actual droplet, while the contact angle of the former increased from 5° to 8°. Benzene had a completely constant angle on annealed glass (in the table it is noted by "const." each time all the observations gave the same angle); however, when I repeated the observations a year later, the same angle was 9°, although here too all the observations agreed with each other and the temperature was the same. Perhaps this could be due to a difference in the type of glass.

Platinum

Liquid		Unannealed	Annealed
Benzene	θ_a	10°, 8°, 10°, 8°	4 ½°, 5°, 4°, 3 ½°, 4°
	θ_r	4°, 5°	same
Ether	θ_a		5 – 10°
	θ_r		5 – 10°
CS ₂	θ_a	10°, 10°	6 – 7 ½°
	θ_r		6 – 7 ½°

The angles of ether and carbon disulphide on platinum could only be estimated approximately, partly because of the rapid evaporation and partly because of the excessive mobility of the droplets, which

(1) The petroleum used was the best purified, commercially known as "Kaiser oil", which does not spread on water but remains lenticular. cf. Ann. 67, 674.

immediately ran downhill when the plate was rotated. Another phenomenon should be mentioned here, which can only be observed on very clean surfaces. If an annealed glass or platinum plate is partially wetted with water and a drop of ethanol hanging from a wire is brought close to it, the layer of water contracts into a drop and, when the drop of ethanol is moved, appears to be repelled from it. Benzene and ether also cause a more or less complete displacement of the water due to the vapours they emit. The extent to which benzene and other volatile liquids are caused by this vapor flow must be left open for the time being.

5. Oil, oleic acid

The observations on these liquids were made one hour after the drop was placed or spread because of the slow setting of the definite contact angle. The oil referred to as purified Provençal oil is oil which has been freed of free fatty acid by repeated shaking with alcohol to such an extent that it does not spread on a pure water surface (1).

Glass			
Liquid		Unannealed	Annealed
Unpurified Provence oil	θ_a		$33\frac{1}{2}^\circ, 32^\circ, 33\frac{1}{2}^\circ$
	θ_r		$18^\circ, 16^\circ, 21^\circ$
Purified Provence oil	θ_a	$33^\circ, 27^\circ, 30^\circ$	$27\frac{1}{2}^\circ, 28\frac{1}{2}^\circ, 29^\circ,$ 27°
	θ_r	$24^\circ, 19\frac{1}{2}^\circ, 22^\circ$	$24^\circ, 25^\circ, 27^\circ, 25\frac{1}{2}^\circ$
Oleic acid	θ_a	$29^\circ, 29^\circ, 28^\circ$	$33^\circ, 30^\circ, 29^\circ, 29^\circ$
	θ_r	$25^\circ, 29^\circ, 24^\circ$	$26^\circ, 27^\circ, 27^\circ, 28\frac{1}{2}^\circ$

Platinum, annealed		
Purified Provence oil	θ_a	$25^\circ, 27^\circ$
	θ_r	$13^\circ, 16^\circ$
Oleic acid	θ_a	$25^\circ, 24^\circ$
	θ_r	$18^\circ, 13^\circ$

While annealing brings θ_a and θ_r closer together for almost all liquids, the purity of the plate, as can be seen, was not important for oil and oleic acid. On the other hand, the purification of the oil from free fatty acids made it much more mobile, so that the drop could be allowed to slide slowly over the plate, whereas it adhered strongly to the plate with unpurified oil.

For a better overview, the mean values in degrees found for annealed glass and platinum may be summarized again in a table. In some cases, more than the observations listed above were used to calculate these values.

(1) A. Pockels, Nature **50**, 223; Wied. Ann. **67**, 671.

Liquid	Glass		Platinum	
	θ_a	θ_r	θ_a	θ_r
Water	<1	0	<1	0
Glycerine	5	0	19	0
Unpurified oil	28	25.3	26	14.5
Purified oil	33	18.7		
Oleic acid	30.25	17.12	24.5	15.5
Turpentine oil	0	0	0	0
Petroleum	0	0	0	0
Ethanol	0	0	0	0
Ether	5	5	7 ½ ?	7 ½ ?
Benzene	6	6	4.1	4.1
Carbon disulphide	12.7	11	7	7

In the case of benzene on glass, the smaller value determined first was used, as this was obtained with the type of glass also used for the other liquids.

It can be assumed that apart from the few liquids I have investigated so far, many other substances, especially organic ones, will have pronounced contact angles on glass, and it is obvious that these must be taken into account when determining the surface tension from rising heights. In the case of water and aqueous solutions, if the capillary tube is freshly drawn or well cleaned, one can be convinced of its wettability, but benzene and oleic acid, for example, will not wet a very clean glass tube from the outset, and it is also very questionable whether in all cases a wetting effect can be achieved by prolonged contact or rubbing with the glass. It is also very doubtful whether wetting can be brought about in all cases by prolonged contact or rubbing with the liquid. For every new liquid whose height of rise is to be measured, the contact angle θ_r with glass would therefore first have to be determined, which I find no mention of in the extensive observations by Walden and Swinnel (1) and other more recent measurements.

Observations on other solid substances

In order to bring other metals besides platinum into the area of investigation, the old surface layer was removed from zinc and copper strips, for which of course the heating process cannot be used, by filing. However, it was not permitted to use a new, unused file for this, but only one that had been used on the same material for some time, as otherwise no clean surface could be obtained. The test medium for cleanliness was also the solution stream here; however, the metal strips themselves did not need to be immersed, but only the filings obtained last needed to be sprinkled onto a clean water surface. If the filing dust sinks immediately, its surface and therefore also that of the filed plate is clean; otherwise, the metal particles float for a while and repel each other due to their solution currents.

The contact angles could only be approximated on the copper and zinc strips, as the file marks made the cleavage pattern appear completely blurred; however, the plate was not polished, as contamination is difficult to avoid with all polishing methods. The following are the results on the cleanest surfaces that I was able to obtain by filing, in degrees.

(1) Zeitschr. f. phys. Chem. **82**, 271, 1912 and **79**, 703, 1911.

Water on zinc

Time	θ_a	Average	θ_r
Immediately after deposition	0, 0, 4, 0, 5, 3, 0, 0, 3, 3	1.8°	0°
After a few minutes	6, 8	7°	0°
After ½ hour	9, 10, 20, 18, 13, 10, 11, 10, 9	12.2°	0°
After several hours	In the first moment after touching down over 30° a little later: 17, 14, 17, 14, 16, 15, 13, 20	15.7°	0°

Water on copper

Time	θ_a	Average	θ_r
Immediately after deposition	2, 3, 4, 0, 4, 1, 3, 3, 0, 0, 5, 0, 0, 3, 3, 2	2.1°	0°
After ¼ hour	20, 10, 15	15°	0°
After ½ hour	20, 25, 30, 25	25°	0°
After 1 ½ to 2 hours	over 30°	>30°	0°
On oxidized copper	approx. 45°	45°	0°

The oxidized copper plate was produced by heating it in an alcohol flame until it started to tarnish immediately after filing.

As can be seen, freshly filed zinc and copper are wettable by water ($\theta_a = 0$) and remain so even after hours, while - θ_a , just as with annealed platinum, increases rapidly with time. This rapid increase in the contact angle during penetration, which appears to occur particularly with metals and has already been observed by Quincke (1), cannot be caused by contamination with solid or liquid substances, as this only occurs again after a much longer period of time. Layers of adsorbed gases may play a role here, as Waidele (2) had already assumed in 1843 to explain Moser's puffs.

The results with some other liquids may follow.

Liquid	Zinc		Copper	
	θ_a	θ_r	θ_a	θ_r
Benzene	3°	>0°	0°	0°
Alcohol	spreading		spreading	
Petroleum	spreading		spreading	
Oil	11.5°	11.7°	14°	0°

Benzene and oil droplets withdrew from zinc, but not from copper. The oil values are the average of 4 to 8 observations each.

Some observations were also made on smooth fracture surfaces of anthracite coal and Westphalian hard coal. Ethanol and petroleum spread on both types of coal; the same was observed with turpentine oil and petrol on Westphalian coal. For benzene, the contact angle $\theta_a = 0$. For oil, $\theta_r = 0$, θ_a was almost but not quite 0, whereas for water the contact angle was always very large when advancing and also > 0 when retreating, so that a slow sliding of the droplets could be observed, especially on very fresh fracture surfaces. Water thus behaves on coal in a similar way to contaminated glass surfaces.

(1) Wied. Ann. 2, 161, 1877.

(2) Pogg. Ann. 59, 255, 1843.

A special study was carried out on the contact angle of saturated solutions on crystals of dissolved salts, the results of which were published at the time (1). Both fracture and cleavage surfaces and freshly formed crystal surfaces of rock salt and alum were always wettable by the saturated solution of the salt concerned and θ_a usually equal to zero or very small, and it may be added here that pure water also spreads on these and other soluble substances, such as soda, sugar, borax, until the contact angle disappears, and in most cases more rapidly and 'energetically' than the solution. In general, however, only those soluble substances which increase the surface tension of the latter are likely to be wetted by the solvent; camphor and salicylic acid, for example, which lower the normal surface tension of water, are not wetted by the latter.

Of particular interest is the behavior of liquids against ice in comparison with that on water. Everyday experience teaches us that ice can be wetted by water. In order to investigate θ_a , fractured surfaces of a broken block of ice were used, as well as pure, rapidly solidified water surfaces. If angles were to be measured, the following procedure was used to obtain a flat reflective surface.

A shallow brass vessel was filled to the brim with water, the surface of the latter was cleaned by overflowing, a well-wetted glass or brass plate was placed on top and, after it had frozen solid, it was reheated in the hand until it could be pushed off. The ice was then exposed to frost again and water at 0° was placed on it in the goniometer.

Both on these surfaces and on fracture surfaces, the contact angle was very small when the water droplets had a temperature close to 0° and the ice a little below 0° . However, it was not possible to make the contact angle disappear completely, as on glass, and when the pieces of ice were very cold, it reached values of up to 10° .

The following was observed with other liquids, mostly on fracture surfaces:

Ethyl alcohol spreads rapidly by dissolving the ice.

Ethyl ether spreads (on solidified water surfaces only $\theta_r = 0$).

Gasoline (benzene solidifies immediately, of course) spreads to form colours, just like on liquid water.

Pure petroleum (which remains lenticular on water) neither spreads nor retracts, which can be described as "neutral behaviour". If it was contaminated by resin or otherwise, it sometimes spread (as it does on water).

Carbon disulphide (solidified water surface) behaved neutrally. (On water lenses).

Turpentine oil (solidified water surface) spreads slowly (on water to colours).

Purified Provençal oil (both methods) does not spread and retreats slowly after forcible spreading. Contact angle irregular.

Unpurified Provence oil, which spreads on water to form colours, behaved in the same way (solidified water surface).

Oleic acid (fracture surfaces) retracts more quickly.

Theoretical conclusions

If, as can be concluded from the neutral behaviour of water on ice, the state of aggregation has no significant influence on adhesion, it is theoretically understandable that most liquids behave analogously on ice than on water. In the case of oil and oleic acid, however, there appears to be a

(1) Naturwiss. Rundsch. **14**, 383, 1899.

deviation. If they are very pure, they do not spread on a pure water surface, or only temporarily; however, they would spread if the water surface in the vicinity of the drop could remain normal. Only the fact that an "invisible oil layer" (solution flow) immediately spreads around the oil droplet, which reduces the surface tension by 18 percent, prevents the droplet itself from spreading.

Since neither a solution flow nor the rapid spread of a monomolecular oil layer is conceivable on ice, and the ice surface in the vicinity of the drop remains unchanged, one would expect the entire oil drop to spread, but this does not occur.

The condition for the spreading of one liquid 1 on another 2 is:

$$\gamma_1 > \gamma_2 + [\gamma'_1 + \gamma'_2 - 2\alpha],$$

where γ_1, γ_2 are the surface tensions of the free surfaces, γ'_1, γ'_2 those of the surfaces adjacent to the other liquid, and 2α is the work performed by the mutual adhesion when the interface is enlarged by unity (1). The expression in brackets is the total stress of the interface. γ'_2 must be set equal to γ_2 if liquid 2 is an oily liquid; if $\gamma'_1 = \gamma_1$, the propagation condition is simplified to

$$2\alpha > 2\gamma_2,$$

or in other words: the adhesion must be greater than the cohesion of the droplet if it is to spread on the lower liquid. Conversely, if the cohesion is greater, the drop floats with a contact angle, and $\alpha = \gamma_2$ means that the drop flattens out to an imperceptible contact angle without spreading over the entire surface.

For fixed supports, where γ_1 and $\gamma'_1 = 0$, this simple relationship (2) naturally also applies.

Thus, for purified oil on ice, the retraction of the droplet results in $\gamma_2 > \alpha$, and the same would apply to oil on water, unless the state of aggregation has a considerable influence on the mutual molecular attraction between the two substances, which is unlikely.

If a drop of purified Provençal oil falls onto a not too large pure water surface, γ_1 in its surroundings immediately becomes equal to 6.24 mg/mm or 0.82 of the normal surface tension of the water, and the oil drop remains in a lenticular shape. However, it begins to spread out as soon as the surface tension is increased slightly above 6.24 mg/mm to about 6.5 mg/mm by rapid expansion of the surface. At this moment

$$\gamma_1 = \gamma_2 + [\gamma'_1 + \gamma'_2 - 2\alpha],$$

or

$$\gamma_1 - \gamma'_1 = 2\gamma_2 - 2\alpha,$$

If one now concludes from the non-spreading of the oil on ice that the right-hand side is positive, then the left-hand side must also be positive, i.e. $\gamma'_1 < 6.5$ mg/mm, i.e. one must assume that the surface tension of the water below the oil drop is just as small (just as strongly anomalous) as next to the drop. The observations I made earlier about the decreasing interfacial tension of oil and water over time (3) could then be interpreted to mean that the interfacial tension measured immediately after the oil is poured on is already anomalous, which is then gradually lowered even further by the effect of the oil's secondary constituents.

According to my hypothesis that oils and many other substances that are otherwise insoluble in water dissolve in the surface layer up to a certain saturation concentration, thereby lowering the surface

(1) The energy quantity designated by Lord Rayleigh in the treatise "On the theory of surface forces" Phil. Mag. 1890, October and November, p. 462, designated as $2T'_{12}$

(2) In a certain sense, one also speaks of a surface tension of solid bodies, but since it cannot be activated by

an actual reduction of the surface, it cannot be considered for the spreading of a drop resting on a rigid surface.

(3) A. Pockels, Wied. Ann. 67, 668, 1899.

tension, it is actually self-evident that this dissolution occurs not only in the vicinity of a floating drop, but also below it, and that any water surface touching an oil drop is immediately saturated with oil. If, on the other hand, as W. B. Hardy (1), H. Devaux (2) and other physicists attribute the reduction of the surface tension of water to the spread of invisible coherent layers of oil, it would be difficult to explain the anomaly of the interface. It is impossible to imagine that under the thick layer of oil there is another thin layer of the same oil on the water! The only remaining assumption is that the adhesion between oil and water is considerably greater than that between oil and ice.

Where a certain contact angle is present, the simple adhesion α is calculated from

$$\alpha = \gamma \frac{(1 + \cos \theta)}{2}$$

The same would be true for benzene glass, for example

$$3.3 \frac{(1 + \cos 6^\circ)}{2} = 3.3 \frac{1.9945}{2} = 3.29 \frac{\text{mg}}{\text{mm}} = 32.2 \frac{\text{dyne}}{\text{cm}}$$

for ethyl ether glass

$$2.1 \frac{(1 + \cos 5^\circ)}{2} = 2.09 \frac{\text{mg}}{\text{mm}} = 20.5 \frac{\text{dyne}}{\text{cm}}$$

for carbon disulphide glass

$$3.8 \frac{(1 + \cos 12^\circ)}{2} = 3.75 \frac{\text{mg}}{\text{mm}} = 36.7 \frac{\text{dyne}}{\text{cm}}$$

for oil glass

$$3.66 \frac{(1 + \cos 26.6^\circ)}{2} = 3.47 \frac{\text{mg}}{\text{mm}} = 34 \frac{\text{dyne}}{\text{cm}}$$

The values of γ determined by myself at a temperature of approximately 10° using the tear-off weight of sheet metal rings are taken as a basis here; for smaller γ , α naturally also becomes correspondingly smaller.

Overview of the main results on wettability

Water

wets: ice, glass, metals, soluble salts, which increase its surface tension, and most inorganic substances in general;

forms contact angles on: coal, solid benzene, fats, resins and many other organic substances.

Glycerin

wets: glass, platinum.

Olive oil

wets: coal, copper;

forms contact angles on: ice, glass, platinum, zinc.

Oleic acid

forms contact angles on: ice, glass, platinum.

Benzene

wets: coal, copper;

(1) W. B. Hardy, Proc. Roy. Soc. (A) **88**, 610, 1912.

(2) H. Devaux, Journ. de Phys. **11**, 699, 1912.

forms contact angles:		glass, zinc, platinum.
Gasoline	} wet	ice, glass, platinum, coal.
Petroleum		
Turpentine oil		
Carbon disulphide		
wets		ice;
forms contact angles:		glass, platinum.
Ethyl ether		
wets:		ice, coal;
forms contact angles:		glass, platinum.
Alcohol		
wets:		ice, glass, platinum, zinc, copper, coal.

It is to be hoped that this still very incomplete investigation will soon be extended to as many liquids and solids as possible. However, I will probably not be allowed to do this myself in the next few years.

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Note by Timothée Mouterde:

This document is an unofficial transcription and translation of a seminal paper written by Agnel Pockels. The original version in German can be found here:

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