

Experiments with Soap-bubbles

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TABLE II.

Temperature, in degrees C., <i>t</i> .	Magnetizing force, <i>M_f</i> .	Permeability, <i>M_p</i> .	Differences between values of <i>M_p</i> at 300° and 320° C. divided by 20, $\frac{\Delta M_p}{\Delta t}$.	$\frac{\Delta M_p}{\Delta t} \times M_f$.
300 320	} 4.959 {	141.0 96.6	} 2.22	11.1
300 320	} 11.571 {	95.5 73.8	} 1.08	12.5
300 320	} 18.183 {	84.8 69.1	} 0.79	14.3

XXVI. *Experiments with Soap-bubbles.* By C. V. BOYS,
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[Plate VII.]

THOUGH none of the experiments I am about to describe depend upon any property of a soap-film which is not perfectly well known and understood, yet they serve to illustrate in a striking and beautiful manner the behaviour of bubbles under special circumstances, and so as lecture-experiments simply I hope they may be considered worthy of the attention of the Physical Society.

Everyone is familiar with the fact that a soap-bubble may be supported or even struck by a piece of baize or wool without coming into real contact with the material; it is also well known that two bubbles supported on the pipes from which they are blown, or on rings, may be pressed or knocked together with such violence as to materially alter their shape, and yet they do not come into real contact; there is a film of air between them which they are unable to squeeze out. This film, though thin to ordinary tests, is so thick that the colours

* Read April 14, 1888.

of Newton's rings are only seen when one of the bubbles is very small, so that the air is squeezed out the more readily. If the pressure is increased so as to make a real contact, the bubbles both instantly burst. That this pressure may be made great before the true contact takes place will be shown in a variety of ways hereafter; but the following simple experiment makes it very evident that the air-film will prevent the contact of two soap-films that are pressed together.

Exp. 1.—Blow a bubble about 9 cm. in diameter, and place it on a ring with a diameter of about 7 cm. This bubble may be pulled or pushed through the ring by means of a smaller wire ring which serves as a handle. (See 'Nature,' 1871, p. 395.) It may be so adjusted that the weight of the ring will not pull it through. Then a ring larger than the bubble, carrying a plane film, can be used to push it up and down through the ring, and yet the two films do not touch (fig. 1, Pl. VII.).

Bearing this fact in mind, that two bubbles may press one another without true contact, I hoped to be able to blow and detach one bubble within another, and let it roll about within the larger bubble. This, however, is made difficult by the accumulation of a small quantity of solution at the bottom of each, the weight of which is able immediately to press through the air-film between them and so cause both bubbles to burst. However, the experiment can be performed in the following manner:—

Exp. 2.—Blow a bubble on the lower side of the same ring that was used in *Exp. 1*, and if a large drop does not remain hanging to the bubble slowly apply solution to any part until as great a drop as can safely be carried has accumulated. Then pass the end of the pipe through the upper side of the bubble, and blow another inside, but take care in this case to have no excess of liquid. When the inner bubble is about twice as large as the outer one was at first, remove the pipe with a rapid movement. The inner one will now fall gently and rest within the outer one, the heavy drop pulling the thick part of the outer bubble out of reach of the inner one. The air of the outer bubble may then be withdrawn until the space between the highest point of the

two bubbles is no more than two or three millimetres (fig 2, Pl. VII.).

The great pressure which the air-film will carry is well shown by the next experiment, which, moreover, is more easily carried out than the last.

Exp. 3.—Proceed as in the last experiment, but instead of making a large drop on the first bubble, hang on a moistened ring of wire rather smaller than the fixed ring. This ring should be weighted until it pulls the bubble so much out of shape that a tangent to the curve at the points where the film meets the hanging ring makes an angle of 20° or 30° with the plane of the ring (fig. 3, Pl. VII.). A bubble may then be blown inside and allowed to drop, when it will be found to rest on the conical seat provided by the outer bubble, while the heavy drops of liquid are kept apart, and thus there is no fear of contact (fig. 4). These drops may now be both removed with the end of the blowpipe; then, if the lower ring is pulled down slowly, it will be found that the inner bubble is being squeezed out of shape until it becomes a beautiful oval, while the outer bubble shows the effect of the pressure by a corresponding enlargement (fig. 5). If the lower ring is pulled down still further, the outer bubble is simply pulled in half, and the inner one, often unbroken, gently floats away. This shows that contact was not made, as in that case both would be immediately broken. If, however, instead of pulling the ring too far, it is held in the position shown in fig. 5, it will be found that it is possible to swing the pair of bubbles round and round, and yet in spite of this violent treatment the bubbles refuse to touch one another. Or, if the lower ring is cautiously inclined and pulled away, the outer bubble will peel off it and remain attached to the upper one only. The two bubbles will now be spherical again, but there will be no heavy drop as in fig. 2. The air of the outer bubble may be withdrawn as before, until the two bubbles are barely separate.

This experiment, and many of those that follow, may be made more beautiful by using for the inner bubble a solution strongly coloured by fluorescine, or still better by uranine (for the knowledge of which I am indebted to Mr. Madan); then, if sunlight, electric or magnesium light is thrown on to

the bubbles, the inner one appears a brilliant green, while the outer one remains clear as before.

The power of the surface-tension to do work is demonstrated by blowing a large bubble below the ring and hanging on the weighted ring. If now a very small ring, a centimetre or more in diameter, is placed on that part of the bubble which is stretched across either ring, and then the part within the small ring is made to burst, the air will escape through the small hole and the heavy ring will be lifted until it comes in contact with the upper one. If the film over the whole of the heavy ring is burst instead, the ring is pulled up so suddenly that it is difficult to follow it with the eye, and it strikes the upper ring with such violence that the noise is loud enough to be heard across a large room.

A suspended ring affords a simple and accurate means of measuring the surface-tension of the soap-film. A plane film is formed across a fixed horizontal ring and a light smaller ring is attached to the plane film, which is then broken within the smaller ring so as to leave an annular film only. Weights are then hung on to the suspended ring until the angle between the film and the plane of this ring approaches 90° . At this point equilibrium becomes unstable, and the lower ring falls away, but now both rings will be found to carry plane films, though the moment before neither did. On repeating the experiment a few times it will often be found possible to use such a weight that the ring will hang for some time, but will gradually sink, while the angle referred to above will approach more and more nearly to 90° as the surface-tension of the film diminishes; and thus the exact surface-tension at the particular moment of separation may be found by dividing weight of the ring and attached moisture by twice its circumference.

Exp. 4.—Bubbles blown with coal-gas are lighter than air and rise. If therefore an inner bubble is blown with such a mixture of air and gas as to rise, it will rest against the upper side of the outer bubble, where there are no heavy drops but where the films are thinnest and cleanest (fig. 6). A pair of bubbles blown in this way will sometimes last an hour when exposed to the air of the room. The inner bubble may

be gradually enlarged by blowing in gas until the outer one can barely withstand the pull. The forms assumed under these circumstances are extremely graceful, and their beauty is increased by the play of colours on the two bubbles which the multiple reflexions seem to intensify. If, when the inner bubble is not too large, as in fig. 6, a little gas is gently let into the outer bubble, it is possible to so adjust the mixture of gas and air that the inner will float either near the top or near the bottom of the outer bubble, or about the middle, as may be desired (fig. 8). If under these conditions the bubbles are left undisturbed, the richer gas above the inner bubble will diffuse into the poorer and heavier gas below, and the bubble will slowly rise or fall, according to the relative quantities of gas and air. The diffusion through the film is well shown in the next experiment.

Exp. 5.—Blow a pair of bubbles, as shown in fig. 6, but make the inner bubble only just light enough to rest against the top of the outer one. Lower a bell-jar over all, and pass a stream of gas into the bell-jar by means of a tube passing through the top. As the air is gradually driven down, the outer bubble begins to feel the want of buoyancy, and gradually settles down, as shown in fig. 9. After a short time, the effect of the diffusion through both bubbles tending to enrich the gas of the outer bubble is made evident by the gentle descent of the inner bubble. If the jar is raised quickly, and a little air is blown into the outer bubble, it is possible to again cause the inner one to rise and float against the top of the outer one as before. The bell-jar may be lowered and the process repeated until the outer bubble is so large that the ring is unable to support its weight when in an atmosphere of coal-gas.

The very rapid diffusion of a vapour which will mix with the solution of which the film is made is easily shown.

Exp. 6.—Into a large inverted bell-jar pour a small quantity of ether, or to fill the jar with the vapour quickly wet a piece of blotting-paper with ether and stand it on edge in the jar. Remove the paper, then blow a bubble and drop it into the jar. The bubble will rest on the ether vapour as on carbonic anhydride, and while floating the most violent

agitation of the colours of the film will be seen. The bubble does not remain floating long at the same level; it gradually sinks into denser and denser layers of vapour until it reaches the bottom or breaks on the way. This gradual sinking is due to the penetration into the bubble of the ether vapour, as may be shown as follows:—The bubble may be taken out of the vapour by means of a ring wetted with soap-solution and carried to a flame, when instantly there is a blaze of ether vapour a foot or more in diameter. That the flame is not due to liquid ether condensed on the film is shown by exposing a plane film to the vapour and carrying it to a light in the same way, when no trace of flame will be seen.

Exp. 7.—At the end of a wide tube, which has been enlarged at the lower end, blow a large bubble and lower it gently into the vapour of ether, holding the finger at the mouth of the tube. After a few seconds it will be found difficult to remove the bubble by means of the tube, because its weight may have become sufficient to tear it away when buoyed up by the air only. If it is removed successfully it will hang like a heavy drop; then, on removing the finger, a light may be put to the issuing vapour, which will burn like a bunsen-burner. If, moreover, the bubble full of ether vapour is held in a brilliant light, the shadow will show the ether vapour oozing through the film and falling away in a heavy stream (fig. 10). This experiment shows in succession the floating of an air-bubble on a heavy vapour, rapid diffusion of a soluble vapour through a soap-film, and the power of the surface-tension to force the heavy vapour up a tube fast enough to supply a large flame.

Exp. 8.—Blow a bubble with oxygen gas in a jar partly filled with ether vapour; on taking the bubble out of the vapour and carrying it to a light, it will explode with a loud report. Sufficient vapour will penetrate the bubble, even whilst it is being blown, to make the mixture violently explosive.

Exp. 9.—The weight of the air is well shown by blowing a bubble with gas on a ring and then trying to blow an air-bubble within it (fig. 11). The inner bubble is then pulled out into a pear-shape, and very soon breaks away from the pipe on account of its great weight.

Exp. 10.—If *Exp. 4* be repeated, but instead of a

heavy fixed ring a light aluminium one be used instead, to which is tied a long piece of thread which may have a sheet of paper at the end, then the whole combination will float and rise in the air, even though, as in fig. 7, practically the whole of the buoyancy is due to the gas in the inner bubble. In this case the inner bubble is the bag of a balloon, the outer bubble is the netting, and the wire and the things carried by it are the car. In this case the power of the air-film to resist contact of the two films is more evident than ever. If any of the former figures 6, 7, or 8 are carrying a wire ring and thread, as described, it is possible by a suitable pull at the thread to release the pair of bubbles, which float away, one inside the other, until the ceiling brings the experiment to a conclusion.

Exp. 11.—If the inner bubble of fig. 6 is made smaller than the ring, then the corresponding experiment to that represented in fig. 5 is shown in fig. 12. The small sphere will always roll to the upper end of the outer bubble, which may be pulled out to the cylindrical form and be inclined either way. This modification of the other experiment was suggested by Mr. Newth, to whom I had shown the previous combinations.

A great many experiments may be shown in which strings of two or more bubbles, filled some with air and some with gas, tend to pull in different directions. Thus an air-bubble with a gas-bubble blown on the top of it will rise till the gas-bubble breaks against the ceiling, when the air-bubble falls again, and may be sent up as often as desired by the addition of a new gas-bubble; or three bubbles, the lower one of air the upper one of gas, so proportioned that the combination just floats, will remain until the middle bubble is touched with the finger, when the other two immediately go opposite ways. There is no occasion to say more about experiments of this type.

Exp. 12.—An experiment which is easily performed shows in a striking way how the air-film resists being broken. If a pair of bubbles are blown as shown in fig. 4, and the vibrating prongs of a large tuning-fork are brought quite close to the line where one bubble rests upon the other, both films will take up the movement of the fork, and a point of light

reflected by the two films is seen spread out into a pair of rings, so violent is the motion, yet the films do not touch. It is hardly possible to suppose that the two films remain as close together where the movement occurs as in other parts of the line of support; if they tend to separate they form an exception to the general rule that a vibrating body attracts an object in the immediate neighbourhood. In this case the inner bubble is heavier than the air in the outer one, both because of the weight of the film and the compression of the air within due to its tension. But if the same experiment is tried when the inner bubble is lighter than the air in the outer one, as it may be by holding one of the prongs close to the highest point of the bubbles shown in fig. 6, or when either bubble is heavier or lighter than air, the same result will be found—the bubbles will refuse to touch one another.

Plateau has described (*Statique des liquides*) a number of very beautiful experiments in which wire frames representing the edges of geometrical solids are dipped in soap-solution, after which they are found to carry combinations of films, plane or curved according to the character of the frame. Thus within a triangular prism, when it is removed from the solution, is found a combination of nine plane films which form three troughs meeting along the axis of the prism and a triangular pit at each end.

Exp. 13.—A spherical bubble may be dropped into one of these troughs and rolled from end to end, it may be taken out of one trough and dropped into another, or the frame may be held with its axis vertical, when the bubble may be dropped into the triangular pit, where, however, it will not remain long.

The characteristic feature of all the laminar figures is that there are never more than three surfaces meeting in a line where the angles are always 120° , or more than four lines or six surfaces meeting in a point. Further, the mean curvatures of the films are always zero so long as no air is enclosed. As Plateau mentions in his book, the screw-surface has no mean curvature, therefore if a frame be made out of a helix of wire with its ends connected by wire to a solid axis, such a frame after being dipped will carry a helical surface of soap-film.

Exp. 14.—If, instead of a single helix of wire, two helices are fixed to the same axis, but not quite symmetrically, so that in any part the wire of one helix is nearer that above it than the one below, two helical films will not be formed, but there will be a single one in an intermediate position which will be joined to the two wire screws by a pair of conical screw-surfaces, these forming with the true screw-surface a screw-shaped trough down which bubbles may be rolled or up which they may be wound, as water is wound up by a screw-pump (fig. 13). Further, if a series of small bubbles are blown along the helical edge in which the three films meet at angles of 120° , a spiral staircase is made of soap-film, down which a bubble will run one or two steps at a time, and from which it will escape uninjured when it reaches the bottom. Of course bubbles lighter than air, in the same way, will rest against the lower sides of a trough or roll up instead of down the screw-surface.

Exp. 15.—One more experiment in which the rolling of bubbles is the chief feature is worth describing. Three rings of wire, seen in section in fig. 14, are joined together by wires, shown dotted, and are carried by a central axis, which may be made to rotate. After this frame has been dipped in the solution of soap, and the three radial planes broken, it is found to carry a circular trough, into which a series of bubbles may be dropped, while at the same time the frame may be kept rotating, so that the bubbles are rolling round and round like marbles on the rim of a solitaire-board. A corresponding frame might possibly be made of light wire, which after dipping would rest on the bubbles in the first frame, thus forming a working model of the ball-bearing. I have not, however, succeeded.

Plateau has mentioned the fact (p. 166) that M. Chautard has found a soap-film a convenient envelope for a gas which is to be tested magnetically. He says that a spherical film above one pole of an electromagnet is visibly disturbed if the gas within has magnetic properties when the exciting current from a battery of 25 to 30 Bunsen's cells is made and broken. If, instead of a spherical bubble, one of cylindrical form, with its length about three times its diameter, is used, the distortion produced by a small disturbing force is so greatly

magnified that, using an electromagnet actuated by five Grove's cells only, not only is the change of form manifest when oxygen is the gas in the bubble, but it is even possible, by making the length such that the form is very nearly unstable, to cause the bubble to divide the moment the current is made to pass round the electromagnet. With the same means I have not been able to detect any change of form in a spherical bubble. Fig. 15 shows a convenient apparatus for producing, as often as may be desired, a cylindrical bubble of any degree of stability.

The short tube *a* is in connexion with a supply of oxygen which is employed to blow the spherical bubble shown by the dotted circle. According to the position of the screw *d* this bubble will be larger or smaller before it comes in contact with the ring *b*, which is held down by the loose weight *w*. The gas-tap is then immediately turned off, and the ring *b* raised by the action of the weight *c*, until the screw *e* brings the movement to a stop. Thus the length of the cylinder depends on the screw *e*, while its volume is determined by the screw *d*, and so whatever degree of stability is found suitable can be reproduced as often as may be required. The poles of the magnet should be placed at about the level of the line *pp*.

There is one other property of a pair of soap-films resting against one another, but not in contact, to which I have not referred. In a lecture at the Royal Institution a few years ago Lord Raleigh showed that two water-jets if perfectly clean will, if directed so as to meet one another at a small angle, be reflected again and fall as two separate jets, never really coming into contact at all. If the water is not perfectly clean, the experiment will not succeed. He showed that such a pair of mutually reflected jets form a very delicate electroscope, so that if a piece of excited sealing-wax is held even at a considerable distance they instantly coalesce. As the two jets in his experiments and the two bubbles in those which I am about to describe are in each case kept apart by a thin film of air, I expected to find a pair of bubbles attached to two rings in the same way act as a delicate electroscope.

Exp. 16.—If a pair of bubbles are blown on rings, which

must be insulated from one another, as shown in fig. 16, and the cover of a small electrophorus is raised even at some yards distance, instantly the two bubbles coalesce as seen in fig. 17, but do not burst as they have hitherto been found to do. Or if the two rings are connected with a key and a single bichromate-cell so that when the key is not pressed the rings are connected together, but when depressed they form the terminals of the cell, then at the moment of making the contact the bubbles unite because the electrostatic attraction between surfaces so very close together is able to squeeze out the air, which mere pressure had hitherto failed to do.

Exp. 17.—Bearing in mind how exceedingly delicate this is as a test of difference of potential, the following experiment seems the more decisive. The cover of the electrophorus may be brought so close to the side of the bubbles, shown in fig. 4, as to pull them completely out of shape, and yet the outer film so completely screens the inner from the electrical action, even though the inner one is to all appearance in contact with the outer one, that there is no difference of potential between them, and so the film of air is not destroyed. I do not know any experiment which so clearly shows as this that electrical force is confined to the absolute surface of a conductor, and is not felt at any depth within it however small.

Plateau has mentioned, p. 168, that a hemispherical film blown on a plate will screen a smaller hemisphere blown within it, and also resting on the plate, from electrical disturbance ; but in this case the two films are widely separate, and there is not the same delicate test as in the case of two bubbles apparently coincident, which instantly join when the smallest electrical stress exists between them.

Exp. 18.—One more experiment, which is a combination of these two, is worth performing. If one of the bubbles of fig. 16 is replaced by the combination shown in fig. 4 while the other remains as before, and if the cover of the electrophorus is raised anywhere in the neighbourhood, immediately the two outer films join and become one, while the inner bubble undamaged and the heavy ring slide down to the bottom of the now enlarged single bubble, and give rise to the form shown in fig. 18.

I am perfectly sensible of the fact that these experiments lie very closely on that ill-defined border-line which separates scientific work from scientific play, but I trust that the beautiful way in which they illustrate the action of certain forces may be sufficient excuse for my showing members of the Physical Society what cannot fail to remind some of them of their nursery days.

The following particulars may be of service to those who wish to repeat any of these experiments.

The solution that I have used is composed of

1	part by weight oleate of soda.
40	„ distilled water.

These, when solution is complete, are well mixed with one third the volume of glycerine and left for a week to settle in stoppered bottles. The liquid is then syphoned off from the impurities which have risen to the surface and clarified with a few drops of ammonia.

The thick wire rings and frames are made of tinned iron wire $1\frac{1}{2}$ millim. in diameter, well cleaned with emery cloth.

The thin wire rings may be made of any thin wire, but aluminium about $\frac{1}{2}$ millim. in diameter does well.

I have found it necessary to make a blowpipe with a trap as shown in fig. 19 to catch condensed moisture, which is apt to cause a failure if it mixes with the bubble. The diameter of the mouth at *a* is 7 millim. For detaching small light bubbles a pipe with a smaller mouth should be used.

When both gas and air are used in any experiment and it is necessary to regulate the proportions very carefully it is well to have a T-piece attached to the blowpipe, so that either gas or air may be blown or stopped at pleasure.