Further Explanatory Remarks Concerning the Chemical Mechanics of Cell-Division.

By

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With 3 figures in text.

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In a previous article[1]) I expressed the view that the division of cells is directly attributable to an equatorial diminution of surface tension. In my original article I illustrated this hypothesis by experiments in which drops of rancid olive oil were floated upon water, and threads, wetted with solutions of strong bases, were laid across the drops. Division resulted owing to the equatorial diminution of surface-tension resulting from the equatorial formation of soaps.

McClendon[2]) took exception to the validity of this analogy, attributing my results to the fact the oil-drop was floating upon the water so that three fluid surfaces were present, whereas under normal conditions of cell-division only one fluid surface is affected. McClendon, accordingly, submerged the oil-drop by adding alcohol to the water, and he found that when the oil-drop was fully submerged no division could be brought about by the equatorial application of soaps or alkalies.

I repeated McClendon's experiment[3]) and confirmed his results, but I found that the failure to bring about division of the droplet in this experiment was attributable to the presence of an excess of

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1) T. Brailsford Robertson, Arch. f. Entw.-Mech. Bd. 27. (1909.) S. 29.

2) J. F. McClendon, Amer. Journ. of Physiology. Vol. 27. (1910.) p. 240.

3) T. Brailsford Robertson, Arch. f. Entw.-Mech. Bd. 32. (1911.) S. 368.

alcohol in the fluid bathing the drop and not to its submergence. If alcohol be added to the water in quantities just insufficient to cause submergence of the oil-drop and alkaline threads be now applied to the equator of the drop no division occurs despite the fact that the drop is floating. I varied McClendon's experiment by causing the oil-droplets to sink through the addition of chloroform to the oil and I found that such drops, when fully submerged, could readily be made to divide by the equatorial application of threads wetted with solutions of alkalies.

This experiment has since been repeated many times by me and not only by myself but by two large classes of medical students and by several of my colleagues without a failure having been noted. Yet McClendon, in a recent article[1]), states without any qualification whatever, or any description of his methods of experimentation, that my statement that division of the drop occurs under such circumstances is false. He dismisses my results in the following sentences »Contrary to Robertson, I have failed utterly to obtain a division of the drop by this method. When the NaOH has diffused over the whole surface, a flattening of the drop occurs, but a constriction newer takes place«.

Such emphatic difference of opinion regarding a simple matter of fact can only be susceptible of one explanation. It is evident that my method of conducting the experiment is different from that employed by McClendon and that some hitherto unspecified factors in my technique are essential to its success. In endeavoring to discover these factors I have subjected the experiment to a very thorough revision and conducted it under a very wide variety of conditions.

If my interpretation of my results be correct, then, it is at once evident that in order to bring about division a strongly (albeit momentarily) localised formation of soap must be brought about in the greater part of the periphery of an equatorial plane section of the drop. The following conditions of the experiment, therefore, present themselves as of importance:

1) The strength of the alkaline solution employed to wet the thread.

2) The depth of the watery layer underneath which the drop is immersed, for, obviously, if the supernatant layer of water is too deep the alkali will be washed off the thread before it has time to reach the drop.

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1) J. F. McClendon, Arch. f. Entw.-Mech. Bd. 34. (1912.) S. 263.

3) The power of the thread to absorb and retain solutions. A silk thread will scarcely absorb the alkaline solution at all and hence we cannot expect the result which I have described if a silken thread be employed.

4) The diameter of the thread. A very thin thread will carry but little alkali and will present a large surface (relatively to its volume) from which the alkali will diffuse out into the water in which the drop is immersed.

5) The weight of the thread. It is not sufficient that a small sector of an equatorial circumference of the drop be touched by alkali; it is necessary that soap should be formed in the periphery of an equatorial plane. This cannot occur unless the weight of the thread is sufficient to cause it to sink a little way into the drop.

6) The diameter of the drop. If the drop be too large and unwieldy, the difference between the tension at the poles and at the equator may not be sufficiently sharp to cause division. If the drop be too small the diameter of a sufficiently heavy thread may be comparable with that of the drop, causing so extensive a diminution of tension over the surface that the drop merely flattens instead of dividing.

I have investigated the influence of these several factors separately with the following results:

1. The strength of the alkaline solution.

As stated in my previous communications this should be between N/10 and N/5. If the alkali be too concentrated the drops flatten out and spread, and although they may divide, the diminution of surface tension over the whole surface of the drop is so great that frequently the tension of the polar regions is insufficient to draw the two portions of the drop away from the equator; if the alkali be insufficiently concentrated, it is washed off the thread by submerging it and the amount left on the thread may be too small to bring about division of the drop.

2. The depth of the watery layer.

Employing the above concentrations of alkali the best results are obtained if the layer of water over the drop does not exceed $^1/_2$ cm. in thickness. The experiment is perfectly successful, however (subject to the conditions mentioned below), if the watery layer is 1 cm. thick.

3. The power of the thread to absorb and retain solutions.

Silken threads are useless for the purpose, as they do not take up the alkaline solution. For this and other reasons mentioned below, linen threads are the most satisfactory.

4 and 5. The diameter and weight of the thread.

Light threads of sewing-cotton cannot be employed with success as they float upon the top of the oil-droplet without sinking into it, the diminution in tension is, consequently, not equatorial. I obtain the best results with linen threads 0.4 mm. in diameter. Linen threads 0.2 mm. in diameter only, float upon the surfaces of the drops and rarely cause division.

6. The diameter of the drop.

I employ drops consisting of from $^1/_{20}$ to $^1/_{10}$ c.c. of a mixture of 20 volumes of chloroform with 30 volumes of rancid olive oil. It is possible with ease to divide a drop consisting of $^1/_{10}$ c.c. into no less than 8 parts by successive applications of the thread [1]).

If these various directions and precautions be observed, there can be no difficulty whatever upon the part of anyone in repeating the experiment and confirming my result. Regarding the plain matter of fact that under these specified conditions division of submerged oil-droplets does occur, there cannot be any legitimate difference of opinion, consequently I must decline to enter into any further discussion of this aspect of the question.

Not only does McClendon call into question the experimental basis of my hypothesis, however, he also impugns its theoretical basis. Since the fallacies which underlie McClendon's objections to my hypothesis are somewhat widely spread in biological literature, it may be of some utility to enlarge somewhat more fully upon the hydrostatic principles involved in this question than I have thought it necessary to do in my previous communications.

The theory advanced by McClendon in the second of the abovementioned articles differs in certain important features from the theory

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1) It is necessary to note here that it is sometimes possible by bringing a thread unwetted by alkali down upon the drop very sharply, so as to deal a blow at it, to cause division. This phenomenon is mechanical and to be sharply distinguished from the type of division to which I particularly refer, and which is brought about by merely gently laying the thread upon the drop and allowing it to sink in gently.

which he advanced in his earlier article. In the first of the articles referred to, he states that cell-division is due to an equatorial increase in surface tension and he cites the fact that cells »round up« immediately before cell-division as evidence of the general increase in surface tension. In the second of the articles referred to, he advances the view that cell-division is due not to an absolute but to a relative increase in equatorial tension, which, we are now told, is due to a diminution of tension at the poles.

We will take the former of these hypotheses first and, assuming its validity, see to what it leads.

Let us suppose that we have a spherical drop, the mean superficial tension of which is T and the surface $4\,\pi\,r^2$. The potential energy of the surface is therefore $4\,\pi\,r^2 T$. We may now suppose, either that a local increase of tension occurs at the equatorial circumference, or, which comes to the same thing, that the tension becomes unequally distributed in such a manner that the equatorial tension is relatively increased while the mean tension of the surface taken as a whole is unaltered[1]). We are now to assume that the drop, merely in recovering the equilibrium which is disturbed by this unequal distribution of tension, and without any external work being performed upon it, divides into two equal parts. The volume of the original drop was $^4/_3\,\pi\,r^3$. The volume of each of the new drops will be $^4/_6\,\pi\,r^3$ and their combined surface will be $\frac{8\,\pi\,r^2}{2^{2/3}} = 5.039\,\pi\,r^2$. The potential energy of the system is therefore increased (since the mean superficial tension remains unaltered) by $1.039\,\pi\,r^2 T$. Work has at the same time been performed in overcoming the cohesion of the oil-particles. Thus work has been performed not merely by the conversion of potential into kinetic energy, but with the actual storing up of additional potential energy and this without the introduction of any energy from without, a phenomenon which is thermodynamically impossible.

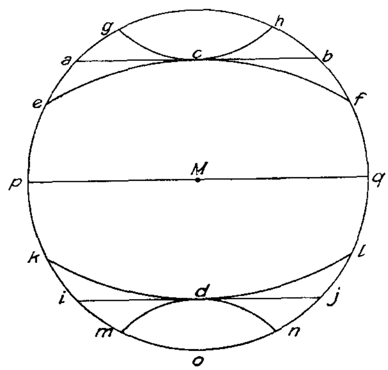
Let us now turn to the alternative hypothesis suggested by McClendon. In this, no contradiction of the laws of thermodynamics is involved, for the mean tension of the surface is supposed to be reduced and the total surface to be increased. There is obviously

[1]) We may regard the matter in this way. The mean superficial tension may be supposed to have originally been T_0. The mean tension may increase to T, following a localised equatorial increase of tension to some value larger than T.

involved, however, the view that in a continuous surface regions of positive curvature (the poles of the dividing cell) are regions of lower superficial tension than those of negative curvature (i. e. convex to the fluid in question, for example the cleft or furrow in a dividing but incompletely divided cell). This view involves a contradiction of the fundamental laws of molecular attraction in fluids, and, in point of fact, the exact contrary can readily be demonstrated to be the fact. As McClendon and others appear to experience some difficulty in appreciating the full force of these facts, it may not be amiss to cite the following very simple demonstration, which is that employed by Millikan [1]).

We know that the attraction of one fluid molecule for another is very great but rapidly diminishes with the distance. Hence at a certain very small distance from its centre the attraction which external molecules exert upon it is negligible in magnitude. A sphere described about a molecule having this distance for its radius is termed the sphere of molecular influence.

Fig. 1.



Let Fig. 1 represent a plane section of the sphere of molecular influence surrounding the molecule M which lies near the surface (enormously magnified in the figure) of a fluid drop. Any molecule lying within the circumference of this circle will attract M and any molecule lying without the circle will not. The same will be true in any plane section of the sphere of molecular influence which passes through M and, consequently, the conclusions which we find to hold good in the two-dimensional section will also hold good when extended to three dimensions. The diameter of the circle $g\,p\,o\,q\,h$ does not exceed .00005 mm. and therefore if $e\,c\,f$, $a\,c\,b$, or $g\,c\,h$ represent the surface of the fluid, M is a molecule lying immediately under the surface and $e\,c\,f$ and so forth are excessively minute portions of the surface of, for example, a fluid drop. Obviously $e\,c\,f$ and so forth

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[1]) R. A. Millikan, »Mechanics, Molecular Physics and Heat.« Boston 1903. p. 184.

may be drawn as close as we please to *M* and therefore the conclusions about to be deduced are valid for molecules actually lying upon the surface.

We will assume first that the portion of the surface which is under consideration has a positive curvature, that is, is concave to the underlying fluid and convex to the surrounding medium. We will represent it by the line *e c f*.

In this case the portion of the fluid which is enclosed within the figure *p e c f q* is exerting an attraction upon *M* which, upon the whole, is an upward pull. But this is exactly balanced by the attraction of *p k d l q*, which, upon the whole, is a downward pull. So far as the fluid enclosed by *k e f l* is concerned, therefore, *M* is under no forces and is constrained by no tension. The downward pull of the portion of the fluid which is bounded by *k m o n l d*, however, is balanced by no upward pull. This, therefore, is a measure of the superficial tension which is exerted upon *M*.

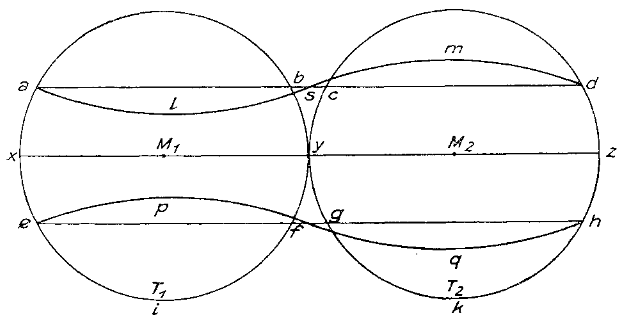
Now let us suppose that in another portion of the fluid drop there is a region which is flat, possesses, that is, a zero curvature, and let us consider the magnitude of the tension which, in this region, constrains a molecule *M* situated exactly as the former molecule was situated. In this case the molecule *M* is subjected to an upward pull by the fluid enclosed within *a p q b* and this is exactly balanced by the downward pull of the fluid enclosed within *i j q p*. The residual downward pull, which is the tension exerted upon the molecule *M* is therefore that which is exerted by the fluid enclosed within *i o j d*. It will be observed that this is smaller than the pull exerted upon a similarly situated molecule at the former point by an amount represented by the pull of the fluid enclosed within *k i d j l*. The superficial tension at points lying upon plane portions of a fluid surface is therefore less than it is at points which lie upon portions which have a positive curvature.

Again let us suppose that in yet another portion of the fluid drop there is a region which possesses a negative curvature, that is, is convex to the fluid and concave to the surrounding medium as would be the case in the cleft of a dividing cell. We may represent a portion of such a surface by *g c h*. In this case the upward pull which is exerted upon *M* is the attraction of the fluid enclosed within *g p q h c*, and this is balanced by the downward pull of the fluid which is enclosed within *p m d n q*. The residual pull of the portion of fluid enclosed within *m o n d* is therefore the tension exerted upon *M*. It will be observed that this is less than the tension which is exerted upon M, when the surface is plane and still less than the tension exerted upon M when the surface has a positive curvature.

We see, therefore, that in a continuous fluid surface acted upon by molecular forces only, regions which are convex to the surrounding medium are regions of relatively high superficial tension while regions which are concave to the surrounding medium are regions of relatively low superficial tension.

It is easy to show, by employing a similar illustration, that not only must the above principle be true for the alterations in tension accompanying alterations in the form of the surface, but also for the

Fig. 2.



alterations in the form of the surface which must accompany changes in superficial tension. Thus in the accompanying Fig. 2 let M_1 and M_2 represent adjacent molecules lying immediately underneath a plane continuous fluid surface *a b c d*, as before, let the circles represent meridional sections of the spheres of molecular influence. The upward pull which the portion of the fluid enclosed by *a x y b* exerts upon M_1 is balanced by the downward pull of the portion of the fluid which is enclosed by *x e f y* and the tension T_1 upon M_1 is due to the unbalanced pull of the portion of the fluid enclosed by *e i f*. Similarly the tension T_2 upon M_2 is due to the unbalanced pull of the portion of the fluid enclosed by *g k h*. So long as T_1 is equal to T_2 in all parts of the fluid surface, it will remain that of a sphere a minute portion of which we may represent as a plane, since the areas under consideration are minute in comparison with the area of the surface of a drop of such a size, for example, as a living cell.

But now suppose that owing to an alteration in the nature of the molecules in the vicinity of M_1 or M_2, T_2 becomes greater than T_1. The resultant force exerted upon the molecules adjacent to M_1 and M_2 will be in such a direction as to produce movements tending to alter the distribution of volume so as to equalise the tension upon M_1 and M_2 and thus annul the force producing movement. Moreover, the total attraction of the sphere around M_2 towards the right, which was formerly balanced by that of the sphere around M_1 towards the left is now not completely balanced and molecules will be pulled over from the neighborhood of M_1 towards M_2. In order to equalise the tensions T_1 and T_2 it is evident that the fluid enclosed above the line yz must be increased in amount in order to annul a larger proportion of the pull of the portion of the fluid below yz, while the fluid above the line xy must be reduced in amount so as to annul a lesser proportion of the pull of the fluid below xy. The redistribution of volume must be such, therefore, as to produce a surface of the form indicated by the curved line $alsmd$. The tension upon M_1 is now represented by the pull of the fluid enclosed within the figure $eifp$, while that upon M_2 is represented by the pull of the smaller volume of fluid enclosed within the figure $gkhq$. Since, however, the pull per molecular unit volume exerted by the fluid within $gkhq$ is greater than that exerted by the fluid within $eifp$, the tensions T_1 and T_2 will again be equalised and equilibrium attained. We see that in a continuous fluid surface of variable tension the regions of high superficial tension must be convex to the outer medium while those of low superficial tension must be concave to the outer medium. If this concavity occurs all round an equatorial circumference a dumb-bell-shaped surface will be produced of which the equatorial (approximately cylindrical) portion may be short or long according as to whether the slope of the cleft is steep or gradual. If this process (reduction of tension) proceeds sufficiently far to cause the length of the equatorial cylindrical portion to become equal to its circumference, it will break and one drop will split into two[1]).

We may conclude that in a dividing cell the polar regions must be regions of relatively high superficial tension while the equatorial region in which the cleft occurs must be a region of relatively low

[1]) Cf. J. PLATEAU. »Statique des liquides soumis aux seules forces moleculares.« Paris 1873. Tome 2.

superficial tension. This is the exact contrary of the situation depicted by McClendon.

So much for the theoretical bases of the hypotheses of Bütschli and McClendon which, it will be seen, are entirely fallacious. It remains to consider the *experimental evidence* which is brought forward by McClendon in support of the more recent version of his hypothesis. It will be found that this is no less questionable than the theoretical assumptions just considered.

Thus McClendon states »The mechanics of cell-division may be illustrated by a more tangible model. A rubber balloon is inflated with air and attains a spherical shape. The rubber may represent the surface film and with uniform thickness of rubber we obtain uniform tension and spherical shape. It the equator of the balloon is re-inforced with a rubber-band, the tension along the equator is increased and the balloon is constricted equatorially«[1].

McClendon forgets that a rubber balloon can in no way afford an analogy to a fluid surface because, in the first place, adjacent non-continuous portions of its surface do not attract one another and in the second place the tension of rubber varies with the degree to which it is stretched, while that of a fluid surface does not. The falsity of this analogy has repeatedly been insisted upon by physicists[2].

Let the accompanying figure represent the form of an equatorial section through the inflated balloon described by McClendon. Let us suppose that the points a and b are the same distance apart as the points c and d, and furthermore, that this distance is less than the radius of sphere of molecular attraction. Now if the material be rubber, the attraction between a and b is negligible or zero, while that between c and d is great. Hence there is nothing to prevent the cleft from extending downwards until the tension of the equatorial region is so reduced by the relaxation of the rubber band that it is balanced by that of the polar regions. But if the surface depicted were a *fluid* surface and the cleft were a region of relatively high surface-tension, the attraction between a and b would, *ex hypothesi*, be greater than that between c and d; the cleft could not possibly extend but must, on the contrary, close up, and, furthermore, since that portion of the surface contracts more strongly

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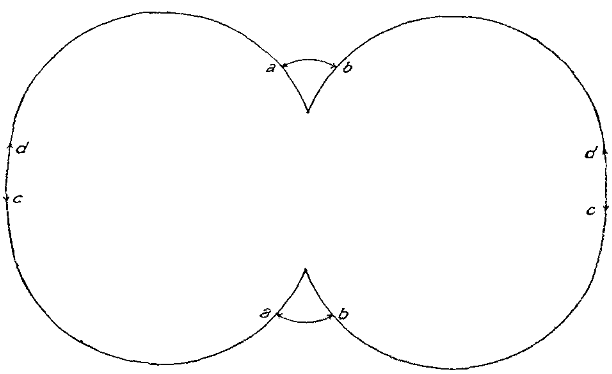
[1] Arch. f. Entw.-Mech. Bd. 34. (1912.) S. 265.

[2] Cf. for example, C. M. Minchin, »Hydrostatics and elementary hydrokinetics.« Oxford 1892. p. 338.

than the rest, it must become more highly curved and the poles relatively flattened so that the form finally assumed, as I have pointed out before, must be that of a flattened disc, the region of high tension forming the highly-curved edge of the disc.

The second experiment which is brought forward by McClendon in support of his hypothesis is the following: — a drop of a mixture of rancid olive oil and chloroform is immersed under water and N/10 NaOH is applied to the poles by means of pipettes. »If the NaOH is applied to the two poles at exactly the same time and rate, the drop constricts as in Fig. 1 and divides in two.« The figure referred to illustrates a dumb-bell-shaped surface having the convexities turned towards the pipettes.

Fig. 3.



I have repeated this experiment of McClendon's a number of times and under a variety of conditions and I regret to have to admit that I have hitherto been unable to obtain precisely the appearance which he illustrates. Doubtless this is due to some defect in my technique, but, granting this to be the case, the phenomenon described by McClendon is only indirectly due to molecular forces and does not bear upon the question of the mechanics of cell division at all.

Briefly, what I observe in repeating McClendon's experiment is the following: — as soon as the alkali touches the drop of oil (which is resting upon the flat bottom of a glass vessel), the drop cases to be spherical and quite suddenly flattens. Transiently, the flattened mass may bulge in irregular shapes towards the pipettes, but the usual effect (if the alkali be not too strong) which immediately succeds this is a gathering up of one or other or both of the equatorial extremities of the mass into a more or less globular form and an elongation of the mass equatorially in a direction perpendicular to the line joining the openings of the pipettes. If this takes place at both equatorial extremities at once, division of the mass into two may actually occur in a plane perpendicular to the plane of division which is depicted by McClendon.

It is easy understand what is really taking place under these circumstances. The forces acting upon a drop which is resting upon a flat surface are not purely molecular, gravity is also acting and tending to flatten the drop and cause flowing in a lateral direction. This tendency is resisted by the surface-tension of the drop, but if the superficial tension be reduced over any considerable area bulging will occur and the fluid will flow towards the side of reduced tension because the centre of gravity of the fluid mass is lowered thereby. Molecular forces, although reduced, are still effective, however, and if the mass be not too large or the tension too much reduced, the region of high tension will become highly curved and the regions of low tension indented in accordance with the principles already made clear, so that the fluid mass becomes elongated equatorially in a direction perpendicular to the line joining the openings of the pipettes.

That the flowing and bulging of the drop towards the region of reduced tension is really due to gravity and not to molecular forces is readily seen from the following experiment.

Saturated NaCl solution is poured into a glass cylinder until it approaches nearly to the top, and then the cylinder is inclined and distilled water poured gently down the side so as to avoid so far as possible mixing of the two fluids. In this way we obtain a cylinder of fluid of continuously varying density increasing from above down. On now introducing into this, drops of the chloroform-oil mixture described above, we find that they float in the fluid at a little distance below the surface, where the fluid is of the same density as the drop. Under these circumstances the drop behaves as if it were weightless, only molecular forces affect it and gravity has no action upon it[1]). On now applying N/10 NaOH to two poles of such a drop by means

[1]) Cf. J. Plateau, loc. cit. Tome 1. E. Mach, »The Science of Mechanics.« London 1902. p. 384.

of pipettes, we find that no bulging of the drop towards the pipettes occurs at all, on the contrary, the poles flatten and the equatorial region becomes highly curved so that the drop is converted into a disc of which the long diameters are perpendicular to the line joining the orifices of the pipettes. If N/1 NaOH be employed the result is in no way different. The rationale of this phenomenon will be apparent from what has preceded.

On the other hand, I have repeated my experiment of causing division by means of alkaline threads equatorially applied to weightless drops suspended as described above, and I obtain the results which I have already described. I find, however, that somewhat stronger alkali (e. g. N/1) is required in order to obtain invariable success, probably because the manipulation required is more delicate and the time during which the thread is immersed in water before it touches the drop is greater. The best method of performing the experiment is to lower an alkaline loop of thread into the water and draw it gently up through the drop. If the drop is neither too large nor too small, division occurs, although as might be expected, the drops frequently re-coalesce if they remain in contact, a phenomenon which is prevented in cell-division by the formation of a pellicle on the outside of the cells which may be dissolved off by appropriate reagents so that the cells re-fuse[1]).

If a thread unwetted by alkali be brought into contact with such a drop it clings to the thread and if the thread be looped around it a disc-shaped drop is formed of which the highly curved edges are the regions of high tension in contact with the thread.

Referring to the experiments of Bütschli and others, McClendon says: »In all of the above mentioned experiments a decrease in surface tension is shown to cause a protrusion of the surface. Robertson, however, claims that a decrease of surface-tension causes a receding of the surface and when the decrease is along an equator the drop is cut in two«. A little further on McClendon unconsciously contradicts this statement and at the same time betrays the cause of the »protrusion« in question in the following sentence: »When the NaOH has diffused over the whole surface a flattening of the drop occurs«. It will be evident that the »protrusion« observed by Bütschli and McClendon is due to gravity and only indi-

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1) J. Loeb, »Die chemische Entwicklungserregung des tierischen Eies. (Berlin 1909.)

rectly to molecular forces. The fact that the surface of a fluid invariably recedes from a region of low superficial tension unless constrained by gravity to do otherwise is shown by a classic experiment which consists in bringing a rod moistened with alcohol or ether towards a glass plate wetted with water. The (plane) water surface recedes from the regions touched by the vapour of the alcohol having a hollow (negative curvature) or even breaks altogether[1]). This occurs at whatever angle the plate may be tilted, because the action of gravity upon thin films is negligible in comparison with that of molecular forces[2]). Since cell-division normally occurs in all planes indifferently, it is evident that here, also, gravity exerts a negligible action.

In passing, it may be useful to point out the bearing of these facts and considerations upon the current theories of amoeboid motion. The majority of writers upon this subject, not excluding myself[3]) have assumed that weakening of the superficial tension upon one side of a drop causes bulging of that side and contraction of the other and in this way appear to imagine that continuous progress of the drop could result. Even taking account of the action of gravity in such a case, it is evident from the Newtonian principle of Action and Reaction that all that could be accomplished in this way is a lowering and no lateral shifting of the centre of gravity of the drop. If we consider only surface tension and gravity to be acting in such a case the amoeba, endeavoring to progress with the aid of these agencies, would be in much the same position as a boy enclosed within a football trying to progress by pushing against the inside[4]). It is evident that if amoeboid motion is to be interpreted along these lines the cohesion between the amoeba and the surface over which it is creeping must be taken into account as well as the superficial tension of the water-amoeba surface.

In conclusion, I wish briefly to refer to the objection which McClendon has raised to another part of my hypothesis of cell-division. The complete hypothesis, as originally presented, was this: That in the polar synthesis of nucleic acid which I presumed to precede cell-division, lecithin is broken up to provide the phos-

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1) Cf. Clark Maxwell, »Theory of Heat«.

2) Cf. E. Mach, loc. cit. p. 393.

3) T. Brailsford Robertson, Trans. Roy. Soc. of South Australia. 29. (1905.) p. 1.

4) I am indebted for this illustration to Professor W. H. Bragg, F. R. S.

phoric acid and cholin or soaps of cholin are liberated as byproducts. The cholin or cholin soap, diffusing from both poles attains a maximum concentration in the equatorial plane, thereby reducing the surface-tension until division of the cell results. McClendon, quoting Masing[1]) and Shackell[2]) states that no synthesis of nucleic acid occurs in cell-division and no decomposition of lecithin.

Now I have repeated the experiments of Shackell two or three times with considerable care, and, without desiring at the present juncture to venture upon any more positive statement, I may say that very numerous and important sources of error enter into Shackell's determinations. These will be dealt with in detail in a subsequent communication, but I have gained the conviction from the experiments which I have conducted, that success in such estimations as those attempted by Shackell can only be rendered possible by a meticulous attention to biological and chemical detail and by the employment of a technique widely differing from that employed by Shackell. The determinations of Masing are even more open to criticism than those of Shackell as any analytical chemist will perceive on glancing at his communication. I therefore consider that at the present there is no valid evidence in support of the thesis put forward by Shackell and McClendon, nor, so far as I am aware, is there any valid evidence in support of its converse in the first stages of the development of holoblastic eggs.

However the case may be in regard to nuclein synthesis in cell-cleavage, there can be little question that cell-division is directly attributable to an equatorial diminution in the surface-tension of the cell. The question of the nature of the mechanism which brings about this decrease in tension is an entirely separate problem.

Summary.

When oil-droplets are submerged by the addition of chloroform to the oil and sufficiently alkaline threads be brought in contact with a sufficient proportion of an equatorial circumference, division of the droplets into two occurs.

In cell-division the cleavage furrow is a region of low superficial tension, the poles of the egg are regions of high superficial

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1) Masing, Zeitschr. f. physiol. Chemie. 77. (1910.) S. 161.
2) Shackell, Science. 34. N. S. 1911. p. 573.

tension. Bütschli and McClendon's view to the contrary is shown to involve a contradiction of the laws of molecular attraction in liquids. McClendon's evidence in support of his hypothesis has been shown to be fallacious.

Zusammenfassung.

Werden Öltröpfchen durch Zusatz von Chloroform zum Öl zum Untertauchen und genügend alkalische Fäden mit einem ausreichenden Teile ihres Äquatorialumfanges in Berührung gebracht, so tritt Zweiteilung des Tröpfchens ein.

Bei der Zellteilung ist die Teilungsfurche ein Bezirk niedriger Oberflächenspannung, die Eipole stellen Bezirke hoher Oberflächenspannung dar. Es wird gezeigt, daß Bütschlis und McClendons gegenteilige Ansicht einen Widerspruch gegen die Molekularattraktions-Gesetze in Flüssigkeiten involviert. McClendons Beweis zur Stütze seiner Hypothese wird als auf einem Irrtum beruhend nachgewiesen.

(Übersetzt von **W. Gebhardt.**)