within their embouchures, as I first ascertained when carrying out my current tests in that river; brackish water was consequently found in the lower depths, percolation of sea-water through the sandy substrata no doubt then partly accounting for its brackish condition. But eddy surface-currents along the sides of the river, under the influence of the prevailing N.W. winds blowing directly into the mouths, no doubt also assist the intermixture as far as it goes—just as the return-current down the European coast is diluted and intermixed in its general and superficial density from the rains and rivers of the north, and thus tends to restore the lost freshness of the equatorial or trade-wind and Gulf-stream currents, as the tropical rivers and rains tend to restore the loss in the low latitudes: thus condensation from evaporation and redilution by surface-currents are throughout mainly maintaining the equilibrium. Dr. Forchhammer shows that this lighter density or dilution of the encircling superficial waters from the equator commences from the American rivers from the parallel a little north of the Bermudas, and that it exists all along the European coast and again on the African coast from the African rivers; and he has shown that the effect of the La Plata is found 900 miles from its mouth. The fact I have given of the condition at the Nile's mouths at certain seasons is an extreme case, quite in accordance with the great undercurrent theorists' views, and I mention it as a fact of interest to them. But nevertheless I believe, from my own experience, and from the facts to be gathered from Dr. Forchhammer's elaborate researches into the temperatures and saline densities, that as it is not an appreciable and measurable movement as an undercurrent at the Nile or Dardanelles, and only chemically testable by the tongue or hydrometer, so are there no great mechanical and appreciable movements as undercurrents in the ocean as a necessary result of the very slight difference in the densities of one part of the ocean and another. Nevertheless a complete investigation into the phenomena of ocean-currents is a most desirable operation, and can be so easily accomplished on the plan I have found so practicable and easy, and recommended several years ago for adoption by all scientific captains when crossing the great oceans, especially when calms detain them and favour the experiment, without fear of the results being confused or mistaken; for then only should it be carried out where there are great depths and where strong surface-currents exist.

XII. "On the Physical Principles concerned in the passage of Blood-corpuscles through the Walls of the Vessels." By Richard Norris, M.D., Professor of Physiology, Queen's College, Birmingham. Communicated by Dr. Sharpey, Sec. R.S. Received June 12, 1871.

In the year 1846 my much-lamented teacher, Dr. Augustus Waller, published in the Philosophical Magazine two able papers relating to the

perforation of the capillaries by the morphological elements of the blood, viz. the red and white corpuscles.

These observations attracted little attention till the year 1867, when the facts made known by Dr. Waller were rediscovered by Professor Cohnheim, of Berlin.

Since the publication of Cohnheim's researches very considerable interest has been taken in the subject, and the experiments have been repeated and the facts corroborated by eminent physiologists and pathologists in all parts of the world.

On a careful consideration of the hypotheses which have been propounded by Waller, Cohnheim, Stricker, Bastian, and Caton, to account for the curious phenomena in question, it will be found that all these hypotheses fall short in one important particular, inasmuch as they afford no explanation whatever of by far the most singular part of the process, viz. the fact that the apertures through which the corpuscles pass again close up and become invisible. The question, indeed, is not so much how the corpuscles get out, as how they get out without leaving any permanent trace of the apertures through which they have so recently passed, and which were so palpable during the period of transit.

Before proceeding to elaborate my own views, it may be well to restate succinctly the various points upon which observers are agreed.

1st. Both white and red corpuscles pass out of the vessels through apertures which can neither be seen before their ingress into or egress from the vessel wall, but only during the period of transit.

2nd. An essential and primary step in the process is, that the corpuscles shall adhere or, more properly, cohere to the wall of the vessel.

3rd. These cohering corpuscles shall subsequently be subjected to pressure from within.

With these conditions fully before our minds, we will proceed to inquire if in physics we can find the analogue of these seemingly mysterious phenomena.

In the first place, this phenomenon of the passage of bodies through films or membranes is by no means confined to the capillary walls, the same thing has been observed in nucleated blood-corpuscles, such, for example, as those of the frog. In these cases no rupture or aperture of exit has been discovered.

It is obvious that the escape of the nucleus from its capsule without rupture, and the passage of the entire blood-corpuscle through the capillary wall without rupture, are phenomena of the same class; and the explanation which will suffice to clear up the one, will also apply with equal force to the other.

As a matter of fact, it will be admitted that we can form no *à priori* conception of one form-retaining body passing through another without either rupturing it or distending certain holes or pores which it may already possess. This, however, is just one of those cases in which con-

ceivability is no test whatever of possibility. To comprehend these phenomena it is necessary to bear in mind the ultimate constitution of the animal membranes, which form alike the capsules of the corpuscles and the parietes of the capillaries*. All the membranes which enter into the animal body may, from a physical point of view, be divided into two orders, —the very fine structureless homogeneous films which must be regarded as simple cohesion-membranes, in contradistinction to the second order of coarser membranes, to which certain mechanical arrangements are superadded, which have the effect of increasing the strength, such, for example, as structure, the result of interlacing fibres; in films of collodion, gelatine, albumen, india-rubber, and soap we have examples of the first class of membrane. It is with this class that we are now concerned, and these are susceptible of two states, the fixed or rigid condition, and the contractile or elastic state, dependent upon the presence of the principle of "flow," which principle may be operative in every shade and degree, from perfect liquidity to absolute rigidity.

It will be sufficient to state here that the more colloid and plastic those membranes are, or, in other words, the more they approximate in their constitution to liquids, so do they proportionately cease to obey exclusively the laws of rigid bodies, and begin to exhibit intermediate properties or qualities, some of which belong to solids and others to liquids.

We may take the soap-film as the best illustration we can find on a large scale of the class of homogeneous cohesion-films, possessing in the greatest perfection this principle of "flow," and as exhibiting to the fullest extent phenomena which I have generalized under the term progressive cohesive attraction†.

By the study of the soap-film we may acquire a knowledge of many

* The parietes of the capillaries are held by modern histologists to consist of protoplasm, a substance which is universally considered to be of a viscid semiliquid nature, and in which it is easy to demonstrate the presence of the property of flowing within certain limits.

† The term progressive cohesion is here used in contrast with that operation of cohesion which simply maintains contact between the particles of two like or unlike substances or bodies, and which, when it occurs between the particles of unlike bodies, is called adhesion. The attraction of cohesion evidently operates for some distance beyond the atom or particle, so that actual contact is not essential to its display. When two small globes of mercury, or of any other liquid, are made to touch at one point, they merge, as is well known, with great rapidity into each other, and the materials which compose them become arranged around a common centre, that is to say, one larger sphere results. The mode of union of these two spheres is clearly a progressive one, the particles nearest to those in actual contact being the next to come into contact, and so on, until the globes become intimately united. In the presence of gravitation there can be no mass-attraction between the two globules.

Again, when a solid is partially immersed in a liquid having a cohesive affinity for it, *e.g.* a sheet of glass, the liquid, as is well known, rises considerably above the water-level. This shows that with unlike bodies the action extends beyond contact, and is progressive in its operation from one line or row of particles to the next above. This term therefore includes all effects of cohesion which arise from and display its opera-

of the laws which are operative in connexion with delicate colloidal films in general.

The steps, for example, in the production of an ordinary soap-sphere are very remarkable, as exemplifying the power which these films possess, under the influence of progressive cohesion, to perfect any absence of continuity which may exist in their structure.

The first essential in the process of forming a soap-sphere is the production upon the mouth of the pipe-bowl of a film stretching evenly across from every point of the circumference.

The production of this film is a far more complex operation than is generally supposed.

If for the pipe-bowl we substitute a ring having a diameter of from 12 to 18 inches, we are enabled to watch, as the process proceeds, the manner in which the film is formed.

Having submerged the ring in a solution of soap, we observe, as we gradually raise it out, that its circumference brings up from the liquid a band-like film of a cylindrical or tubular form which is attached to the ring above and the liquid below; raising up the ring still higher, we find that this annular film contracts in diameter at every part except at its attachment to the circumference of the ring, which is of course fixed. This quality of the film to contract between opposing points of extension causes it to take on the shape of an inverted cone with curved sides, the convexities of which are directed inwards. The tendency to assume the inverted-cone shape is further assisted by the fact that the film, in contracting, travels inwards upon the surface of the solution towards a central point, so that from the ring downwards to the surface of the solution the diameter of the tubular film is continually decreasing. The shortest diameter is not, however, immediately upon the surface of the liquid, but at a little distance from it; and consequently, as the contraction proceeds, it will be at this spot that the union of the sides of the film and the separation will take place. This arises from the fact that this is the weakest point of tension between the ring and the liquid, and therefore the one in which circumferential contraction can take place with the greatest ease and effect. Thus we see that the tubular film which we have raised really becomes constricted into two portions,—an upper portion, which immediately contracts into a plane surface upon the ring, and a smaller and lower portion, which, in consequence of including air, becomes a hemisphere and remains attached to the surface of the solution. If, having formed such a film upon a ring or pipe-bowl, we proceed to blow down upon it, we distend it into a sphere; but it is obvious that until the sphere is detached

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tion beyond the line or boundary of actual contact. All capillary phenomena may be regarded as due to this progressive action of cohesion operating at one and the same time in diverse directions.

there exists a free opening into it at its upper part, which becomes suddenly sealed up by cohesion of the sides of the film at the moment preceding detachment; and this detachment is seen to be a repetition of what takes place in the formation of the primary film.

The next point to which I would draw attention is the power possessed by these films to repair breaches of continuity that may be made in them subsequently to their formation. If any rigid body be wetted, it is quite possible to thrust it through one of these films, move it about, and again withdraw it without interfering with the integrity of the structure, as may be proved by passing a smooth bulbous rod of glass through the film. It is not, however, essential that the body should be either smooth or regular, for the same thing may be done with the naked fist and arm.

I have demonstrated elsewhere that the blood-corpuscles undergo a mode of aggregation in obedience to progressive mutual attraction in precisely the same fashion as soap-spheres,—that is to say, if they touch at any one point they gradually, by the operation of double cohesion (capillary attraction), convert each other into polyhedral-shaped bodies*. If we wet any smooth rigid surface and allow one point in the circumference of a bubble to impinge against it, we find that it becomes so drawn down to the plate in every direction, from this point as a centre, as to take on a hemispherical form. But if for the rigid surface we substitute a delicate flowing film, such as the soap-film, and allow the bubble to come in contact with it at one point, taking care that there is a free supply of liquid upon its exterior at this point, we observe that the result is different. In this case the soap-sphere takes on the form of two watch-glasses in apposition at their edges, one of the curves being present on each side of the film. The soap-sphere has, in fact, penetrated the film, and arranged itself so that half is on one side and half on the other.

Now this is precisely analogous to what takes place with the capillary when the corpuscle has entered into cohesion with its wall; "a protuberance is seen on the outer surface."

If we can subject this soap-sphere to pressure on one side only, we shall cause it to protrude through the film still further; this we can do by forming one sphere within another. This inner sphere protrudes more than in the case of the simple film. That there is pressure within a bubble may be known by the fact that, if left with an aperture in it, it will gradually force out the contained air and become again a simple film by its strong cohesive tendency.

Further, it will be seen that we can with the greatest ease separate these cohering spheres, bringing them bodily through the film without injury to one or the other; and this may be taken as a parallel case to the passage of the nucleus through the capsule of the corpuscle, and of the corpuscle itself through the capillary wall.

I have previously shown that the corpuscles are amenable to the same

* Proceedings of Royal Society, vol. xvii. p. 429.

laws as the soap-spheres, and we have only to infer that they bear the same relation to the capillary walls as these spheres and films bear to each other. The margin of speculation is therefore small.

In the case of the corpuscles this relation is of course only seen under abnormal conditions, simply because it is a physical law which in the normal working of the animal economy required to be antagonized.

It must also be observed that it is only under certain conditions that the soap-spheres attract each other, or are attracted by rigid surfaces or plastic films. This occurs only when free liquid is cohering to their surfaces. If before bringing them into contact we allow the soap-film and sphere to become moderately dry, they will not attract each other, but the former will support the latter as a perfect sphere instead of drawing it down by progressive cohesion and arranging it halfway through itself.

Just so with the corpuscles; they do not unite either with each other or with the capillary wall, unless their normal osmotic relations are disturbed, the exosmotic current setting in excessively when their external surfaces become coated with content-matter, and they become instantly attractive of each other, of the capillary wall or glass slide, as the case may be.

In the paper before referred to, "On the Laws concerned in the Aggregation of the Blood-corpuscles," I have given numerous examples of the operation of progressive cohesive attraction; but in this place I wish to call attention to the demonstration there given of its relation to plane surfaces.

Taking this experiment as a starting-point, we will extend the consideration to surfaces of a different character. In the first place, we find that this law continues to operate with great facility in connexion with surfaces curved in one direction only, whether the surface used be convex or concave; in both cases the film of paper or collodion applies itself evenly to the surface in the gradual progressive manner before explained.

If, however, for surfaces curved in one direction only, we substitute such as are curved in all directions (for example, the outer or convex, or the inner or concave surfaces of a hollow sphere), we find ourselves confronted with a new set of difficulties, out of which we may evolve the statement that, for any film to apply itself evenly and regularly to either the convex or concave surface of a sphere under the influence of progressive attraction, it is necessary that the film should be, in several particulars of its constitution, very different from the class of films by means of which we have been able to illustrate the three preceding experiments.

If, by way of illustration, we apply a film of wetted collodion or fine cambric paper to the sphere, so that one point of the convexity of the latter may come in contact with the centre of the film, the attraction will only succeed in pulling it down to the surface of the sphere at certain points; the intermediate puckered parts are not in contact, and can by no possibility become applied. From this we see that for the film to be laid down evenly, it would be necessary that it should contract in certain parts,

that, in fact, the puckered or surplus material should be taken up. We may say, then, that any film which can adapt itself to the surface of a spherical body must possess the twofold quality of facile contraction and expansion, these qualities being controlled in their operation by progressive cohesive attraction. Such a film must be a simple colloidal cohesion-membrane in possession of the property of "flow."

Further, if we apply to a sphere a film known to possess facile properties of expansion and contraction under the influence of slight forces, such as progressive cohesive attraction, the first thing seen to occur is cohesion of the film to the sphere at the point of contact; and from this point as a centre of operation the film proceeds to apply itself gradually in all directions, so that the sphere becomes coated or covered evenly by it: this process goes on till such time as the attraction becomes balanced or fully antagonized by the elasticity of the film, that is to say, the attraction is only powerful enough to stretch the film to a certain extent; so that if the rigid object be fixed, as is the case with the glass bulb when held immovably, we get a flattened form of the film. A sufficient degree of attachment of the film to the bulb has taken place to stretch the former backwards out of its normal plane. If, now, we push the bulb further forwards, the film still continues to apply itself to its surface, and having reached the equatorial line of the sphere, descends on the opposite hemisphere till the bulb is completely coated. But it will be said the bulb does not then really produce an infraction of the film, but merely attracts it down to its surface, and in so doing stretches it, so that it is in reality a new conformation of the film and not a breach of its continuity. That this is true to a certain extent there is no doubt, but it is not all the truth; for we may wipe the bulb dry after it has passed through the film without interfering with the continuity of the latter. All that appears to be necessary for these effects to display themselves is, that there should be mutual cohesion between the film and the body passing through it; for if we press against one of these delicate films with a substance which has no cohesion for it, *e.g.* a current of air or a dry soap-sphere, it simply distends the film, neither bursting it nor giving rise to an aperture in it; while in the case of a body to which the film can cohere, it would appear to be easier for the latter to allow the passage of the cohering body than to suffer distension by it, and this because it has under these conditions as great an attraction for the particles of the body as for its own particles. When the cohering body has become perfectly applied to the film, the latter, by the cohesiveness of its own particles, contracts to the greatest degree possible consistent with still maintaining its attachment to the cohering body; and this in spherical-shaped bodies leads to a condition of things in which half the body is within and half without the film or wall*; therefore the rest of the process must be

* An excellent illustration of this principle is afforded when a light india-rubber ball or balloon is suspended from a fixed point, its surface having previously been wetted with a solution of soap. When a soap-film formed upon the ring, as in the previous

accomplished by pressure from within. It is easy to see that the manner or degree to which the corpuscle or body coheres to the film will determine very materially the method of its transmission.

All, then, that is essential for a rigid or plastic body to pass through a colloid film is :—1st, an intimate power of cohesion, either mediately or immediately, between the film and the body; 2nd, a certain amount of pressure from within; 3rd, power in the substance of the film to cohere to the surface of the body (or to some intermediate matter which already coheres to the surface) during its passage; 4th, cohesive plasticity of the particles of the material of which the film itself is composed, so that the breach in it may again become reunited as it descends upon the opposite surface of the body which is being extruded.

It is quite remarkable to how great an extent these conditions appear to be complied with in the passage of the white corpuscle through the capillary wall, as affirmed by independent observers.

In the factitious examples by which I have sought to illustrate these effects, the film moves over the body, or the body through the film, by virtue of the intermediate agency of the solution which has cohesive attraction for both; and the film does not rupture, because, while the body is travelling through, it can continue to cohere till such time as it is brought again into contact with its own particles at the opposite pole of the extruded body.

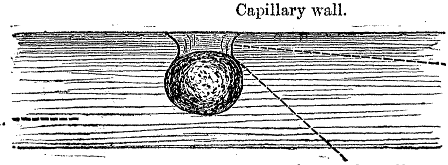
Theoretically, as it leaves the sphere or protruding body, the aperture should gradually narrow to absolute union at a focal point, or, according to the laying-down view, having resealed itself from the bulb; practically, however, I find that the film rarely leaves the bulb or sphere without forming on it a small hemispherical bubble, which is large in the ratio of the rapidity with which the detachment is effected.

If detached with very great care, the bubble is exceedingly small; but I could not succeed with a spherical bulb in getting rid of it altogether; with a more conical bulb, however, this was readily effected. In the case of the sphere, the film is in reality drawn out into a little neck, as in the other examples in which continuity is effected; and this neck is pulled into two, and both parts cohering at the point of severance, we get on the one side the perfected film, and on the other a small enclosure of air which takes on the hemispherical form. This is owing to the annular contraction of the tubular part. If the body were small or less spherical, or the film a trifle more rigid, this would not occur. I find, in fact, by experiment that smaller bodies, more conical in their termination, do not do this, but draw out a kind of streak of solution as they leave the film—a fact I have often observed with the white corpuscles. In

experiments, is brought into contact with one point of its convexity, the ball is at once drawn into the film as far as its equator, and is compelled to retain this position in opposition to the force of gravity. This is the exact converse of the case of the fixed bulb, in which the attraction is satisfied at the expense of the expansibility of the film.

this case the film is brought to a focus upon the body, and not at a slight distance from it; so that either or both these modes might obtain with the corpuscle. In some cases the streak of solution is absent. The method of sealing, which leaves behind a portion of the film, is probably a necessity of every case of repair of continuity, with the exception of that of transmission of a foreign body through a film.

In the case of the blood-corpuscle it would not appear that the capillary wall became applied over the surface of the corpuscle to any great extent, but that, having effected cohesion, it becomes easier for the capillary wall to give way and glide over the corpuscle than to be distended by it; and this is effected much slower than in the case of the factitious examples which I have placed before you. For capillarity to come into play, the presence on the exterior of the corpuscle of another and cohesively dissimilar liquid to the liquor sanguinis is required; and this we obtain by the outward passage, under the influence of osmosis, of the content-matter (hæmoglobin) of the corpuscle; a magnified view of the relations present may be thus represented:—



We may conclude in the appropriate words of Herbert Spencer:—"We have in these colloids, of which organisms are mainly composed, just the required compromise between fluidity and solidity; they cannot be reduced to the unduly mobile conditions of liquid and gas, and yet they do not assume the unduly fixed condition usually characterizing solids; the absence of power to unite together in polar arrangement leaves their atoms with a certain freedom of relative movement, which makes them sensitive to small forces, and produces plasticity in the aggregates composed of them."—*Principles of Biology*, p. 23.

The Society adjourned over the Long Vacation to Thursday, November 16th.

Presents received May 25, 1871.

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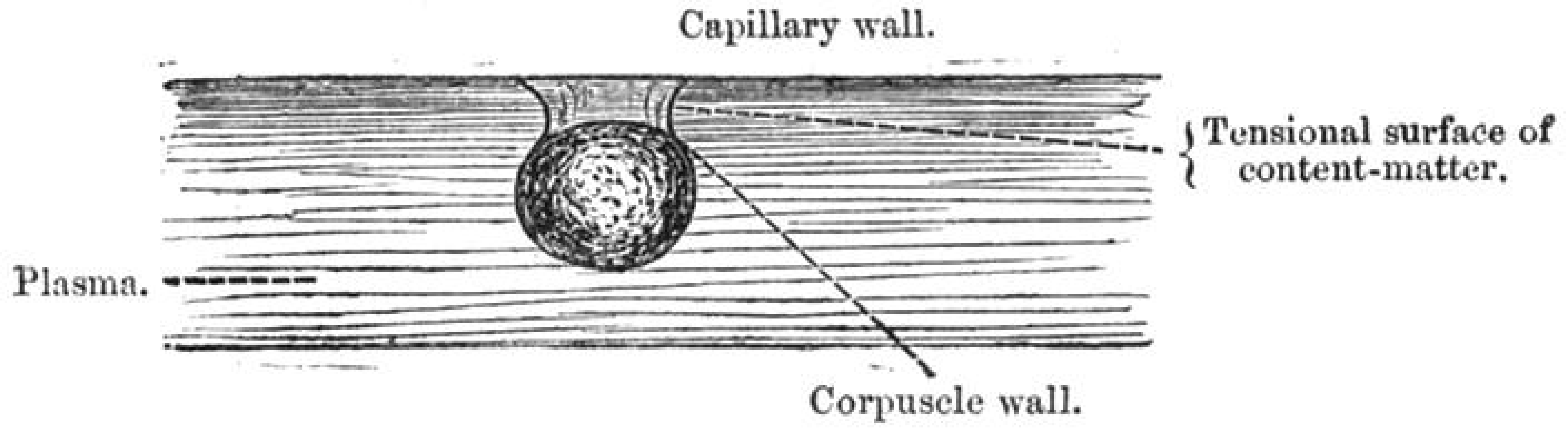
Capillary wall.
Tensional surface of content-matter.
Plasma.
Corpuscle wall.