Chemistry. — *Stationary, checked and other states of osmotic systems.* III.
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Stationary states in osmotic systems, in which more substances can diffuse.
(Continuation.)

If we leave an osmotic system

$$inv\ i_1 \mid L\,(d + d_1 + d_2 + n) \mid inv\ i_2 \quad \ldots \ldots \quad (1)$$

in which L is a variable liquid, alone, then, as we have seen in Comm. II, a stationary state sets in.

When this variable liquid is "enclosed", then the system

$$inv\ i_1 \boxed{\begin{array}{ll} m \times stat.\ L\,(d + d_1 + d_2 + n) & \\ P\ def. & m\ def. \end{array}} inv\ i_2 \quad \ldots \quad (2)$$

sets in, no matter whether there are non-diffusing substances yes or no (viz. n zero yes or no). The pressure P, the quantity m and the composition of the stat. liquid will then be completely defined.

When the var. liquid is "open", and it is under a constant pressure, we distinguish two cases. When n is not zero, so that there are one or more non-diffusing substances, we get:

$$inv\ i_1 \left| \begin{array}{ll} m \times stat.\ L\,(d + d_1 + d_2 + n) & \\ P\ const. & m\ def. \end{array} \right| inv\ i_2 \quad \ldots \quad (3)$$

The quantity and the composition of the stat. liquid now are defined.

When $n = 0$, so that there are no non-diffusing substances, (1) will pass into the system:

$$inv\ i_1 \left| \begin{array}{ll} m \times stat.\ L\,(d + d_1 + d_2) & \\ P\ const. & \triangle\, m \gtreqless o \end{array} \right| inv\ i_2 \quad \ldots \ldots \quad (4)$$

The composition of the stat. liquid has also been determined now, but its quantity continuously increases or decreases.

In all these stationary systems the osmosis is going on; so various substances will continuously pass through the two membranes; only in the special case that d in (2) or (3) is zero, the osmosis will be over when the stationary state sets in; I shall refer to this later on.

It also appears from (2), (3) and (4) that the quantity of a stationary liquid can increase or decrease only then, when it is open and does not contain non-diffusing substances.

If we leave an osmotic system

$$inv\ i_1 \,|\, L_1 \,|\, L_2 \,|\, L_3 \,|\,|\,| \qquad |\, inv\ i_2 \ldots\ldots \quad (5)$$

with an arbitrary number of var. liquids alone, then, as is easy to see, a stationary system will set in now also, which we represent by

$$inv\ i_1 \left| \begin{matrix} stat. \\ L_1 \end{matrix} \right| \begin{matrix} stat. \\ L_2 \end{matrix} \left| \begin{matrix} stat. \\ L_3 \end{matrix} \right|\,|\,| \qquad \Big|\, inv\ i_2 \ldots \quad (6)$$

Substances diffusing through all membranes will now occur also in all liquids; substances, which can diffuse only through one or more successive membranes, will occur only in the liquids adjoining these membranes. When a var. liquid of (5) contains non-diffusing substances, then they will of course occur in the same quantity in the corresponding stationary liquid of (6).

Each of the stationary liquids of (6) can be enclosed as well as open. For an enclosed stat. liquid the same rules now obtain as in (2), for an open stat. liquid the same as in (3) or (4).

We may also extend these considerations to liquids, which are in osmotic contact with more than two other liquids through more than two membranes and also to the case that there are more than two invariant liquids; in fig. 1 such a tissue with the 4 inv. liquids i_1, i_2, i_3 and i_4 has

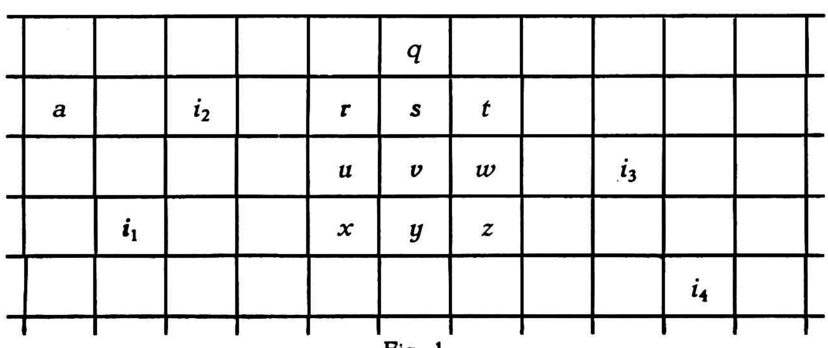

Fig. 1

been drawn. We may imagine these inv. liquids as being currents of liquid, moving upwards or downwards perpendicular to the plane of drawing. If we now imagine a series of other cells placed on the top of every cell of fig. 1, then every cell (except of course those forming the boundary plane of the tissue) is surrounded by 6 other cells; every invariant current will then be surrounded by four vertical series of cells.

Without further discussion it will be clear that a stationary state now will set in, of which the pressure, the quantity and the composition of the stat. liquid in every cell are defined; they will depend on the factors discussed before, namely the pressure and the composition of each of the inv. liquids, the nature and the surfaces of the different membranes, etc.

When there are d substances (W, X, Y, Z etc.) diffusing through all membranes, then also d diffusing currents will flow through the tissue, namely a W-, an X-, a Y-current etc. The W-current e.g. will flow through the tissue from i_1 towards i_2, i_3 and i_4; the X-current e.g. from i_1 and i_3 towards i_2 and i_4; the Y-current e.g. from i_2 and i_3 towards i_1 and i_4; etc. The occurrence of these currents is not influenced by the presence in, or abscence from each of these d diffusing substances in each invariant current, provided all invariant currents together contain only these d substances.

The water now will have an other distribution of the current [1]) than the substance X; this again an other one than the substance Y, etc. and the diffusing quantities of W, X, Y etc. may be different also.

We may imagine also that the invariant current i_1 also contains a substance R (or more substances) which can diffuse through all membranes, except through those of the invariant currents i_2, i_3 and i_4. As long as the stationary state has not yet set in, also an R-current starting from i_1 will flow through the tissue; this R-current disappears, however, as soon as the stat. state has set in; each of the cells will then have taken in a quantity of R determined by the factors previously discussed and this substance R will then no longer play a part in the osmosis.

If, however, this substance R can besides diffuse through the membranes of one or more of the other inv. currents, e.g. i_3, then, also after the occurrence of the stationary state, the R-current will continue to flow through the tissue from i_1 towards i_3 or reversally.

If we only consider one cell of the tissue (e.g. cell a or s or z) then it is clear that each of the W-, X-, Y- and other currents will generally flow inwards through one or more of the membranes of this cell and flow outwards again through its other membranes. Further it is clear that at every moment in the stationary state as much of each of the diffusing substances W, X, Y etc. in the cell will flow inwards as outwards.

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[1]) For some simple cases of a distribution of the current, when all membranes are permeable for water only, comp. Comm. I.

So in general every W-, X-, Y-current etc. flows in some direction or other through all the membranes of a cell; through one or more of these membranes, however, only a few of these currents can flow; we shall refer to this later on.

We now imagine the special case that only one of the walls of a cell is permeable, e.g. in cell v of fig. 1 only the wall between u and v; then no current will flow through this cell v in the stationary state. The pressure, the quantity and the composition of the liquid in this cell v, which is now in osmotic equilibrium with the stationary liquid of cell u, are now completely defined. If the two cells contain diffusing substances only, then the two liquids have the same pressure and composition; if, however, one or both cells also contain one or more non-diffusing substances, then in general pressure and composition will be different in the two cells [1]).

All that has been said above for óne cell obtains also of course for an arbitrary group of cells (e.g. for group *rsuvw* or group *rstuvwxyz*); then, however, we must pay attention to all the membranes, by which this group is surrounded.

In order to elucidate some of the preceding considerations we first take the osmotic system

$$L(W+n)\,|\,L'(W+n') \rightarrow W \quad . \; . \; . \; . \; . \; . \; . \quad (7)$$

in which the membrane is permeable for water only; on the left side are still n, on the right side still n' non-diffusing substances. If we now assume that L' has a greater $O.W.A.$ than L, then, as has been indicated in (7), the water will diffuse $\rightarrow$, namely from the liquid with the smaller towards that with the greater $O.W.A.$ or, in other words: in congruent direction.

As the $O.W.A.$ of a liquid depends not only upon its W-amount but also on its pressure and on its non-diffusing substances, liquid L' can have a smaller as well as a greater W-amount than liquid L. So for (7) the two symbols

$$\underset{\rightarrow}{>} W \quad \text{and} \quad \underset{\rightarrow}{<} o_{\star}\; W \quad . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

may obtain.

In the first case the water flows positively, namely from the liquid with the greater towards that with the smaller W-amount; in the second one as has been indicated by the sign $\star$ the water flows negatively, namely from the liquid with the smaller towards that with the greater W-amount.

If we apply the above to the adjoining liquids of a stationary tissue,

[1]) Comp. F. A. H. SCHREINEMAKERS, These Proceedings, **35**, 1038, 1131, 1235 (1932); **36**, 285 (1933).

through which only a current of water flows (Comm. I), then follow among other things:

1⁰. the water flows through all membranes of the tissue in congruent direction.

2⁰. the water can flow through the membranes not only positively, but also negatively, or in other words: in a tissue there may be cells (or groups of cells) from which the water flows towards cells (or groups of cells) with a greater W-amount.

We now take a system with a membrane, permeable only for W and X, namely the system

$$L(W+X+n)\,|\,L'(W+X+n') \quad . \quad . \quad . \quad . \quad . \quad (9)$$

We now may imagine the 4 D.T.'s

$$\begin{array}{ll} a) \leftarrow W \leftarrow X & c) \rightarrow W \leftarrow X \\ b) \leftarrow W \rightarrow X & d) \rightarrow W \rightarrow X \end{array} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

one of which, however, always is incongruent and therefore impossible.

We can easily deduce that now every direction of W and every direction of X may be congruent; it depends upon the pressure and the composition of the two liquids what direction will be so in a special case.

If e.g. the congruent direction of W is $\leftarrow$ and that of X also $\leftarrow$, then (10) passes into:

$$\begin{array}{ll} a) \leftarrow W \leftarrow X & c) \rightarrow oW \leftarrow X \\ b) \leftarrow W \rightarrow oX & d) \rightarrow oW \rightarrow oX \end{array} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

in which the incongruent directions have been indicated by the sign o. The D.T. *a* now is congruent and *d* incongruent, so that *d* is impossible; the three others are possible, however; it depends upon the nature of the membrane which of these three D.T.'s will occur in a special case.

If the congruent direction of the water is $\rightarrow$ and that of X $\leftarrow$, (10) passes into:

$$\begin{array}{ll} a) \leftarrow oW \leftarrow X & c) \rightarrow W \leftarrow X \\ b) \leftarrow oW \rightarrow oX & d) \rightarrow W \rightarrow oX \end{array} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Now the D.T. *c* is congruent and *b* incongruent, so that now only the D.T.'s *a*, *c* and *d* are possible [1]).

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[1]) This always obtains in the special case that n and n' in (9) are zero, so that this system contains the diffusing substances W and X only, and when the liquid with the smaller W-amount is placed on the left side of the membrane.

Because, as has been said already above, every direction of W and every direction of X may be congruent as well as incongruent, each of the 4 D.T.'s of (10) the congruent as well as the incongruent one; it depends upon the pressure and the composition of the two liquids which D.T. will be congruent or incongruent in a special case.

Above we have seen that in system (7) the water can diffuse in positive as well as in negative direction; in system (9) this obtains for the water as well as for the substance X.

Of course corresponding considerations obtain for systems in which more than 2 substances can diffuse; if we call their number d, then, instead of the 4 D.T.'s (10) now 2^d are imaginable; what has been said above obtains for them also.

If we apply the above to the adjoining liquids of a stat. tissue, in which the substances W, X, Y etc. diffuse, then follow among other things:

1°. the substances W, X, Y etc. can flow through the membranes of a tissue not only congruently, but also incongruently; all of them however cannot flow incongruently through the same membrane at the same time.

2°. the substances W, X, Y etc. can flow through the membranes not only positively, but also negatively; or in other words: there can be cells (or groups of cells) in tissues, from which one or more of the substances W, X, Y, etc. flow towards cells (or groups of cells) with a greater amount of these substances.

It appears from the above that the stationary state of a tissue depends upon a whole series of factors, viz. the pressure and composition of each of the invariant currents; upon the nature of the membranes and the ratio of their surfaces; upon the number of membranes of every cell, upon the nature and the quantity of the non-diffusing substances of every cell; upon the volume of every cell under a given pressure and the elasticity of its membranes and walls, etc.

Every change in one or more of these factors will also cause a change in the stationary state, namely an other quantity and distribution of each of the d currents of the tissue [1]); of the pressure and composition of the cells; perhaps also of the transition of congruent into incongruent and of positive into negative osmosis or reversally of one or more of the substances through one or more of the membranes, etc.

If we imagine the membranes between the cells r, s, t, u, v, w, x, y and z left out, so that these 9 cells pass into a single greater cell, then we get fig. 2, in which, however, we must imagine besides cell q of fig. 1.

Now it is clear that the stationary state of this tissue will be quite different from the one in fig. 1. We saw this already for the quantity and

[1]) For the influence which the change in one membrane can have already on the quantity and the distribution of the W-current of a tissue, of which the membranes are permeable for water only, comp. (22) and (24) of Comm. I.

the distribution of the W-current in (14) and (25) of Comm. I; of course this is also the case with all other currents flowing through the tissue.

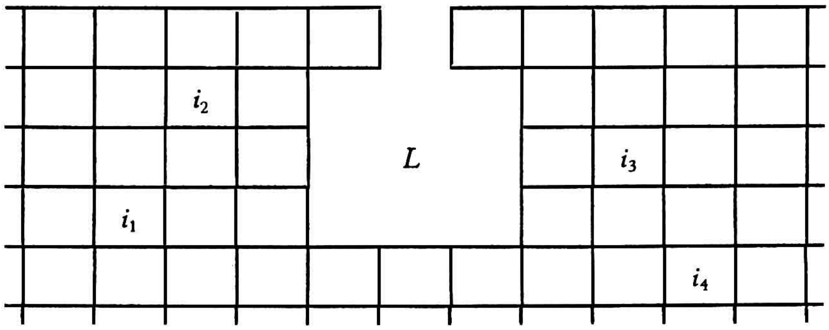

Fig. 2

If we now imagine in the way it has been drawn in fig. 2, that cell q of fig. 1 is omitted too, the stationary state will again become quite different, especially because liquid L now becomes an "open" stationary liquid, e.g. under the pressure of 1 atmosphere.

Previously we have seen (comp. 4 and 6) that the quantity of an open stationary liquid will increase or decrease continuously. If we imagine that this quantity increases, this open cell can be compared to the cavity of a gland and the stationary liquid to the fluid secreted by the gland.

Through each of the numerous membranes of this cavity a W-current will now flow, perhaps inwards through all membranes, perhaps through a few membranes also outwards; of course the same obtains also for each of the other currents. All that has been discussed above regarding congruent and incongruent and positive and negative osmosis, of course obtains also for the walls of this cavity, so that liquid L can contain several substances in greater concentrations than occur in the surrounding tissue.

Now it is also clear that every change in the factors discussed above will also cause a change in the quantity and in the composition of this liquid L. We may even imagine that this quantity now begins to decrease so that the cavity will stop functioning as a gland.

The cause may then be found in the immediate vicinity of the cavity, e.g. in a change of its membrane; it can be found also, however, in the membranes of other cells at a greater distance or in a change in the membranes, the pressure or the composition of one or more of the invariant currents.

It will be clear to the reader, without my emphatic statement of it that in these considerations I would not and could not either give anything but a rough sketch of what in real tissues may take place, in which not only still other factors known to us play a part, but surely also many factors still unknown at the present moment. I shall refer to this later on.

(To be continued).

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