

The Influence of Temperature on the Absorption of Water by Seeds of Hordeum vulgare in Relation to the Temperature Coefficient of Chemical Change.

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Attention has previously been directed by one of us to the existence of a differential septum enclosing the seeds of *Hordeum* (barley).^{*} When the seeds are immersed in aqueous solutions of most electrolytes, and of many non-electrolytes, this covering behaves as a very efficient differential septum, water alone entering the seeds under the attractive influence of the finely granulated contents.

The rate at which the water enters is considerably affected if substances are dissolved in it, being increased by some and diminished by others; it is also markedly dependent on the temperature of the water or solution in which the seeds are immersed. Variations of the rate at which water enters with alterations of the experimental conditions are presumably due mainly to changes in the water, and the seeds of *Hordeum* would thus appear to be a very suitable medium for the investigation of the nature of the changes produced in water by the presence of dissolved substances or by alterations of temperature.

In this communication, attention will be confined to the influence of temperature on the rate at which water is absorbed by the seeds of *Hordeum vulgare*.

Known weights of the seeds were immersed in water at definite temperatures constant to within 0.7° throughout the experiments. The mean temperatures at which observations were made are 3.8° , 21.1° , and 34.6° . After different intervals of time, the weight of the water absorbed by the seeds was ascertained by removing the seeds from the water, rapidly drying the surfaces, and then weighing. After weighing, the seeds were immediately returned to the water, and soaked during a further period.

The results of one series of observations are recorded in the following table, and shown graphically in the accompanying diagram (I).

It will be noticed that, during the earlier stages of the experiment, the rate at which the entry of water takes place increases very rapidly as the temperature rises; subsequently, when the saturation point is approached,

* 'Roy. Soc. Proc.,' 1909, B, vol. 81, p. 82.

and equilibrium is established between the seed systems and the water, the curves tend to run together towards the same asymptote.*

Table I.

| Temp. 34·6°. | | Temp. 21·1°. | | Temp. 3·8°. | |
|--------------|-----------------|--------------|-----------------|-------------|-----------------|
| Time. | Water absorbed. | Time. | Water absorbed. | Time. | Water absorbed. |
| hrs. | per cent. | hrs. | per cent. | hrs. | per cent. |
| 5·00 | 16·80 | 5·25 | 9·32 | 5·58 | 4·42 |
| 24·00 | 35·64 | 24·33 | 24·80 | 24·75 | 11·82 |
| 48·25 | 43·44 | 48·50 | 35·98 | 48·83 | 18·52 |
| 71·50 | 45·36 | 72·00 | 43·42 | 72·25 | 23·42 |
| 96·00 | 45·74 | 96·25 | 46·90 | 96·50 | 27·42 |
| | | | | 144·25 | 34·02 |

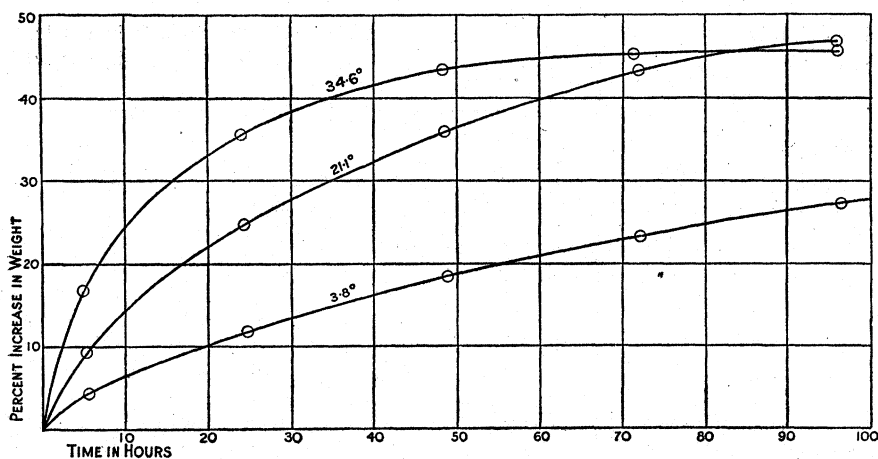


DIAGRAM I.

In order to study more closely the effect of temperature on the velocity with which water is absorbed, in the first instance it is desirable to ascertain the relative rates at which water enters the seeds at the different temperatures. As the rate at any particular temperature decreases as the amount of water absorbed becomes greater, it is necessary, however, to ascertain the relative rates at different temperatures under comparable conditions.

As the conditions of the seeds throughout the experiments at the different

* The slight decrease in the weight of the seeds at the highest temperature in the latter part of the experiment is due, in all probability, to secondary changes, perhaps in part to actual loss of weight through dissolution of solid matter, but more particularly to alterations in the attractive forces as water accumulates within the seeds.

temperatures are the same only when equal quantities of water have been absorbed, the rates of entry of water at the three temperatures were deduced at points where amounts of water corresponding to 5, 7·5, 10, 15, 20, and 25 per cent. increase in weight had been absorbed in each case. Higher percentages were not dealt with, on account of the possible influence of secondary changes in the latter parts of the experiments.

The rates were deduced from the curves drawn carefully to express the result (Diagram I), by finding the values of the tangents at the required points by means of a stretched thread. The rates thus obtained, expressed in terms of the amount of water (percentages of initial weight) absorbed per hour, are given in the following table:—

Table II.

| Water already absorbed. | Velocity. | | | $\frac{\text{Velocity at } 21 \cdot 1^{\circ}}{\text{Velocity at } 3 \cdot 8^{\circ}}$ | $\frac{\text{Velocity at } 34 \cdot 6^{\circ}}{\text{Velocity at } 21 \cdot 1^{\circ}}$ |
|-------------------------|-----------|-----------|-----------|--|---|
| | At 3·8°. | At 21·1°. | At 34·6°. | | |
| per cent. | | | | | |
| 5·0 | 0·506 | 1·72 | 4·50 | 3·40 | 2·62 |
| 7·5 | 0·416 | 1·51 | 3·83 | 3·63 | 2·54 |
| 10·0 | 0·356 | 1·27 | 3·07 | 3·57 | 2·42 |
| 15·0 | 0·282 | 0·897 | 2·30 | 3·18 | 2·56 |
| 20·0 | 0·216 | 0·679 | 1·68 | 3·14 | 2·47 |
| 25·0 | 0·164 | 0·570 | 1·16 | 3·48 | 2·04 |
| Mean..... | | | | 3·40 | 2·44 |

If the sequence of ratios at the three different temperatures be compared, it will be seen that there is an approach to constancy in their relation; that this is the case is more clearly seen, however, on examination of the numbers in the fifth and sixth columns of the table, which express the proportional values obtained from a comparison of the three series of ratios.

Taking the mean values of the ratios, it appears that the velocities with which absorption takes place at the three temperatures 3·8°, 21·1°, and 34·6° are in the proportion of 1 : 3·40 : $3 \cdot 40 \times 2 \cdot 44$, *i.e.* 1 : 3·40 : 8·30.

The temperature coefficient is obviously high and of the order of that of a number of chemical actions occurring in solution. Moreover the velocity with which water is absorbed by the seeds is almost exactly an exponential function of the temperature. If this be so, the logarithms of the velocities plotted against the temperature should lie on a straight line. The results obtained on plotting the logarithms of the velocities given in Table II, including those of mean ratio of the velocities, are given in the following diagram.

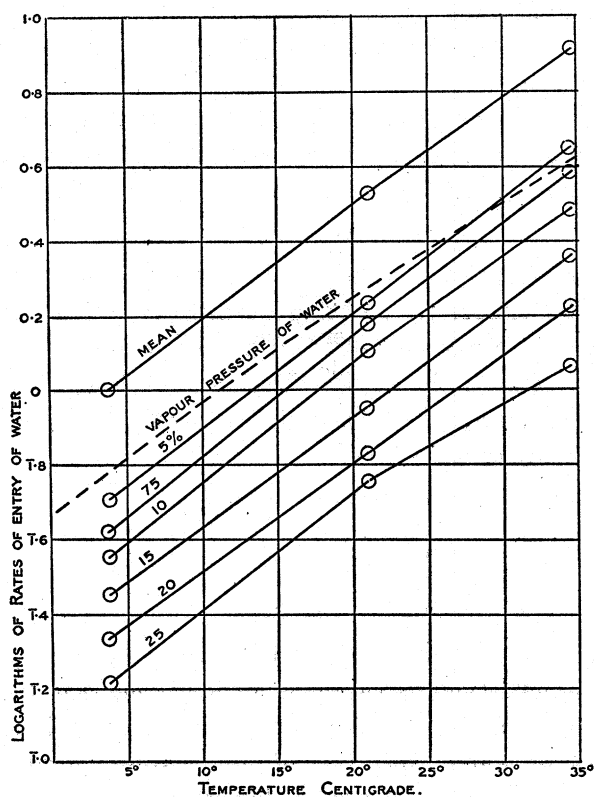


DIAGRAM II.

The course of the lines in the diagram, in respect both of straightness and agreement of inclination, furnishes evidence of a most conclusive character that the rate at which water is absorbed by the barley seeds is an exponential function of the temperature.

Such a conclusion is of special interest, not only on account of the rarity of an exponential increase of a physical property with rise of temperature,* but more especially as the vapour pressure of water is also approximately an exponential function of the temperature.

In Diagram II the logarithms of the vapour pressure of water over the range of temperature covered by the absorption experiments are plotted against the temperature as a dotted line. The highly important fact is thus

* "An exponential increase of any physical property with rise of temperature is very rare. The increase of the vapour pressure of a liquid with rise of temperature is an exception and, in consequence, Arrhenius concludes that the increase of the velocity of a chemical reaction with temperature cannot be explained by any change in the physical property of the solution with temperature." Mellor's 'Chemical Statics and Dynamics, 1904, p. 394.

brought out that the slope of the curve is almost exactly the same as that of the curves representing the velocity at which water is absorbed by the seeds of *Hordeum*.

Expressed in other terms, the relation between the temperature and either the rate of entry of water into the seeds or the vapour pressure of water may be approximately expressed by the equation

$$v = ae^{k\theta},$$

in which v represents either the velocity of absorption of water or vapour pressure, and θ the temperature, a being a constant.

The value of k in the case of the absorption of water by *Hordeum* seeds, derived from the mean ratios of the velocities, is 0.069; in the case of the vapour pressure of water, it varies slightly, having the following mean values between the temperatures cited:—

| | | | | |
|-------|---------|----|-----|----|
| 0.071 | between | 0° | and | 5° |
| 0.069 | | 5 | | 10 |
| 0.066 | | 10 | | 15 |
| 0.063 | | 15 | | 20 |
| 0.061 | | 20 | | 25 |

So close an agreement in the general character of an exceptional property common to liquid water and its vapour is an indication that the phenomena may have a common origin. In the case of an exponential increase of the vapour pressure of water with rise of temperature, presumably we are dealing mainly with the influence of temperature on the proportion of molecules of "hydrone" (OH_2), and, in the light of our experiments, when measures are obtained of the velocity with which the passage of water takes place at varying temperatures through a differential septum under the attractive influence of minute particles, we may be obtaining measures of the activity of the simple molecules existing in the water. It would appear that only these simple molecules are directly assimilated by the seeds or transmitted by the differential septum.

The above results appear to throw light on the cause of the high temperature coefficients of chemical interactions occurring in solution. In a number of instances it has been shown that the rate of chemical change is approximately doubled by an increase of 10° . It is noteworthy that the value of k calculated above for the rate of absorption of water by the seeds of *Hordeum* corresponds almost exactly to a doubling of the rate for a rise of 10° , for which the exact value of k would be 0.0693. It appears highly probable that the velocity of chemical interactions occurring in aqueous solution is mainly dependent on the activity of water as expressed by the proportion of "hydrone" molecules. The importance of the part played by

water and especially by the active hydrone molecules in chemical interactions has been frequently emphasised by H. E. Armstrong in various recent communications to the Society, and the above views are in complete harmony with the explanations recently advanced by Armstrong and Worley in discussing the nature of hydrolytic change.

Experiments with Aqueous Solutions of Ethylic Acetate.

Ethylic acetate belongs to the class of solutes (Hormones) which are capable of penetrating the seed covering, and it is further remarkable on account of its power of accelerating the velocity with which water enters the seed.*

In view of the results previously described in this paper it appeared desirable to study the velocity with which water is absorbed at different temperatures in the presence of the acetate.

Table III.

| Temp. 34.6°. | | Temp. 21.1°. | | Temp. 3.8°. | |
|--------------|-----------------|--------------|-----------------|-------------|-----------------|
| Time. | Water absorbed. | Time. | Water absorbed. | Time. | Water absorbed. |
| hrs. | per cent. | hrs. | per cent. | hrs. | per cent. |
| 4.50 | 19.38 | 4.75 | 11.82 | 5.08 | 5.28 |
| 23.50 | 38.48 | 23.83 | 29.22 | 24.25 | 15.12 |
| 47.75 | 45.26 | 48.00 | 41.12 | 48.33 | 23.58 |
| 71.00 | 45.98 | 71.50 | 44.42 | 71.75 | 29.32 |
| 95.50 | 44.06 | 95.75 | 45.58 | 96.00 | 34.16 |
| | | | | 143.75 | 40.84 |

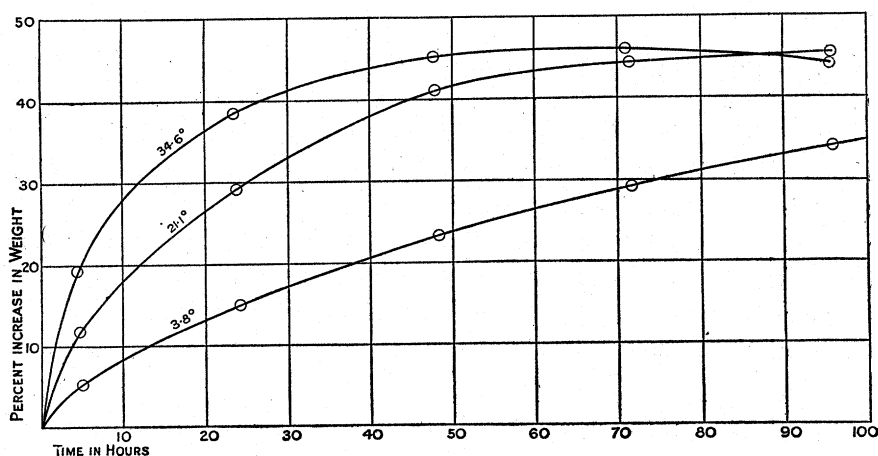


DIAGRAM III.

* *Loc. cit.*, p. 92.

A series of experiments was made in which seeds of *Hordeum vulgare* were steeped in "weight normal" solutions of ethylic acetate at different temperatures as in the experiments previously described. Curves representing the rate of absorption in these experiments are plotted in the diagram (III) from the values given in the preceding table.

It will be noticed that the curves resemble very closely in form the water curves (Diagram I), but their general course tends to run at a higher level, indicating an acceleration in the velocity of absorption in the presence of the acetate.

The values expressing the velocity of entry of water into the seeds were determined, as in the earlier experiments with water alone, from the curves at points representing 7.5, 10, 15, 20, and 25 per cent. of water absorbed. The values so obtained are given in the following table:—

Table IV.

| Water already absorbed. | Velocity. | | | Velocity at 21.1° Velocity at 3.8° | Velocity at 34.6° Velocity at 21.1° |
|-------------------------|-----------|-----------|-----------|---------------------------------------|--|
| | At 3.8°. | At 21.1°. | At 34.6°. | | |
| per cent. | | | | | |
| 7.5 | 0.575 | 2.12 | 5.25 | 3.69 | 2.48 |
| 10.0 | 0.505 | 1.72 | 4.27 | 3.41 | 2.48 |
| 15.0 | 0.406 | 1.23 | 3.26 | 3.03 | 2.71 |
| 20.0 | 0.337 | 0.99 | 2.18 | 2.94 | 2.77 |
| 25.0 | 0.274 | 0.76 | 1.55 | 2.77 | 2.04 |
| Mean | | | | 3.28 | 2.50 |

On plotting the logarithms of these values the results shown in Diagram IV were obtained.

It will be noticed how closely the lines approximate to straightness, indicating that the velocity of absorption of water from a solution of ethylic acetate is an exponential function of the temperature as in the case of the experiments with water alone. Furthermore, as in the previous case, the slope of the lines is practically the same as that for the logarithms of the vapour pressure of water plotted as a dotted line in the diagram.*

The only noticeable point in which the results obtained with "weight

* The form of the curves in Diagrams I and III is very approximately hyperbolic. Making use of this fact, it is possible, by plotting against the time the logarithms of the amount of water finally absorbed minus the amount absorbed at any given time, to arrive at the relative initial rates of absorption. Proceeding in this way, results similar to those described above are obtained.

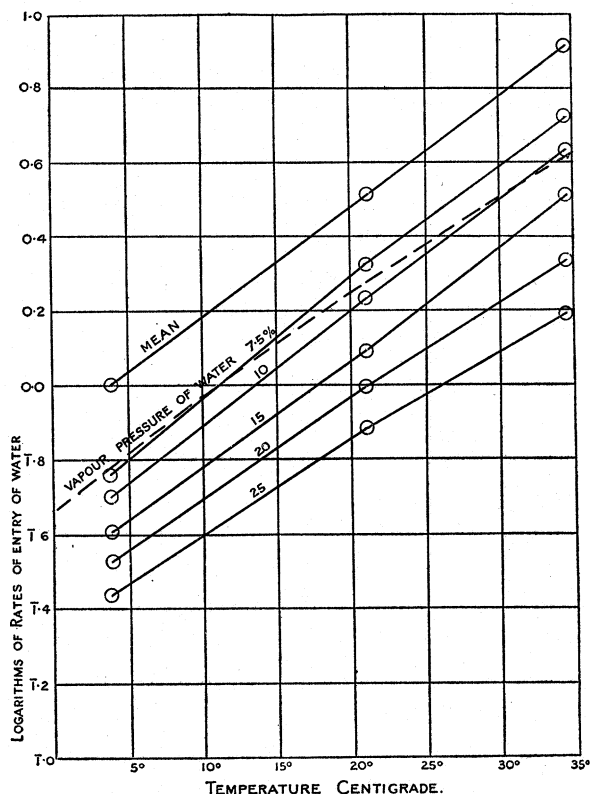


DIAGRAM IV.

normal" solutions of ethylic acetate differ from those obtained with water is in the actual velocity with which absorption takes place under corresponding conditions. This is higher in the presence of ethylic acetate than in the presence of water alone. The temperature coefficient is apparently unaffected. Viewed in the light of previous remarks, this observation suggests that acceleration of the velocity of absorption in the presence of ethylic acetate may be due, in a large measure, at least, to the simplifying action of the solute on the molecular structure of water. If this be the case, it seems probable that the partial pressure of the vapour of water should be increased in the presence of small proportions of ethylic acetate or, in any case, that the lowering of the vapour pressure through osmotic effects should be in part counteracted by an increase due to the simplifying action of ethylic acetate and such substances as butylic and amylc alcohols. Investigation of this question is proposed by one of us.