

This I find to be the case, and to a very remarkable extent. I am still investigating this matter, but as I have so much on hand it may be some time before I can finish the work, so I wish to place on record the results so far as I have proceeded. I find that glass, when at a temperature of about 200° , absorbs a large quantity of gas when the latter is under a pressure of 200 atmospheres. Oxygen and carbon dioxide have been used, and have been found to be largely absorbed, and on cooling the glass under pressure the gas is retained permanently fixed. So much is absorbed that, on quickly raising the temperature to the softening temperature of the glass, the sudden escape of gas drives the glass into foam. On slowly raising the temperature and retaining it at 300° , most of the absorbed gas is given off without any visible action.

The frothing up of the glass by the outrush of gas is very striking. Other silicates, and also borates and phosphates, absorb gas, especially carbon dioxide, under great pressure. Metals absorb hydrogen and some of its compounds with carbon. As the treatment of quantities of matter sufficient for analysis at these high pressures and temperatures is a matter of great difficulty, the majority of experiments being failures, the work proceeds but slowly; but I hope during the summer and autumn to be able to elucidate the subject quantitatively, when I shall detail the results to the Society.

XV. "On the States of Matter." By J. B. HANNAY, F.R.S.E., F.C.S. Communicated by Professor G. G. STOKES, D.C.L., &c., Sec. R.S. Received June 4, 1881.

The conception which had been held from the earliest times that the three recognised states of matter were clearly separated from each other received a rude blow from the interpretation put upon the work of Andrews, that the liquid and gaseous states were really continuous, and that the two states could only be classified under one head—the fluid state. Andrews demonstrated that by placing a liquid under a pressure greater than the critical, and then raising the temperature, the liquid might be made to pass to an undoubtedly gaseous state without any sudden change having been visible. Thus the continuity of the liquid and gaseous states seemed established. I say seemed, because I have shown in former papers that under any pressure the fluid passes at a given temperature from a state where it possesses cohesion, capillarity, or surface tension—the distinguishing property of liquid, which prevents it freely mixing with a true gas—to a state where it possesses no cohesion, capillarity, nor surface tension, and where it mixes freely with any gas—in fact, to the gaseous state; and this change takes place at a fixed temperature independent of pressure.

As MM. Cailletet and Hautefeuille have recently come to the conclusion that the continuity claimed by Andrews does not exist, and have thus corroborated my work, I wish to place on record more fully the conclusions to which this work has led me.

In examining a subject of this kind it is important that we should first arrive at a clear understanding of the meaning of the language we use; second, of the means we have of proving our knowledge of the state of matter; and, third, of the value of such proof.

First, then, as to the meaning to be attached to the words solid, liquid, and gaseous. The solid state is that state of matter which in an isolated portion free to move displays sufficient rigidity of its substance to retain permanent irregularity of figure. The liquid state denotes that state of matter which in an isolated portion free to move displays sufficient freedom of motion in its substance to assume a form in accordance with the forces acting upon it, but which when partially filling an inclosed space retains a permanent limiting surface exhibiting capillarity. The gaseous state denotes that state of matter in which it assumes no surface nor definite figure, and which is so extensible that any quantity will distribute itself throughout a space.

Having defined the nomenclature, let us see what means we have of proving our knowledge of any state. Let us conceive that we are working with what we rarely or never have—pure substances. When water is nearly pure it freezes perfectly transparently; in fact, except for rigidity and difference in density it could not be distinguished from liquid water. Now consider a vessel frozen quite full of pure ice; there is no free surface to examine, therefore one test of its state is gone. Now let enormous pressure be brought to bear upon the ice till its density is reduced to that of water at the same temperature, and let the temperature be the new freezing-point; then there is no way of knowing whether the inclosed water is liquid or solid, without applying special tests. Either the vessel must be broken to test the rigidity of the contents or motion must be given to the vessel, and dynamic tests made as to the behaviour of the contents; but what I wish to impress is, that *sight* can teach us nothing directly as to the condition of the contents. A free surface is required to indicate the state of matter. So it is with the liquid and gaseous states, but just as they are more subtle, so are the modes of experimenting with them more difficult. Let us consider the case of a liquid inclosed in a space bounded by transparent sides having a piston free to move. When the pressure of the piston is less than that of the vapour of the liquid, there will be a space occupied by vapour over the liquid, and the surface of the latter will be visible and its state recognisable at a glance; but let there be more pressure upon the piston than equals that of the vapour, then no vapour will be formed, and the liquid will fill the whole

cavity, in which state the whole substance cannot be determined by sight alone, because no free surface is visible. It might be solid for all our eyes could tell us. Here, again, we see that a free surface is necessary for determining the state. In Andrews' experiments there is no free surface, for at pressures greater than the critical a free surface is impossible. It was towards the procural of this free surface at any pressure that my work tended. The last definition is that of the phrase "free surface." A free surface is that surface of a solid or liquid matter which is in contact with vapour or gas, in fact, a surface in contact with a space where it has freedom of motion.

The difference between the solid and liquid states being easily recognisable, need not be stated, but that between the liquid and gaseous requires some consideration. Regnault has shown that every liquid has a certain molecular activity corresponding to each temperature, in virtue of which it throws off from its free surface with a definite mean velocity, a certain number of molecules per unit of surface. When the space over the liquid is limited, some molecules pass back again into the liquid, and when this number equals that of those outgoing, the space is said to be saturated. The pressure which the molecules by their impacts cause upon the sides of the vessel is called the vapour tension of the liquid. When the temperature rises, a greater number of molecules are thrown off than with the liquid, and the density of the vapour increases until it is nearly equal to that of the liquid. But still there is a limiting surface indicating the lower portion to be liquid. Let the temperature be now raised till the densities of the upper and lower portions are equal, then we have a state of matter in which the substance "assumes no surface nor definite figure, and which is so extensible, that any quantity will distribute itself throughout a space," as we before defined the gaseous state.

Now as to the proof that it is really in the gaseous state. The general effect of the attraction of the molecules of a liquid for each other and for solids, yields three measurable phenomena. First, the property of tensile strength measurable in liquid films (as soap-bubbles), second, capillary attraction, and third, the cohesion by reason of which the neck of a drop can support it as a wire supports a load. It has been shown by experiment, that all these three manifestations of attraction decrease as the temperature rises, and each may be used as a measurement of the other. As "surface tension" is *the* feature of the liquid state, it was necessary to investigate how it is affected by the gas or vapour with which it is in contact, and the results showed that the height of a liquid in a capillary tube is not perceptibly affected by replacing the air by hydrogen, or removing everything except the vapour of the liquid. Even when hydrogen was compressed at 200 atmospheres pressure over a liquid in which it is nearly insoluble, the capillarity only fell very slightly. It appeared

that the cohesion or capillarity of a liquid depends upon temperature alone, and that pressure has no effect upon it.

Practically, it was found that the less soluble a gas is in a liquid the less effect does its presence cause at any pressure, and it is certain that had we a gas totally insoluble in a liquid, we might compress that gas under any pressure over the surface, without effecting the slightest change in the capillarity of the liquid.

To return to Andrews' experiment. It was seen that to determine the state of every quantity of matter, it was necessary to have a free surface, but by Andrews' mode of experimenting at pressures greater than the "critical," this was impossible, the tube being filled with a homogeneous fluid; but it is possible to have a free surface, and to watch the alteration of the capillarity at any pressure, provided a gas can be obtained which is insoluble in the liquid. We have seen that when a gas dissolves in a liquid, the capillarity of the mixture is lower than that of the liquid alone, so by these means we can tell whether or not a gas is soluble. In this way it was found that hydrogen was insoluble in several liquids, and thus the conditions were established for examining loss of capillarity with rise of temperature at any pressures, the hydrogen keeping a free surface without affecting the liquid. It was found that the capillarity fell to zero at the same temperature, independent of pressure; in other words, the matter passed from a state where it "retains a permanent limiting surface exhibiting capillarity," to a state where it "assumes no surface nor definite figure, and which is so extensible, that any quantity will distribute itself throughout a space," as we defined the liquid and gaseous states.

The state of affairs in those experiments is this:—The hydrogen takes the place of a portion of the vapour of the liquid, but unlike the molecules of the vapour, its molecules are unable to penetrate the surface of the liquid, in any quantity, but merely act by striking against the molecules which would otherwise pass out, and driving them back into the liquid. Could there be any greater proof than this of the special properties of a liquid surface? Let the temperature be very near the critical, yet the mixture over the liquid retains a very much lower density than the liquid, as the hydrogen does its work in keeping back a portion of the vapour molecules. In this case the upper does not become equal in density to the lower portion of the fluid as in Cagniard de la Tour's experiment, yet when the critical temperature is reached the meniscus disappears and diffusion occurs between the upper and lower portions. This phenomenon is seen at any pressure up to five times the "critical" pressure, showing that the change of state is independent of pressure. Gaseity is dependent upon molecular velocity (thermal activity), and to give it this velocity a very strong cohesion must be overcome. The velocity is not in any way dependent upon the pressure or upon the size of the vessel, and

therefore the gaseous state proper cannot be altered by pressure alone. The liquid state is thus bounded by an isotherm which marks the thermal activity equivalent to the attraction of the molecules, and the continuity of the liquid and gaseous states enunciated by Andrews is only apparent.

The passage from the liquid to the gaseous state might be represented by a curve where the line representing decrease of capillarity passes through zero to a negative side, which in reality represents repulsion. In other words, the curve for liquid represents excess of attraction over repulsion, that for gas excess of repulsion over attraction.

The existence of this cohesion in liquids has been too much overlooked by the statistical method of looking at the states of matter. It is something very great compared with the amount of energy required to give the molecular velocity required to sustain the gaseous state. Let us by Dr. Joule's method make a calculation. Suppose the molecules in a gram of steam to be at rest it would require 92 gram-degrees, or, in absolute measure, $383,161 \frac{\text{mtr.}^2\text{grm.}}{\text{sec.}^2}$, to give them

velocity enough to exert a pressure of one atmosphere. Now the energy added to cause a gram of water to become steam at one atmosphere pressure is 540 gram-degrees (or $2,244,780 \frac{\text{mtr.}^2\text{grm.}}{\text{sec.}^2}$), or

about six times as much work to be done. And this is not all. We started from rest in the other calculation, here we start from water whose molecules are in motion. Five-sixths of the energy has gone to overcome the cohesion of the liquid. As we know, that to bring matter to the same state we must expend the same amount of energy, and as we may bring matter to the gaseous state either by boiling or by Andrews' apparently continuous method; in the first case we would say the heat used up represents the latent heat of steam, and in the other the specific heat of water, but they are both really measures of the thermal value of the energy required to overcome the attraction of the molecules. When, therefore, this energy has been given to the water, the cohesion has been overcome and the liquid state passed, whether or not it has been visible to our eyes. Thus from all evidence, experimental and theoretical, the liquid state has a limit, and the liquid and gaseous states are not really continuous.

The definition of the gaseous state as a state of matter not alterable by pressure alone leads us to a clear division of aeriform matter into two states, the vaporous and gaseous, the first alterable, the second unalterable by pressure alone. Another distinction between vapour and gas is this: gases are solvents of solids; vapours are not. Let a liquid be coloured by having some non-volatile coloured solid dissolved in it, and let it be heated under pressure, the liquid will remain

coloured while the vapour will be quite colourless, and will remain so up to the critical point.

Now let the fluid be raised above its critical point, all the internal space will be coloured, showing that (the contents being gaseous) the gas dissolves the solid while the vapour does not. We have here a clear separation of the two kinds of aeriform fluids. The definition which I applied to the gaseous state at the beginning of this paper does not apply to the vaporous state, as we know that any quantity of it will not distribute itself throughout a space, because if we try to force vapour into a space already saturated, we cause a change of state, and a portion of the matter becomes liquid. Thus, instead of only two we have four distinct states of matter: solid, liquid, vaporous, and gaseous.

XVI. "The Relation of the White Blood Corpuscles to the Coagulation of the Blood." By L. C. WOOLDRIDGE, B.Sc. Lond., Physiologische Anstalt, Leipzig. Communicated by Dr. LAUDER BRUNTON, F.R.S. Received June 8, 1881.

(Abstract.)

The following is an abstract of some researches which have been carried out by the author in the Physiological Institute of the University of Leipzig.

It has long been known that the white blood corpuscles are concerned in the coagulation of the blood.

Alexander Schmidt, to whom we principally owe our knowledge of this fact, has distinctly formulated the part they play. He considers them as the source of two of the three factors which are, according to his well-known theory, necessary for the formation of fibrin.

The two components which arise from the white blood corpuscles are, according to Schmidt, paraglobulin and fibrin ferment.

The recent researches of Hammarsten have made it very probable that paraglobulin is not directly concerned in the formation of fibrin.

If this be true, and if the views of Schmidt concerning the participation of the white corpuscles be also correct, the latter must necessarily only play a very subordinate part; that is, they must be mere *ferment producers*.

In order to arrive at exact conclusions on this subject, the author has considered it necessary:—1st. To attain some more knowledge than we at present possess concerning the chemical nature of the white blood corpuscles. 2nd. To have exact data for the amount of white blood corpuscles which disappears during coagulation.