X. *Observations on the Freezing of the Albumen of Eggs.* By James Paget, *Esq.*, *Professor of Anatomy and Surgery to the Royal College of Surgeons of England. Communicated by* Thomas Bell, *Sec. R.S.*

Received September 26, 1849,—Read January 24th, 1850.

In 1777, John Hunter communicated to the Royal Society a series of experiments on the heat of animals and vegetables, among which were some showing that an egg, after having been frozen and thawed, will, on a second exposure to cold, freeze more quickly than it did before, and more quickly than a fresh egg does when exposed to the same temperature. From these and other experiments, he concluded "that a fresh egg has the power of resisting heat, cold and putrefaction in a degree equal to many of the more imperfect animals;" and he adds, "it is more than probable this power arises from the same principle [*i. e.* a living principle] in both*." Mr. Hunter's pupils generally adopted this conclusion: and the facts on which it was based have formed a chief part of the evidence for the existence of a special vital principle capable of resisting, by a kind of passive opposition, the changes that physical forces produce in dead organic matter.

In the course of some inquiries into the nature of the life of the blood, I repeated and extended Mr. Hunter's experiments, and obtained results which, I venture to hope, may be deemed worthy of the consideration of the Society.

My experiments consisted chiefly in submitting to temperatures near to zero of Fahrenheit, fowls' eggs, into which thermometers with slender bulbs were introduced. The decrements of heat were registered every minute, and the time was noted at which each egg began to freeze, the general indication of that event being the swelling of the albumen, and its protrusion from the aperture through which the thermometer was passed.

I found, as Mr. Hunter did, that a fresh egg generally resists freezing longer than one does which, having been previously frozen and thawed, is exposed, in all similar circumstances, to the same temperature. The result of twenty experiments, in which such eggs were placed in temperatures ranging from zero to 10° Fahr., was, that the fresh eggs were frozen, on an average, in 26 minutes, and the eggs that had been previously frozen and thawed, were frozen for the second or third time in 15½ minutes.

I next determined, by similar experiments, the respective times of freezing of fresh eggs, and of such as were variously changed in structure and chemical composition. Similar results appeared. If the yelks of the eggs were broken, so as to be mingled

* Hunter's Works, by Palmer, vol. iv. p. 150.

with the albumen; if their whole substance were decomposed, so as to emit a more or less putrid odour; if a powerful electric shock had been passed through them,—in all these conditions, they froze more quickly than fresh and uninjured eggs did, that were exposed with them to the same low temperature. The average difference in the respective times of freezing was nearly the same as that already stated.

All these experiments tended to confirm Mr. HUNTER's explanation; for all seemed to show that, by the influence of such forces as commonly destroy animal life, eggs lose some capacity of resisting the abstraction of heat. But when I examined the registers of the decrements of heat sustained by the several eggs during each minute of their exposure to the cold, it appeared that the fresh eggs almost always lost heat more rapidly than those did which had been frozen, broken, decomposed, or electrified. An average result of experiments upon thirty-three eggs of each class was, that, between the fifth and fifteenth minutes after first exposure to a temperature of from 5° FAHR. to 10° FAHR., the fresh eggs lost 17° of heat, and the others only $13\frac{1}{2}$°. The reason why the fresh eggs, though they lost heat more rapidly than the others, yet were longer in freezing, was, that in most cases their temperature was reduced some degrees below 32° before freezing took place; while the eggs that had been frozen before, or that were in any other way spoiled, always began to freeze as soon as they reached the temperature of 32°.

Mr. HUNTER had remarked this difference. In one of his experiments, he says, "a fresh egg sank to $29\frac{1}{2}$°, and in twenty-five minutes later than the dead one, it rose to 32°, and began to swell and freeze." But I found that fresh eggs could be reduced to a much lower temperature without freezing. In several experiments they fell to 20°; in some to 16°, before, with a rapid rise to 32°, freezing took place; and from some observations, which will be hereafter mentioned, I believe that, under favourable circumstances*, the temperature of a fresh and unbroken egg may be reduced to within 5° of zero of FAHRENHEIT without freezing, although its proper freezing-point, and that to which its temperature rises when it begins to freeze, is 32° or between 31° and 32°†.

It thus appeared that a fresh egg does not resist freezing as a living animal does, which either parts with its heat slowly, or else produces heat, compensating in some measure for that which is lost. It is as much the peculiarity of the fresh egg to lose its heat more quickly than another does, as it is to be longer in freezing; and, indeed, this quicker loss of heat seems essentially connected with the ability to be reduced far below 32° without freezing; for, among thirty-two fresh eggs, there were eleven which began to freeze at 32°, and all these had lost heat slowly; the average decrement between the fifth and fifteenth minutes of their exposure to cold being only $13\frac{2}{3}$°.

* The chief of these circumstances are, that the egg should be unmoved, and that its albumen should be not even so much disturbed as it is by the introduction of the thermometer.

† With so slender thermometers as I was obliged to use, it was not possible to determine within half a degree the precise freezing-point.

Many things observed in the course of these experiments seemed to indicate that the freezing of the fresh egg was retarded by some peculiarity of its mechanical construction, which was destroyed by the several means supposed to destroy its life. It was, therefore, desirable to ascertain whether the capability of being reduced far below 32° without freezing, and the consequent apparent resistance to freezing, could be destroyed by any means that would not at the same time prevent the egg from manifesting, by development in incubation, the surest evidences of vitality. In experiments to determine this point, I found that one might, with a bent probe, gently detach the whole of the albumen of an egg from its connection with the membrane of the shell, and that after this the chick would be developed, although, perhaps, not to perfection. But when eggs with the albumen thus disturbed were exposed to cold, they did not descend below 32° without freezing; they lost heat less quickly, but froze sooner, than uninjured eggs did, when exposed with them to the same temperature; they froze like the eggs which Mr. Hunter considered dead.

Again, cracking the shell of an egg does not prevent the development of the young bird, although, in consequence of the excessive evaporation through the fissures, the development may be imperfect. But when eggs with their shells cracked in many places, and with slight injuries of the membrane of the shell, were exposed to cold, they lost heat and froze just as those did which might be reputed dead. Thus, then, mechanical injuries, such as could not have affected the chemical composition of the fresh egg, and such as did not prevent its development in incubation, were found sufficient to deprive it of its power of resisting freezing; and thus its power of resistance appeared to be due, not to any vital principle, but to some peculiarity of mechanical construction.

It may be very difficult to prove what this peculiarity of construction is. That it is a property of the albumen was proved by some experiments, in which albumen, gently removed from fresh eggs, exhibited the same mode of freezing as the entire fresh eggs did: and the following facts, as well as those already mentioned, are favourable to the opinion, that the property which enables fresh albumen to descend far below 32° without freezing, is its peculiar tenacity or viscidity, by means of which the water combined with it is held so steadily, that the agitation favourable, or even necessary, to the freezing at or near 32° cannot take place.

1. The decay and putrefaction of an egg, the freezing and again thawing of one, and (as egg-preservers well know) the stirring and frequent concussion all tend to diminish the viscidity of the albumen to such a degree, that, instead of forming a consistent substance, the greater part of it will flow like a thin liquid from an aperture in the egg-shell.

2. The albumen of eggs does not freeze like a dense solution of albumen, or of saline substances, in water, but like water of which the ordinary freezing is prevented. The freezing-points of aqueous solutions are, according to their densities, more or less below 32°; and if, in exposure to intense cold, the temperature of any

such solution be reduced below its freezing-point, it will, at the instant of freezing, rise to that point, whatever it may be, and not to 32°. Thus, I placed in a freezing-mixture of which the average temperature was 10° FAHR., solutions of common salt in the proportions of 3, 5, 6 and 9 parts to 100 of distilled water; they fell to from one to six degrees below their several freezing-points, and then, in the act of freezing, rose respectively to 28°, 25°, 24½°, and 23°. At these temperatures they remained till they were thoroughly frozen, and then they all descended to the temperature of the medium in which they were placed. The same is observable in the freezing of serum and blood, which, in their relations to heat, may be regarded as mere solutions of albumen and saline matters: they freeze at from 29° to 31°, and retain these temperatures till they are thoroughly frozen. I found the same also in the freezing of milk and of thick mucilage of gum; the former froze at 30°, the latter at 28°, but neither of them in freezing rose to 32°. Unlike all these substances, the albumen of fresh eggs, however far below its freezing-point it may have descended, always in freezing rises to 32°; it freezes therefore like water, or like a very weak saline solution, which, by some mechanical disposition of its particles, is prevented from freezing as soon as it is reduced to 32°, or a few degrees lower.

3. The sudden strong agitation of fresh albumen, when its temperature is reduced several degrees below 32°, will often cause it to freeze at once*, as water under the same circumstances freezes.

4. It is well known, that when once a portion of any given quantity of water is frozen, the portion in contact with the ice cannot be reduced below 32° without freezing. I thought, therefore, that if I could bring ice just formed into contact with the albumen of an egg, the water in the albumen would freeze as soon as it fell to 32°, and so it proved; for in three experiments, in which the air-cavities of fresh eggs were filled with water before exposing them to cold, the albumen did not descend below 32°, but froze at that temperature.

Whether the explanation here offered of the peculiar property of the albumen of fresh eggs be right or not, the property will, I think, merit consideration in reference to both the nature and the purpose of the substance to which it belongs.

For, in regard to the nature of this form of albumen, its mode of freezing proves it to be essentially different both from all solutions of albumen and from organic tissues holding albuminous matter in suspension. As I have already stated, the freezing-

* In the course of the experiments, I observed that the effect of agitation, on either albumen or a saline solution, when its temperature is reduced below its freezing-point, depends in some measure on the temperature of the medium in which it is placed. Thus a saline solution, whose freezing-point was 28°, might be reduced to 25° in a medium of 24°, and, on being now agitated, it would not freeze; but a similar solution, reduced to 25° in a medium of 10°, would freeze at the instant of agitation. In a medium of which the temperature averaged 21°, no length of exposure and no agitation would, in one of my experiments, make albumen freeze, though it fell to the temperature of the medium; but in others, when albumen, in a medium averaging 10°, fell to 28°, it froze as soon as it was agitated.

points of albuminous solutions are lower than 32° in direct proportion to their densities; they do not, in freezing, rise to 32°, but freeze in all respects like saline solutions. And the same mode of freezing may be observed in organic tissues in which albuminous fluids are suspended or infiltrated. An eye, or its vitreous humour, a piece of muscle, gland, or brain, exposed to intense cold, loses temperature to 32° or $31\frac{1}{2}$°, and remains at this, its freezing-point, till it is frozen hard throughout, and then descends to the temperature of the medium in which it is placed.

The purpose or utility of this peculiar property of the albumen of eggs is manifest in the defence which it provides for eggs exposed to a temperature below 32°. If an egg be frozen, the damage sustained by its structure is such that the germ cannot be fully developed; but mere cold, however intense, if freezing does not take place, does not prevent the complete development of the young bird. I placed three eggs in a freezing mixture, varying from zero to 5° Fahr.: one of them froze, and its shell was cracked from end to end; another froze, and when it thawed, its yelk was burst and mixed with the albumen. In incubation, two spots of blood were developed in the former, and an enlargement of the cicatricula ensued in the latter of these two eggs,—sufficient indications that the intense cold and freezing had not killed them, though it had spoiled their structure. But in the third egg, which had been exposed for nearly an hour to a temperature below 5° Fahr., perfect development took place in incubation. Even this degree of cold therefore had neither killed nor frozen the egg, though, according to the average rate at which eggs part with heat, its whole substance must have been for half an hour at a temperature between 5° and 10° Fahr.

This security of eggs from the injurious influence of cold has also been proved, on a large scale, by the ingenious inventor of the hydro-incubator, Mr. Cantelo. He has told me, that, to test the truth of the popular belief that eggs are always destroyed by exposure to a frosty air, he sometimes exposed baskets of eggs, through the whole of a Canadian winter's night, to a temperature ranging, he believes, between 5° and 10° Fahr. Some of them were cracked, and these he threw away; they were doubtless frozen and spoiled; but the rest were placed in his incubator, and the usual proportion were hatched.

The need of such a provision against the influence of cold must exist in the case of many, or perhaps of all, birds that breed in cold climates; for accident must occasionally drive from their nests even those parent-birds that have not, like the common fowl, the custom of leaving their eggs for a certain time exposed to the open air.

In conclusion, I may repeat that the experiments I have related show that it is not by the power of a vital principle that eggs resist the influence of cold. They show that certain things will destroy the power of resisting cold without affecting the capability of being developed, and of therein manifesting the best evidence of life; and that when eggs yield to the influence of intense cold, they are not damaged unless

they are frozen, and are not killed even when frozen. The experiments thus remove almost the only remaining support of the hypothesis that such a vital principle may exist in organized bodies, as may enable them, even while inactive and displaying no other signs of life, to resist passively the influence of physical forces.