XLIII. *Experiments on Animals and Vegetables, with respect to the Power of producing Heat.* *By* John Hunter, *F. R. S.*

Redde, June 22, 1775.

THE ingenious experiments and obſervations lately preſented to this learned Society, upon a power which animals ſeem to poſſeſs of generating cold, induced me to look over my notes of certain experiments and obſervations made in the year 1766, which indicate an oppoſite power in animals; whereby they are capable of reſiſting any external cold while alive, by generating within themſelves a degree of heat ſufficient to counteract it. Theſe experiments were not originally inſtituted in view of the diſcovery, which in the event reſulted from them, but for a very different purpoſe; which was no other than to ſatisfy myſelf, whether an animal could retain life after it was frozen, as had been confidently aſſerted both of fiſh and ſnakes. I mention this, to account for what might otherwiſe be attributed to negligence and inattention; namely, that little nicety was uſed in meaſuring the preciſe degrees of the cold applied in theſe experiments. Accuracy in this particular was not aimed at, being of no conſequence in the

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inquiry more immediately before me. The cold produced was firft by means of ice and fnow with *fal ammoniac* or fea-falt, and was about 10° of FAHRENHEIT'S thermometer. Then ice, fo cooled, was mixed with fpirit of nitre; but what degree of cold was thus produced I did not examine. This cold mixture was made in a tub furrounded with woollen cloths, and covered with the fame, to prevent the effects of the heat of the atmofphere upon the mixture itfelf, and to preferve as much as poffible a cold atmofphere within the veffel. The animal juices, the blood for example, freeze at 25°; fo that a piece of dead flefh could be frozen in fuch an atmofphere.

EXPERIMENTS.

I. The firft experiment was made on two carp. They were put into a glafs veffel with common river water, and the veffel put into the freezing mixture; the water did not freeze faft enough; and therefore, to make it freeze fooner, we put in as much cooled fnow as to make the whole thick. The fnow round the carp melted; we put in more frefh fnow, which melted alfo; and this was repeated feveral times, till we grew tired, and at laft left them covered up in the yard, to freeze by the joint operation of the furrounding mixture and the natural cold of the atmofphere. They were frozen at laft, after having exhaufted the whole powers of life in the production of heat. That this was really the cafe, could not be known, till I had compleated that part of the expe-

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riment, for which the whole was begun; *viz.* the thawing of the animals. This was done very gradually; but the animals did not with flexibility recover life. While in this cold, they ſhewed ſigns of great uneaſineſs by their violent motions. In ſome of theſe experiments, where air was made the conductor of the cold and heat, that the heat might be more readily carried off from the animal, a leaden veſſel was uſed. It was ſmall for the ſame reaſon; and as it was neceſſary, for the animal's reſpiration, that the mouth of the veſſel ſhould communicate with the open air, it was made pretty deep, that the cold of the atmoſphere round the animal might not be diminiſhed faſt by the warmth of the open air, which would have ſpoiled it as a conductor.

II. The ſecond experiment was upon a dormouſe. The veſſel was ſunk in the cold mixture almoſt to its edge. The atmoſphere round the animal ſoon cooled; its breath froze as it came from the mouth; an hoar-froſt gathered on its whiſkers, and on all the inſide of the veſſel; and the external ends of the hair became covered with the ſame. While this was going on, the animal ſhewed ſigns of great uneaſineſs: ſometimes it would coil itſelf into a round form, to preſerve its extremities, and confine its heat; but finding that ineffectual, it then endeavoured to make its eſcape[(a)]; its motions became leſs violent by

(a) This ſhews, that cold, carried to a great degree, rather rouſes the animal into action than depreſſes it; but it would appear, from many circumſtances and obſervations, that a certain degree of cold produces inactivity both in the living and ſenſative principle, which will be farther illuſtrated hereafter.

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the finking of the vital powers; and its feet were frozen; but we were not able to keep up the cold a fufficient time to freeze the whole animal, its hair being fuch a bad conductor of heat, that the confumption was not more, than the animal powers were capable of fupporting(b).

III. The third experiment was made upon another dormoufe. From the failure of the laft experiment, I took care that the hair fhould not a fecond time be an obftruction to the fuccefs of our experiment. I therefore firft wetted it all over, that the heat of the animal might be more inftantaneoufly carried off; and then it was put into the leaden veffel. The whole was put into the cold mixture as before. The animal foon gave figns of its feeling the cold, by repeated attempts to make its efcape. The breath, and the evaporating water from its body were foon frozen, and appeared like a hoar-froft on the fides of the veffel, and on its whifkers; but while the vigour of life lafted, it defied the approach of the cold. However, from the hair being wet, and thereby rendered a good conductor of heat, there was a much greater confumption of it than in the former experiment. This haftened on a diminution of the power of producing it. The animal died, and foon became ftiff; upon thawing it, we found it was dead.

(b) Thefe experiments were made in prefence of Dr. GEORGE FORDYCE and Dr. ERWIN, teacher of Chemiftry at Glafgow; the latter of whom came in accidentally in the middle of our operations.

IV. The fourth experiment was upon a toad. It was put into water juſt deep enough not to cover its mouth, and the whole was put into the cold mixture, now between 10° and 15°. It allowed the water to freeze cloſe to it, which as it were cloſed it in; but the animal did not die, and therefore was not frozen: however, it hardly ever recovered the uſe of its limbs.

V. The fifth experiment was with a ſnail, which froze very ſoon, in a cold between 10° and 13°; but this experiment was made in the winter, when the living powers of thoſe animals are very weak: it might have reſiſted the cold more ſtrongly in the ſummer.

To aſcertain whether vegetables could be frozen, and afterwards retain all their properties when thawed, or had the ſame power of generating heat with animals, I made ſeveral experiments. Vegetable juices when ſqueezed out of a green plant, ſuch as cabbage and ſpinnage, froze in a cold about 29°; and between 29° and 30° thawed again, which is about 4° above the point at which the animal juices freeze and thaw.

I. I took a young growing bean, about three inches long in the ſtalk, and put it into the leaden veſſel with common water, and then immerſed the whole into the cold mixture. The water very ſoon froze all round it; however, the bean itſelf took up a longer time in freezing than the ſame quantity of water would have done; yet it did freeze, and was afterwards thawed, and planted in the ground, but it ſoon withered. The ſame expe-

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riment was made upon the bulbous roots of tulips, and with the ſame ſucceſs.

II. A young Scotch fir, which had two compleat ſhoots and a third growing, and which conſequently was in its third year, was put into the cold mixture which was between 15° and 17°. The laſt ſhoot froze with great difficulty, which appeared to be owing in ſome meaſure to the repulſion between the plant and the water. When thawed, the young ſhoot was found flaccid. It was planted; the firſt and ſecond ſhoot we found retained life, while the third, or growing ſhoot, withered.

III. A young ſhoot of growing oats with three leaves, had one of the leaves put into the cold mixture at 22°, and it ſoon was frozen. The roots were next put in, but did not freeze; and when put into the ground, the whole grew, excepting the leaf which had been frozen. The ſame experiment was made upon the leaves and roots of a young bean, and attended with the ſame ſucceſs.

IV. A leaf taken from a growing bean was put into the cold mixture, and frozen, and afterwards thawed, which ſerved as a ſtandard. Another freſh leaf was taken and bent in the middle upon itſelf; a ſmall ſhallow leaden veſſel was put upon the top of the cold mixture, and the two leaves put upon its bottom; but one-half of each leaf was not allowed to touch the veſſel by the bend; the cold mixture was between 17° and 15°, and the atmoſphere at 22°. The ſurfaces of the two leaves which were in contact with the lead were ſoon

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frozen in both; but thoſe ſurfaces which roſe at right angles, and were therefore only in contact with the cold atmoſphere, did not freeze in equal times; the one that had gone through this proceſs before, froze much ſooner than the freſh one. The above experiment was repeated when the cold mixture was at 25°, 24°, and the atmoſphere nearly the ſame, and with the ſame ſucceſs; only the leaves were longer in freezing, eſpecially the freſh leaf.

V. The vegetable juices above mentioned being frozen in the leaden veſſel, the cold mixture at 28°, and the atmoſphere the ſame, a growing fir-ſhoot was laid upon the ſurface, alſo a bean-leaf; and upon remaining there ſome minutes, they were found to have thawed the ſurface on which they lay. This I thought might ariſe from the greater warmth of theſe ſubſtances at the time of application; but by moving the fir-ſhoot to another part, we had the ſame effect produced.

VI. A freſh leaf of a bean was exactly weighed; it was then put into the cold atmoſphere and frozen. In this ſtate it was put back into the ſame ſcale, and allowed to thaw. No alteration in the weight was produced.

It appears from the above experiments, that an animal muſt be deprived of life before it can be frozen. Secondly, that there is an exertion, or an expence of animal powers, in doing this, in proportion to the neceſſity; and that the whole animal life may be exhauſted in this way. Thirdly, that this power is in proportion to the

the perfection of the animal, the natural heat proper to each ſpecies, and to each age. It may alſo perhaps depend, in ſome degree, on other circumſtances not hitherto obſerved: for from experiment II. and III. upon dormice, I found that in theſe animals, which are of a conſtitution to retain nearly the ſame heat in all temperatures of the air, it required the greateſt cold I could produce to overcome this power; while in experiment IV. and V. this power in the toad and ſnail, whoſe natural heat is not always the ſame, but is altered very materially according to the external heat or cold, was exhauſted in a degree of cold not exceeding 10° or 15°: and the ſnail being the moſt imperfect of the two, its powers of generating heat were by much the weakeſt.

That the imperfect animals will allow of a conſiderable variation in their temperature of heat and cold, is proved by the following experiments. The thermometer being at 45°, having introduced the ball by the mouth into the ſtomach of a frog, which had been expoſed to the ſame cold, it roſe to 49°. I then put the frog into an atmoſphere made warm by heated water, and allowed it to ſtay there twenty minutes; when, upon introducing the thermometer into the ſtomach, it raiſed the quickſilver to 64°. But to what degree the more imperfect animals are capable of being rendered hotter and colder, at one time then another, I have not been able to determine. The torpidity of theſe animals in our winter is probably owing to the great change wrought in their

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by the external heat and cold. The cold in their bodies is carried to ſuch a degree, as in great meaſure to put a ſtop, while it laſts, to the vital functions. In warmer climates no ſuch effect is produced. In this reſpect they reſemble vegetables.

From the foregoing experiments it appears; firſt, that plants when in a ſtate of actual vegetation, or even in ſuch a ſtate as to be capable of vegetating under certain circumſtances, muſt be deprived of their principle of vegetation before they can be frozen. Secondly, Vegetables have a power within themſelves of producing or generating heat; but not always in proportion to the diminution of heat by application of cold, ſo as to retain at all times an uniform degree of heat: for the internal temperature of vegetables is ſuſceptible of variations to a much greater extent indeed than that of the more imperfect animals; but ſtill within certain limits. Beyond theſe limits the principle of vegetable, as of animal life, reſiſts any further change. Thirdly, the heat of vegetables varies, according to the temperature of the medium in which they are, which we diſcover by varying that temperature, and obſerving the heat of the vegetable. Fourthly, the expence of the vegetating powers in this caſe is proportioned to the neceſſity, and the whole vegetable powers may be exhauſted in this way. Fifthly, this power is moſt probably in proportion to the perfection of the plant, the natural heat proper to each ſpecies, and the age of each individual. It may alſo perhaps depend, in ſome degree, on other circumſtances not hitherto obſerved; for in experiment

periment II. the old ſhoot did not loſe its powers, while that which was young or growing did; and in experiment III. and IV. we found, that the young growing ſhoot of the fir was with great difficulty frozen at 10°, while a bean-leaf was eaſily frozen at 22°; and in experiment V. the young ſhoot of the fir thawed the ice at 28°, much faſter than the leaf of the bean. Sixthly, it is probably, by means of this principle, that vegetables are adapted to different climates. Seventhly, that ſuſpenſion of the functions of vegetable life, which takes place during the winter ſeaſon, is probably owing to their being ſuſceptible of ſuch a great variation of internal temperature. Eighthly, the roots of vegetables are capable of reſiſting cold more than the ſtem or leaf; therefore, though the ſtem be killed by cold, the root may be preſerved, as daily experience evinces. The texture of vegetables alters very much by the loſs of life, eſpecially thoſe which are watry and young; from being brittle and criſp they become tough and flexible. The leaf of a bean when in full health is thick and maſſy, repels water as if greaſy, and will often break before it is conſiderably bent; but if it is killed ſlowly by cold, it will loſe all theſe properties, becoming then pliable and flaccid; deprived of its power of repelling water, it is eaſily made wet, and appears like boiled greens. If killed quickly, by being frozen immediately, it will remain in the ſame ſtate as when alive; but upon thawing, will immediately looſe all its former texture. This is ſo

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remarkable, that it would induce one to believe, that it loſt conſiderably of its ſubſtance; but from experiment VI. it is evident that it does not. The ſame thing happens to a plant when killed by electricity (c). If a growing juicy plant receives a ſtroke of electricity ſufficient to kill it, its leaves droop, and the whole becomes flexible.

So far animal and vegetable life appear to be the ſame; yet an animal and a vegetable differ in one very material circumſtance, which it may be proper to take particular notice of in this place, as it ſhews itſelf with remarkable evidence in theſe experiments. An animal is equally old in all its parts, excepting where new parts are formed in conſequence of diſeaſes; and we find, that theſe new or young parts in animals, like the young ſhoots of vegetables, are not able to ſupport life equally with the old; but every plant has in it a ſeries of ages. According to its years, it has parts of all the ſucceſſive ages from its firſt formation; each part having powers equal to its age, and each part, in this reſpect, being ſimilar to animals of ſo many different ages. Youth in all caſes is a ſtate of imperfection; for we find that few animals that come into the world in winter live, unleſs they are particularly taken care of; and we may obſerve the ſame of vegetables. I found that a young plant

(c) To kill a whole plant by electricity, it is neceſſary to apply the conductor, or give a ſhock to every projecting part; for any part that is out of the line of direction will ſtill retain life.

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was more eafily killed than an old one; as alfo the youngeft part of the fame plant.

This power of generating heat feems to be peculiar to animals and vegetables while alive. It is in both a power only of oppofition and refiftance; for it is not found to to exert itfelf fpontaneoufly and unprovoked; but muft always be excited by the energy of fome external frigorific agent. In animals it does not depend on the motion of the blood, as fome have fuppofed, becaufe it belongs to animals who have no circulation; befides, the nofe of a dog, which is nearly always of the fame heat in all temperatures of the air, is well fupplied with blood: nor can it be faid to depend upon the nervous fyftem, for it is found in animals that have neither brain or nerves. It is then moft probable, that it depends on fome other principle peculiar to both, and which is one of the properties of life; which can, and does, act independently of circulation, fenfation, and volition; *viz.* that power which preferves and regulates the internal machine, and which appears to be common to animals and vegetables. This principle is in the moft perfect ftate when the body is in health, and in many deviations from that ftate, we find that its action is extremely uncertain and irregular; fometimes rifing higher than the ftandard, and at other times falling much below it. Inftances of this we have in different difeafes, and even in the fame difeafe, in very fhort intervals of time. A very remarkable one fell under my own obfervation, in a gentleman who was taken with an

apoplectic fit; while he lay insensible in bed, and covered with blankets, I found that his whole body would, in an instant, become extremely cold in every part; continue so for some time; and, in as short a time, he would become extremely hot. While this was going on for several hours alternately, there was no sensible alteration in his pulse.