THREE LECTURES

ON

THE PRINCIPLE OF LEAST ACTION IN NATURE,
ILLUSTRATED BY ANIMAL MECHANICS.*Delivered at the Royal Institution of Great Britain.*

BY THE

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LECTURE I.—Tuesday, May 23rd, 1871.

Science of Animal Mechanics defined as the application of the principles of Geometry and Mechanics to Comparative Anatomy.—General Principle of Least Action, as observed in Astronomy and Physics.—Application of this principle to Animal Mechanics.—Illustration of the Pleasures and Difficulties of the Study of Animal Mechanics, from the Lecturer's Adventures in Search of the Coefficient of Muscular Force.

I TAKE it for granted that there is no one of those whom I now address who has not read both with profit and pleasure *Gulliver's Travels*. But of the many thousands that have read that charming book, there are very few that know the real circumstances of the history of its production. It is only a fragment of a much greater work which was contemplated and which the world has lost for ever—a work which was to have been the combined result of the genius of three of the most remarkable men that our country has produced; one an Englishman, another a Scotchman, the third an Irishman. More than 150 years ago, in the good old times when Queen Anne reigned in England, and science, literature, and art were patronised by her court, three of the most remarkable men that ever lived in this city were friends and companions. The Englishman was Pope, the Scotchman was Arbuthnot, and the Irishman—I may be permitted as a fellow-countryman to say, greater than either—was our illustrious Swift. It was proposed by Pope that a novel should be written by these three men, which would have been a novelty not only in that age of literature but in our own, by which the combined efforts of the genius of three such men should be brought to bear upon the production of a work of fiction. The fragments of that work of fiction remain at the end of the large editions of Pope's works under the name of *Memoirs of Martinus Scriblerus*. Pope was to have taught Martinus Scriblerus literature, logic, and metaphysics; Dr. Arbuthnot was to have taken charge of his medical education and have brought him to Holland and Germany to study medicine; while Swift was to have written his travels. *Gulliver's Travels* were produced as a separate work by Swift in consequence of the troubles at the close of the reign of Queen Anne, which scattered this remarkable triumvirate. The travels that were originally intended to illustrate the life and memoirs of Scriblerus appeared under the name of, and are known to you all as, *Gulliver's Travels*.

The accession of George I not only destroyed the prospect of the world seeing the memoirs and travels of Martinus Scriblerus, but it also lost for England the credit of producing a great work on Animal Mechanics. It can be shown from several passages in his writings, that Dr. Arbuthnot, who was himself a most skilful geometer and a most expert anatomist, had conceived the project of uniting these sister sciences of anatomy and geometry in one great science, and so creating a new field for discovery, for thought, and for research. His appointment as court-physician to George I withdrew him, I regret to say, from the ranks of science; and England lost, by his appointment to that office, the opportunity of producing a great work on Animal Mechanics. It was reserved for an Italian, Alphonso Borelli, one of the greatest men that modern times ever produced, to lay the foundations of this most remarkable science. Alphonso Borelli taught mathematics in the university of Naples at the close of the seventeenth century. He was also professor of anatomy in this same university; and his book shows that the union of anatomy and geometry had the honour of being approved by the Pope, and pronounced to contain nothing dangerous to faith or morals. He produced his remarkable book on Animal Mechanics, which he

entitled *De motu animalium*, in the year 1680; but he died before this book was produced, and he died also, unfortunately, without knowing what our distinguished countryman, Sir Isaac Newton, had discovered of the laws of the composition of forces. The result is that, although his book *De motu animalium* carries in every part traces of his brilliant genius, it is full of mistakes arising from the false notions on mechanics which were inevitable in the case of a person not acquainted with the composition of forces discovered by Newton. But it remains in its present state, with all its defects and errors, I say without hesitation, the only book that can be called a systematic scientific treatise on Animal Mechanics.

In later times an attempt was made by two remarkable Germans, who were brothers, Edward and Wilhelm Weber, professors of anatomy and mathematics in the universities of Göttingen and of Leipsic. From conversing together, these two men came to the conclusion that, if mathematics or geometry and anatomy could be brought into contact, the result would be the production of a third science, perfectly novel and of great value. They compared their observations and notes together and produced a treatise on the motions of the human body, which will always be quoted as a model of accuracy and a standard of scientific observation; but, from the necessary want of unity and uniformity produced by two minds being brought to bear upon the same subject instead of one, it cannot be regarded as so systematic or complete a treatise as that of the illustrious Borelli.

The progress of science of every description, and the extraordinary and interesting results that have been produced in recent times by the union of sciences apparently diverse from each other, have rendered it almost inevitable that now, in some quarter or other, a science of Animal Mechanics must arise which shall be worthy of being called an exact science, and worthy of taking its place amongst the most perfect of all our modern sciences.

In order to found such a science, the great want is the discovery of some general principle. I believe that I have succeeded in discovering the true principle on which this science must be founded, and have been enabled to sketch out the broad outlines of the foundation of such a science; though it must remain for abler mathematicians and more expert anatomists than I can pretend to be to fill up the details of the outline and bring them to the perfection at which I am confident they will ultimately arrive. The principle on which I propose to found the science of Animal Mechanics is a principle of almost universal application—it is called the Principle of Least Action. This is well known to mathematicians in its application to inanimate nature; and, with your permission, I will call your attention to one or two remarkable instances of the application of the principle of least action, well ascertained in physics and astronomy, before proceeding to apply it, as I hope to do in these lectures, to the study of organic nature, and particularly of muscular mechanics.

The celebrated Kepler, who died before Sir Isaac Newton's laws of gravitation were discovered, as must be well known to you all, discovered by patient observation the laws of the motions of the planets. He discovered, in particular, the important law that a planet revolves round the sun in an ellipse, the sun occupying a focus of this ellipse; and that every portion of the path of the planet is an ellipse, each portion of the path being characterised by a velocity of motion peculiar to itself, and different from that which is found in any other part. It is not necessary for me to describe to you the simple laws by which the motion of this planet varies; but if you will imagine a planet moving from point A to point B (diagram) in its path round the sun, Kepler succeeded in discovering that it moves along that path by regular laws, by a regular motion belonging to each part of that path, and never deviating from it. He published his celebrated laws, which are known as Kepler's laws, from which, in later times, Sir Isaac Newton deduced by mathematical demonstration the celebrated law of gravitation. It is extremely interesting to us who look back upon these discoveries with the reflected light which Newton's genius has thrown upon them, to read Kepler's writings, and see in what manner this remarkable man regarded his own discoveries. Kepler was a scholar as well as a mathematician; and he was a profound student of the *Timæus* of Plato, and he was charmed with that beautiful fiction in which Plato imagines the cosmogony of the world, and describes it as the Demiurgus persuading Chaos to become Cosmos; and ends by the assertion, bold for his age, considering that it was in opposition to the heathen mythology of the times, that the sun was an animal, the earth an animal, the moon an animal; that the gods, as Venus, Diana, and Mercury, were deities who were subordinate to these great beings. Kepler was caught with the beauty of this Platonic fiction. He imagines the earth swimming in her orbit round the sun as an animal with intelligence. He discusses in his book, *Harmonices Mundi*, the possibility of the earth seeing without eyes, and hearing without ears; and arrives at the conclusion that

the earth must be an animal, for three reasons. First, the earth moves uniformly on her axis, and none but an intelligent being could know how to keep uniformly moving without going faster at one time than at another. Secondly, he says, the earth, as he has proved by his laws, describes a particular path round the sun and no other, and moves with a particular velocity at each portion of that path; and this, he says, the earth can only do by observing the angles made by the heavenly bodies, calculating its position—going slowly when it had to go slowly, and fast when it had to go fast—by observing the planetary angles. Lastly, he says, the earth must be an intelligent animal, for the highest and best of all reasons, which he also learned from Plato—because the earth is a great geometer. The earth, he says, produces within her bosom crystals such as these which are before you, which are related to certain forms shown in the diagram—Euclidean solids capable of being inscribed in spheres. No creature, says Kepler, could know the mysterious properties of the solids inscribed in spheres, excepting an intelligent geometer. The earth produces crystals and forms closely related to these in her own bosom, and therefore by the maxim *de opifice testatur opus* (which we may translate by “the carpenter is known by his chips”), we come to the conclusion that the earth must be a geometer, for she produces perfect geometrical forms. Kepler goes further, and proceeds to discuss the question what sort of an animal is this earth? He says the earth is no lively animal like a lap-dog, ready to obey your nod; she is a sluggish, lazy, intelligent creature, like an ox, or perhaps, I should say, like an elephant. Now, a very remarkable fact bearing upon this is well known to mathematicians. The celebrated principle of least action, as it is applied in mechanics and astronomy, consists in showing that a certain integral $\int v \, ds$, v being the velocity at each point, and ds the elements of its motion, must be the minimum. If I take the points A and B in the planets’ path, s representing the sun, I only require to know those points A and B and the sun, s , to calculate for you, from the principle of least action—which I can do to the millionth part of an inch at each portion of this orbit—the path that the planet must describe, on the supposition that it is a lazy, intelligent animal, trying to swim round the sun in such a manner as to give the least trouble to itself. It is perfectly well known to astronomers that the imaginary idea of Kepler may be converted into a real fact; and that, if we grant the hypothesis that the earth is an intelligent animal swimming round the sun, we can calculate and predict its path as certainly as we could from the Newtonian law of gravitation.

Pondering this idea over in my mind, it seemed to me to afford in such a science as Animal Mechanics a possible key which would unlock the secrets of that science. It was an hypothesis invented by Kepler in the early ages of astronomy when more perfect hypotheses were impossible, but which, when carefully followed out, would lead to results as accurate and as perfect as the exact hypothesis; and the hypothesis I have to lay before you as the foundation of the science of Animal Mechanics is similar to that of Kepler, and will ultimately, I doubt not, be replaced by a higher and more perfect law, such as that with which Newton replaced Kepler’s law. My hypothesis is, that in every arrangement of bones, muscles, joints, and parts of animals, the arrangement must be such as—on the hypothesis that the muscles were a living intelligent thing, trying to save itself trouble—the motion would be. We can calculate, as I shall show you in the subsequent lectures, with a certainty as perfect as we can calculate the path of a planet, the positions of bones and sockets as we find them in nature. If, therefore, I can prove my hypothesis, we are entitled to regard it as a key for the present, to be substituted ultimately by some higher law, but a valuable and precious key to unlock for us the secrets of animal mechanics.

Before proceeding to apply it to the muscles, I must give you one or two more illustrations of it, to show you the power of the instrument which I propose to use. When a ray of light passes from one medium into another, it always describes a bent path. A ray of light passing from the air into a glass of water will be bent at the junction of the two bodies. Taking the point A (diagram) to be the ray of light in the air, and point B the ray of light in the glass, if I imagine the fiction that the molecule of light is a living, intelligent, lazy animal, trying to go from A to B with the minimum of trouble to itself, I can predict, as certainly as by the law of refraction and reflection, the path which it would describe. This principle has been actually applied—the principle of least action—by Sir Isaac Newton to discover the path of a ray of light. It will apply, as astronomers and mathematicians are aware, to many other branches of science; it will apply also, I believe, to the unconscious actions of intelligent animals like ourselves. Some years ago, I had the opportunity of observing an unconscious application of this remarkable principle made by an extremely unintelligent class of old women. These were the oyster-women of the Mumbles Harbour, near Swansea. These poor old creatures carried their baskets down to the oyster-beds empty; they filled the baskets with oysters, and then they had to carry

them to the Mumbles along a road which consisted of two parts; there was the slippery shingle of the beach where they collected the oysters, and after they left that slippery shingle there was a smooth common. Now, this placed the oyster-women in the same position as the ray of light. The velocity of the light in air and its velocity in water are different. The velocity of these poor women in the rough shingle, where they occasionally fell, and their velocity on the smooth road, were, as you may suppose, also different, and the friction different. I saw these poor women, to my great amazement, not going from point A to point B as I should have done, nor going perpendicularly so as to get from the shingle in the shortest time on to the common, but making a tack at some point which they seemed to guess at along the line of shingle, and so getting home with less trouble than they would otherwise have done. I had the curiosity to measure the angles made by their path, and made a rough calculation to determine the relative roughnesses of the two roads. I do not suppose that these poor women had any more consciousness of what they were doing than the ray of light or the planet has; they were describing a path of minimum trouble. I can hardly do them the injustice to say that they were lazy animals, because they were the most industrious, hard-working poor creatures I have ever fallen in with, but they were performing unconsciously and instinctively the great problem—the problem of doing a given amount of work with a minimum amount of effort; and I venture to say that they performed that problem as the planet describes its path, not by their own intelligence, but by the intelligence of Him who made them both.

I shall take yet another example from organic nature before proceeding to the subject of muscular action. I will take the well-known problem of the cells of bees. Every one knows that the cells of bees are constructed in hexagons, and that the ends of these cells are terminated by the faces of a rhombic dodecahedron. That was the solid so greatly admired by Plato, that he considered it was worthy of representing the earth itself. The tetrahedron represents fire; the octahedron represents air, the cube represents water, but this solid body was reserved in the Platonic system for the dignity of representing the earth itself. The bee constructs this solid; and ancient geometers such as Pappus were so struck with the beauty of these cells that they considered the bee to be a mathematician and geometer; they reckoned the bee amongst themselves as worthy of being called mathematicians, and they accepted the bee-cells as a challenge. Pappus says angrily in one of his works: “I cannot admit that the bee is so expert a geometer as we are, for we can perform a problem greater than the bee, describing polygons with the least perimeter.” He proceeds to show how he could make cells more perfect than those of the bee. There is in this an unconscious supposition of the same kind as in the case of Kepler, that the bee makes the cell by some knowledge or intelligence of its own. Now, the cell of the bee possesses remarkable properties: it possesses the property of making the largest quantity of cell-space with the minimum quantity of wax; or, in other words, it performs the problem of doing a given work with the least amount of trouble to the bee. It costs the bee trouble to make wax, and, therefore, if he acted consciously or unconsciously on the principle of least action, he will make his cells in such a form as to produce a given space for the accommodation of the honey with the minimum or smallest quantity of trouble to himself and of wax as material. In all these cases, in the motion of the planet, in the motion of light, or in the case of living beings like the bee or the unconscious oyster-woman, we have the same principle at work. Nature aims at producing a given quantity of work with the least quantity of material, and this is the precise form which the principle of least action takes in muscular mechanics. Nature has to produce a certain quantity of muscle to do a certain quantity of work. The production of that quantity of muscle costs an effort which is exhausting to the animal; the muscles so produced from day to day, from hour to hour, from minute to minute must be fed by blood-vessels, must be nourished and sustained, and this causes a daily waste of labour. It is, therefore, obviously the interest of nature, whatever be the intelligence that guides her movements, it is the interest of the creatures that she makes, that they should do the work which they have to do with the minimum amount of muscle. The principle of least action is that the arrangement and mutual position of all muscular fibres, bones, and joints must be such as to produce the required effect with the minimum amount of muscular tissue. I hope to show you in my lecture on this day week by two very remarkable examples from the limbs of the tiger and the wings of the albatross a complete and perfect demonstration of the truth of this principle; and in my closing lecture I shall ask your attention to the most interesting and attractive of all the applications to which animal mechanics can be applied, namely, to the heart and other involuntary muscles of great importance.

Before proceeding to apply this principle of least action or least

trouble to nature, it is necessary for us to obtain what I call the coefficient of muscular force. If you take a rope made of hemp, of silk, or of iron, engineers are well-acquainted with the importance of obtaining its coefficient, which represents the number of pounds or tons weight necessary to break it across. Now, I ask you to imagine a rope of muscle. A muscle consists of filaments or fibres very frequently parallel to each other in the form of a rope. Imagine a rope of muscle, one square inch in cross-section, hanging from the ceiling to the ground: let that muscle contract by the order of the will, what weight will it lift from the ground? This is what I define as the coefficient of muscular contraction. It has cost me twelve years of hard work to obtain the coefficients I now place before you, which are represented in pounds per square inch for human muscle. I have not succeeded in obtaining it for any other animal but man. No other animal that I have met with, not even the hairy quadrupeds with long tails, are intelligent enough to submit to the necessary experiments. 94.7 lbs. per square inch is the weight that the arms of a young man accustomed to athletic exercise are capable of lifting. 110.4 is the corresponding coefficient for the muscles of the legs of a similar class; and 107 for the muscles covering the abdomen.

When you bear in mind what I shall now call your attention to, the extreme difficulty of obtaining these results at all, I hope you will agree with me that the differences between them fall within the necessary limits of observation and of error, and that therefore the final result of 104 per square inch may be regarded as an extremely close approximation to the real coefficient of muscular force exerted in healthy strong men. At least, it is the only coefficient that I am able to lay before you. We must undertake, and I did undertake, two extremely laborious classes of observations in order to obtain that coefficient. Without that coefficient I can make no step further in the application of geometry and mechanics to anatomy. This became an absolutely necessary preliminary step. The determining of that coefficient consists of two totally distinct classes of observations. I had to make observations on the force exerted by the muscles during life; and, secondly, I had to make most careful measurements after death of those same muscles. With regard to observations on the force of the muscles exerted during life, it is not nearly so easy to make them, as many of you, who are not anatomists, would at first sight suppose. There is hardly an action of the body—the lifting my hand to my head, walking across a room—that does not involve the co-ordination and co-operation of many scores of muscles; and the moment I get many muscles into play, the difficulty of separating their action becomes immense. Although it is easy to measure the force used in rowing and other actions with the utmost precision, when you come to distribute the action amongst the many muscles that have produced it, you find it impossible to separate and give to each muscle its part, so as to obtain the true coefficient of muscular exertion. You will only, by such processes, obtain empirical results informing you what strength animals or men could exert when performing certain actions, but you cannot work back and get the coefficient which science demands, the precise force per unit of cross-section which these muscles exert. Again, measurements of the muscles made after death presented difficulties, to which I shall presently call attention, much greater than any but an anatomist would suppose. In making my observations on the force exerted by the muscles during life, I often found (as medical men are well aware) that in unexpected forms of disease phenomena will be presented bearing upon muscular forces that solve problems in animal mechanics that no voluntary effort on the part of the sufferer could possibly produce. Contortions of the body will be produced by the agonising spasms of cholera, of lock-jaw, or, as I have seen in cases of poisoning by strychnia, which, while they are dreadful to behold, are yet, to the intelligent observer, of most extreme importance. While you are helping a sufferer on his bed of pain there is nothing to prevent your catching the solution of your problem for the coefficient of animal mechanics. You need not be less kind or hearty in your zeal to help the sufferer because you are at the same time taking scientific note of a curious combination of muscles of which he is entirely unconscious, and that no voluntary effort on his part or on the part of any other man would enable you to obtain. Partly for this cause, and partly I hope from higher motives, I became personally and intimately acquainted with all the phenomena of cholera. In cholera, hydrophobia, lock-jaw, and for the study of the muscle of the heart in fever, it is absolutely necessary to come into contact with these diseases, to study them at the bedside, and so to become acquainted, as I did through twelve years of hard work with a most interesting class, concerning whom it will be wrong for me to proceed in my lecture without bearing my humble testimony. I am not acquainted much with the poor of England, though I doubt not their qualities are as estimable and as excellent as those of my own country; but I may be permitted to bear my humble testimony to the

qualities which I have observed myself amongst our Irish poor when in sickness and in trouble. Their devotion to their friends and neighbours in time of trouble is most extraordinary. Those who have quarrelled in prosperity forgive each other in times of sickness. Their impulsive nature and their heartfelt gratitude, even unto death, for a hearty word of sympathy and kindness from those who visit them, and their brave cheerfulness in facing death, cannot be described by my words. One fact stands out prominent to the observation of any person who studies our Irish poor in time of sickness and trouble, the extreme devotion of the poor to the poor. The rich often will give money, sometimes kind words; but the poor give all they have—their food, their money, their hearts to each other in time of sickness. I believe, and I am sure my experience will be confirmed by that of every physician who hears me, that those sufferers who have themselves drunk the bitter cup of life to its very dregs are the most ready to offer to the lips of a dying brother or sister the cup of cold water in the name of their Divine Master.

My efforts to obtain a coefficient of muscular force were not confined to observations upon the poor in hospitals; I also had to come in contact with a more uninteresting, but perhaps not less curious, class—the criminals in our jails. It is necessary for the student of animal mechanics to become an expert in the use of the treadmill, to understand the mysteries of shot-drill, and to know how to use the crank. My object was to learn how to work upon the treadmill as an intelligent lazy burglar, trying to do my work with the least trouble to myself; and I can assure you, after much labour, I perfectly succeeded, and can go through shot-drill, turn the crank, and work the treadmill, as the laziest burglar in London might do, working my muscles involuntarily by the principle of least action, and doing my hated task in a lazy manner, with the least trouble to myself. How did I obtain this knowledge? How did I learn these things? I have been taught the use of jemmies, and burglars' tools as well. I know the slate trick, which is a secret known to Irish thieves only; I also know where to place myself to the best advantage on the treadmill; and I learnt all this by a plan extremely simple, and which I would heartily commend to our criminal reformers as a most powerful weapon in their hands—an ounce of tobacco. An ounce of tobacco will draw the dearest secret from the heart of a burglar; it will make the most discontented, sulky wretch in the gaol obedient and quiet for a week, the promise of an ounce of tobacco at the close. I believe it is done in some prisons, and it ought to be done in all. Instead of the extreme severity which characterises our treatment of these poor men, the occasional offer of rewards, which the men would prize, would do more to reform them than all our severity and all our stripes. I must say for them that I have found them, as a class, both English and Irish burglars and thieves, much better than I had expected.

Having made my observations upon the work done by groups of muscles in various conditions of action, I then had, as you will see, to proceed to the examination of the measurements of these muscles after death. Now, this was no easy task. The observations on the forces employed were made upon men in health—generally young men in the full vigour of life—for I was anxious to ascertain what the coefficient of muscular exertion in healthy men and in full condition was. But the examinations of muscles after death were necessarily made upon persons who had died in their beds after they were wasted by long illness, and in a condition of body presumably quite different from that of those same persons when in health. I saw very quickly that if I relied upon mere observations and measurements of muscles made after death, comparing them with living forces, I should get a false result, and a coefficient much too great, because the cross-section of the muscle in life is certainly much larger than it is after death from long illness. Therefore I had two courses before me: I had my choice of waiting for persons who had died suddenly a violent death, and obtaining permission to examine them, or of waiting for an opportunity of examining persons who had died violently by the hands of the law. Now, in a country like Ireland, there were unusual and extraordinary impediments to both these processes. I placed myself in communication with the hospitals of Dublin, and got early notice of every bad accident that came in. The patient in the cases, such as I was sent for generally, died, but the cause of death was so apparent that the coroner could not venture to interpose and order a legal investigation of the body, which would have given an opportunity for examination; and the sympathy of friends in the case of accident—the determination to wake the deceased person—is so strong in Ireland that it is impossible to obtain permission from them to make an examination. A wake is a matter of great necessity in all cases in Ireland where it is possible, but in a case where the sensations and feelings have been aroused and sympathies excited by a fall from a scaffold, or an accident in a mill, or any violent death, an anatomist would be most unwise, if he attempted to make an examination in such a case. Again, when I turned my attention to executions, I had extreme difficulty, part of which is creditable to my

country—social or private crime is so extremely rare in Ireland that it was almost impossible to find a case for examination. In such a case there would have been no sympathy with the convicted criminal, and the surgeon would have been permitted to conduct his investigation at his leisure; but in the majority of cases in Ireland the crime for which executions are performed is agrarian crime, and is semipublic in its character, exciting sympathy among large masses of the misguided population who agree with the murderer; and this calls for great care and caution on the part of any scientific man who would make a man who has shot his landlord a subject for investigation. At last, ladies and gentlemen, a brilliant idea came across my mind, which, however, I was reluctantly compelled to set aside. I thought to myself, what in the world is to hinder me from taking a farm in Westmeath, deliberately and wilfully refusing to pay my rents, and in due time shooting my landlord, and, instead of using him as a New Zealand tenant would, dissecting him at my leisure. Then I have my muscular coefficient problem and all my problems resolved. I need not say that further consideration led me to the conclusion that there were inconveniences attached to this course, and public opinion in Ireland, I can assure you, would not sanction the shooting of a landlord for the purpose of determining the coefficient of muscular force.

In conclusion, I would wish to say a word as to the principle I have adopted. I have shown you that the planet moves in its orbit as a lazy intelligent creature would who was anxious to perform an allotted task with the least trouble to itself; that a ray of light describes its path by the same sort of apparently instinctive action; that the poor old oyster-woman, ignorant of what she is doing, instinctively walks across the varying road she has to travel in the path of the least action; that the bee constructs its wonderful cell so as to produce a given amount of storage for its honey with the least possible amount of trouble to itself; and in a case that I was not able to bring before you for want of time, of the tendons of the legs and arms of animals, I could show that these are constructed with a wonderful economy of force of the same kind as that with which the bee constructs its cell; and I hope to show, in a future lecture, that the limbs or muscular organs of every animal are also constructed on this strange principle; as if each one of these things was itself instinct with life and reason, as Kepler really and from his heart believed. Is it by the intelligence of the planet that it moves in its orbit? Does the light travel in its path by its intelligence? Does the poor oyster-woman calculate the road by which she goes as she instinctively walks across the strand? Who has weighed out and regulated the weight of the tendons of our arms and hands? And by what force or by what intelligence do the limbs of animals describe their proper path? Who places the socket of each joint in the exact position (which can be calculated with unerring certainty by mathematics) which enables the muscle to perform its allotted task with the least amount of trouble to itself? It is not by their intelligence, by their instinct: it is not the instinct of the planet, or of the oyster-woman, or of the bee, that guides them in their path. There is instinct; there is knowledge; there is foresight; there is calculation: it is the knowledge, the foresight, the wisdom, and the calculation, of the Great Architect and Geometrician of the Universe.

ON THE TREATMENT OF POISONING BY CARBOLIC ACID.

By CHARLES ROBERTS, Esq.

ACCIDENTAL and suicidal poisoning by carbolic acid is now of such frequent occurrence, that it is a matter of importance that we should come to some definite conclusion as to the best antidote and the most suitable treatment to be adopted in such cases. Considerable difference of opinion exists as to the manner in which death is produced by this substance. Some believe that it is due to nervous shock, produced by the local lesions of the mouth, gullet, and stomach; and that the carbolic acid is not absorbed into the system. Others, again, believe that it is absorbed, and produces death by acting on the brain as a narcotic poison; while a third class hold that its action is due to chemical changes produced in the blood, and consequent impediment in its circulation, congestions of the brain, lungs, etc. It is much to be regretted that more complete reports have not been made of the numerous cases which have occurred, especially in public practice.

In the cases reported by Dr. Ogston and Dr. Irvine, of Aberdeen, in the *BRITISH MEDICAL JOURNAL* for February 4th, 1871, and by Dr. Barlow, of Manchester, in the *Lancet* for March 20th, 1869, the carbolic acid was recognised by its odour in the brain, liver, and other organs, and the blood was coagulated and otherwise altered in character. It will be remembered, too, that one person died, and the lives

of two others were endangered, by the application of the acid to the skin for the cure of itch. In one of the provincial hospitals, a patient died from the administration of an enema containing carbolic acid; and numerous cases have been recorded in which the application of dilute carbolic acid lotions to wounds have produced urgent and often dangerous symptoms of poisoning. There can be little doubt, therefore, that the poison is absorbed into the system. When the acid is concentrated, and in large quantity, and the stomach empty, it would, like any other corrosive substance, by destroying a large surface of mucous membrane, produce death by shock; but even where this has occurred, as in Dr. Barlow's case, some of the poison was absorbed.

In all cases, whether death has resulted or not, the symptoms have been those of collapse; the milder cases often accompanied by severe vomiting, the severer ones by convulsions. These symptoms, following rapidly on the administration of the poison, point clearly to the nervous system as the part first affected, the circulatory derangements being secondary, or, in a great measure, even *post mortem*. An interesting case reported by Dr. Lightfoot in the *BRITISH MEDICAL JOURNAL* for April 2nd, 1870, confirms this view. A lotion containing only two per cent. of carbolic acid was employed as a dressing to a case of excision of the elbow-joint, on three successive occasions, and on each occasion severe vomiting and dangerous symptoms of collapse followed, but again subsided on substituting a poultice for the lotion. It is quite incredible that so small a quantity of acid, absorbed by so small a surface, could have produced such urgent symptoms by any chemical action on the blood. Dr. Lightfoot refers to similar cases in the Guy's Hospital and University College Hospital Reports; and it is quite probable that symptoms, which are often attributed in surgical practice to anaesthetics, are due to the carbolic acid employed as dressings.

The indications for treatment are—to remove the poison from the stomach as speedily as possible, to neutralise its action, and to treat the general symptoms of collapse in the ordinary way. A mixture of olive oil and castor oil has been recommended, and employed in some cases, with the object, I suppose, of diluting and carrying off the poison by the bowels, on the theory that it acts only as a corrosive, and is not absorbed. As we know that it is absorbed, it would be doubtful practice to continue this treatment, and to make the acid run the gauntlet of the fat-absorbing surfaces of the small intestines. As carbolic acid is very slightly soluble in water, probably the speediest and most effectual way of removing it mechanically from the stomach, would be to administer large quantities of warm water, or mustard and water. As it is very soluble in glycerine, that substance, with water and sulphate of zinc, might be employed, after the bulk of the poison had been removed by the former plan. From the serious action of the acid on the mucous membrane, the stomach-pump should be employed with great care, and probably would often be inadmissible. I know of no substance capable of neutralising the acid chemically; but its well known affinity for albuminous compounds would point to eggs, and finely mixed or powdered raw meat, as likely to be of service. If eggs were used, it would be necessary, for obvious reasons, that they should be very much diluted, by being whipped up with milk or cold water. Milk is not coagulated by carbolic acid, and therefore would not act as a neutraliser, but it would be a more suitable application than oil to the injured mucous membrane, and less likely to produce further discomfort to the patient. The general symptoms of collapse must be treated in the usual manner, by internal stimulants, and friction and warmth to the skin. The rectum would be the most suitable part to which stimulants should be applied. If raw meat were given, it might be well seasoned. As brandy dissolves carbolic acid, and is itself speedily absorbed, its administration by the stomach would be contraindicated.

POISONING BY NITRATE OF SILVER.

DURING the period of my house-surgeoncy at St. Mary's Hospital, Paddington, a similar accident to that recorded by Mr. Scattergood of Leeds occurred to me. A piece of nitrate of silver, with which I was painting the fauces of a child four years old, broke, and the larger part of the caustic stick was swallowed. I produced immediate vomiting by forcing my fingers on to the gullet, and sent to the kitchen for a large supply of milk, of which I pumped several pints into his stomach and out again. The child had dysenteric symptoms during the next three days, and occasional vomiting. It was kept on an exclusively milk diet, and recovered. Milk is an excellent antidote to nitrate of silver, in virtue of its large proportion of suspended albumen. I use it in lieu of salt and water for neutralising the excessive effects of even the mitigated caustic, when employing it locally on the mucous membrane of the eyelids.

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