AN ELECTRIC CHIME.

By the Late GEORGE M. HOPKINS.

NOTWITHSTANDING the fact that much of the music produced by chimes is rendered with discords and a clangor little less than barbarous, most people like this sort of music and are ever ready to listen to it. Possibly one reason for this is that this music is not so common as other kinds; another is that there is a kind of unwritten poetry about bells that appeals to everybody.

Tower chimes are for the public, and rich and poor alike can enjoy them, but smaller chimes are mainly for those who are able to purchase them, in fact, they may be classed among luxuries. However, house clock chimes bring bell music out of the list of the extraordinary and place it within the range of everyday home life. There is no reason why any one with a mechanical turn of mind cannot construct a chime without much expense. All that is needed is a lathe, a few tools and eight or ten ordinary hand bells. The bells are to be tuned so that when struck they will yield the notes of the diatonic scale. Tuning is a comparatively simple matter. If the workman does not happen to have a musical ear, he can procure the assistance of some one who has.

A fine bell made of genuine bell metal is one thing, and the ordinary hand bell sold at the hardware and house furnishing goods stores is quite another thing, still the latter afford the most available material for a chime, and withal answer a very good purpose.

The writer had the good fortune to find a dealer who was kind enough to allow him to select from a large number eight bells having approximately the required pitch for an octave, and two additional bells, one above and the other below the octave. These bells first of all had to be tuned to render them useful in a chime. This, although a simple operation mechanically, requires some skill in determining the pitch, as an ordinary bell generally yields two or more discordant notes.

The bell to be tuned is chucked on the lathe by

turning tool is used. If the pitch of the bell is too high, and it is required to lower it, the thick part of the rim is turned off on the line, *a*, as shown in Fig. 1. If, on the other hand, the pitch is too low, it is raised by turning off the edge of the rim on the line, *b*. Whenever it is desired to test the note of the bell, the block is removed and the bell is struck with a small wooden mallet. The note can be compared with that of a piano or other musical instrument, or the proper pitch can be arrived at by comparing the bells with each other. It is scarcely practicable to tune the chime to

FIG. 1.

any particular key unless the majority of the bells are near the required pitch at the start.

After the bells are tuned they are each provided with an electric bell hammer, as shown in the first bell of the series in the upper part of Fig. 2. As this bell hammer is almost identical with that of an electric bell of comparatively recent invention, the writer in justice to himself must say that this electric bell was devised by him long before the bell alluded to was known to the public.

The magnet core is reduced in diameter at its upper end and extends through the aperture at the top of the bell and is threaded to receive two nuts, between which a wire is clamped. These wires from the several bells are connected with the contact springs or keys of the current-controlling mechanism shown at the center of Fig. 2. The core is insulated from the bell, and between the lower nut and the bell is clamped a yoke or loop which is in electrical contact with the bell, but insulated from the core. On the core is placed a bobbin wound with No. 24 wire. To the lower end of core is attached a pole extension, which reaches beyond the periphery of the bobbin and is provided with a short copper stud to prevent the sticking of the armature. To the core above the bobbin is pivoted the armature which extends downward over the side of the bobbin to a point opposite the pole extension. The armature is prolonged beyond its pivot and drilled to receive the hammer wire, which extends downward toward the mouth of the bell and carries a hollow metal hammer containing a wooden plug. The hammer is arranged to strike on the thicker portion of the bell rim. One terminal of the bobbin is connected with the magnet core, the other with the bell; each bell is supported by a bracket, the end of which enters the yoke or loop.

The brackets are connected together electrically and communicate through a wire with one pole of the battery, the other pole of which is connected with a spring which presses on the shaft of the metallic drum of the current-distributing machine. The springs before alluded to press on the cylinder through perforations in a strip of paper on which is arranged the music to be played. The springs are attached to a bar which may be turned back so as to remove the springs from the paper strip and the drum to facilitate the introduction of a new paper strip. Above the drum is placed a wooden roller, the gudgeons of which are pressed downward by springs—the roller being designed to insure sufficient friction of the paper to carry it with a positive motion through the machine. A worm wheel secured to the shaft of the metal drum is driven by a worm on a shaft extending at right angles to the drum and carrying a spur wheel which receives its motion from a pinion on the shaft of the electric motor. The motor is of the kind described in SUPPLEMENT No. 783, and will therefore require no detailed description here.

When the electric chime is connected with a clock, as shown in Fig. 3, it is necessary to provide a very long perforated paper strip or to employ a perforated endless paper belt, and to provide means for starting the motor at the proper time and stopping it when the piece is finished. The mechanism for doing this is shown diagrammatically in Fig. 4. In this case the let-off mechanism is arranged to operate every half hour, but, of course, it could be made so as to operate every quarter hour.

On the minute hand arbor are secured two cams, *a*, and to the frame of the clock is secured the spring arm, *B*, furnished with a triangular arm projecting into the path of the cams, *a*. The free end of the spring arm carries a weight, and in an insulating bar, placed between the arbor, *A*, and support of the spring arm, *B*, is inserted a contact screw, *C*. The spring arm, *B*, is held normally out of contact with the contact screw, *C*. When the arm, *B*, is raised by one of the cams, *a*, and released, the momentum of the weight attached to the free end of the arm carries the arm beyond its normal position and momentarily closes the circuit on the contact screw, *C*. The electrical contact is prolonged by virtue of the momentum of the weight and the bending of the spring arm.

The contact screw, *C*, is connected with one pole of the battery, and the remaining pole is connected with one terminal of the magnet, *D*, the other terminal being connected with the spring arm, *B*. The contact screw, *E*, is connected with the battery in parallel with the magnet, *D*, and a wire running from the battery is connected in parallel with the wire leading to the contact screw, *C*. This wire connects with the motor, *F*, which drives the paper-carrying drum, and also with

the auxiliary contact spring, *c*. The paper strip has a single perforation, *f*, located at the end of the piece of music, through which the spring, *c*, may touch the cylinder. The armature lever, *d*, is pivoted midway between the magnets, *H D*, and it is held in either of the two positions it may assume by the double-acting spring, *e*.

When one of the cams, *a*, raises the spring arm, *B*, and allows it to fall, the current from the battery is momentarily sent through the magnet, *D*, thereby drawing over the armature, *b*, and bringing the contact spring carried by the armature lever into contact with the screw, *E*; and although the magnet, *D*, ceases to act when this is done, the spring remains in contact with the screw and the current flows from the battery to the screw, *E*, thence through the armature lever to the motor, *F*, and from the motor back to the battery. This starts the motor of the current-distributing mechanism, and the current is sent to the one or the other of the bells, according to the position of the holes in the paper strip.

When the end of the piece is reached, the spring, *c*, forms an electrical contact with the metallic drum through the hole, *f*, in the paper strip, *G*. The current from the battery then flows through the screw, *P*, and armature lever, *d*, to the magnet, *H* (whose resistance is somewhat less than that of the motor), thence through the metallic drum back to the battery. The armature, *b*, is thus drawn over to the magnet, *H*, and the circuit is broken when the motor stops, but all the parts are ready for another operation and the circuit of the battery is left open.

The contact springs are $\frac{1}{4}$ inch apart from center to center, consequently the longitudinal lines on the paper on which the holes are punched must be $\frac{1}{4}$ inch apart.

FIG. 2.—ARRANGEMENT OF THE BELL CIRCUIT.

means of a concave wooden chuck secured to the face plate. If the lathe has a hollow mandrel, the bell may be held in place by a long bolt extending through the bell and lathe mandrel. After the bell is centered, so that its rim runs true, a block is fitted to it at a point within the thicker portion of the rim and held in place by the tail stock of the lathe. This prevents vibration and the chattering of the tool; an ordinary hand brass-

FIG. 3.—CLOCK WITH ELECTRIC CHIME.

The transverse or time divisions may be $\frac{1}{4}$ inch or more apart. The distance will depend on the speed of the motor and the character of the music. In the example shown in Fig. 5 the transverse lines are $\frac{1}{4}$ inch apart; the music being composed entirely of quarter notes permits of this arrangement. This example shows the beginning and the end of the tune "Vespers." The holes represent the position of the notes on the staff. It is a very simple matter to transfer any piece of music to a strip

of paper ruled in the manner indicated, it being only necessary to remember that on the position of the note in the scale depends the location of the hole on the transverse line, while the relative positions of the holes on the longitudinal lines determine the time and the length of the notes.

The following is the music of the Westminster

screws passing through the springs into the mallets.

Behind the springs, at or near their mid-length, is placed a diagonal strip of wood, having secured to its outer edge a strip of felt or chamois skin. The spring strikes this piece and allows the mallet to strike the tube and spring back without jarring. Behind the springs is supported a small shaft on which is placed

boring a small block, A, of hard wood in two diameters to receive the head and back of the pearl collar button, B, the back of which is held in place by the apertured piece of veneering secured to the face of the block by small screws, while the head of the button rests on a curved brass spring, C, secured in a slot in the back of the block, A, by a screw. The outer end of the spring projects beyond the side of the block to receive one of the circuit wires. This slot is filled below the spring with insulating material, and a brass plate, D, is secured to the back of the block, A, and has upon one edge an apertured ear for receiving the other circuit wire. The plate, D, is secured to the back of the block by small screws. The free end of the spring, C, is curved over to a point near the brass plate, D, so that when the spring is depressed by pressing the button, B, it will touch the plate and close the circuit.

The annexed diagram shows an appliance which enables the chime to be used in connection with a clock. In front of the dial of an ordinary clock are secured the rings, A, B, made of 1/16 inch square brass wire. The supports are of insulating material, and the rings are concentric with the arbor carrying the hands. The hands are bent outwardly to permit of extending over the rings without touching them, and to insure the hands against electrical contact with the rings a thin short sleeve of paper is slipped over each hand near the free end. Each ring has several small radial holes bored in it to receive the brass nails, the heads of which project sufficiently beyond the front surface of the rings to enable the hands to touch them as they pass.

The circuit wires connecting the battery and the chime are connected one with the outer ring, A, the other with one of the springs of the cut-out switch shown in the opening formed by the breaking away of the dial. The other spring is connected with the inner ring, B. The springs are insulated from each other.

On the sleeve which carries the hour hand is mounted the crossed slotted cam, C, also shown detached in the larger figure. In the slot of this cam is a boat-shaped follower which slides easily in the slot and is longer than the width of the slot, so that it can, in following the slot, take the inner and outer portions of the slot in alternation. The following is pivoted to the angled lever, a, which is pushed by the cam between the parallel springs and withdrawn from them in alternation once in 12 hours. The object of this arrangement is to cut out the chime at night and put it in the circuit in the daytime. The cam, C, and the angled lever, a, are insulated from the clock movement.

A switch, D, is provided for throwing the device out of action at any time.

It will be seen that the hour hand must come into contact with the nail on the inner circle and the minute hand must touch the nail in the outer circle to complete the circuit, and cause the chime to sound. The duration of the chiming is limited by the time the minute hand is in contact with the nail. The clock when arranged as here shown sets off the chime at 8 o'clock, 12 o'clock and 5 o'clock. It is now about to ring the chime for 12 o'clock.

Note by the Editor.—We give an engraving of an electric chime clock made by one of our readers, after instructions given by Mr. Hopkins, the builder of which informs us that it works well and gives him a great deal of satisfaction.

Owing to the fact that the bells procured by him were too small to receive the electro-magnets, he placed them outside of the bells, in the manner illustrated in Fig. 9, the bells being suspended from brackets attached to a board at the back of the clock, the electro-magnets being secured to the rear surface of this board. The armature lever is attached to a spring, which serves as a pivot, and also retracts the armature after it has

FIG. 4.—LET-OFF MECHANISM.

FIG. 5.—THE MUSIC.

FIG. 6.—CHIME WITH CLOCK CONNECTION.

chimes for the first, second, and third quarter of the hour and the hour:

This music can be readily transferred to a strip of paper like that described. It is necessary to bear in mind that if, on paper divided as shown, one space represents the duration of a quarter note, two spaces would represent a half note, and four spaces a whole note.

To secure practice in mechanics or in electrical work, the amateur may as well construct something for actual use. A very useful and pleasing electro-mechanical device is an electric chime to be used as a door bell or call bell, or in connection with a clock. It serves its purpose as a call and gives an ever-changing series of harmonic notes.

The first step toward the construction of this device is to purchase the toy known as the tubophone, and select three of the tubes which produce a chord, or if the maker prefers it, he may buy a piece of mandrel drawn brass tubing, 5/8 inch external diameter, with walls 1/32 inch thick, and cut off three pieces respectively 7 7/8, 8 3/8, and 9 3/8 inches in length; each of these should be laid upon two short pieces of soft woolen cord, with the cord touching at nodal points, that is, at exactly one quarter of the length from the end. Arranged in this way the tubes give out a clear note when struck with a small wooden mallet. By comparing these notes with those of a piano or other musical instrument, the tubes may be tuned. The pitch is raised by shortening the tube, but as there is no practical way of lowering the pitch after the tube has once been shortened, it would be advisable to cut the tubes a little longer than the measurements given. A base-board having a short standard is provided, and to the upper portion of the standard is secured a board into which are driven three pairs of wire nails, the nails in each pair corresponding in position with the nodes of one of the tubes. The tubes are suspended from these nails by soft cords passing around the tubes at the nodes or points of no vibration, leaving the tubes free to vibrate at the center and at the ends.

Now it remains to construct the electro-mechanical device for striking the tubes. To the baseboard are secured the angled ends of three strips of spring brass, 7/32 inch wide and 1/32 inch thick, which extend above the tubes and carry small wooden mallets in position to strike the middle portion of each tube. The mallets are secured to the springs by means of ordinary wood

a wooden cylinder about 1 inch in diameter and 2 1/2 inches long. In the cylinder and opposite the springs are inserted wire nails, arranged to strike short inclined strips riveted to the springs. The nails are placed so that they will strike the inclined strips in different orders; for example: 1, 2, 3; 3, 2, 1; 2, 3, 1; 1, 3, 2.

A toy electric motor having a three-pole armature

FIG. 7.—PUSH BUTTON.

is used for turning the cylinder, and two clock wheels and a pinion are employed for reducing the speed. A worm is placed on the armature shaft of the motor, which engages the first of the clock wheels. This worm may be cut in a lathe, but if this is inconvenient, a wire may be wound spirally around the armature shaft and soldered. It will, of course, be necessary to wind the spiral so that it will fit the teeth of the clock wheel, and the surplus solder should be scraped from the wire to diminish friction. The motor is provided with binding posts to receive the battery wires. One or two cells

FIG. 8.—ELECTRIC CHIME.

of dry battery will run the chime. The chime is used in place of an ordinary call or door bell, or it may be used in connection with a clock, as shown, for making calls at certain hours.

The push button shown in the sectional view is made to close the circuit when the chime is used in place of a call bell or door bell. The button is readily made by

FIGS. 9 AND 10.—DETAILS OF ELECTRIC CHIME CLOCK.

made a stroke. A small disk of felt is secured to the pole of the magnet and a loop of felt is attached to the back board. The armature plays between these two pieces of felt, and is, therefore, noiseless in its operation. The upper roller of the pair which moves the perforated paper is supported in an overhanging frame,

as shown in Fig. 10, so that an endless piece of music can be slipped between the rollers and played over and over.

The clock movement is an 8-day lever movement. This, being a compact form of clock, affords ample room for the favorable disposition of the bells and machinery. The case is of very neat design, made entirely of quartered oak, well filled and finished. The glass doors and sides are beveled. Taken altogether, it is as fine a piece of hall, dining room, or parlor furniture as one would wish to have.

HOW MANY GNATS OR MOSQUITOES ARE THERE IN A GIVEN AREA?

By Major RONALD ROSS.

We can not anywhere state the exact number of mosquitoes to the square mile or yard, and we can not, therefore, accurately gage any local decrease which may have resulted from operations against them. A method of doing this may be invented in the future; but for the present we must employ another means for resolving the problem—one which has given such great results in physics—namely strict logical deduction from ascertained premises.

As another preliminary we should note that mosquito-reduction is only part of a larger subject, namely, that of the local reduction of any living organisms. Unlike particles of matter (so far as we know them) the living unit can not progress through space and time for more than a limited distance. The diffusion of living units must, therefore, be circumscribed—a number of them liberated at a given point will never be able to pass beyond a certain distance from that point; and the laws governing this diffusion must be the same for all organisms. The motile animal is capable of propelling itself for a time in any direction; but even the immotile plant calls in the agency of the winds and waters for the dissemination of its seeds. The extent of this migration, whether of the motile or the immotile organisms, must to a large degree be capable of determination by proper analysis; and the logical position of the question of local reduction depends upon this analysis.

The life of gnats, like that of other animals, is governed by fixed laws. Propagation can never exceed, nor mortality fall below, certain rates. Local conditions may be favorable either to the birth rate or to the death rate; and the local population must depend upon the food supply. Diseases, predatory animals, unfavorable conditions and accidents depress the density of population; and in fact local reduction, that is, artificial depression of the density of population, practically resolves itself into (a) direct destruction and (b) artificial creation of unfavorable conditions.

Let us now endeavor to obtain a perfectly clear picture of the problem before us by imagining an ideal case. Suppose that we have to deal with a country of indefinite extent, every point of which is equally favorable to the propagation of gnats (or of any other animal); and suppose that every point of it is equally attractive to them as regards food supply; and that there is nothing, such for instance as steady winds or local enemies, which tends to drive them into certain parts of the country. Then the density of the gnat population will be uniform all over the country. Of course, such a state of things does not actually exist in nature; but we shall nevertheless find it useful to consider it as if it does exist, and shall afterward easily determine the variations from this ideal condition due to definite causes. Let us next select a circumscribed area within this country, and suppose that operations against the insects are undertaken inside it, but not outside it. The question before us is the following: How far will these operations affect the mosquito density within the area and immediately around it?

Now the operations may belong to two categories—those aimed at killing the insects within the area, and those aimed at checking their propagation. The first can never be completely successful; it is in fact impossible to kill every adult winged gnat within any area. But it is generally possible to destroy at least a large proportion of their *larvæ*, which must live for at least a week in suitable waters, and which may easily be killed by larvacides, or by emptying out the waters, or by other means. This method of checking propagation consists, in the case of these insects, of draining away, filling up, poisoning or emptying out the waters in which they breed. Obviously the ultimate effect is the same if we drain away a breeding pool or if we persistently destroy the larvæ found in it; though in the first case the work is more or less permanent, and in the second demands constant repetition. If we drain a breeding area we tend to produce the same effect at the end of a year as if we had destroyed as many gnats as otherwise that area would have produced during that period. Thus, though we can not kill all mosquitoes within an area, even during a short period, we can always arrest their propagation there for as long as we please, provided that we can obliterate all their breed waters or persistently destroy all their larvæ—which we may assume can generally be done for an adequate expenditure. We must, therefore, ask what will be the exact effect of completely arresting propagation within a given area under the assumed conditions?

The first obvious point is that the operation must result in a decrease of mosquitoes. If we kill a single gnat there must be one gnat in the world less than before. If we kill a thousand every day there must be so many thousands less at the end of a given period; and the arrest of propagation over any area, however small, must be equivalent to the destruction of a certain number of the insects. But this does not help us much. It may be suggested that, after the arrest of propaga-

tion over even a considerable area, the diminution of mosquitoes within the area remains inappreciable. What is the law governing the percentage of diminution in the mosquito density due to arrest of propagation within an area?

The number of gnats (or any animal) within an area must always be a function of four variables, the birth rate and death rate within the area, and the immigration and emigration into and out of it. If we could surround the area by an immense mosquito bar, the insects within it (after the death of old immigrants) would consist entirely of native insects; on the other hand, if we arrest propagation, the gnat population

Distance from center	nl	$(n-1)l$	$(n-2)l$	$(n-3)l$	etc.	total
Number of gnats	$2 + 4n$	$+ \frac{2n(2n-1)}{2!}$	$+ 2 \frac{2n(2n-1)(2n-2)}{3!}$	$+ \dots$	$= 2^n$	

must hereafter consist entirely of immigrants. The question, therefore, resolves itself into this one: What is—what must be—the ratio of immigrants to natives within an area? What factors determine that ratio?

Ceteris paribus, one factor must be the size of the area. If the area be a small one, say of ten yards radius, suppression of propagation will do little good, because the proportion of mosquitoes bred there will be very small (under our assumed conditions) compared with those which are bred in the large surrounding tracts of country, and which will have no difficulty in traversing so small a distance as ten yards. But if we completely suppress propagation over an area of ten miles radius, the case must be very different—every gnat reaching the center must now traverse ten miles to do so. And if we increase the radius of the no-propagation area still further, we must finally arrive at a state of affairs when no mosquitoes at all can reach the center, and when, therefore, that center must be absolutely free from them. In other words, we can reduce the mosquito density at any point by arresting propagation over a sufficient radius around that point.

But we now enter upon more difficult ground. How large must that radius be in order to render the center entirely mosquito-free? Still further, what will be the proportion of mosquito reduction depending upon a given radius of anti-propagation operations? What will be that proportion, either at the center of operations, or at any point within or without the circumference of operations? The answer depends upon the distance which a mosquito can traverse, not during a single flight, but during its whole life; and also upon certain laws of probability, which must govern its wanderings to and fro upon the face of the earth. Let me endeavor to indicate how this problem, which is essentially a mathematical one of considerable interest, can be solved.

Suppose that a mosquito is born at a given point, and that during its life it wanders about, to and fro, to left or to right, where it wills, in search of food or of mating, over a country which is uniformly attractive and favorable to it. After a time it will die. What are the probabilities that its dead body will be found at a given distance from its birthplace? That is really the problem which governs the whole of this great subject of the prophylaxis of malaria. It is a problem which applies to any living unit. We may word it otherwise, thus: Suppose a box containing a million gnats were to be opened in the center of a large plain, and that the insects were allowed to wander freely in all directions, how many of them would be found after death at a given distance from the place where the box was opened? Or we may suppose without modifying the nature of the problem that the insects emanate, not from a box, but from a single breeding pool.

Now what would happen is as follows: We may divide the career of each insect into an arbitrary number of successive periods or stages, say of one minute's duration each. During the first minute most of the insects would fly toward every point of the compass. At the end of the minute a few might fly straight on and a few straight back, while the rest would travel at various angles to the right or left. At the end of the second minute the same thing would occur—most would change their course and a very few might wander straight on (provided that no special attraction exists for them). So also at the end of each stage—the same laws of chance would govern their movements. At last, after their death, it would be found that an extremely small proportion of the insects have moved continuously in one direction, and that the vast majority of them have wandered more or less backward and forward and have died in the vicinity of the box or pool from which they originally came.

The full mathematical analysis determining the question is of some complexity; and I can not here deal with it in its entirety. But if we consider the lateral movements as tending to neutralize themselves, the problem becomes a simple one, well known in the calculus of probabilities and affording a rough approximation to the truth. If we suppose that the whole average life of the insects contains n stages, and that each insect can traverse an average distance l during one such stage or element of time, then the extreme average distance to which any insect can wander during the whole of its life must be nl . I call this the limit of migration and denote it by L , as it becomes an important constant in the investigation. It will then be found that the numbers of insects which have succeeded in reaching the distances nl , $(n-1)l$, $(n-2)l$, etc., from the center will vary as twice the number of permutations of $2n$ things taken successively, none, one, two, three at a time, and so on—that is to say, as the successive coefficients of the expansion of 2^n by the binomial theorem. Suppose, for convenience, that the

whole number of gnats escaping from the box is 2^n —a number which can be made as large as we please by taking n large enough and l small enough—then the probabilities are that the number of them which succeed in reaching the limit of migration is only 2; the number of those which succeed in reaching a distance one stage short of this, namely, $(n-1)l$, is $2.2n$; of those which reach a stage one shorter still is

$$\frac{2n(2n-1)}{2!}$$

and so on. Hence the whole number of gnats will be found arranged as follows:

It, therefore, follows from the known values of the binomial coefficients that if we divide the whole number of gnats into groups according to the distance at which their bodies are found from the box, the probabilities are that the largest group will be found at the first stage, that is close to the box, and that the successive groups, as we proceed further and further from the box, will become smaller and smaller, until only a very few occur at the extreme distance, the possible limit of migration. And the same reasoning will apply to a breeding pool or vessel of water. That is, the insects coming from such a source will tend to remain in its immediate vicinity, provided that the whole surrounding area is uniformly attractive to them.

The following diagram will, I hope, make the reasoning quite clear.

DIAGRAM I.—THE CHANCE-DISTRIBUTION OF MOSQUITOES.

P, central breeding pool. L, limit of migration. The numbers denote the proportions of 1,024 mosquitoes starting from P which die at the distances 1, 2, 3, 4, 5, respectively. The continuous line denotes a continuous migration always in one direction; the dotted line, the usual erratic course.

We suppose that 1,024 mosquitoes have escaped during a given period from the central breeding-pool P, and we divide their subsequent life into 5 stages—the numbers 1,024 and 5 being selected merely for illustration. Rings are drawn around the central pool in order to mark the distance to which the insects may possibly wander up to the end of each stage; and the continuous line shows the course followed by one which has wandered straight onward all its life and has died at the extreme limit to which an insect of its species can generally go, namely, the outermost circle, L. On the other hand, the dotted line shows a course which is likely to be followed by the largest number of the 1,024 insects liberated from the pool—that is to say, a quite irregular to-and-fro course, generally terminating somewhere near the point of origin. The numbers placed on each ring show the number of mosquitoes calculated from the binomial coefficients when $n=5$, which are likely to reach as far as that ring at the time of their death. Thus only 2 out of the 1,024 mosquitoes are ever likely to reach the extreme limit; while, on the other hand, no less than 912, or 89 per cent, are likely to die somewhere within the second ring around the center.

The same reasoning will apply whatever may be the number of mosquitoes liberated from the pool, or the number of stages into which we arbitrarily divide their subsequent life. Suppose, for example, that 1,048,576 mosquitoes escape from the pool and that we divide their life into 10 stages. Then only two of all these insects are ever likely to reach the extreme limit of the outermost circle; only 40 will die at the next circle; only 190 at the next; and so on—the large majority perishing within the circles comparatively close to the point of origin.

This fact should be clearly grasped. The law here enunciated may, perhaps, be called the *centripetal law of random wandering*. It ordains that when living units wander from a given point *guided only by chance* they will always tend to revert to that point. The principle which governs their to-and-fro movements is that which governs the drawing of black and red cards from a shuffled pack. The chances against our drawing all the twenty-six black cards from such a pack without a single red card among them are enormous; as are the chances against a mosquito, guided only by chance, always wandering on in one direction. On the other hand, just as we shall generally draw black and red cards alternately from the pack, or nearly so, so will the random movements of the living unit tend to be alternately backward and forward—tend, in fact, to