and that of the Lee; the chalk passed with a gentle slope from the Thames under the Lee, but in the latter it was covered by the clay, which in the Thames had been abraded by the wash of the river. Notwithstanding the improvements that had been effected, most of the mills would find it preferable to use steam-power instead of the old water-wheels: this plan had now been adopted, with great advantage, at all the tidal mills, except one.

Gaugings of the river Lee had been regularly taken twice every day, over an extent of twenty miles, from the year 1851, to the present time, as well as observations with the rain-gauge, which were in the possession of the President. He hoped to be able to complete the Tables, with observations of the floods which had taken place during the same period in the lower reaches of the Thames, and to present them at some future time to the Institution.

Mr. SIMPSON,—President,—promised his aid in the preparation of the Tables: when properly checked and balanced, they would afford an authentic and very interesting record of the effects of the floods of the River Lee, upon the lower reaches of the Thames.

February 14, 1854.

JAMES SIMPSON, President,
in the Chair.

No. 902.—“On the Principles and Construction of Locks.”¹
By ALFRED CHARLES HOBBS, Assoc. Inst. C.E.

THE object of this Paper is to review briefly the mechanical principles involved in the construction of locks, and to show how far the security expected from them has been achieved by manufacturers. It will be proper to commence, therefore, with a clear expression of what may be called the real aim of every invention of this kind.

The greatest point of security that can be attained in the

¹ The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

construction of locks, is, that the possibility of picking, or opening them, without their true keys, shall depend entirely upon chance. It has, therefore, been the object of every inventor and manufacturer of locks having any pretensions to security, so to construct them, that there shall be no possible means left, by which the form of key, or the requisite position of the parts can be ascertained, except by having possession of the original key, or by an examination of the interior mechanism of each particular lock.

Now although each of the great number of inventors in this branch of mechanism, has produced a lock more, or less, new in form, and the varieties of arrangements may, therefore, be innumerable, there are really but three distinct principles. These it will be the endeavour of the Author to describe, by a few instances selected from each class.¹

1. The first class consists of locks having a series of fixed obstructions, or wards, in and about the key-hole, to prevent any instrument, but the proper key, being turned in the lock. These were the only kind in general use, in this country, so far as has been ascertained, until the year 1778, when Mr. Barron introduced his first patent. The comparative security, or chances of opening the warded locks were supposed to depend upon the complexity, or simplicity of the form of key required; consequently, great ingenuity was displayed in varying the forms of the keys, and the wards corresponding to them.

But it matters very little how great the complexity, or how varied the shape, while the wards themselves afford the means for ascertaining the form of key required to open the lock. The manner of making a false key to pass the most complex wards, that can be put in a lock, is very simple. A blank is first fitted to enter the key-hole. The sides of the blank, or 'bit' are coated with a composition of bees'-wax, sweet oil, and pulverized charcoal, the 'bit' is then inserted into the key-hole, and by attempting to turn it round, the impression of the wards will be left on the soft composition. The blank in this state, will serve as a model from which a key may be made; for, as the detent of the bolt in the warded lock is,

¹ A series of wood-cuts explanatory of the mechanism of the different locks, will be found in Minutes of Proceedings Inst. C.E., 1849, vol. ix., p. 310 *et seq.*

usually, either a back spring, or a single acting tumbler, any key that will pass the wards will open the lock. It is therefore evident, that chance has nothing to do with forming a key to open locks depending upon fixed wards for their security; but that any person having ordinary mechanical skill and a small amount of patience, can easily open such locks. Notwithstanding this, however, there are many so-called 'safes' and 'strong rooms' in London, dependent for their security entirely upon warded locks of the simplest construction.

2. The second class is the letter, or puzzle-lock series; there is perhaps no lock that appears to carry out so fully the doctrine of chance as the letter, or puzzle lock, of which a description is given in a book published at Amsterdam, in 1682, called "*Silvestri a Petrasancta Symbola Heroica*." But this was a simple and somewhat rude production. The letter lock was much improved, and was brought into general notice, about the middle of the seventeenth century, by M. Regnier, of Paris: such locks are usually made in the form of padlocks, but they are sometimes applied to doors, and are then called dial locks. When the puzzle, or letter padlock is to be locked, the rings are so adjusted, that the grooves on the inner side shall be brought into a straight line. The end piece is fixed on; the shackle is shut down; and the spindle is thrust in. The rings are now moved round so as to throw the interior grooves out of a right line, thereby preventing the withdrawal of the spindle. In order then, to open a lock thus fastened, the letters on the outside of the rings must be brought to precisely the same positions which they occupied in locking, and until that be done the spindle cannot be withdrawn. A lock having four rings, with twenty letters on each ring, is susceptible of 1,581,580 changes in the relative positions of the grooves, and it has, until lately, been supposed, that such a lock would possess this identical number of chances against being opened by any one but the person who knew the particular combination on which it was locked. It will presently be seen, however, how far this is true.

The form of the letter, or puzzle lock, suitable for doors, consists of two, or more dials, secured to the door, with a series of letters, or figures stamped on them. To each dial, there is a hand, or pointer connected by a spindle, with a wheel inside

the lock. In each wheel is a notch, which has to be brought into a certain position to allow the bolt to be withdrawn; there is also a series of false notches intended to add to the difficulty of surreptitious opening. In the puzzle lock, as in the padlock, the number of changes is so great, that did it depend upon the chance of hitting the right combination, a person might work a life-time without opening the lock. But the doctrine of chance is as easily superseded in opening this, as the warded lock.

The letter padlock can be opened, without any knowledge of the combination by which it was locked, by putting between the ends of the lock, a small piece of common wire, bent in the form of the shackle; the spring, or tension of the wire forces the ends apart, and causing the pins on the rod to bear against the rings; on feeling the latter, some of them will be found to bind, and by turning those that bind, the notches are successively felt and brought into a straight line: so that the lock can easily be opened. The same principle applies to the dial lock; by trying to withdraw the bolt, and by feeling the bind, or friction of the pointers, the result will be the same, entirely destroying the supposed security of the letter, or puzzle lock.

3. The third, or last class of locks embraces all those which depend for their security upon a series of moveable pieces called slides, pins, tumblers, &c., and placed within the case of the lock. These pieces must be operated upon and moved into a certain position by a key, before the bolt can be moved. In this class are great varieties of form, great diversities of motion, and an almost endless variety of combination. But it appears, that notwithstanding these wide diversities, the same principle for security, and the same defects existed in all, until a recent date.

The most ancient lock constructed on this principle, of which the Author has any knowledge, is the Egyptian, or pin lock. The case of the lock which is fastened to the door has a wooden bolt, passing through it. In the part of the case over the bolt, are a series of cells to receive a certain number of pins, and in the bolt are an equal number of holes, into which the pins fall when the bolt is projected. In this position the pins prevent the withdrawal of the bolt. On the key are a series of pins so arranged as to meet the holes in the bolt, and of the right number and length to press the pins out of the bolt

and allow it to be moved. The comparative security of this lock was supposed to depend upon the number of pins used. Ancient as this lock is, it appears to possess all the principles of security, which are observable in most of the patent locks of the present day; and the only circumstances that seem to have prevented its general adoption, were the rudeness of its form and the size of its key.

Whether, or not, our machinists knew anything of the Egyptian lock, the principle upon which it was constructed was entirely neglected, until the insecurity of warded locks was rendered apparent. In the year 1778, Mr. Barron directed his attention to what is called the 'tumbler' principle, and added it to the warded locks. In his patent, enrolled October 31st, 1778, he claims "the gateing, or racking to allow a stump on the tumbler to pass through the bolt, or an opening in the tumbler to allow a stump on the bolt to pass through." In constructing his lock, Mr. Barron introduced two double-acting tumblers, similar to those in use at the present time.

The celebrated Bramah lock was patented in the year 1784. Mr. Bramah, in speaking of the Barron lock in his pamphlet, published about that date, says:—"Greatly as the art is indebted to the ingenuity of Mr. Barron, he has not yet attained that point of excellence in the construction of his lock, which is essential to perfect security."

It is quite evident, from his subsequent observations, that Mr. Bramah had no idea of any means, by which a lock having moveable obstructions could be opened, except by forming a false key, and that only by means of an impression taken of the parts through the key-hole. The ingenious lock, which was the result of Mr. Bramah's speculations on this point, may now be described.

The Bramah lock has a revolving cylinder, or barrel, the turning of which moves the bolt; and the safety of the lock depends upon the barrel being held in its position by means of a series of slides fitting into a steel plate. In each of these slides is a notch, which, when pressed to a certain position, allows the barrel to be turned, but should any of the slides be pushed too far, or not far enough, the barrel remains immovable. The key has a series of slots so arranged as to press all the slides to the proper extent, and at the same time the nib of

the key, fitting into a notch on the side of the barrel, turns it round. Too great, or too little motion of any of the slides will prevent the revolution of the barrel and the moving of the bolt.

Mr. Bramah's calculation of the number of chances against such a lock, with eighteen slides, being opened without the aid of the proper key, is very striking. If a trial had been made every second from the beginning of the world, to the present time, there would still be left more than six thousand billions of chances to one, against the successful opening of the lock.

A lock very similar in its arrangement has recently been introduced by Mr. Cotterell, of Birmingham; the only apparent difference being in the motion of the slide. In the Bramah locks the slides move parallel to the motion of the key as it is pressed into the lock; while in the Cotterell lock, they are pressed from the centre by the inclined grooves on the key. This lock consists of an internal cylinder, having a series of grooves to receive the steel slides, which are pressed to the centre by a series of spiral springs: it is also provided with a circular groove, to receive the projections on the ring, which is securely fastened to the case of the lock. It is impossible to move the cylinder until the slides are so adjusted as to bring the notches in a line with the circular groove in the cylinder: this is effected by the inclined grooves in the key, the nib of which then carries the cylinder round, causing a piece to project and withdraw the bolt. This lock was (for the second time) invented by Mr. Saxby, of Sheerness, and in 1853 obtained a premium from the Society of Arts.¹ The Saxby lock was the same in its arrangement as the Cotterell lock, with the exception of its having four slides instead of eight.

The next lock of this class, which calls for notice, is the tumbler lock, patented by Bird, in 1790. The security of this lock consists in its having four distinct double-acting tumblers, all of which must be raised to a particular height, neither more, nor less, in order that the bolt may pass. The tumblers are flat pieces of iron, or brass, with the plane of the surface vertical, and pivoted at one end. A stud, or stump is riveted on one surface of the bolt, and it is to oppose obstructions to the passage of this stud, that the tumblers are provided. There is

¹ *Fide* Journal of the Society of Arts, vol. i., p. 366.

a longitudinal slot in each tumbler, large enough to receive the stud of the bolt, and unless all the slots coincide, in height, or position, the stud will not have a clear passage; now the slots are purposely cut differently in the different tumblers, so that the tumblers must be raised, to different heights, in order that the slots may be brought exactly one behind another. To effect this raising, the key has the bit cut into four steps, or inequalities, each to raise one particular tumbler, exactly to the proper height. When the key is used, all the tumblers are raised at once, a clear passage is left for the stud through the slots, and the bolt is shot, or locked. But if any one tumbler be raised, either in excess or deficient of the proper quantity, the bolt cannot move. The doctrine of chances was depended on by Bird here, as it had been by Bramah, for giving security to the lock.

From the year 1790 to 1815, there was no marked novelty, or improvement introduced in locks, although several patents for locks were taken out. In the last-named year, Messrs. Mitchell and Lawton added to the tumbler lock a series of detectors, the object of which was to give notice to the proprietor when any attempt had been made to open the lock during his absence. In their specification, they mention several ways by which this may be effected. One arrangement was to have a bolt, which should shoot across the key-hole, if any attempt were made to use any but the proper key, thereby retaining the instrument, or false key in the lock. But, as there was no means by which the instrument could be released, the lock had to be destroyed in order to open the door, and for this reason the detector never came into use. In the more simple detector which they subsequently introduced, the bolt and tumblers are the same in action as in Bird's lock, but they differ slightly in form. A right-angular lever, with a small curve, or hook, is so placed, that the tumblers in being lifted by the key, just reach it; but should any one of the tumblers be raised too high, the lever would be moved, and a piece resting on the arm of the lever, would be released and pressed down by its spring. To this piece is riveted a small stud, that comes through to the front of the drawer, desk, or other article, to which the lock is fastened, and is filed flush with the surface, so that, should the lock have been attempted, the owner would observe the recess, as he

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inserted the key; there being no means of restoring the detector to its place, without first unlocking the lock.

In the year 1818, Mr. Chubb patented a new detector, which was the only peculiarity in his lock, as he used the same kind and arrangement of tumblers as Bird in 1790. The difference in the operation of the detector of Mitchell and Lawton and that of Mr. Chubb, is chiefly this:—the former acts as a tell-tale only, while Mr. Chubb's forms a detent upon the bolt, in case any of the tumblers should be raised too high in attempting to pick, or open the lock with a false key.

From the year 1818 to 1851, although there were many patents taken out for locks, the same principles of security were relied upon, the difference being some slight alterations of form, or new arrangements of the parts.

It will now be shown, how great the mistake has been to suppose, that the opening of these locks depends on the mere chance of hitting upon the particular combination in any case.

So long as no force is made to act in the same manner as the bolt-bit of the key in attempting to unlock the lock, the prospect of adjusting tumblers, slides, and pieces to the proper position, is indeed almost hopeless; but the case becomes wholly different when a force is applied sufficient to open the lock, if the obstructions were pushed aside. Thus, in bringing to bear upon the barrel of a Bramah lock with six slides, a force which would turn it round, if the slides would permit, it causes them to press on the steel plate, and by pushing the slides endwise, with a suitable instrument, this pressure can be sensibly felt; but no mechanism is so perfect, or so delicate, that the pressure shall be quite equal on all the slides: some slides bind, or cling more than others. The operator then gently touches each slide in turn, moving those which bind most, and he finds, ultimately, that when all the slides cease to bind, their notches have been brought into the plane of the steel plate; and the barrel which is under the influence of the pressure revolves and shoots the bolt. There is certainly no visible reason, why the same result would not be produced on the Cotterell lock. So likewise, in the instance of tumbler locks, the theory of pressure conquers the theory of chances. When a pressure has been brought to act upon the bolt, sufficient to move it as soon as the stump is free, the tumblers are tested in succession, by an instrument

introduced through the key-hole; those which bind, or press against the stump are gently moved, successively, until they are all felt to be free, when it will be found, that the whole of the slots are parallel. The stump having, then, free motion along the slots, the bolt is impelled by the force which has been acting on it. For the purpose of additional security, false notches in slides and tumblers have been introduced, and revolving curtains placed within the key-hole. But in respect to the former, they simply require a modification of the instrument with which the pressure method would have to be carried on, but without modifying the principle; and in respect to the latter, as hitherto constructed, where a key can go, a substitute for a key can follow, and the result is, that a revolving curtain adds to the expense of the lock, without materially increasing the difficulty of picking it.

It may be laid down as a principle, that whenever the parts of a lock which come into contact with its key, are so affected by any pressure applied in attempting to withdraw the bolt, as to indicate the points of resistance, that lock can be picked. That all the tumbler, and slide, and pin locks, that have been described, are so affected, there can be but little doubt. This proposition being admitted, the necessity of devising some simple and effective means of remedying the defect is apparent. But it should be borne in mind, that the common mode of applying pressure to the bolt by a weight and lever, is by no means the only method by which a lock can be picked.

The Author of this Paper has introduced into the tumbler lock, an improvement, for the purpose of overcoming the defects that have been described, without adding, materially, to the cost of the lock.

The lock resembles, in its general construction, the usual tumbler locks, but it has, in addition, a peculiar piece of mechanism attached to the tumbler stump. The bolt and the tumblers, with the usual slots, or gatings, for the passage of the stump, are the same as in other locks.

The stump, instead of being riveted into the bolt, is riveted into a detached piece. The hole in this piece fits on a centre, or pin in a recess at the back of the bolt; and there is a small binding spring to prevent the piece from turning, except at the right time. When the key is used, the stump, meeting with no

obstruction, passes through the slot of the tumblers ; but should an attempt be made to withdraw the bolt, before the tumblers are all properly raised, the stump, meeting with a slight resistance, gives a rotary movement to the piece to which it is attached, and brings a portion of it into contact with a stud riveted into the case of the lock, thereby preventing the possibility of withdrawing the bolt, at the same time releasing the tumblers from any pressure that may be applied, to ascertain their proper position. There is a dog, or lever, catching into the top of the bolt, which is raised by a pin overlapping the tumblers, thus serving as an additional security, against its being forced back. Since the introduction of this lock, attempts have been made to produce the same effect, without exactly copying the original. A patent has been taken out for what is called a receding tumbler, wherein the difference is, that instead of the stump that bears against the tumblers being moveable, the stump, or pivot, on which the tumblers turn, is made to move. Another attempt has been made, by the introduction of a false bolt, working on the lock bolt. In this lock, should too great a pressure be applied to the false bolt, in attempting to withdraw it, before the tumblers are properly adjusted, it is raised by the pressure, so as to prevent the bolt stump from pressing against the tumblers. In the receding tumbler lock, the springs which press the tumblers to their places, bear against them, in such a manner, as to hold the stump in its place ; so that a pressure, equal to the strength of all the springs, can be brought against the tumbler stump, which is quite sufficient to bring this lock within reach of the pressure principle. So with the false bolt, which having a spring constantly pressing it down, affords the means of ascertaining the position of the tumblers.

A description of a new lock, invented by Mr. E. B. Denison, was given at the rooms of the Society of Arts,¹ during the last year. This lock was brought forward, in compliance with a requisition in the premium list of that Society. It possesses a small key, compared with the strength of the tumblers, and of the bolt ; and this desideratum is secured, by giving the key nothing to do, except raising the tumblers, the actual move-

¹ *Vide* Journal of the Society of Arts, vol. i., p. 253.

ment of the bolt being effected by a separate handle. The lock depends for its security, upon a curtain, which completely closes the key-hole, during the time the bolt is being moved. This arrangement necessarily involves some additional difficulty in the operation of the lock ; and as the users of locks require great simplicity in the action, the arrangements for locking and unlocking, in this case, appear likely to prevent its being extensively adopted.

No especial allusion has yet been made, in this Paper, to the locks invented in America. The pressure principle of picking has been well understood there, for the last ten, or twelve years ; previous to that time the same principles were relied upon there for security, as in this country, but latterly, the addition of false notches, revolving curtains, false bolts, check and reverse tumblers, have all been successively tried and have yielded to the skill of the machinist. In the permutation, or American bank-lock, an attempt is made to introduce an additional principle of security, to those hitherto named. Whatever may be the value of wards, tumblers, slides, pins, or moveable stumps, if a stranger gets possession of the right key, and has it sufficient time to take an impression, he can open the lock. But how to make the right key useless, in the hands of any but the right person, is a problem of great difficulty. In the lock, now under notice, this is effected by means of a permutating key. Such keys have before been used, but they required, that the lock itself should be altered, to suit any new adjustment of the bits of the key, whereas in the American lock, the key employed produces its own adjustment in the lock. If the lock has ten tumblers, the key has ten moveable bits, which may be changed and re-adjusted at pleasure, and they are held securely in their places by means of a small screw-pin ; after having shot the bolt of the lock, the owner can, if he please, alter the bits of his key, and in its altered form it will not open the lock, so that it becomes wholly useless to any other person into whose hands it may fall. The owner, should he change the form of his key, after locking his door, must remember the former arrangement and re-adjust the bits when he wishes to open the lock. If the lock has twelve tumblers, the twelve-bitted key is susceptible of 479,001,600 different adjustments, and any one of these will close the lock ;

but as the lock can be opened only by the same adjustment as that which closed it, the owner may be said to possess, virtually, 479,001,600 different keys. The mechanism by which this result is brought about may now be briefly described. The lock is provided with three different series of moveable slides, or tumblers, having springs for the first series, with separating plates between them: there are also springs for lifting the third series of tumblers. On each of the secondary tumblers is a series of notches, corresponding in distance with the difference in the lengths of the moveable bits in the key. When the key is turned in the lock to lock it, each bit raises its tumbler, and the bolt is made to move; the bolt carries with it, in its motion, the secondary tumblers, and some one of the notches, in each of these tumblers, is caught by a tooth, on the lever. In this position the tongues are withdrawn from between the jaws of the third series of tumblers, and the first and third series fall into their original position, while the secondary series are held fast by the tooth in the notches.

The sources of security here embodied may now be separately traced. In the first place, if an attempt is made to unlock the bolt, by any but the true key, or even by the true key, in any but its proper state of permutation, the tongues will abut against the jaws, thus preventing the bolt from being withdrawn. In the second place, all attempts to discover which tumblers bind, with a view to releasing them, are rendered nugatory, because the tumblers which suffer the pressure are those of the secondary series, and are placed beyond an iron wall, fixed completely across the lock, preventing the possibility of reaching them through the key-hole. In the third place, the primary tumblers, although they may be easily reached, are neutral; and they tell nothing concerning the state of the tumblers which retain the bolt. In the fourth place, a revolving curtain turns with the key, and prevents any inspection of the interior of the lock, through the key-hole; and should this curtain be turned, to bring the opening upwards, a detector-plate, on the cap of the lock, is immediately carried over the key-hole, by the motion of the pin upon the auxiliary tumbler, which is lifted by the revolution of the curtain. In the fifth place, the bolt is held from being unlocked, by a stud, bearing against the detector-plate; and in the sixth place, a

lever holds the bolt, when locked, until it is released, by the tail of the detector-plate pressing the pin. Thus there are provisions introduced, to meet almost every imaginable mode of opening the lock. The triple sets of tumblers, a portion of which retain the position given to them by the key, and the wall of iron, which shields the most important of these from any contact with the key, point to the guiding principle of this lock ; but there are, in addition, peculiar adaptations of contrivances already well known.

In conclusion it may be remarked, that questions will continually arise as to the violability, or inviolability of particular locks, and especially of new inventions. The hints already given may serve to show, that any new modification, or arrangement of the parts which do not affect the principle of construction, can have no particular claims to security, or conversely, if it can be shown, that any lock is constructed on a principle not hitherto violated, it may be deemed 'secure, but certainly not unless such a claim can be established.

With respect to the locks alluded to in this Paper, and their alleged insecurity, the Author finds justification for what has been said in these two facts:—that he has pointed out the principles on which the picking may be conducted, and that he has himself performed all that he describes. And it is to be hoped, that what has been done and said to enlighten the public, as to the insecurity of many locks now in use, instead of causing any unpleasant personal feelings, will stimulate lock manufacturers to produce what the public really require, viz., secure locks, adapted to all purposes, of good workmanship, and at a moderate price.

The Paper is illustrated by a series of diagrams, explanatory of the mechanism of the different locks.

Mr. HOBBS explained in detail the action of the permutating lock, and pointed out the additional security gained by the division of the tumblers into primary and secondary, the former alone to be acted on by the key and the latter to act upon the bolt. Any inspection of the interior of the lock was prevented by the revolving curtain: should this be displaced, it brought into action the detector-plate, which not only covered the key-