DETENT OR CHRONOMETER ESCAPEMENT.

CHAPTER I.

Preliminary.

800.—The detent to which this escapement owes its name may be made of two principal forms and these constitute two varieties of the escapement.

In the one the detent, termed by the Swiss makers *bascule*, is mounted on a pivoted axis. The arm of this detent against which the wheel locks is brought back to its position of rest, whenever it has been displaced, by a straight spring fixed to the plate, or, more usually, by a flat spiral spring attached to its axis.

In the second arrangement the detent and spring form one piece; and this spring, which is merely a prolongation of the detent, terminates at the end farthest from the balance in a small block which serves as a means of fixing it to the plate. The elasticity of the spring or thin portion of the detent renders it possible to unlock the wheel by drawing the locking arm aside, and brings this arm back to its position of rest whenever it is so drawn aside.

The first of these is known as the *pivoted detent* escapement and among Swiss makers as the escapement *à bascule.*

The second is termed the *spring detent.*

The first detached detent escapement was invented and made by Pierre Le Roy (**589**).

F. Berthoud first employed the spring detent and he attached the small spring, often known at the present day as the *gold spring*, to the roller on the balance-staff.

The pivoted detent escapement has been constructed in France chiefly by L. Berthoud and after him by Motel. These two makers brought the workmanship to a high state of perfection and obtained excellent results.

J. Arnold adopted the spring detent of Berthoud in a modified form, transferring the unlocking spring from the roller to the detent itself and altering its shape.

Earnshaw subsequently proposed a different form of escape-wheel from that of Arnold; he made them flat instead of having teeth projecting above their surface; he also changed the direction of the pressure during locking. These modifications in conjunction with certain others, suggested mainly by Breguet, have resulted in the spring detent escapement as now constructed.

The mode of action of the chronometer escapement is simple, but it does not admit of any error in the application of its principles nor any inferior workmanship.

It absolutely requires an isochronal balance-spring and a compensation balance. It must be carefully treated by its owner and only works satisfactorily in veritable chronometers intended for scientific observations; it should never be employed in ordinary watches.

The remarkable regularity, mainly due to it, that is observed in the chronometers employed by astronomers, naval and scientific men, and constructed chiefly by English and French makers, has led the manufacturers of ordinary watches to fancy that they would secure more accurate timing by the mere employment, in their best watches, of more or less accurate copies of detent escapements. Their attempts have always turned out to be failures.

The higher class of watchwork cannot be attempted with any chance of success except by makers who, besides being skilful, possess a sufficient amount of scientific knowledge. Without this there can be no progress, and, although we may occasionally meet with good imitators, there are no real artists, much less originators.

A mere trading watchmaker should never offer a chronometer or watch for sale as a thoroughly reliable timekeeper unless it is by a maker of proved ability, well-known for the success of his marine timekeepers or for watches supplied to scientific men who are accurate observers. Let him remember that the name, however well it be engraved on the plate of a watch, cannot replace workmanship and make its rate reliable; and that for everyday use the detent escapement, even if perfectly made, will never be successful except in the most careful hands.

Denomination of the several parts.

801.—This escapement consists of:

(1) A flat wheel with pointed teeth. It is shown at A, fig. 5, plate IX.;

(2) A locking detent against which the wheel rests. This

is termed a *spring detent* (*p* B C, figs. 5 and 6) when fixed to the plate by a small foot, and made thin at C so that it bends about that point; and it is a *pivoted detent* when supported on an axis, as D F and M *r* in figs. 10 and 11 respectively. The spring which restores the pivoted detent to its position of rest is known as the *recovering spring*.

A small cylindrical ruby, half of which is cut away at the upper end, projects at right angles to the detent at the point B, figs. 5 and 6. The tooth of the wheel, when locked, presses against the flat face of this hemi-cylinder; hence it is termed the *locking stone* or simply *locking*.

The light spring *m n*, figs. 5 and 6, also fixed to the detent, is known as the *gold spring*, *unlocking spring*, or *auxiliary spring*. This presses against a pin *p* projecting from the detent body, so that it can be inclined from *p* towards *n*; but it cannot be deflected from *n* towards *p* without the detent moving with it;

(3) A balance carrying on its staff a steel disc D in which is cemented a ruby *impulse pallet* J. This disc is known as the *impulse roller*.

On the same staff and below the roller a second or *discharging roller* E is held by friction and it carries a ruby *discharging* or *unlocking pallet e*.

The screw *f g*, whose head determines the resting position of the detent, is often termed the *banking screw*.

Action of the escapement.

802.—If the mainspring be wound up when the balance is at rest, with the balance-spring in its neutral position, no movement of the escapement will ensue; there will merely be a pressure exerted against the flat face of the locking stone.

But if the balance be made to vibrate, by giving a rotatory movement to the entire mechanism, say from left to right, the discharging pallet *e* (fig. 5, plate IX.) coming against the extremity *n* of the gold spring *m n*, forces it aside and continues moving beyond it.

On being brought back by the balance-spring, the pallet *e* again presses against *m n*, forcing it to move in the opposite direction; but, as this spring is now opposed by the pin *p* of the detent body, the detent is forced aside, bending at the part C, and it is thus released from the tooth *v*.

At this instant the wheel is free. As the pallet J is now slightly in advance of the tooth *r*, this tooth engages with it and the pallet is driven forward through a certain lifting angle.

The lift terminates with the tooth *s* falling against the locking stone B of the detent, which is brought back by its own elasticity, before the end of the lift, to the position it occupied before the impact of the discharging pallet.

The balance has thus received the impulse and performs the supplementary arc. The return vibration is *dumb*, since the only action that occurs during that period is the slight displacement, by the discharging pallet, of the gold spring, which yields so as to allow of its passage; the balance on again returning effects the next unlocking, receives a fresh impulse, and so on.

It will be seen that this escapement bears some analogy to the duplex, as the balance only receives an impulse at every second vibration.

It is liable to set; in other words it is unable to start itself from a position of rest when the mainspring is wound up. This necessitates that the balance be set in motion by a direct impulse, due to a shake or twist given to the entire mechanism.

PROPORTIONS RECOMMENDED BY VARIOUS AUTHORITIES.

SPRING DETENT.

803.—ARNOLD*.—Fig. 7, plate IX., represents Arnold's escapement as he made it for his best chronometers.

The teeth project above the flat of the escape-wheel and act by their curved sides against an impulse pallet directed towards the centre of the balance-staff. The pressure against the locking stone tends to elongate the detent; in other words it is directed from the detent foot *b* towards the extremity *a*.

The unlocking of the tooth is effected by drawing the detent *towards* the escape-wheel axis, so that the released tooth passes behind the locking stone.

804.—EARNSHAW† replaced Arnold's wheel by one that was flat with inclined pointed teeth, fig. 8, plate IX. He arranged

* Two watchmakers of this name have been celebrated in England, where the seccnd, the son, followed up the successes of the first.

J. Arnold's chronometers were acknowledged to be superior to those of Mudge, and in 1790 they secured him a reward of £1320. The younger Arnold obtained in 1805 a further sum of £1680, making a total of £3000.

† The modifications that Earnshaw introduced in the detent escapement and the excellent rates of his chrcnometers secured for him an equal Government recompense in 1805.

Without wishing to detract from the merits of these makers, who are justly celebrated, we may be permitted to point out that, as early as 1784, L. Berthoud in France that it should rotate in the opposite direction, and thus it results that the pressure of the locking tends to force the detent towards its foot. It is driven *from* the wheel at the unlocking.

The direction of the impulse pallet passed through the middle point of a radius of the roller.

805.—TAVAN. — This author refers to three different forms of escapement as Arnold's of which one was certainly not designed by that maker.

The principles of construction adopted by Tavan and inserted after his descriptions may be summed up as follows.

"There are no fixed proportions to be observed in the unlocking pallet: if it is short, it must be pitched deeper with the auxiliary spring; if long, the pitch should be less deep.

"If it be required to ascertain the length of impulse pallet that will secure a lift of 60°, the best adapted to this escapement, the following is the method of procedure:—With a 15-tooth escape-wheel divide the distance between the centres of the wheel and balance into 21 parts and take 15 of these for the radius of the wheel and 6 for the length of impulse pallet."

This author, considering it highly important to secure great certainty in the lockings, places the resting point of the locking stone a little short of the tangential position when the detent is to the right of the wheel, and a little beyond it when to the left, so that the wheel always has a slight tendency to draw the detent towards itself.

806.—JURGENSEN. — The following are the principal proportions of this escapement:

The radius of the impulse roller should equal the interval between the points of two teeth.

The face of the locking stone should be inclined so as to occasion a slight recoil of the escape-wheel at the unlocking. (In the first edition of his work he made the locking tangential.)

The unlocking spring can be directed towards the centre of the balance-staff. The action of the escapement is rendered more certain by making the unlocking pallet act slightly before the line of centres rather than beyond it, when on the point of unlocking the wheel.

The escape-wheel teeth should accomplish the lead as uniformly as possible, and (in Arnold's escapement), so far as

had introduced into his pivoted detent escapement most of the improvements that were so liberally rewarded in England.

is practicable, perpendicular to the impulse pallet. (In his first edition Jurgensen states that the curve of the teeth of Arnold's escape-wheel should approximate to an epicycloid.)

The position of the impulse pallet should be so related to that of the unlocking pallet that there is sufficient drop, between the unlocking and the fall of the tooth on the impulse pallet, to ensure the proper action of the escapement. This drop should be rather greater in pocket chronometers than in marine timekeepers that are supported in gimbals.

The detent should be displaced to such a distance by the unlocking pallet that it does not fall back against the banking screw until the liberated tooth has travelled to a distance of about a quarter the interval between two teeth beyond the locking stone.

The banking screw of the detent is to be placed as near as possible to the centre of percussion of the latter.

807.—MOINET.—The unlocking spring should point very nearly towards the centre of the roller, but so as to be struck *after* rather than before the line of centres, in the case of a spring detent. (This is the converse of what Jurgensen recommends.)

The banking screw and locking stone are set at about a quarter of the length of the detent from its extremity, this being approximately its centre of percussion.

All the other data given by Moinet are to be found in the previously published work of Jurgensen.

808.—A. BREGUET.—Fig. 9, plate IX. represents a plan of the spring detent as suggested by Breguet.

The locking is practically tangential to the escape-wheel, the tangent passing just in front of the centre of the balance-staff. The auxiliary spring is directed towards this centre or very approximately so, and reaches almost to a line joining this centre and the point of flexure of the detent. In very many English forms of the escapement its direction differs considerably from that here indicated.

Finally, the point of rest on the locking stone and the point at which the unlocking pallet is struck are so taken that the force effecting the unlocking and the resistance at the locking stone act on the two detent springs in such a manner that the detent itself is protected from the effects of torsion.

The banking is carried at the extremity of a small arm or bar parallel to the detent.

This system possesses certain advantages but it entails rather more labour than those previously considered. It might perhaps have been definitively adopted had it not been employed in conjunction with that objectionable arrangement which places the balance and roller at opposite ends of the staff. Irregularities in the rate, due in great part to this mechanical error, brought this form of spring detent into disrepute, although it was one of the best known at the time.

The Swiss escapement-makers have modified Breguet's detent, but unfortunately without understanding it. Thus they varied the position of the locking point and of the point at which the auxiliary spring is struck, and yet continued to make an aperture in the flexible portion of the detent; this converted what was a rational proceeding into an absolute contradiction.

809.—GANNERY.—He considered a certain amount of draw essential and made the lift about 45°.

The distance between the centre of movement of the detent and the extremity of the auxiliary (or gold) spring is to the radius of the escape-wheel as 2·33 is to 1, or 7/6ths of the diameter.

Its entire movement during the unlocking is 2° produced by a balance motion of about 22°.

When about to accomplish the unlocking the pallet should come into action a little before the line of centres; a double advantage is thus secured; the greater portion of its lifting action is employed to effect the unlocking, and the remainder of the arc becomes proportionately less; and this diminishes still further the already feeble resistance of the auxiliary spring.

PIVOTED DETENT.

810.—L. BERTHOUD, MOTEL.*—Fig. 10, plate IX. represents, as accurately as is possible in a drawing of such dimensions, the detent employed by L. Berthoud and subsequently by Motel.

The rest is tangential to the wheel. The direction of the

* Louis Berthoud (nephew of F. Berthoud) improved the calliper of French chronometers and constructed 150 of them. This is a great number for that day, especially when we consider their excellent quality. He died in 1813.

H. Motel was the pupil and successor of L. Berthoud; he acquired considerable reputation by the great number of chronometers he made; they were beautifully constructed and possessed remarkable rates. He died in 1859.

auxiliary spring is such that the action of the balance is practically equal on either side of the line of centres, *b c*, and it terminates close to this line. The spring was formerly made of steel and the pin against which it rested was of gold. The point of contact required to be oiled.

The necessity of applying this oil and of preventing it from passing to the unlocking pallet compelled them to form a projection in front of the pin, at the extremity of the auxiliary spring; this occasioned a slight flexure and a cutting action against the pin.

The surface of the impulse pallet where it engages with the tooth is so curved as to facilitate the engaging and the lifting action.

In the chronometers made by L. Berthoud and in very many of those by Motel, the inclination of the teeth is less than that indicated in fig. 10.

The banking of the detent consists of a pin fixed excentrically in the head of a screw which is firmly held in the plate.

A simple examination of the figure will make evident the mode of action of the recovering spring *r b*. Its effective length is about equal to the diameter of the wheel.

L. Berthoud's pivoted detent, amended by the use of a spiral recovering spring and a gold auxiliary spring at a less inclination to the detent itself, is an arrangement that bears comparison with the best escapements made.

If it has been less studied than the spring detent this fact must be mainly attributed to the practice of the majority of French makers of arranging the balances of their marine chronometers to beat 18,000 vibrations per hour; an excessive velocity which made every fault of construction or error in principle the more manifest; and it is further due to the high degree of finish and the manipulative details in which these makers took so much pride in their best chronometers, at the very time that the English-made instruments were characterized by marked simplicity.

811.—TAVAN.—In the memoir that describes the researches of this authority, all that refers to the detent escapement appears to be the result of a mere examination of chronometers by other makers and not from experiments made by Tavan himself.

In addition to two drawings of the spring detent, he gives a very bad arrangement of the pivoted detent, and then concludes in favour of the latter in the following terms.

"The system that has the locking piece supported on a pivoted axis provided with a flat spiral spring to restore it to its locking position is preferable, because the resistance opposing the unlocking can be more easily modified by means of this spring. The locking action is more secure when the locking stone forms part of a rigid lever than when it is fixed to a flexible spring."

812.—MOINET.—"The pivoted detent is not thinned down to a spring and, instead of being provided with a foot, it has a fine axis at its extremity, the pivots rotating or rather oscillating in holes in the plate and a bar. A flat spiral spring of 3 or 4 turns and of sufficient strength is held by one end in an ordinary stud held friction-tight in the plate, while the centre is attached to a collet on the axis of the detent, precisely as in the case of the balance-spring of the ordinary balance.

"As the pivoted detent has been the less used, we are not possessed of comparative results that would suffice to decide us in our choice; the spiral spring, being the longer, would appear to be characterized by a less rapid change in the resistance; but the detent opposes a greater mass, and between these two effects, so delicate in the case of an escapement, it is impossible to decide except by special experiments, the nature of which appears, so far, to be but little known."

813.—M. HENRI ROBERT.—Figs. 11 & 12 of plate IX. represent, in plan and elevation, a pivoted detent escapement as made by M. H. Robert; he is, to the best of our knowledge, the only chronometer-maker, if we except M. L. Berthoud the younger, who has employed it in marine timekeepers.

"The front faces of the teeth are inclined in the direction *q o*, making an angle of 30° with the radius *n q*. This inclination is very generally adopted at the present day." The face of the impulse pallet *l* forms the same angle with the radius of the roller.

The small spring *s* is a strip of gold bent at right angles so as to form the foot *s'*; this foot has a slot cut in it, so that it can be passed under the head of the screw without the necessity of removing the latter.

The direction given by L. Berthoud to this spring was modified by M. Robert, who made it less inclined to the body of the detent and directed towards the centre of the balance-staff. He also set the banking screw, *t*, nearer to the centre of motion.

Summary of this chapter.

814.—If the various forms of escapement that have been enumerated above be examined attentively, one is struck with the great differences in their several proportions, which seem to imply the absence of any precise basis founded on the laws of Mechanics.

When an art or industry first commences it cannot be otherwise: even science herself is forced to rely on carefully observed facts, on a mass of experimental data, before she can enunciate her laws; just as in mathematics it is impossible to determine the *unknown* terms except by the aid of quantities that are already known.

It is, then, not without some advantage that the reader can here examine, side by side, the principal proportions adopted by the above authorities.

Direction of the Impulse Plane.

815.—The face of the impulse pallet, against which the teeth of the wheel act, was directed towards the centre of the balance-staff by L. Berthoud, Arnold and Motel; and towards the middle point of a radius of the roller by Earnshaw and Breguet.

Direction of the Unlocking Spring.

816.—The small unlocking or auxiliary spring should be directed towards the centre of the balance-staff, or very nearly, according to all the authorities; but with this difference, that, whereas some consider the action should be equally divided on either side of the line of centres, others assert that there is an advantage in effecting it before this line rather than after, and a directly opposite opinion also has its supporters.

This difference in the mode of action might be caused by alteration of the direction given to the spring, and of the mode in which the small acting extremities are rounded.

The line joining the point of flexure and the free extremity of the auxiliary spring is almost parallel to the body of the detent in Arnold's and Earnshaw's escapements; on the other hand, it is inclined at a considerable angle in the escapements by L. Berthoud, Breguet and Motel.

Banking of the detent.

817.—The banking screw in the construction of Arnold and of Earnshaw (*c* & *d*, figs. 7 & 8, plate IX.) may be regarded as a rigid obstacle. In that of Breguet it is a cam (*a*, fig. 9) carried on an arm whose only fault consists in its being too massive. Berthoud's arrangement (*a*′, fig. 10) is the best of those in use at his day.

Number of Vibrations and Lift.

818.—Earnshaw and Breguet made their marine chronometers to beat 14,400 vibrations per hour. L. Berthoud and Motel increased the number to 18,000 or even beyond that point.

A lifting angle of 60° was very generally adopted by the old makers.

Position of the Balance and Balance-spring.

819.—L. Berthoud, Arnold and Earnshaw placed the balance and impulse pallet near the middle of the balance-staff, and they thus conformed to the principles so clearly laid down by Pierre Le Roy. The balance-spring occupied the upper portion of the staff. Motel brought the lifting action too near to the pivot; but the system adopted by Breguet was, as regards this point, the most objectionable. He placed the balance at one end of its staff, the impulse roller at the other end and the balance-spring between them.

Escape-wheel and Impulse roller.

820.—Arnold and Earnshaw made their wheels with 12 teeth. Those of other makers had 15 teeth.

The size of impulse roller is variable, because it depends both on the number of teeth and the distance between the centres; and these quantities are not constant.

L. Berthoud and Breguet made smaller rollers than did the English makers.

All the early authorities employed very large wheels in comparison with those in use at the present day. The diameter has been gradually reduced and there is actually now some fear that makers will fall into an extreme in the opposite direction.

Proportion between the detent and wheel.

821.—Taking the radius of the wheel as a basis of comparison in each case, the following table gives the length of the detent, measured from the centre of flexure or from the centre of rotation, to the extremity of the auxiliary spring.

ARNOLD (the elder).—Spring detent ...	... ...	about	2.0
more recently ...	... ...	,,	3.0
L. BERTHOUD, MOTEL.—Pivoted detent	... ...	,,	1.1
EARNSHAW.—Spring detent ...	... ...	,,	3.0
BREGUET. ,,	... ...	,,	2.0
GANNERY. ,,	... ...	,,	2.3
H. ROBERT.—Pivoted detent	... ...	,,	1.2
ARNOLD according to TAVAN — ,,	... ...	,,	1.4
ARNOLD according to TAVAN — Spring detent	... ...	,,	1.6
ARNOLD according to TAVAN — ,,	... ...	,,	2.0

On comparing these figures among themselves and examining the different forms of modern escapements, we at once notice two facts: (1) pivoted detents are much shorter than the others (measuring from the centre of motion to the end of the unlocking spring); and, (2) whereas the French makers have retained, very approximately, the same length of detent as was adopted by Breguet and have materially diminished the size of the wheel, the chronometers of English design are, as a rule, characterized by both shorter detents and smaller wheels than those of earlier construction.

OBSERVATION.

822.—The detent escapement, in its two forms, as made at the present day is a composite invention.

The principle of the free detent and the first escapement constructed on that principle are due to P. Le Roy.

F. Berthoud applied a flexible blade to the detent in place of the axis, and he attached to the roller a light unlocking spring bent at right angles.

Subsequently Arnold in England and L. Berthoud in France altered the form of this auxiliary spring, sometimes termed *deer's foot* spring, and attached it to the detent itself.

Breguet set the banking screw at the extremity of an arm, and very approximately determined the length of detent best suited to marine chronometers. Prior to him L. Berthoud had employed an arrangement for banking the detent that is preferable to the one in favour in England at the time.

Arnold's form of escape-wheel was abandoned in favour of the flat wheel with pointed teeth of L. Berthoud and Earnshaw.

The detent escapement, then, independently of any minor improvements, cannot be regarded as the invention of any one of the watchmakers we have quoted above, but it is the outcome of the collective labours and experiments of all these great authorities.

To attribute it solely to one of them and to describe it, for example, as Arnold's escapement, which is still very often done in England and Switzerland, is a great injustice and utterly at variance with history.

CHAPTER II.

RULING PRINCIPLES IN THE CONSTRUCTION OF THE DETENT ESCAPEMENT.

General Considerations.

823.—The reader will do well to read again our observations in article **686**; and these we will complete and supplement by the few following remarks.

Chronometers by Arnold, Earnshaw, Berthoud, Breguet and Motel, as well as by their respective successors, have maintained excellent rates at sea. But the special arrangements adopted by these highly skilled watchmakers differed materially, for they employed long and short detents, large and small wheels, spring and pivoted detents; and in this we have evidence of the fact that success is not secured by the mere selection of this or that escapement or of a particular size for any part, but that it depends, as has been already demonstrated in our theory of escapements, on a number of proportions and a certain initial relation between the several elements of the mechanism; a relation which should be such that its modification by time (the thickening of oil, etc.) has the least possible effect on the rate of the mechanism, assuming it to be, in the first instance, properly timed.

We do not include among these disturbing causes the wear of the parts that is brought about by an unsuitable mechanical combination, the employment of inferior materials, careless workmanship, or the ignorance of workmen. When the mechanical execution is at fault everything becomes uncertain.

Thanks to the labours of our predecessors we are now able to realize an efficient arrangement, and to secure results that are somewhat better than those to which they attained, with almost absolute certainty, although we are still ignorant of the scientific explanation of several points. But they have opened out the way and set the limits to it; it is for us to avoid straying from it.

THE TANGENTIAL ESCAPEMENT.

Is it possible for the centre of the balance and the locking to be on one and the same tangent?

824.—It is often regarded as an elementary rule in the workshops that, to secure the best results with this escapement, the locking point and the centre of the balance-staff should lie on a line tangential to the wheel.

This condition, assumed to be of primary importance, is open to the objection that it only deals with the question from one point of view, and it confines the problem within too narrow limits, since the data to be considered become too few.

The locking point can always be set tangential, but the position of the centre of the balance varies with the lifting angle.

825.—Let the circle *a r v* (fig. 4, plate X.) indicate the circumference of the escape-wheel, one tooth of which is held against the locking stone at *r*. The line *r c* is a tangent at this point *r*.

If the wheel has 15 teeth, three of these will occupy the positions *r*, *b′*, *b*; the balance must, then, be set at *d* to be on this tangent. The lifting angle *b d b′* will in round numbers be 70°.

With a 12-tooth wheel the three teeth will be at *r*, *a′*, *a*. The centre of the balance is then at *c*, and the lifting angle *a c a′* is 60°.

Under similar conditions a wheel with 10 teeth will give a lift of about 45°, and this is the amount most generally employed.

Both theory and experience have indicated the objections to an excessive lift (**97**), and we know that, in practice, it is possible to secure a sufficient extent of vibration of the balance by a lift of about 45°. Hence we shall do well to limit ourselves to this angle; but it will be evident the application of the so-called rule would compel us to employ a wheel of 10 teeth in order to do so.

Now, if the movement of the balance be adjusted, for example, to 14,400 vibrations in an hour, the 10-tooth wheel must move through an angular distance of greater extent in approximately the same period of time. It must, then, travel with a greater velocity than a wheel of 15 teeth; but, since an increased velocity corresponds to a much greater relative increase in the force producing it (**121**), it is evident that a greater motive force will be required.

We here have a new calliper of escapement to calculate and experiment upon; but a simple drawing at once shows that, ignoring the different velocities of the two wheels, when the one with 10 teeth is substituted for that with 15 teeth, it will involve longer acting surfaces, a larger detent and roller, increased motive force, etc., without any counteracting advantages that can, *a priori*, be detected.

Tangential locking.

826.—We have just seen that, in modern chronometers with a small lifting angle, it is impossible to set the axis of the balance on the tangent drawn through the point of locking. It remains for us to ascertain whether any real advantage is secured by making this locking absolutely tangential.

The gain is manifest if the face of the locking-stone is concentric with the centre of movement of the detent; but, when draw exists, not only is there no such advantage in making this point tangential, but actual inconvenience may result from it.

Three cases may present themselves:

The locking face may be inclined and half of the stone removed, so that the surface would lie accurately on *x z* (fig. 52), the prolongation of a radius of the wheel, or more may be cut away, as *c d* or *i g*; the points of contact will in these cases be at *b*, *a* and *c*.

On the first assumption the pressure will act in a direction towards the right of the detent; in the second case it will tend from the locking stone towards the centre of movement of the detent, along the line *a h*; and in the last case it will be directed towards the left.

If the resting point is at *a*, the detent will have no tendency to move to the right or left; and this practically secures a concentric locking face. But there is no advantage in this, because the resistance occasioned by draw must be overcome before the unlocking can be accomplished; a resistance which is mainly due to the height of the small incline that produces the recoil of the wheel (**623**).

The setting of the locking point at *b* is very objectionable; the resistance opposed to unlocking will be sensibly the same as it was for the plane *a*, and, since the pressure tends to force the detent from the wheel, the least shake will cause the detent to leave its banking screw. And it is easy to see, by using a powerful eyeglass, that occasionally a slight interval exists between the two when this condition obtains.

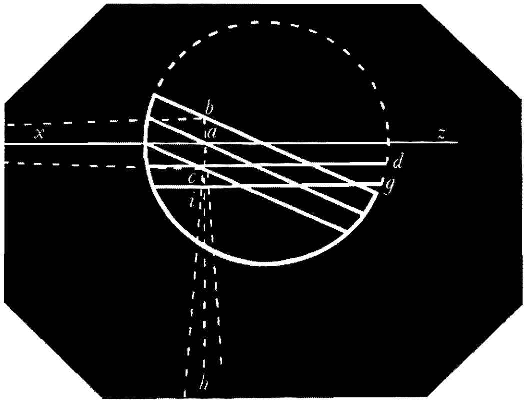

Fig. 52.

The only logical course is to set the locking-point *below* the tangential position or, approximately, at *c*. The steadiness of the detent against its banking being then more secure it will be possible to slightly diminish the height of the incline that causes the wheel to recoil, and, if this is done, rather less of the energy of the balance will be absorbed in the unlocking (**630**).

827.—The height of this small incline gives a measure of the resistance to unlocking.

The direction of the pressure against it indicates the degree of steadiness that the detent will possess during the locking.

By intelligently combining these two elements we shall be able to determine the most favourable position for the locking point.

The Draw.

828.—The resting surfaces in the earliest detents by L. Berthoud were concentric with the centre of movement of the detent, so that the wheel was not made to recoil. At the present day the tooth rests near the base of a straight incline, so that the wheel is impelled slightly backwards at the moment of unlocking.

Some few watchmakers still maintain that draw is useless both in the lever and chronometer escapements; and their main argument is based upon the fact that the pressure takes place in the direction of the centre of movement and that the detent, in virtue of its inertia and state of perfect equilibrium, has no tendency to move either in one direction or the other.

Without instancing the opinion held by a very great number of distinguished makers who have practically recognized the necessity of draw, or the fact that it is at the present day almost universally adopted (although this must have some weight in the discussion of the question), we would point out to the advocates of concentric lockings that, when they deny that movements of rotation in the plane of the pallets or detent have any influence, they are justified, since such motion is exceedingly rare; but they appear to forget or to ignore the fact that the displacement of any form of locking piece by reboundings or quiverings when it is not properly held against its banking, etc., is mainly caused by a shake, or by the reciprocal action that occurs between moving bodies.

Theory clearly establishes this fact, and we have given experimental proof of it in article **635**. An experiment, moreover, that can be easily made will suffice to convince the most incredulous.

829.—If a chronometer or watch with detent escapement be so placed that the balance can be stopped at will while performing the supplementary arc, and if, in several trials, the balance is checked while at the same time the mechanism is subjected to sudden shakes and blows, the observer may perceive, not indeed always but in very many cases, on carefully watching the escapement held up to a cross-light, that the detent is at times held by the tooth of the wheel so as not to touch the banking.

This fault is very common in escapements of Swiss construction, where the draw is secured by slightly rotating the locking stone, cut so as to make the locking tangential; and it is especially noticeable when the detents are at all soft or insufficiently rigid.

This question of draw has been very fully discussed in **622** and the following articles; we therefore refer the reader to them.

An experimental datum, which, however, allows of considerable latitude, fixes 12° as the best inclination for the locking face. The maker must modify this amount according to special circumstances; it will be rather less for marine chronometers and more for pocket timekeepers.

When the draw is somewhat considerable but at the same time the pitch of the wheel and locking stone very shallow, this draw will remain constant for the longest period; (it must, of course, be understood that the pitch is sufficient to guarantee perfectly safe action).

830.—In practice, when it is required to set the face of the locking stone at the proper inclination, the detent is fixed on a plate made for the purpose and provided with a projecting pin that serves to centre the detent. The ruby is placed in position and, while the shellac is still warm, small tweezers that are centred on the same pin enable the workman to rotate the stone to the amount required, as indicated by a long pointer; this forms a prolongation of the prong of the tweezers that is in contact with the face of the locking stone, and the free extremity traverses a graduated circular arc.

The Lifting angle.

831.—In the detent escapement the lift takes place precisely as in the duplex. The lifting angle must conform to the conditions laid down in **96**, etc., **700**, and **701**; we therefore refer to them to avoid repetition.

In chronometers of modern construction, which are superior to those of older date because a more perfect harmony exists among their several parts, the lifting angle has been considerably reduced. It has a mean value of 45°.

This reduction secures an action that is less oblique to the line of centres; it has therefore made the character of the lead and of the friction more satisfactory, and the escapement is less sensitive to the resistance opposed by thickened oil; especially when the acting surfaces are supplied with oil, or when it has worked up to them.

The Lead.

Form and inclination of the acting surfaces of the Teeth and Impulse pallets.

832.—Arnold's escape-wheel had teeth projecting from the flat, like a crown wheel; and they are rounded so as to act on a straight pallet directed towards the centre of rotation of the wheel, as in an ordinary depth.

L. Berthoud and Motel employed inclined pointed teeth; but the face of the pallet, while being directed towards the centre of the balance-staff, was curved to a certain pre-determined extent where it engaged with the teeth, the radius of curvature being considerable (fig. 10, plate IX.).

Earnshaw's wheel is the same as that of L. Berthoud, except that the faces of the teeth are much more inclined because the pallet lies in a very oblique plane passing midway between the edge and centre of the roller.

In each case the lifting angle measured about 60°.

Assuming the same diameter of wheels, if we endeavour to ascertain their respective merits we observe that:

Arnold's wheel rests against the locking by a short arm and exerts a proportionately increased pressure. The rounding off of the teeth causes a loss of some degrees in the lead (so that in order to obtain the same lifting angle a larger wheel will be necessary). We thus have an impulse of rather less energy communicated to the balance, and in effecting the unlocking it will be called upon to overcome a somewhat greater resistance.

Berthoud's wheel, with a pallet slightly curved at its extremity, has less drop before engaging and an increased velocity towards the end of the lead, as compared with Earnshaw's wheel, which acts against a straight pallet set at an inclination. In this latter case the tooth falls against the locking stone with rather less energy but it gives rise to a species of draw on the impulse pallet which increases the lateral pressure on the pivots of the balance. The tooth, moreover, can never be so far inclined as only to act with its point; and this accounts for the frequency with which we find the teeth of wheels thus formed to be worn on the face.

833.—The systems of Earnshaw and L. Berthoud are, with reason, regarded as of equal value; they are preferable to that of Arnold because, rather less force being wasted, a heavier balance can be employed, and this diminishes the risk of setting since the unlocking absorbs less energy.

Each of them, although having some faults, possesses important advantages. Modern makers have thus been led to adopt a combination of the two, which has as far as possible the advantages of both systems. The straight impulse pallet is usually preferred, and it is set so as to cut a radius of the roller at right angles, at about a quarter of its length from the centre (figs. 5 & 13, plate IX.).

834.—The inclination of the front faces of the teeth should increase with that of the pallet. As a general rule, in practice the face of the tooth is inclined at an angle of about 27° to the radius of the wheel (A *h z*, fig. 5, plate IX.).

To reduce the weight of the wheel, without at the same time diminishing the acting faces beyond what is necessary

(**41**), it is hollowed out on both sides, or more deeply on one side only. Fig. 53 shows two of the forms (*a*, *n*) of teeth that are employed, the one at *n* being more generally preferred.

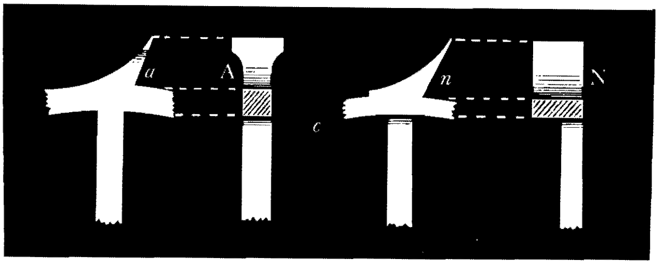

Fig. 53.

A and N are vertical sections of the flat of the wheel, viewing the face of the teeth.

THE DETENT.

On the form of the detent and of the unlocking spring.

835.—Detents and auxiliary springs are to be met with that are bent in the most fanciful manner; their makers flattered themselves that they would secure novel properties in the escapement, whereas they have only succeeded in proving themselves utterly ignorant of the very rudiments of Mechanics. Whatever be the form given to the detent and spring, it is always the virtual length of these levers that has to be considered (**135** & **623**).

This applies to an unlocking spring when it only bends at one point; but if it is thin throughout its entire length or for a certain part of its length, twisted forms, etc., will give rise to flexure that is often very complex and always detrimental.

The auxiliary or unlocking spring.—Its direction.

836.—A steel unlocking spring occasions wear in the course of time; the cause of this has been already indicated in article **810**. It is best to make it of alloyed gold (when it is sometimes known as the *gold spring*) resting against a steel pin or simply against the extremity of the detent.

We believe that the English makers were the first to employ a spring of this metal.

837.—Should the spring be directed towards the centre of the balance-staff? A reply can only be obtained to this question by examining actual escapements.

Three different forms are represented in figs. 10, 13* & 5 of plate IX.; they are shown on a larger scale and detached, in figs. 1, 2 & 3 of plate X., where the details will be more clearly visible.

838.—The lines *e b*, *e d*, fig. 1, join the centre of the balance-staff with the centres of movement of the detent and unlocking spring, and, since the extremity of this latter is at *s*, it will be struck *after* the line *b e* when the unlocking occurs; this action will therefore be unaccompanied by engaging friction. On the return of the balance the spring will only be touched *after* the line *d c* and the friction will still only be disengaging.

Remark.—The great inclination of the spring gives rise to a considerable pressure at the point of contact with the pallet and against the pin, since the spring is, as it were, bent up on itself.

This obliquity of the spring to the body of the detent, besides having the disadvantages mentioned here and in **810**, is objectionable in that it involves an increase in the weight of this detent by the addition of the arm carrying the spring, and indeed by more than this amount if it is desired to distribute the metal equally on either side of the detent.

839.—We will now consider figure 3.

The pallet engages with the spring when on the line *a r* joining the centre of the balance with the centre of flexure of the detent. On returning, the spring is struck on the line *m a*. Both actions will be accompanied by only disengaging friction on condition that the thickness of the extremity *n* of the spring does not exceed the interval between the lines *a m*, *a r* at the point *n*. As this condition involves a point of extreme thinness, there will always occur in practice some engaging friction, according as the spring projects beyond *a m* or *a r*.

When the form of detent represented in fig. 5, plate IX., is employed, the auxiliary spring is set so that it lies slightly to the left, as nearly as possible forming a tangent to the circumference of the balance pivot; and this causes a little engaging friction at the unlocking.

840.—In fig. 2, plate X., the unlocking commences *before* the line *g c* and in the dumb vibration the engagement is also *before* the line *f c*. In both cases the friction is partially engaging.

* By an engraver's error the extremity of the detent is brought too much to the left. It should be nearer to the line joining the point of flexure *m* and the balance centre *a*.

As regards friction then this system is inferior to the two previously considered; if some makers do prefer it, this is doubtless due to the fact that it is characterized by great simplicity, and that it is easy to correct any slight error in the position of the extremity of the spring, by bending or straightening either the end of the detent or of the spring itself.

We must assume that one advantage balances the other, for both systems are adopted by makers who are well-known for the excellence of their productions.

We shall further consider this subject in the following article.

The friction of the unlocking spring.

841.—The fact of the friction being partially engaging when the unlocking takes place does not appear to influence in any way the makers who adopt the forms of detent shown in figs. 5 & 13 of plate IX. (observing the footnote on page 494).

The unlocking should be effected with *absolute certainty;* but, in pitching the escapement, it is almost impossible to guarantee that each face of the spring is accurately on a line of centres. It will be in advance or fall short of it by an amount which, although doubtless very small, is apt to be increased by the movement of pivots in their holes and at times by the quivering of the detent itself.

If the gold spring is struck beyond the line of centres, a given angular displacement of the detent will involve a deeper pitching of the spring and pallet, and thus both the extent of acting surfaces and the amount of engaging friction, when the spring is lifted in the dumb vibration, will be increased.

Many of the best makers allow part of the action to occur before the line of centres, for they consider the advantages and objections of each of the cases under discussion to balance one another, and they further take account of the fact that it is impossible, in practice, to attain to mathematical accuracy, especially in the case of an operation that is so rapid as the unlocking of a detent; the engaging friction thus produced is assumed to be neutralized by advantages in other directions.

The entire question is thus shown to be one of experience; in other words, we must ascertain the nature of the contacts in a large number of chronometers that have been proved by long trial to be satisfactory; but so far as we are aware such observations have never been made on an extensive scale.

All that we can assert is that several chronometer makers deny that they have ever been able to detect traces of the influence of the unlocking pallet more frequently on one system than on another.

The detent must bank at its centre of percussion.

842.—Some makers appear to attach but little importance to the exact determination of the point at which a detent is banked. We think they are wrong in doing so; for if, when the point is improperly placed, they also have a detent a trifle thin, liable to quivering and unequally elastic at different parts, etc. (and this is by no means of rare occurrence), anomalies may exist whose cause will be long sought in vain.

If the banking screw is carefully located the detent will expend, in striking it, all the force with which it is impelled and will at once become stationary. On the other hand, if the banking does not occupy its theoretical position, the detent will quiver and will engage with the teeth when pressing against the banking with a variable force.

843.—The point or centre of percussion (for a given distance between the locking stone and balance) varies according as the detent is long or short; it follows that those makers who set the banking screw so that the detent rests with the locking stone against it, cannot make the detent of an arbitrary length: both this length and the general distribution of the material constituting the moving portion of the detent must be such that the point of percussion coincides with the banking point.

Very many escapement makers, whose only aim is to make a servile imitation of the works of their superiors, demonstrate in this one point their complete ignorance of a simple mechanical principle.

By using a very delicate micrometer, all the dimensions of a detent may be taken, a drawing can be made and the position of the banking determined by calculation.

We thus obtain a good first approximation. It may be experimentally verified as follows.

Employing an eyeglass of high magnifying power and conveniently situated, it is easy to ascertain whether the detent quivers on striking against the banking screw; but this verification must be made with the plate held in several different positions, first horizontal and then vertical.

If the whole is well arranged, no difference will be detected in the movements of the detent however the position be altered.

The Banking Screw.

844.—The detent must not be held against an absolutely rigid body (**35**).

The two methods of banking shown at *c*, fig. 7 & *d*, fig. 8 of plate IX., as well as those in which the detent rests against the head of a screw or a cam screwed to the plate of the movement, systems that are much used in Switzerland, are unsatisfactory.

The cam presents a too great surface of contact, and the slightest angular motion changes the position of the point of banking.

A screw head carrying a pin as arranged by L. Berthoud (*a*, *a'*, fig. 10, plate IX.) is good; but only if we avoid rotating the screw (for the purpose of adjusting the pitch of the wheel and locking stone) as then the position of the banking point is altered.

It is better to fix a banking screw in an arm projecting from the foot of the detent. This arrangement, shown at *g*, fig. 13, & *h*, figs. 5 & 6, plate IX., is the same as that adopted by Breguet; but less massive and the cam is removed.

A pin set in the head of a screw as well as an arm carrying a banking screw must be of but moderate volume; if completely wanting in elasticity they would in time wear at the point of contact; on the other hand, if made too thin they will oscillate at each blow of the detent. Experience must decide as to the most convenient dimensions.

Diameter of the locking stone.—Angular movement of the detent.

845.—When the locking takes place at the middle of a ruby cemented into the detent, the radius of the cylindrical face of this ruby is determined by the angular movement of the detent in effecting the unlocking.

At the present day the locking does not occur at the middle of the stone and it is necessary to slightly increase the diameter. This diameter is generally made about one quarter of the interval between the points of two teeth. A large ruby needlessly loads the detent, and, if its corner is not considerably bevelled, it renders a greater angular motion of the detent essential; in other words, it would be liable, on returning to its position of rest, to strike against a tooth with its curved surface.

846.—In a well-made marine chronometer escapement, that is not characterized by heaviness in any of its parts or resistances due to bad arrangement as a whole, the angular deflection of a spring detent measures about 2° (brought about by an angular movement of about 22° at the balance, inclusive of the action on the gold spring during the dumb vibration). This amount of lead may be divided into two portions differing somewhat in extent; the first effects the unlocking and the second draws the detent aside to such a distance from the wheel as to ensure that the tooth just released has sufficient time to advance out of reach of the detent returning to the banking.

It is hardly necessary to observe that, for a given balance movement, the angular path of the detent increases as the centres of motion are brought nearer together.

A light detent or one that is at all stiff requires that the angular movement *after* the unlocking should be of rather greater extent than is necessary with a heavy or weak detent of the same length.

It is impossible to give definite figures in relation to the subject for detents are found to vary in this respect. Recourse must be had to experience and observation as the best guide (**854**).

Long and Short Detents.

Experimental Data.

847.—Let *c n* (fig. 5, plate X.) be a detent with its centre of motion at *c*, the locking of the wheel at *b* and the extremity of the gold spring at *n*. Assume the unlocking pallet *r* to be centred at *a*.

The angular displacement of the detent will be *n c g*; and the centre *b* of the locking stone will be displaced to *x*.

Now consider the centre of movement to be transferred from *c* to *d*. The angular motion will become *n d s*; that is to say, the displacement of *n* will be somewhat greater, and the centre of the locking stone *b* will be carried to *y*.

The friction occurs through a longer period but the angle is rather less oblique, so that we may regard the friction in the two cases as the same. It will be noticed, however, that the greater displacement of the locking with this detent, which is necessarily heavier than the other, requires that it return more rapidly to its banking and therefore that its spring be more stiff. To avoid this increase in the resistance to unlocking, the pitch of the detent and pallet must be diminished so as not to exceed the arc ij, if it is required not to displace the locking further than x; a distance that is assumed sufficient in the case of the detent $c\,n$.

We thus avoid one fault only by falling into another, for, if the pitch of the detent, $c\,n$, with the pallet were no more than is requisite to secure certainty in the action, then the pitching of the longer detent, $d\,n$, would be insufficient. It would, moreover, be liable to much greater variations through changes in relative positions due to play of the pivots.

848.—From the theory of the lever we obtain the following results:

Detent $c\,n$.—Power arm $c\,n = 4$
Resistance arm $c\,b = 2$
Detent $d\,n$.—Power arm $d\,n = 8$
Resistance arm $d\,b = 6$,

which proves that the long detent offers the greater resistance to unlocking.

On the whole, then, the long detent has two advantages: a less rapid progressive increase in the elastic resistance or tension and a less oblique action against the pallet; but, at the same time, it is objectionable in offering a greater resistance to unlocking, and in being heavier, less firm, and less certain in its action; so that the faults far outweigh the advantages.

This demonstration shows us what an error is committed by the Swiss makers, who form the detent of immoderate length under the false impression that they thereby diminish the resistance to unlocking.

849.—Consider now the case of a short detent and assume its centre of movement to be at t; the length will be $t\,n$.

Unlocking under the assumed conditions will be impossible, and to bring the point b to x, the detent must be prolonged to k.

A glance at the figure will show that this detent, $t\,k$ or $t\,z$, will involve a much greater effort on the part of the balance than does the detent $c\,n$, owing to the great loss of force occasioned by the deep pitching, necessarily rapid bending of the spring, etc. We have already said enough on the subject; it seems useless to insist on this point.

It is, then, evident that those discussions as to whether a long or short detent is preferable are as utterly idle as in the case of the long and short balance-springs, levers, etc. The horological art does not admit the existence of long and short detents. It fixes for each particular escapement the length that secures an absolute certainty in the several actions, and which offers such resistance to the balance as shall have the least possible disturbing effect on its performance, and therefore on its regulating power.

850.—In the case of the marine chronometer as now made, it has been experimentally ascertained that the acting length of the spring detent should not be less than the diameter of the escape-wheel, nor more than the radius of the balance.

A pivoted detent, measured from the centre of motion to the extremity of the auxiliary spring, should be much shorter (by rather more than one-third this amount); for otherwise its weight, being increased by that of a counterpoise, would render the action of the escapement uncertain, especially in pocket chronometers beating 18,000 or 21,600 vibrations per hour.

On advancing the locking stone by one tooth.

851.—As a rule the escape-wheel rests against the locking stone by the second tooth in front of the one which will give the immediately succeeding impulse to the balance.

Would there be any advantage in making it lock against the third tooth?

The preceding article has already settled this question.

The choice of the third tooth renders a long detent essential. For, if of moderate length, the portion *n b* (fig. 5, plate X.) becomes considerable in comparison with *b c*, and such an arrangement entails all the inconveniences that are involved in an excessive angular movement, etc.

Locking by the third tooth can have no advantages except in the case of a wheel of higher number or different diameter than those in ordinary use. At the present day such a system is only of service under certain special circumstances, and a watchmaker who is thoroughly conversant with the theoretical principles and possesses sufficient practical knowledge, will be able to decide for himself without difficulty.

Impulse Roller.—Unlocking Roller.

852.—The size of the impulse roller depends directly on the number of teeth of the wheel and the lifting angle (**824**).

For a given wheel it varies directly with the lifting angle.

Its diameter as compared with the other dimensions of the escapement may be determined by means of a large scale drawing or, as is more usually done, by tracing the calliper of the escapement (**866**).

The diameter of the unlocking roller is usually from a quarter to a third of that of the impulse roller.

Number of Vibrations; determining the amount of angular motion of the detent.

853.—Marine chronometers with detent escapements have been made to beat 21,600, 18,000 and 14,400 per hour.

The last number has been generally preferred, and this circumstance can be explained by the fact that with a higher number, 18,000 for example, and all the other parts to correspond, it is necessary to employ a lighter balance, impart a more rapid motion to the wheel, increase the lifting angle as compared with the supplementary angle, and, lastly, to multiply the number of wheels in the train or increase their angular velocities.

Makers have, then, done wisely in not exceeding 14,400 vibrations in the case of marine chronometers, where the parts are somewhat large and heavy and therefore render a powerful balance essential. In the case of pocket chronometers the comparative lightness of the mobiles makes it advantageous to use the number 18,000 or 21,600, as by so doing the effects of shakes, etc., are rendered less detrimental.

854.—The adoption of higher numbers, moreover, enables us to diminish the extent of the angular movement of the detent, for it must return more promptly to the banking screw.

In marine chronometers this motion, varying from 2° to 4°, is effected by a balance movement measuring rather less than *half* the lifting angle (**846**).

In pocket timekeepers with this escapement, that give 18,000 vibrations, it need not be more than about one-third, and, for 21,600, one-fourth. These figures have been obtained by some of the best makers from extended series of observations; but it must be remembered that they cannot be regarded as in any sense absolute.

Is the spring detent superior or inferior to the pivoted detent?

855.—This question has been very often asked and has given rise to long controversies between some of our most skilful chronometer makers; several interesting articles have appeared in Vol. III. of the *Revue Chronométrique* on the subject.

Without being in any way partial or desiring to do more than determine which is preferable, we shall discuss it, holding the opinions of our eminent fellow-workers in all respect, but at the same time being independent, as we can be from our complete disinterestedness.

These observations will necessarily be brief; for very many points in the discussion have already been settled by the preceding explanations.

Here in a few words is the history of the subject.

The pivoted detent, invented in France by P. Le Roy and perfected by L. Berthoud, was experimented upon in England, mainly by Arnold in his chronometers without the fusee. Fig. 8, plate X., represents one of Arnold's detents, taken from a drawing by Tavan, who copied it from an English chronometer.

This form of detent is radically wrong. The length from *d* to *o* is enormous as compared with that from *o* to *e*: it requires a considerable angular movement to effect the unlocking, for otherwise the pitch of the wheel and locking stone would be insufficient to ensure certainty of action.

The banking screw *s* is too near the centre of motion; the quivering occasioned by the weight and the great length of the arm *o d* will cause the detent to engage with the tooth of the escape-wheel when resting sometimes firmly, sometimes lightly and at times even not at all against the banking screw. This effect will be the more serious and difficult of detection according as the point of banking is brought nearer to the centre of movement, and as the pivot-holes are larger and allow of a lateral displacement that will vary according to the state of the oil.

If to these remarks we add that the English workmanship of that day was much less delicate and more massive than that of French chronometers, it will be evident why detents of this construction were irregular in their action and became sluggish in the course of time. Dissatisfied with the results arrived at, Arnold assigned to the resistance of oil effects that were mainly due to faults of construction and to the general mechanical arrangement. Compare Arnold's pivoted detent with that of L. Berthoud (e' o' d').

We would observe that Arnold's recovering spring was attached to a collet set concentric with the axis.

His arrangement of the escapement with spring detent (fig. 7, plate IX.) is infinitely superior; this accounts for his having abandoned the experiments on the pivoted detent.

The pivoted detent is undoubtedly a French invention; but this is no proof that we must give the entire credit of the invention of the spring detent to England. We have set this historical point in its true light in article **822**.

Advantages and disadvantages of each form of detent.

856.—It is urged against the spring detent that:

It offers a greater opposition to the unlocking;

This resistance varies with the position in which the escapement is held, for it is supplemented by the weight of the moving part or diminished by this amount according as the escapement is held vertical or horizontal;

It is apt to be strained.

857.—The objections to the pivoted detent are:

Its necessarily greater weight;

The increased friction on the gold spring, since the pitch is deeper and the angular movement greater;

The resistance at the pivots;

Lastly, very great care is necessary in its adjustment and in determining the position of the banking screw. The most careful workman is often obliged to pitch the detent two or three times before arriving at the exact position.

858.—The spring detent is advantageous in that:

It permits of the force being more advantageously distributed;

The difference in the resistance opposed in various positions cannot come into play in the case of marine chronometers;

With a broad flat spring, such as is employed at the present day by the best makers, distortion, even if it does occur, has no sensible effect.

859.—The defenders of the pivoted detent urge that:

It is more solid and there is no possibility of this straining;

There is no change in resistance when the position is varied;

It is more efficient in diminishing the detrimental effect of the fall on to the banking screw (**861**).

As to its being more easy of construction we cannot grant this to be true. Both systems of detent require the hand of a first-rate workman in their construction. Such pivoted detents as *can* be made with ease are bad and heavy; they are simply useless.

860.—Ignoring the question of the resistances that depend on the form of recovering spring and the presence of oil on the pivots, points which will be discussed in the two succeeding articles, we think very little of the fact that an unequal degree of force is required to effect the unlocking, just as we regard the difference as to difficulty of construction of no moment; for this inequality, which is very slight and mainly results from the difference in the lever arms, is partially neutralized by the somewhat greater friction owing to the lead being of longer duration; and the want of equality thus often quite disappears.

The influences that have to be considered are almost instantaneous, and the practical differences, in the case of good workmanship, slight, and we have come to the conclusion, after consulting experienced makers in order to ascertain which offered the greatest facilities of manufacture, that the spring detent is justly preferred to the pivoted detent for marine chronometers (with 14,400 vibrations); and that the pivoted detent offers more advantages (**853**) in the construction of pocket chronometers (with 18,000 vibrations).

In conclusion, they are two distinct mechanisms having valuable qualities of different kind, but they likewise have objections that differ. In the hands of a skilful chronometer maker equally good results may be secured, and success may be relied upon with either form. He will know how to make the most of their good points and diminish their faults; we must therefore not make either system responsible for errors committed by unskilful imitators.

The friction at detent pivots.

861.—A pivoted detent does not rotate on its axis but merely oscillates through a very short arc. The contact between the pivot and pivot-hole gives rise to a simple pressure or a very limited rolling. This action, then, cannot be supposed to resemble the true friction at the other pivots of the mechanism.

The side of the hole is subjected to an elastic pressure analogous to that exerted on the head of the banking screw; as in that case, too, the elasticity of the support (the staff of the detent) diminishes the effect of the fall. Two very remarkable consequences follow from this fact: (1) the face of the *steel* banking does not deteriorate, although there is a constant succession of impacts on the same point, which cannot be said of the spring detent; (2) the pivots of the detent and the sides of the pivot-holes maintain their initial condition.

Seeing then that, when the locking stone is of ruby instead of steel, the points of the escape-wheel teeth suffer no wear, and that the pivots of a well-made pivoted detent remain intact, two results follow: firstly, it is unnecessary to apply oil to the locking stone, and, secondly, the oil applied to the pivots will remain good. This latter fact is rendered the more certain by the circumstance that these pivots are only subjected to a slight pressure, without sensible friction; and the oil is not continually being intermixed by rotation, as in the case of other pivots.

This preservation of the oil is now a proved fact; it is therefore not usual to employ jewelled pivot-holes.

862.—The resistance opposed by the detent pivots to motion has its source, not in friction properly so called, but in the effects of adhesion and capillarity. We are probably not far from the truth if we look upon it as analogous to the friction that opposes the commencement of motion of a stationary body.

What is its value? It is impossible to decide this question *a priori*, and the experiments it would involve are of so delicate a nature that we cannot reasonably expect an exact figure. It appears certain however that, whatever its value, it varies in time, for the resistance opposed by adhesion to the separation of two bodies is in proportion to the extent of surfaces in contact and the consistency of the lubricating body between them.

If the detent pivots are fine and not too long, this resistance has been considered to be inappreciable by some eminent makers, notably by H. Robert and the younger Berthoud.

At the same time, small though it may be, it certainly does exist; and, without making either too much or too little of it, since a suitable recovering spring can easily counteract its influence, it should not be entirely ignored (end of **863**).

Straight and spiral recovering spring.

863.—Moinet, in comparing the two forms of detent, observes that the pivoted detent would appear to offer a less rapidly increasing resistance, since the action of the spring detent depends on a short straight spring, whereas in the other a relatively long spiral is employed.

We will assume for the present that such is the case.

Suppose that to the same detent recovering springs have been applied of the two kinds, and of equal force, that is to say such that, when deflected through the same angle, they maintain the detent against its banking screw with equal steadiness.

For a given angular displacement of the detent, the resistance will become greater as the length of the spring is diminished.

The velocity of its return will, then, vary approximately in inverse proportion to this length.

Would it then be better that there should be less resistance during the lead, involving a diminished velocity in the return? Or is it preferable to have a somewhat greater resistance opposed to the unlocking and, at the same time, a more rapid recovery.

A series of comparisons, continued for a sufficiently long time, in which different recovering springs were employed in conjunction with the same detent, might decide these questions. It would be imprudent to attempt their solution solely from a theoretical point of view and with our present knowledge; the results might easily be erroneous, for there are frictions, flexures, etc., that are so rapid and minute as to escape detection, which cannot be represented by even approximate figures.

We have assumed that the resistance increases more rapidly with the straight spring and this point could be easily settled with angles of deflection of some extent, but, the angle in this case being *very small*, 2° or 4°, the straight spring may be compared to a spiral spring of sufficient strength and suitably arranged.

If it were demonstrated that the velocity with which a detent is brought back by a spiral spring diminishes with time, it would prove that the resistance opposed by the pivots ought to be taken into account.

864.—Although these questions still remain in abeyance, the following conclusions are accepted as true at the present day.

Observation has proved that a straight spring is sometimes oxidized at the point of contact and still more frequently adhesion occurs that has a sensible effect on the very limited movement of the spring; in many cases both these circumstances will in time check the return of the detent.

A carefully fitted spiral spring gives rise to neither friction nor lateral pressure, and its action may be relied on if it possess the strength necessary to restore the detent to its position of rest with sufficient rapidity; in this case the resistance opposed to unlocking is approximately the same as with a spring detent, assuming all other conditions to be the same. In using a spiral recovering spring, then, we cannot count upon the slight difference in the action due to the less resistance offered to unlocking by a pivoted detent; an advantage, by the way, which we have always regarded as insignificant.

The spiral spring should not be longer than is necessary to secure a motion fairly concentric with the pivots (3 to 5 turns). As the length is increased it will become more sensitive to variations of temperature and to shakes.

To design the Escapement.—To calculate its proportions.

865.—The methods and details given in **749** and the following articles are applicable here, and we have given such exhaustive explanations that it seems needless to do more than give the directions for tracing the calliper; these will be found below.

The same may be said as to calculating the proportions of the escapement when the wheel is known. The details of articles **748, 754,** etc., will suffice.

CHAPTER III.

PRACTICAL DETAILS.—CAUSES OF STOPPAGE AND VARIATION.

To draw the calliper of the escapement.

866.—Through a perfectly smooth brass plate drill a fine hole (*a*, fig. 7, plate X.) for the centre of the escape-wheel, and trace out the circumference. Assume the wheel to have 15 teeth.

This plate is centred on the wheel-cutting engine by the hole *a* and waxed on the table; then draw the lines *a c i* and *a b*, with the pointed cutter, inclined at an angle of 24°, and draw *a d* at 24° to the second line.

Lastly draw *a m*, which accurately divides this second angle into two equal parts. The centre of the balance will lie on this line.

The lift, inclusive of the drop, having been previously fixed upon, say 50°, two methods may be adopted for ascertaining the position of this centre.

First Method.—Draw with very great care the angle *q z p* (fig. 6) of 50° on a piece of metal, and accurately bisect this by the line *x z*. The portion must then be cut out, of the form shown in fig. 6, and placed on the calliper so that the line *x z* coincides with *h a*. Maintaining this coincidence, let the sector *q z p* slide from *a* towards *m* until its two sides pass through the points at which *a d* and *a b* cut the circumference: the angular point then fixes the point *m*.

A spot is made there strictly coinciding with the apex of the sector and fixing the centre of the balance.

Second Method.—If a line be drawn through *d* and *b* (fig. 7) it will be observed that the triangle *m d b* is isosceles; so that, the angle *b m d* being 50°, each of the two other angles of the triangle will be 65°. Hence, by drawing through *b* and *d* lines inclined at an angle of 65° to *d b*, the point of intersection of the lines *b m*, *d m* will give the required centre.

Or this centre might be determined by calculation; but those who are in a position to employ this method will not require further details than those above given.

The angle is verified by a protractor fitted with an index and centre pin, or on a wheel-cutting engine. If any error is detected, it is corrected by moving the centre towards or from the point *a*, and a fine hole is then drilled at *m* on the drilling tool.

From this centre draw the circumference of the roller. It should be at such a distance from the points *d* and *b* as to allow of the necessary play and secure the proper action of the wheel and roller.

Draw the circumference of the unlocking roller; its diameter is between a quarter and a half of that of the impulse roller, varying according to the size the balance-staff is required to be.

867.—The most delicate operation in the entire tracing of the calliper is the determination of the centre of the locking stone.

We know that this locking should occur a little in advance of the tangential position (**826**). In order to satisfy this condition draw *a s* inclined to *a c i* at an angle of a few degrees; through this line *a s* draw, from the point of contact of the tooth *c*, a perpendicular *c r*, which fixes the direction of the body of the detent.

Draw through the point of contact *c* another line *c t* forming an angle of about 12° or 15° with *a s*, and the centre of the cylindrical face of the locking stone will lie on *c t*; it must be remembered that the pitching (generally amounting to from one-quarter to one-third the diameter of the stone) should not be more than is absolutely necessary to render the several actions certain (**829**).

Drill a hole to indicate the position of the locking stone, increasing its diameter as required; it is then easy, by examining the finely drawn lines with a powerful eyeglass, to make sure that the hole is properly located.

Drill the hole for the detent foot screw, and draw a line to indicate the direction of the unlocking spring, etc.

When the calliper has been completed in the manner explained, a well-proportioned escapement must be made, using it as a guide; the maker ascertains that the parts are properly proportioned by causing them to work together when placed in position on the calliper.

868.—*Remark.*—The wheel-cutting engine is the most accurate instrument for the measurement of angles, but in its absence the circumference of the wheel may be traced on the plate of the calliper and then, placing the wheel itself on the plate, mark with very great care the points of three successive teeth by fine dots. The calliper must then be completed by means of a well-made ruler and compass. The accuracy of the drawing will be increased by making it on a plate of considerable surface so that all the lines can be prolonged; the chances of error will of course diminish as the divergence of lines becomes greater.

PRACTICAL DETAILS.

869.—We shall be brief under this heading, confining ourselves to such points as are peculiar to the detent escapement. For any watchmaker that undertakes to make it must be assumed to possess sufficient practical knowledge, and to have already had experience in other forms of escapement. The manipulative details are in great part identical with those already given so fully either in the preceding chapter or in our discussions of the duplex and lever escapements, to which the reader is referred.

The Escape-Wheel.

870.—The wheel is made of well-hammered brass or of an alloy of gold, silver, and copper. It is hardened by a suitable annealing. It is cut with a circular cutter or, more frequently, a single rotating or hooked cutter as in the case of duplex or lever escape-wheels. Fig. 16, plate X., shows, in section, the forms of the two cutters; one of these is used to cut out the spaces and to form the front faces of the teeth, and the other to make the back of the required shape.

The tooth must not terminate in a sharp angle but in a small rounded surface. (See the articles on the duplex and lever escape-wheels.)

Most makers are content to gently rub the points of the teeth with a piece of oiled wood, after the escape-wheel has been set in position in the chronometer.

To make a spring detent.

871.—The most difficult case that can present itself is the replacing of a broken detent. For then its position is rigorously determined.

On a finely smoothed plate mark all the centres of movement with very great care; also the holes for steady-pins, screws, etc.: then draw the several lines (if possible on the wheel-cutting engine) including the direction of the detent. Enlarge with care the escape-wheel hole until its pinion enters the hole, where it must turn truly and with gentle friction.

If the pinion is at a distance from the wheel, turn (on the mandril) a hollow in the plate, which the wheel just enters, being held by the slight contact of the teeth.

Having now set the wheel in its position on this calliper, adjust the roller on it with a staff or arbor passing without play through the enlarged hole corresponding to the balance. It then becomes easy to verify and, if needful, to correct the position of the locking stone (**867**).

872.—Very great care and prudence are essential in the selecting and working of the steel of which the detent is made, for otherwise there is likelihood of the expenditure of much trouble to no purpose. Square fibrous English steel, exhibiting a fine grain when fractured, close-grained and of a grey silvery shade, is most usually preferred. It must be annealed and then hammered, the blows being slight and always directed on to the face of the plate. It is then tempered to a blue shade and, after filing it up square and perfectly flat on each face, mark the several holes for the locking stone, etc., and drill them on the drilling tool; then shape the detent with a file.

The filing of the spring requires close attention lest the metal be in any way strained. The position of the detent should be varied during the operation so that the metal may be removed evenly, for the hand always has a slight tendency to lean to one side.

The spring must be no stronger than is necessary. It should be smooth and gradually increase in thickness from the foot.

The lantern spring, having an opening in the middle, is bad. The elasticity of the two sides is rarely the same; they are nearly always unequally hardened, and their centres of flexure are therefore seldom on the same axis.

873.—The hardening of a detent requires not only the most minute precautions on the part of the workman, but it is also essential that he possess considerable skill in conducting the operation, to avoid distorting or over-heating the spring. The hardening may be accomplished before the requisite thinness is attained; finishing it subsequently with an iron and oilstone dust.

Every escapement maker has his own mode of hardening, the success of which is solely dependent on skill. One of the processes enumerated in paragraph **496** may be adopted, or the following modification.

Make an oblong box in platinum foil, about 5 or 6 millimetres (0·2 ins.) in diameter and longer than the detent, closed at one end. It must be provided with a base to fix it on the charcoal and this latter should be cut away so that the box is supported by its two ends. After introducing the detent, it is raised to a red heat by directing the flame against the platinum jacket and, when the whole is heated to the required temperature, the detent is allowed to slide into oil.

Some workmen previously direct the blowpipe flame on to the surface of the oil at two or three points, and they assert that such a practice prevents any distortion of the detent. We have never tried this method and are therefore unable to speak as to its efficacy.

The detent must not be enveloped in powdered charcoal or animal black: for particles would adhere to the spring at certain points and cause those portions of the metal to receive a less degree of hardness.

874.—When the detent is finished and the auxiliary spring attached, fix a temporary locking stone of steel in position. If the whole has been carefully made it will be possible to correct any error of position by slightly varying the inclination of the locking face or its pitching with the wheel, and the adjustment should then be complete. The steel locking piece will, after all corrections have been made, be given as a model to the lapidary.

Drill holes for the steady-pins of the detent foot, after placing it so as to be maintained with sufficient force against the banking screw.

Pivots and Pivot-holes.—Balance-Spring and Balance.

875.—The details necessary on these points have been already given under the same headings in Chapter III. of the Lever Escapement. The reader must refer back to those articles and he should be competent to select for himself what is applicable to the present case.

876.—As the isochronal spring and compensation balance are absolutely necessary with this form of escapement, we refer to the chapters in the Third Part of the work that specially treat on these subjects and on Timing.

We would, however, at once mention that the position adopted by many chronometer makers for pinning in the spring, because it diminishes the risk of setting, is that which places the discharging pallet in the position shown in fig. 5, plate IX., for zero tension of the spring; so that a very slight motion of the balance will effect the unlocking.

This rule, although sufficient, is vague; and the following is more precise.

The spring should maintain the balance, when at rest, in such a position that on turning it either to the right or left, it has to describe the same arcs to permit the detent or the unlocking spring to escape.

Causes of Stoppage and Variation.

877.—The detent escapement does not admit of any second-rate workmanship. All the causes of stoppage and variation result from bad manipulation or errors in principle.

It is useless to enumerate these causes, which we have indeed already indicated. Any watchmaker of ordinary intelligence should be able to detect them; otherwise he must proceed to study the escapement from first principles before he undertakes either to make or repair it.

With regard to the faults that are inherent in this particular mechanism, such as *setting*, *tripping*, and *banking*, they have been reduced to a minimum, and need not be feared in a well made timekeeper, except when it receives a jerk during winding or if it is subjected to violent shaking, as in walking, riding, etc.; but we must again repeat that the chronometer escapement is not suitable for daily use; it should only be employed in instruments intended for scientific observations and by those that know how to take care of it.

Nevertheless we would add, in conclusion, that the chronometer maker should attach very great importance to: determining the effects of rebounding and shaking, especially sensible in the case of light detents;—the condition of the spring of the detent which may give rise to complex and unlooked for effects of flexure, according as it is directed more or less approximately to correspond with the pressure on the locking stone, as it is more or less straight, or curved crosswise in the polishing, etc.;—banking screw out of place;—the velocity with which the detent returns to this screw variable with temperature; etc., etc. In a word, all the several actions must take place *with absolute certainty*, notwithstanding any changes that may be brought about by the age of the oil and alterations of temperature.

878.—We will conclude by referring to the necessity of a perfect equipoise with the pivoted detent, made sufficiently evident by the experiments described in article **635**; we would also draw attention to the rebounding action, to which detents banked against their poise end are more especially subject when the banking screw is not exactly in its proper place. These influences have been more especially marked in pocket chronometers without fusees, and they are attributed, rightly or wrongly, to the excessive force applied to lift the detent. This conclusion has been due to the fact that, on examining the escapement against the light with a powerful eyeglass, in several cases the interval between the detent and its banking when a rebound occurs was found to be most marked with the mainspring fully wound up.

Why was Arnold's detent abandoned?

879.—In the arrangement adopted by Arnold, the pressure of the wheel against the locking stone tended to elongate the detent; in Earnshaw's, the tendency was to press it towards the foot. The latter system has been retained.

It is, nevertheless, inconvenient in that, other things being equal, it renders the steadiness of the detent less certain: the spring of Earnshaw's detent is therefore usually made somewhat thicker than in Arnold's.

But, if the plan adopted by the latter authority is preferable from this point of view, it has the grave objection of being only available with the teeth projecting from the flat of the wheel, as in those made by Arnold himself. For a given diameter such a wheel would be heavier at the circumference than a wheel with pointed teeth, and would give a less lifting angle; it would exert a greater pressure on the locking stone and this would be as objectionable as the stiffness of Earnshaw's spring; and, lastly, the wheel must be made true with the greatest possible care.

DOUBLE-WHEEL CHRONOMETER ESCAPEMENT.

880.—This escapement, shown in fig. 12, plate X., was first made by Owen Robinson, an English chronometer maker. Shortly afterwards U. Jurgensen* made it with success, and he brought it to a high state of perfection.

At first two superposed wheels were used. They underwent a similar modification to those of the duplex, and are now combined into one; triangular prismatic teeth, projecting from the flat of the great wheel, replace the small wheel.

The use of two wheels is advantageous in that it facilitates the setting of the impulse wheel in position, but their total weight was greater than that of the single wheel, which, moreover, only requires as much care as is devoted to the cutting of the best duplex wheels.

881.—As will be evident from the drawing, this escapement only differs from those already described in having a double wheel. The impulse is applied by an arm D *s* that is shorter as compared with the resting arm. The pressure on the locking stone should be sufficient to ensure the steadiness of the detent, and, if we assume this pressure to equal that of the escape-wheel in an ordinary chronometer, it necessarily follows that the lifting action in the double-wheel escapement will be more energetic than in that of ordinary construction; but it should be observed that this slightly increased pressure, which may be considered beneficial, is opposed by the inertia of a heavier wheel, absorbing a greater amount of energy.

With a 15-toothed wheel, the balance will be planted

* Urbain Jurgensen, a Danish chronometer maker, was born in 1776 and died in 1830: he associated himself with the best makers of his day, and especially Breguet. He is justly celebrated for the construction of excellent chronometers and very good astronomical clocks, and has left us a work on the exact measure of time that can even now be studied with advantage.