Jan. 26, 1932. A. MATTICOLI 1,842,975

MULTIPLYING MECHANISM FOR CALCULATING MACHINES

Filed Dec. 5, 1927 5 Sheets-Sheet 1

Fig. 1

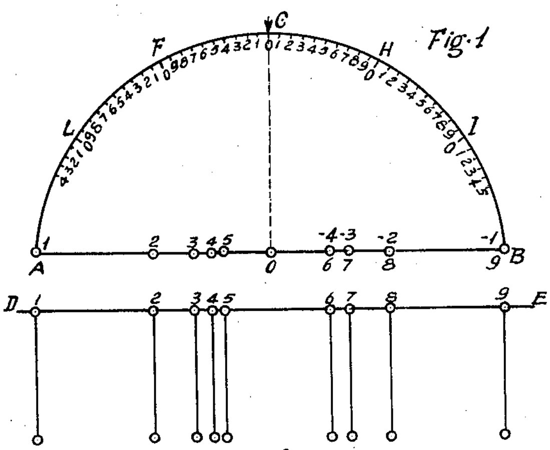


Fig. 2

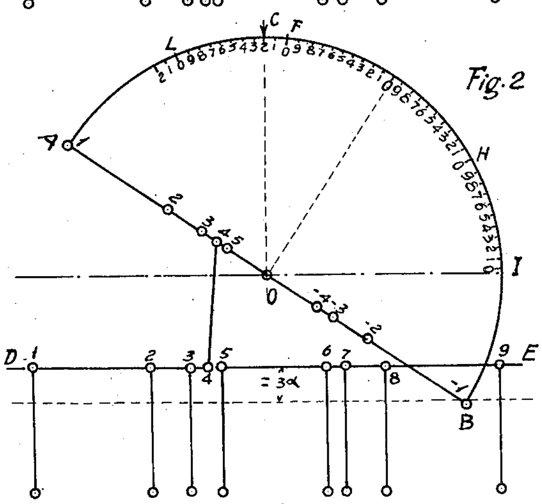


Fig. 3

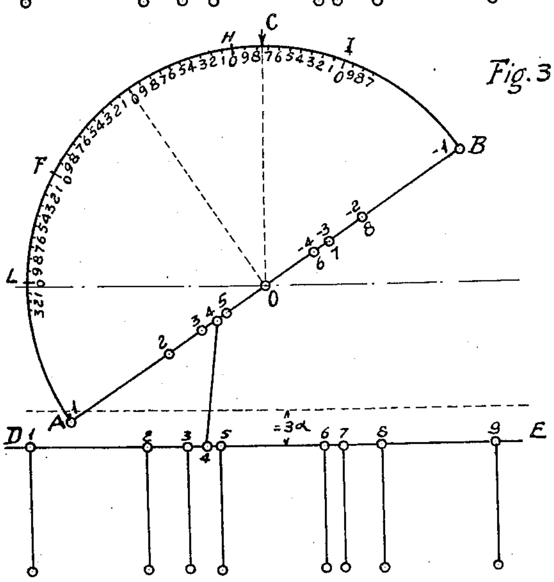


Fig. 4

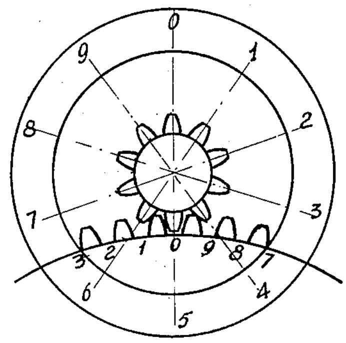
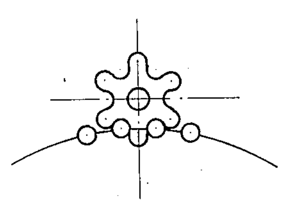


Fig. 5



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MULTIPLYING MECHANISM FOR CALCULATING MACHINES

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Fig. 6

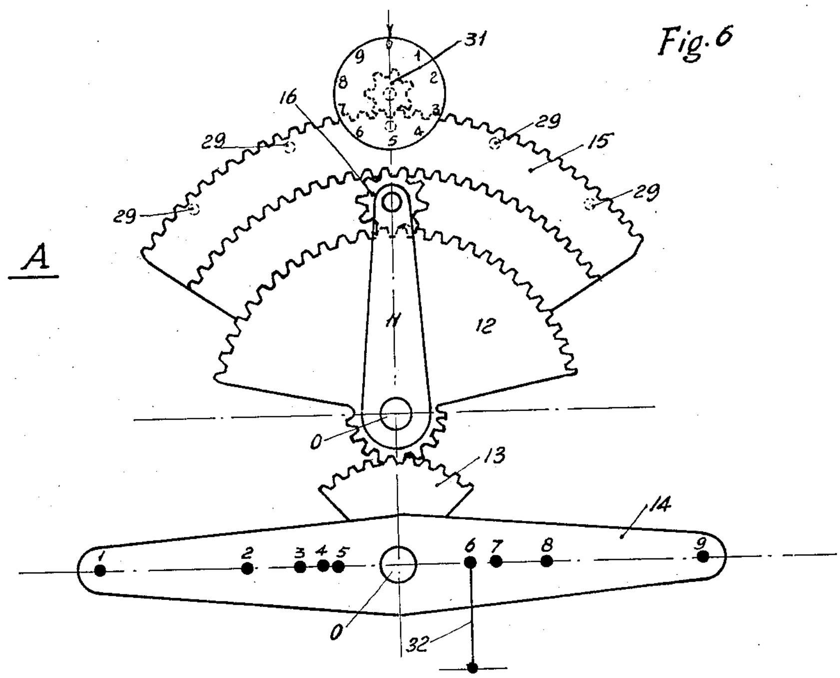
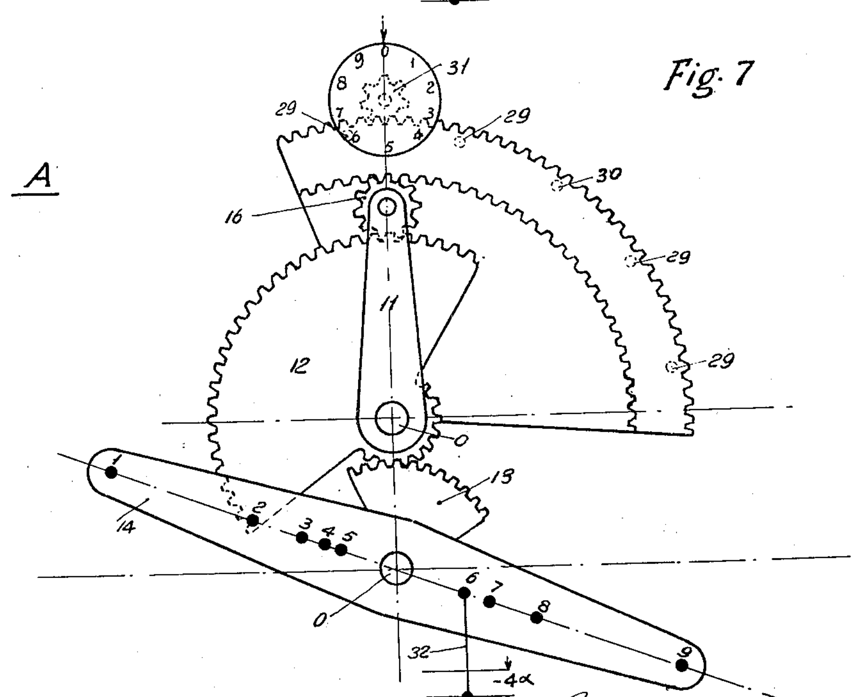


Fig. 7



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MULTIPLYING MECHANISM FOR CALCULATING MACHINES

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Fig. 8

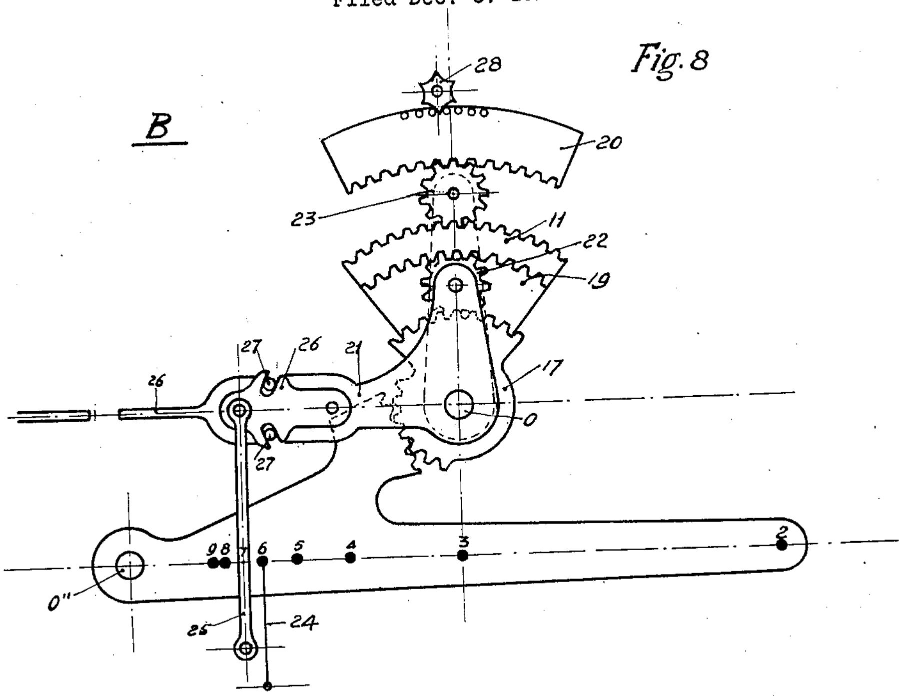
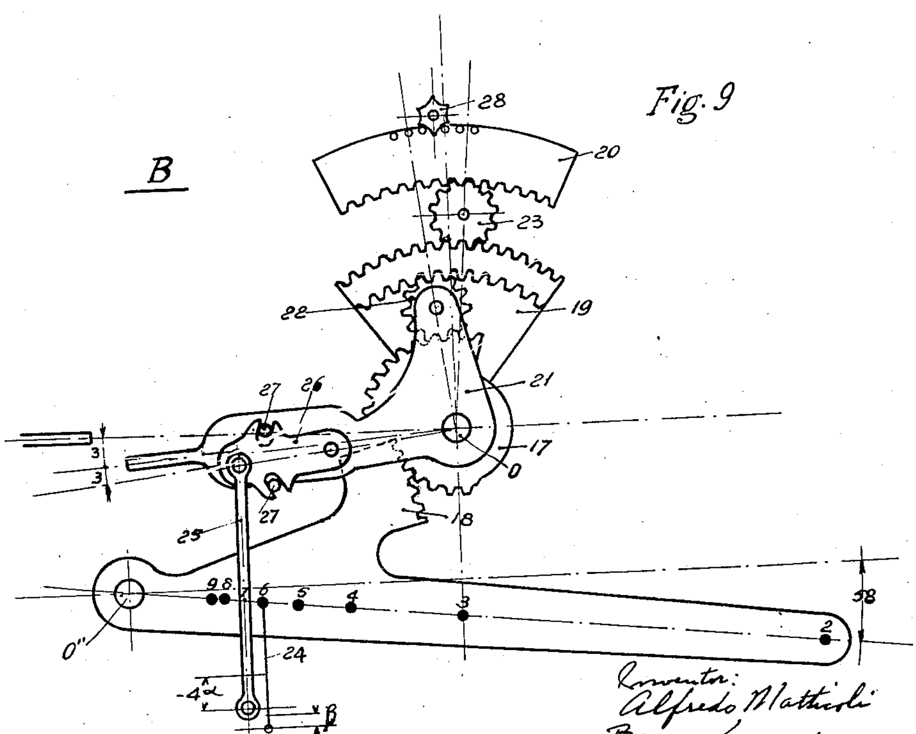


Fig. 9



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MULTIPLYING MECHANISM FOR CALCULATING MACHINES

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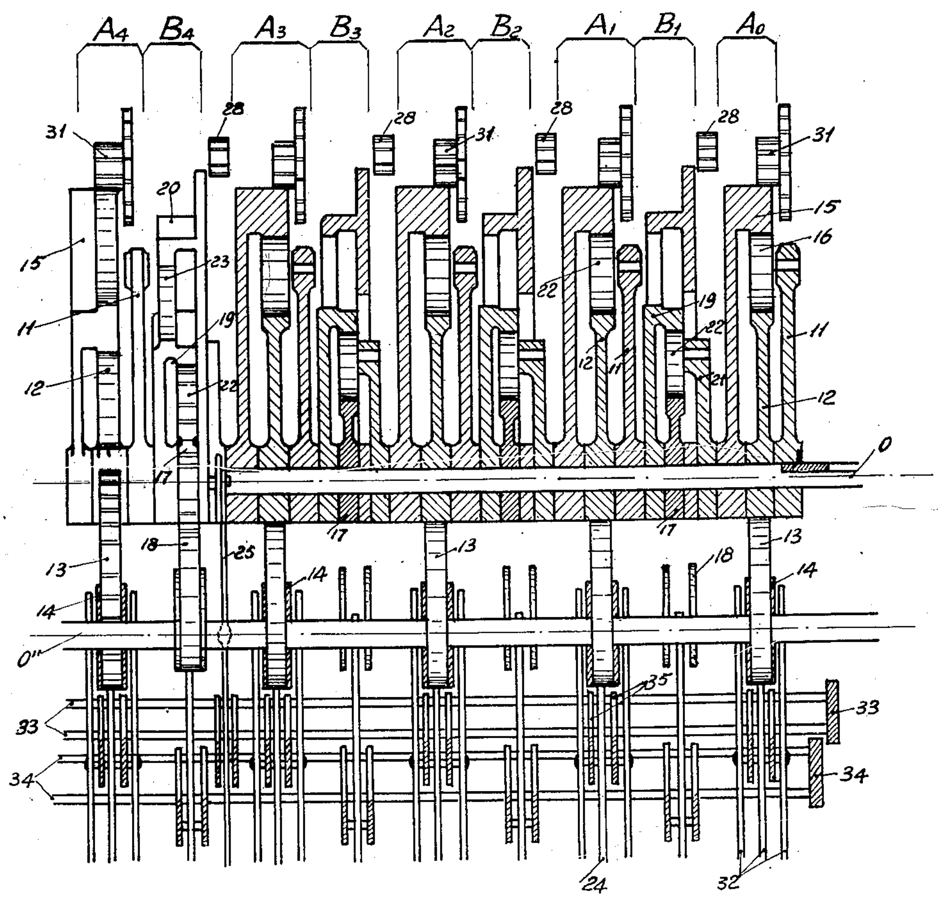
Fig. 10



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MULTIPLYING MECHANISM FOR CALCULATING MACHINES

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Fig. 12

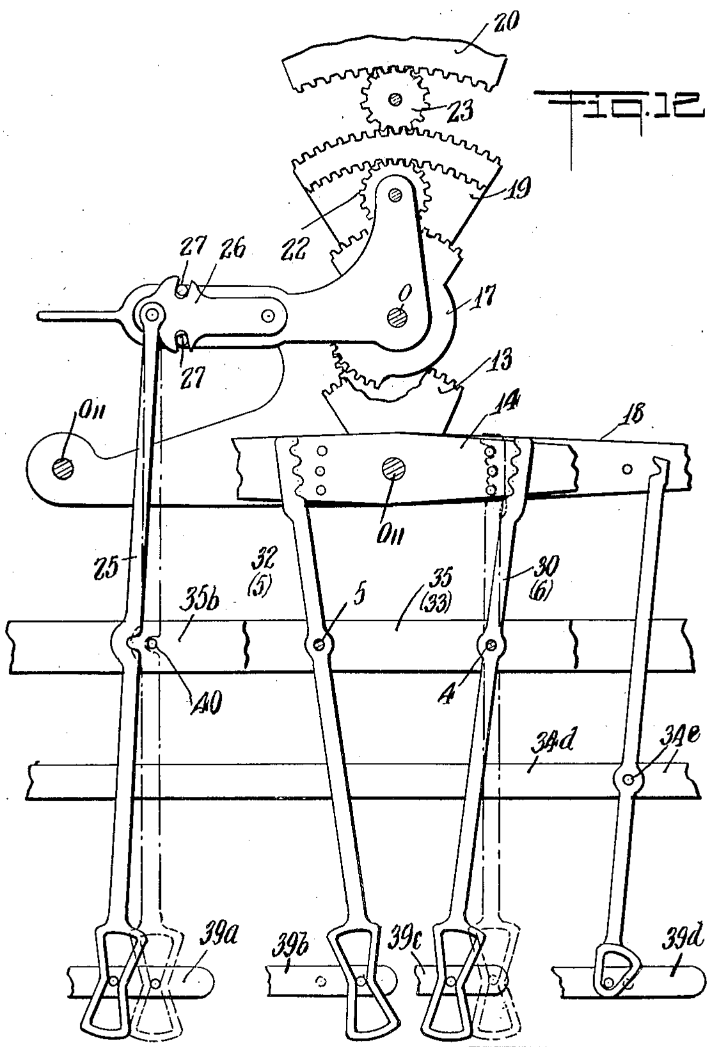
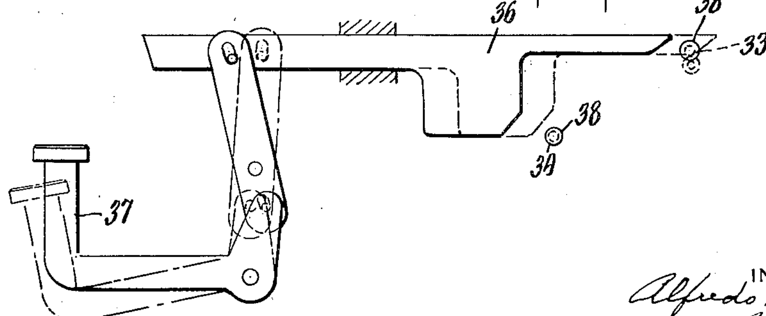


Fig. 11



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BY
ATTORNEY

Patented Jan. 26, 1932 **1,842,975**

UNITED STATES PATENT OFFICE

ALFREDO MATTICOLI, OF ROME, ITALY

MULTIPLYING MECHANISM FOR CALCULATING MACHINES

Application filed December 5, 1927, Serial No. 237,944, and in Italy December 4, 1926.

The object of the invention is multiplying mechanism for a calculating machine for carrying out multiplication of numbers by following the same process indicated by the usual arithmetical rules, with the difference that while in the mental operation, every figure of the multiplicand has to be multiplied by all the figures of the multiplier, successively, with the present machine, by lowering the key, corresponding to a multiplier figure all the figures of the multiplicand are instantaneously and contemporaneously multiplied by that multiplier figure and the final result appears on the totalizing counter.

Many types of multiplying mechanisms are known, but to accomplish the multiplication, up to the present, no better system has been found than that of summing up the whole of the multiplicand as many times as indicated by the figure of the multiplier; all such mechanisms therefore do not depart from the principle of real and true adding machines.

The present invention instead is based on a peculiar property of the multiplication table, which placed in quite a new analytical form, allows of the immediate formation of each partial product of the operation, without successive additions.

All inventors who have studied a system to get from a mechanism directly, that is to say without successive addition, the product of two factors, have started from the fundamental principle to give a point a lineal or rotary motion proportionately to the products of every two single digits.

But if mechanically the problem is easy to resolve in regard to the lengths of the lineal motions or to the angles of rotation of a lever, it raises so many difficulties when the mechanical proportional motion has to be translated into digit numerals that no such system, up to the present has apparently been successful.

The main difficulty of the question is that the product of any two single digits varies from 1 to 81 so that the elementary motion of a point cannot be given such a practical value as to secure the perfect numbering of the counting wheels. Moreover the total number of products of two single digits are 45 and only 13 are represented by numbers with one digit, and all the others have two digits, tens and units; and the carrying of the tens in a calculating machine is the most delicate device.

According to my invention the proportional movement forming the products is reduced to 25 units instead of 81 as in some prior mechanisms.

My mechanism is based on a quite new theoretical principle which is based upon the table of Pythagoras, and which comprises the substitution of the digits greater than 5 by their complement to 10 in both the multiplicand and the multiplier. This has a functional importance in the mechanism as I shall demonstrate hereinafter.

The carrying of the tens is obtained by an ordinary or usual device for the products up to 5×5 and by special means (as hereinafter described) for the products between two digits one of which is or both of which are greater than 5.

The specification which follows with the annexed drawings, in addition to illustrating further the theoretical principle on which the invention is based, gives by way of example a practical realization of a mechanism for obtaining the desired results.

In the drawings:—

Figures 1, 2 and 3 are geometrical diagrams in illustration of the theoretical working of the machine;

Figures 4, 5, 6 and 7 indicate the mechanism for the formation of the products;

Figure 8 shows further details of the mechanism specified in Figures 4 and 6;

Figure 9 illustrates mechanism for inserting the multiplicand in the machine;

Figure 10 illustrates an assemblage;

Figure 11 illustrates the particulars of the lever for the multiplying figure; and

Figure 12 illustrates the differential actuating mechanism of the mechanism of Figure 10.

If in the series of the natural numbers from 1 to 9, the numbers over 5 are substituted by their respective complement to 10 and given a negative sign, a series is obtained which has the property of being symmetrical with respect to its middle term, or the number 5.

The unit figure of the number which represents the product of any two terms of the series thus obtained is the same as that of the products of the corresponding terms of the natural series, only that, if the product in the symmetrical series is a negative number, the unit figure of this is the complement to 10 of the unit figure of the corresponding product of the natural series.

In fact, if a and b be two digits greater than 5 and r and s the respective complements to 10, one can write:—

$$a\,b=(10-r)\ (10-s)=10^2-10\ (r+s)+r\,s$$

and since in the last expression the first and second terms do not alter the units figure of the result, this is identical in both the products $a\,b$ and $r\,s$. If a is less than 5 and b more and consequently s its complement to 10 we have

$$a\,b=a(10-s)=10\ a-a\ s$$

here also the first term of the last expression does not alter the value of the units figure of the result but the product being $a\ s$ negative its units figure is the complement to 10 of that of the product $a\,b$.

If keeping count only of the units figure of the products, the multiplication table is written, adopting the proposed notation, the following is obtained:—

					−				
	1	2	3	4	5	−4	−3	−2	−1
1	1	2	3	4	5	−4	−3	−2	−1
2	2	4	6	8	0	−8	−6	−4	−2
3	3	6	9	2	5	−2	−9	−6	−3
4	4	8	2	6	0	−6	−2	−8	−4
−5	−5	−0	−5	−0	−5	−0	−5	−0	−5 +
−4	−4	−8	−2	−6	0	6	2	8	4
−3	−3	−6	−9	−2	5	2	9	6	3
−2	−2	−4	−6	−8	0	8	6	4	2
−1	−1	−2	−3	−4	5	4	3	2	1
					+				

If the two orthogonal lines are marked according to the line and the column of 5, the mechanical property of the scheme results clearly. The four quadrants are perfectly symmetrical and positive or negative according to the direction of the rotation of each axis of origin.

A O B C A (Figure 1) is a graduated sector pivoted at O. The extremities of the diameter AB are also marked 1 (at A) and −1 or 9 (at B). The other points of the series 2, 3, 4 . . . −3, −2 are marked on the diameter at a distance from the centre determined according to the reciprocal of every term, thus the 2 at a distance 1/2, the 3 at 1/3, the 4 at 1/4, the 5 at 1/5, the −4 or 6 at 1/4 beyond the centre of rotation 0, the −3 or 7 at 1/3, the −2 or 8 at 1/2. The circumference is divided into a suitable number of parts, the perpendicular CO registering zero and the circumferential divisions corresponding to the series of the natural numbers from 0 to 9 consecutively as shown in the drawing. The indicating pointer C is outside the segment and is therefore stationary.

If you consider clockwise rotation of the segment around 0 as positive and anti-clockwise as negative, it will be seen that by turning the segment in the negative sense by one or two divisions the pointer C passes over the numbers 9, 8, 7 . . . which correspond with the series −1, −2, −3 etc. Therefore with this numeration of the divisions on the segment the real number is always indicated whether the rotation be positive or negative, and not the complement to 10 or negative numbers.

Suppose there is under the segment A O B C A a rigid rod DE with connecting links 1, 2, 3, 4, . . . jointed on to the rod at points corresponding to the points 1, 2, 3, 4, . . . of the diameter AB, and which can be connected singly to the segment to form a connection between two homonymous points. Suppose now the rod be mounted to move only vertically upwards or downwards, considering the first sense of the movement positive and consequently the second negative. Supposing further the rod be moved by one of nine levers (not shown on the figure) and which lever when lowered displaces the rod through a number of unit spaces α corresponding to one of the digits 1 to 5 upwardly (positive sense) or downwardly (negative sense). The unitary spaces are of course such that when connection is made between the segment and the rod by one of the connecting links 1 or 9 (at points 1 or −1) one unit displacement α of the rod causes an elementary rotation of the segment through an angle ϵ equal to one interval of its graduations. It is to be observed that in this mechanical arrangement the diameter AB of the segment represents the points 1, 2, 3, 4, . . . −2, −1 of the abscissa of the table of the products given above (multiplicand), the rod DE by its displacement represents the points of the ordinate (multiplier) and finally the graduation of the segment represents all the numbers of the product.

Supposing that now the product of 4×3 is to be found:—You fix the connection 4 between the segment and the rod and lower the lever corresponding with 3. This displaces the rod as has been said three spaces α upwards (Figure 2) and since the degree of rotation determined by the point 4 is four times that of point 1, supposing for the moment the arcs are proportional to the chords, it is clear that the segment will rotate through twelve divisions of its graduation and will bring the number 2, after the first zero on the left, under the pointer C.

Supposing the product of 4×7 is to be

found:—The connection 4 is already fixed, you have only to lower the lever of the 7 which displaces the rod three spaces downwards (Figure 3) and the segment will rotate in a contrary sense to the preceding, but through twelve divisions bringing the number 8 after the first zero on the right under the pointer C. Every possible case can be done, and this determines that with a maximum rotation of 25 divisions the units figure of all the products of the 9 digits taken two by two can be found.

The tens figures of the products are obtained according to the following rules comprising four cases in all, rules in which a represents the real figure of the multiplicand and consequently is always positive, and b the spaces through which the multiplier bar rises or descends and which therefore can be either positive or negative:—

same, and in the first case (multiplicand and multiplier greater than 5), there is a simpler formation when the complement of 10 negative is adopted for the tens figure, as for the determination of the units figure; in fact the tens figure of the product is equal to the algebraical sum of the two negative factors above mentioned providing the rotation of the segment is less than ten divisions of the numeration; thus, for example the tens figure of the product 8×9 is $-2-1=-3$ or 7; but that of the product 7×6 is $-3-4+1=-6$ or 4 etc.; but for reasons which will be understood hereafter it is preferable to take the tens figure always positive and consequently represented by the real number.

The 2nd and the 3rd cases can be reduced to one only as a and b are interchangeable; but also here the multiplicand a is made always positive, because expressed by the

1st case—multiplicand > 5 Tens $=(a-1)-(b-1)$	Multiplier > 5, (b negative) if in the positive rotation of the segment, the zero at F does not arrive under the pointer C.
2nd case—multiplicand = or < 5 Tens $=(a-1)$	Multiplier > 5 if in the negative rotation of the segment the zero H although arriving under the pointer C does not pass it.
3rd case—multiplicand > 5 Tens $=(b-1)$	Multiplier = or < 5, (b positive) if in the negative rotation of the segment the zero H although arriving under the pointer C does not pass it.
4th case—multiplicand = or < 5	Multiplier = or < 5:

The tens figure is unity if the zero F arrives under the pointer C or passes it; it is equal to 2 if the zero L reaches the pointer; it is nil, that is to say, the product consists of one single figure if no zero reaches the pointer. The digit 5 can be indifferently taken either positive or negative, but it has been considered positive for both multiplicand and multiplier.

From an analysis of these formulæ it is evident that:

If the multiplicand digit is greater than 5, that is to say a negative one, (1st and 3rd cases) the tens formula has a term in b which is negative if the multiplier is also negative (1st case) and positive if the multiplier is positive (3rd case). Mechanically it means that by introducing in the compound-mechanisms, a multiplicand digit greater than 5, that is to say, a negative digit, a feeding-in element has to be bound to the multiplier organ so as to subtract or add as many tens units as unitary spaces less one it moves in negative or positive sense.

If on the contrary, the multiplier digit is greater than 5, that is to say a negative one (1st and 2nd cases) the tens formula has the term in a which is always positive. Mechanically it means that to the negative movement of the multiplier organ a positive movement of a feeding-in element in the compound mechanism has to be associated to add as many tens units as the real multiplicand digit indicates less one.

It is to be noted that in effect there are only 3 cases, as cases 2 and 3 are substantially the

real number, and distinguished from the direction of movement of the multiplier which is positive or negative. It will thus be seen that there is a reason for placing the expressions in that form which is rather artificial algebraically, but which gives a more pleasing solution from the mechanical point of view.

In the positive rotation of the segment, as soon as a zero reaches the pointer, one ten has to be carried over to the next numeral wheel, while in its negative rotation it is not sufficient for the zero to reach the pointer but it has to pass it to subtract one ten from the value in the next numeral wheel. As in all counting-wheel systems, the device for carrying over the tens has to be placed between the zero and the 9 of every counting-wheel so in the present system such a device has to be placed between 9 and the central zero C. Of all the transfer devices of the segment only those at F, L, H, I act in the formation of the figure of the tens of the product as the one under the pointer C has no influence in the carrying over of tens for the working out of the product of two single numbers.

In the product of a number of several digits (multiplicand) by a single digit multiplier, it is necessary to sum up the tens figures of each single product with that of the units of the product with the successive figure on the left of the multiplicand. The tens figure of the products with the rules adopted is always ultimately positive while the units figure may be positive or negative. Supposing that one has worked out all the products of all the digits of a number (multiplicand) by a one digit multiplier, and that one has written the units figure (always in the new notation) of each single product in a column with the tens figure of the preceding product in the corresponding place:—

If in the same column the units figure is positive and summed up with that of the tens, and also positive, it gives as result a number equal to or higher than ten, it is clear that a unit must be added in the successive column on the left.

If the units figure is negative, summed with that of the tens, as said also positive, three cases may present themselves:—

1. The result is negative—it is clear that the absolute value of the real figure which it represents is less than ten;

2. The result is zero—

3. The result is positive—

In these last two cases the result is either equal to 10 or it is higher than 10; in fact the negative units figure represents the complement to 10 of the real figure, and therefore the sum of the terms in the column calling $-c$ the units figure and d that of the tens, is in effect $(10-c)+d$ and if the algebraical sum $-c+d=0$ it is clear that the real sum to follow that determining the units figure of the product, thus avoiding two contemporaneous movements of the segment ending either in a nullity of the movement or in a movement of mere positive rotation.

Thus by arranging the mechanism suchwise that the transfer device at the middle zero C acts only during positive rotation of the segment, that is, adding one unit to the value in the successive column on the left, and this only after a negative rotation which brings the zero at C on to the left of C without actuating the tens device succeeded by a positive rotation causing the zero to pass C again, one unit is added to the value in the next column when the unit digit is negative and the result of the sum is nil or positive. By mounting the transfer pin at C on a movable pivot a mechanical realization of this function is readily obtained.

We end this theoretical exposition with an example of multiplication in which the units figures of the single product are all placed on the first line, and in the succeeding lines, the respective tens figures derived by employing the rules given, and which for the convenience of checking, are written separately product by product:—

	4	6	2	8	3	9	
						6	9×6 Figs. tens=(9−1)−(4−1)=8−3
	−6	+6	−8	+8	−2	+4	3×6 Figs. tens=(3−1)−1 =2−1
+3	+5	+1	+7	+2	+8		8×6 Figs. tens=(8−1)−(4−1)=7−3
−1	−3		−3	−1	−3		2×6 Figs. tens=(2−1) =1
	+1		+1	+1			6×6 Figs. tens=(6−1)−(4−1)+1=5−3+1
2	−3	+7	−3	0	+3	+4	4×6 Figs. tens=(4−1)−1 =3−1

of the column is 10; if instead the algebraical sum $-c+d=p$ and this is a positive quantity, substituting it in the first expression, we find that the sum is really $10+p$. It follows that if the algebraical sum of the column is nil or positive when the units figure is negative, the successive column on the left must be increased by one unit.

Being able to work out, with addition or subtraction of angles, the algebraical sum, in every column, on the segment which determines the units figure of the elementary product corresponding to that column, it is clear that in the case of a positive units figure, and of a result greater than 10, an addition to the units in the adjacent column on the left must take place as for ±1 according to the tens figure of the product, that is to say upon the arrival or passage of the zeros F, L under the pointer C; but for the two cases in which the units figure is negative, having results nil or positive in the sum, it can be understood that a negative rotation of the segment must coincide with a positive rotation of the same to make the zero at C remain under the pointer or to displace it in the positive direction. To effect this adding of a unit to the left-hand column the tens figure of the product is always kept positive and the movement for its formation is made

the two units underlined, one in the third, the other in the fourth column, are those resulting from the transfer to the column due to the algebraical result of the sum, which in the second column, gives a positive number, while the units figure is negative, and in the third column, in which the units figure is positive, the result of the sum is equal to 10.

By substituting in the final result the real figures for the negative numbers we have the number 2 7 7 7 0 3 4 which is exactly the product of 462839×6.

All these operations, with the simple lowering of the multiplier key of Figure 6, after having set up with the respective keys, all the digits of the multiplicand, are accomplished with mathematical accuracy by the mechanism which I now describe.

The groups $A_0, A_1, B_1, A_2, B_2, \ldots$ (Figure 10) represent the numeration columns and excepting the first group A_0 on the right formed by one single system, they are composed of two systems of epicyclic gearings A and B (Figures 6 and 8) connected by a common lever 11; in the first group A_0 the lever 11 is joined to the fixed parts of the machine.

System A (Figure 6) is composed of a differential sector 12 having two sectors of which one sector (that of minor radius) gears with a sector 13 which is integral with a lever 14 on which are situated, on the left and right of the fulcrum O′ (centre of rotation of the sector 13), the pivots 1, 2, 3, . . . as on the diameter AB of the segment of Figure 1. The other sector of greater radius is connected with a sector 15 by means of a satellite 16 carried by the lever 11.

System B (Figure 8) is composed of a differential sector 17 having two sectors one of which is geared, like that of system A, to a sector integral with a lever 18; of an intermediate sector 19; of an external sector 20; of a bell-crank lever 21, which supports the connecting satellite 22 between 19 and 17, and the lever 11 of system A which carries a satellite 23, which is on the same axle but on the opposite side to 16 and serves as connection between the sectors 20 and 19.

On the lever 18 are to be found the pivots 2, 3, 4, . . . 8, 9 the distances of which from the centre of rotation O″, unity being the distance between O″ and 2, are such that that of pivots 3 is 1/2, that of pivot 4 is 1/3, that of pivot 5 is 1/4, . . . that of pivot 9 is 1/8, so that the connecting rod 24 joined successively to each of the pivots, and moving vertically through a small distance β constant for every pivot forces the lever 18 to turn through angles varying according to the pivot chosen; thus, if applied, to pivot 2, to turn through an angle β; if to 3 an angle 2β; if to 4 an angle 3β; . . . and if to 9 an angle 8β.

System B effects the mechanical working out of the rule given for the formation of the tens figure of the product (which figure is of course absent when the multiplicand figure is unity); now the first term of the rule for the 1st and 2nd cases is $(a-1)$ always positive, therefore the rotation of the lever 18 is only positive and on it the numbers of the series less 1 are marked; and the ratios of rotation

$$\frac{1}{a-1}$$

are consequently

$$\frac{1}{2-1}=1 \text{ for the 2,}$$
$$\frac{1}{3-1}=\frac{1}{2} \text{ for the 3,}$$
$$\frac{1}{4-1}=\frac{1}{3} \text{ for the 4,}$$
$$\frac{1}{9-1}=\frac{1}{8} \text{ for the 9.}$$

It is known that the proportion of the angles cannot be strictly exact, however, small β may be, if the points of lever 18 were perfectly in the ratio indicated, the arcs not being in proportion to the chords, but it is easily understood that in the present case, by arranging the points suitably, the ratios of the rotations can be obtained just as desired according to the points of application of the connecting rod.

The horizontal arm of the bell-crank lever 21 has pivoted to it a small plate 26 which is joined to the upper end of a connecting rod 25. The small plate 26 which in the normal position has its axis on the axis of the horizontal arm of the lever 21, when forced by the connecting rod 25, must, before transmitting movement to the lever 21, rotate about its own pivot, in one sense or the other, through a certain angle $\pm\omega$ the limits of which are defined by pins 27 fixed on the lever 21, and corresponding to one space α.

In the normal position of the lever 21 the arm on which is pivoted the small plate 26 is connected to the fixed parts of the machine by springs or like elastic elements which oppose its rotation in either direction so that it remains stationary until an external force, by means of the connecting rod 25 and the small plate 26 arrested by one of the pins 27, obliges it to rotate about its pivot.

As can be observed, the operation of the lever 21 serves to give the term $\pm(b-1)$ of the rules for the tens of the product, a term which in the first two cases is negative, and it will be seen that the rotation of 21 in this case is also negative, while in the 3rd and 4th cases it is positive and consequently also the rotation of 21 must be positive.

The external sector 20 (Figures 5 and 8) gears with a star shaped pinion 28 mounted on a fixed part of the machine, by means of pins, in order to make the sector itself rotate by one pin pitch to the right or the left according to the sense of rotation of the annular sector 15 of the preceding group and upon the passing over of one of the pins 29 situated on it, the angle at the centre of the sector determined by these pins 29 being the angle corresponding to 10 pins of the annular sector 20. The star shaped pinion 28 by means of spring pawls or the like, from which the said sector 15 disengages it on the passage of the pin 29 (mechanism which for simplicity and because such is well known is omitted from the drawings but an example thereof is to be found in the specification and drawings of United States Patent No. 996,523), prevents rotation of the sector 20 unless this is provoked in the way mentioned, by the pin of the sector 15 of the preceding group.

As is referred to hereinbefore where ± 1 is mentioned in the formation of the ten of the product, the pivot of the pinion 28 is situated on the bisectrix of the angle ϵ determined by the two adjacent pins of sector 20 one which is on the centre vertical line of the sector 20 and the other next following on the left, seeing that clockwise rotation of the sector has been taken as positive. The sector 15 (Figures 4 and 6) has also external teeth the pitch of which determines at 0 the same angle ϵ as between two consecutive pins of the sector 20, teeth which mesh with the pinion 31 having 10 cogs and which can be disengaged from sector 15 and engaged either directly, or by means of ordinarily interposed gearing with the wheels of an accumulator in order to transfer thereto the number represented by its degree of rotation resulting from the rotation forced upon it by that of the sector 15 to which it is geared.

The pins 29 of the sector 15 are rigid and transmit an intermittent movement to the star shaped pinion 28 both in a positive and negative direction, while the pin 30 situated on the bisectrix of the sector 15, is yieldable and has the same function as a one-way catch so that on encountering the star shaped pinion 28 during negative rotation of the sector it yields, while upon positive rotation of the same it makes it rotate by one cog, namely, it works the pinion 28 by making it rotate one cog only when passing from left to right of it, while it leaves it motionless when passing from right to left.

The levers 14, 18 and 21, and, intermittently the external sector 20, are the feeding-in elements, while the sector 15 is the sole receiving element of each group of compounded epicyclic gearing A B.

The radii of the circumferences of the gearing and the extent of rotation of the levers 21 determined by the pivot to which the connecting rod 25 of the small plate, 26 is joined, are calculated in a way so that on one elementary angle of rotation ω of the lever 21, and elementary rotation ϵ of the sector 15 follows, exactly as for an elementary rotation α of lever 14 or an elementary rotation β of the lever 18; angle ϵ corresponds to the rotation by one cog of the external gearing of the sector 15 and consequently to the rotation through 1/10 of the circumference of the pinion 31.

Making, as has been said, clockwise rotation positive and anti-clockwise negative, it can be verified that on the positive or negative rotation of the feeding-in elements 14, 18, 21, 20 there corresponds a positive or negative rotation of the receiving element 15.

The setting-up of the digits of the multiplicand is accomplished by joining the feeding-in elements of the systems to the connecting rods 32, 24, 25 joined to the two movable frames 33, 34 (Figure 10) common to all the systems; and this is repeated for every digit of the number to be set-up, uniting the frame 33, by means of the relative connecting rod 32, to the corresponding pivot of lever 14 of system A, and frame 34, by means of the corresponding connecting rod 24, to the corresponding pivot of lever 18 of system B of the successive group AB on the left. For example, the first digit on the right of the number is set-up by determining the couplings peculiar to the digit between the frame 33 and lever 14 of system A_0 and between the frame 34 and the lever 18 of system B_1 of the group A_1B_1; the second digit is set-up by determining the junctions peculiar to this between 33 and 14 of A_1 and between 34 and 28 of B_2 of the group A_2B_2 and so forth. Only if the digit is over 5 there must be in addition to the two connections of the connecting rods 32 and 24 the linking up of the connecting rod 25 with the frame 33 which is thus joined to the lever 21 of the system B on the left of the group to which column the digit belongs.

Supposing that the system A of Figure 6 represents the particulars of system A_0 and system B of Figure 8 that of system B_1 of group A_1B_1 (Figure 10) and supposing there has been inserted into the machine the number 6; the connecting link 32 joined to the frame 33 is fastened to the pivot 6 of the lever 14 of the system A_0, and the connecting link 25 of system B_1, 6 being greater than 5, is also fastened to the frame 33, while the connecting link 24 connected to the frame 34 is fastened to the pivot 6 of lever 18 of system B_1.

Suppose that the figure of the multiplier is also 6, then lowering the "6" key 37 of the multiplier lever (Figure 11) determines the lowering of the frame 33 (corresponding to the rigid rod DE of Figure 1) through four elementary spaces α, and during the motion of 33 but only after this has passed through the first space α it determines the lowering of the frame 34 for the space β so that at the end of the movement the two frames 33 and 34 have been displaced vertically downwards amounts corresponding to 4 α and β (Figure 9). The connecting link 32 has also forced the lever 14 of system A to rotate in a positive sense; through an angle corresponding to 16 divisions. The connecting link 25 has also been lowered with 33 through a space 4α and has forced the lever 21 of system B_1 to rotate in a negative sense, through an angle 3ω, for the movement through one angle ω affects only the small plate 26, and the connecting link 24 has forced the lever 18 of the same system B_1 to rotate through an angle 5β because, as has been explained the degree of rotation of the pivot 6 of 18 is 5 times that given by the pivot 2 if connected and moved through the space β.

Since in the system A_0 (Figure 10) the lever 11 is rigidly connected to the fixed part or frame of the machine, and is therefore motionless, the positive rotation of the lever 14 causes by the gearing connection (sectors 13 and 12, pinion 16) a positive rotation of sector 15 through 16 divisions which makes the numeral disc 31 turn through one complete revolution plus 6/10 of a revolution to display the number 6. The pin 29 passing under the star shaped pinion 28 determines rotation of the sector 20 in a positive sense in system B_1 through one angle.

For the investigation of the movement resulting in system A_1B_1 it is to be remembered that in any system however joined, the movements are compounded as if each movement could take place separately. Imagining all the other conducting elements of the system motionless, by rotation through a positive angle of the sector 20 the satellite 23 is forced to roll in the positive sense on sector 19 (Figure 9) which satellite transporting the lever 11 makes also satellite 16 roll over the sector 12 of system A_1 forcing the sector 15 to rotate positively through one angle ϵ so that the disc 31 joined to it accomplishes 1/10 of a revolution in the contrary sense and displays number 1.

Now considering the rotation of lever 21 and imagining all the other conducting elements of the system motionless, this rotates in a negative sense, as has been seen, through an angle 3ω and causes the satellite 22 to roll over the part of sector 17 with which it cogs imparting a negative rotation to the sector 19 which forces the satellite 23 to roll internally on the sector 20, motionless, moving in a negative sense the lever 11, which in its turn by causing satellite 16 to roll over the sector 12, also motionless, imparts to the sector 15 a negative rotation through an angle 3ϵ which causes the disc 31 to rotate in a contrary sense 3/10 of a revolution so that it displays the number 8.

Finally the lever 18, imagining 20, 21, 14 motionless, rotates in a positive sense through an angle 5β forcing the sector 17 to turn in a negative sense which by means of the satellite 22, joined to lever 21, motionless, rotates in a positive sense the sector 19 which in its turn causes the satellite 23 to roll inside the sector 20 moving in a positive sense the lever 11 which by means of the satellite 16 forced to roll over sector 12, motionless, makes the sector 15 rotate in a positive sense through an angle 5ϵ to which responds a contrary rotation by 5/10 of a revolution of the disc 31, which displays ultimately the number 3. Thus while the disc 31 of A_0 displays the figure 6, the disc 31 of A_1 displays the figure 3 which together form the number 36 the product of 6×6.

If a second figure (for example 2 in the tens column) had been set-up the feeding-in elements of systems A_1 and B_2 are set correspondingly about the same frames 33 and 34 which ties the connecting link 32 of 33 to the pivot 2 (in the example given) of lever 14 of the system A_1 and the connecting link 24 of 34 to pivot 2 of the lever 18 of system B_2. The frame 33 by being lowered a distance of 4α causes the lever 14 of the system A_1 (placed adjacent to system B_1 in which the ten of the precedent product has been formed) to rotate negatively through an angle of 8 divisions to which there corresponds a negative rotation (considering the lever 11 of the system motionless) of the sector 15 of A_1 through an angle of 8 divisions and the disc 31 (which displayed the number 3) rotating in a contrary sense 8/10 of a revolution would display the figure 5, while the frame 34, by being lowered through the space β causes to rotate in a positive sense the lever 18 of system B_2 through an elementary angle β to which correspond a positive rotation of the receiving element 15 of the group A_2B_2 through an elementary angle ϵ determining a contrary rotation of 1/10 of a revolution of the corresponding disc 31, which will thus display the digit 1.

The three discs 31 of groups A_2B_2, A_1B_1 will then display the digits 1 5 6 which form the number representing the product of 26×6.

This is how the compound systems AB, bound by the frames 33 and 34, determine the simultaneous formation of all the single products of the digits of the multiplicand inserted in the machine by a single digit multiplier and at the same time work out the algebraical sum of the units figure of each product with the tens figure of the preceding product, by means of the compounding of positive and negative rotations of the feeding-in elements of the mechanism.

Supposing a multi-digit multiplicand is to be inserted in the machine. It happens that, in one or more (according to the digits of the inserted number) of the compound systems AB all the feeding-in elements 14, 21 and 18 are locked to the frames 33 and 34. Supposing now that the above multi-digit multiplicand is to be multiplied by a negative digit, then both the frames 33 and 34 have to be displaced. Supposing again that by means of lever 14, in some of the systems AB the corresponding sector 15 had to rotate in negative sense whilst by means of levers 21 and 18 it had to rotate in positive sense, the compound movements on the receiving element 15 can be negative, nil or positive.

Example: $392919\times7=2750433$

	3	−1	2	−1	1	−1 −3	
	$A_5\,B_5$	$A_4\,B_4$	$A_3\,B_3$	$A_2\,B_2$	$A_1\,B_1$	A_0	
	−9	3	−6	3	−3	3	
2	8	1	8	0	8		+(a−1)
	−2		−2		−2		−(b−1)
2	−3	4	0	3	3	3	
		+1		+1			
2	7	5	0	4	3	3	Final result

In the 6th column (group A_5B_5) the algebraical sum is negative.

In the 4th column (group A_3B_3) the sum is nil,

In the 2nd column (group A_1B_1) the sum is positive.

As has been demonstrated in the theoretical discussions above, when in a column the algebraical sum is nil or positive, it has to be carried to the tens transfer.

Now if the motion of frames 33 and 34 is accomplished at the same time, the movements of the feeding-in elements 14, 21 and

18 can be counterbalanced in the group A_3B_3 so that the receiving element 15 does not move at all, or the compounding motion in group A_1B_1 can have as result a positive motion for element 15.

It is clear that in these two cases no tens transfer should occur.

To prevent this, frame 33 precedes in its movement at least by the time it takes to be displaced through one space α, the movement of frame 34, so that element 15 has to turn in negative sense bringing its yieldable pin 30 to the left of the tens transfer device 28 (without acting on it). When by the motion of frame 34 element 15 has a positive rotation with the result of the compounding movement as in the 4th and 2nd columns it comes back to its starting position or passes it in positive direction and the pin 30 is compelled to pass again to the right of the device 28 and effect the tens transfer.

The frames 33 and 34 (Figure 10) are formed of two parallel members connected to the fixed parts of the machine in such manner that the only movement allowed them is a simple rectangular movement perpendicular to their common plane which is parallel to the arms of all the levers 14, 18 and 21.

Referring now to Figure 12, frame 33 is composed of as many bars 35*a* and 35*b* as there are levers 14 and 21 in all groups AB of the machine. The bars 35*a* are situated under the levers 14 and each carries nine connecting-levers 32 set on the nine pivots corresponding to the points 1, 2, 3, 4, 5, −4, −3, −2, −1 of the respective lever 14; the bars 35*b* have the unique pivot 40 to engage the connecting-tie 25 of lever 21.

Frame 34 is positioned under frame 33 and is composed of as many bars 34*d* as there are levers 18 in all systems B of the machine; they are situated under the same levers 18 bearing the connecting-ties 24 set on the pivots 34*e* which correspond to the points 2, 3 . . . 7, 8, 9 of lever 18.

The connecting-ties 32 are toothed at one end for the purpose of engaging the corresponding pivots of lever 14 (these pivots form a sector of a spindle-gear to insure a proportional angular rotation of lever 14) and at the other end have together with connecting-tie 25 a suitable hole to allow the sliding-bars 39*b*, 39*c* and 39*a* of the keyboard system to command them for engaging and disengaging connecting-ties 32 on lever 14 or connecting-ties 25 on pivot 40 and at same time to be free from the motion of frame 33 which goes only upward and downward.

For instance: at the normal position in which all connecting-ties 32 on frame 33 are disengaged from lever 14 and connecting-tie 25 is out of pivot 40, frame 33 is free to move downward or upward carrying in its motion connecting-ties 32 without acting the keyboard sliding bars system 39*a*, 39*b* and 39*c*. The time arrives when one of the connecting-ties 32 is coupled to lever 14 and connecting-tie 25 is coupled to frame 33 as is shown in the drawings by broken lines when frame 33 is still free to move without acting on the sliding bars 39*a* and 39*c* as is the case at all times.

The connecting-ties 24 are pivoted on frame 34 and are provided at one end with a hook to engage a corresponding point on lever 18 and at the other end with a suitable hole which allows the sliding-bar 39*d* to act the connecting-ties 24 and to be free from the motion of frame 34 which goes only downward.

There is a sliding-bar 39*a* for every system B, whilst there are five sliding-bars 39*b* for the numbers (1, 2, 3, 4 and 5), and four 39*c* for the numbers (−4, −3, −2, −1) that is 6, 7, 8, 9, for every system A and the sliding-bars 39*d* are 8 in number for every system B.

The drawings show the lever 14 of a system A_n and the system B_{n+1} adjacent.

As above mentioned and shown in Figure 10, the multiplier system is formed by the groups AB in which 4 feeding-in elements give the compounding of their angular rotation to the receiving element of system A. But the insertion of the digits forming a number requires for each digit to bind to the primary movable elements the feeding-in element of the corresponding system A and the feeding-in elements of system B in the adjacent group. Schematically the insertion of a number in the machine can be represented as follows:

		1000's	100's	10's	Units
$B_{n+1}A_n$	B_n	. . . A_3	B_3A_2	B_2A_1	B_1A_0

The sliding-bars which act the connecting-ties 32 have been indicated with 39*b* from 1 to 5 and 39*c* from 6 to 9 to make easy the illustration of the insertion of a digit in the machine.

When a digit has to be inserted in the machine, one pushes down the corresponding key which acts at the same time by the respective sliding-bars 39*b* or 39*c* and 39*d* the corresponding connecting-ties 32 and 24. But if the digit is greater than 5 the key acts also, by the sliding-bar 39*a*, on the connecting-tie 25.

For instance: 3 be the digit to be inserted in the machine.

Pushing down the key 3 the corresponding sliding-bar 39*b* and 39*d* engage connecting-tie 32 at the point 3 of lever 14 and connecting-tie 24 at point 3 of lever 18.

Had now the digit 3 to be multiplied by 3: Frame 33 will be raised for 3 spaces and the corresponding numbering wheel by the rotation of lever 14 is forced to turn for 9 teeth in positive direction and signal the number 9.

If on the contrary the digit 3 be multiplied by 7: Frame 33 will be pulled down three spaces and frame 34 only one space. The corresponding numbering wheel of system A_n is forced to rotate for 9 teeth in negative direction and signals the number 1, whilst the number wheel of the adjacent system B_{n+1}, by the rotation of lever 18, is forced to rotate for two teeth (3−1) in positive direction and signals the number 2. Thus the numbering wheel system indicates the number 21, that is the product of 3×7.

Be now 7 the digit to be inserted in the machine.

The key 7 upon being pushed down acts on the corresponding connecting-tie 39*c* which engages lever 14 at the point −3 of the system A_n and couples the connecting-tie 25 of the adjacent system B_{n+1} to the bar 35*b* of frame 33; at the same time engages the corresponding connecting-tie 24 with lever 18 of the same system B_{n+1}.

If the digit 7 is to be multiplied by 3:

Only frame 33 will be raised for 3 spaces but the sector of system A_n is forced to rotate in negative direction for 9 teeth and signals the digit 1 whilst the lever 21 makes the receiving element of group A_{n+1} B_{n+1} rotate in positive direction for two teeth (3 spaces less 1) so that it signals the digit 2 giving the result 21.

When the digit 7 is multiplied by 7: frame 33 is pushed down for 3 spaces and the sector of system A_n rotates in positive direction for 9 teeth signalling the digit 9, while lever 21 makes the receiving element of group A_{n+1} B_{n+1} rotate for 2 teeth in negative direction, but also frame 34 is pushed down for one space with the result that the receiving element of group A_{n+1} B_{n+1} rotates in positive direction for 6 teeth (7−1). The compounding of the two rotations in group A_{n+1} B_{n+1}, one by lever 21 and the other one by lever 18, is that the receiving element of this group rotates for 4 teeth in positive direction giving as result the number 49.

Thus the multiplier keys of digits from 1 to 5 act only on frame 33 raising it 1, 2, 3, 4 or 5 unit spaces upward; and those of digits from 6 to 9 act on frames 33 and 34 pushing frame 33 respectively 4, 3, 2 or 1 unit spaces downward and frame 34 always 1 space β downward.

The sliding bars 36 are actuated through a system of levers by the keys 37 corresponding to the digits of the multiplier. Their path of movement is constant and their upper surface or under surface is so fashioned and stepped as to render the movement safe and with less friction. The height of the step varies according to the digit and is 1, 2, 3, 4 or 5 spaces α for the keys from 1 to 5 and 1, 2, 3 or 4 spaces for the keys from 9 to 6. The edge of the bar engages the frame 33, which is provided with a roller 38 to reduce friction, and the relative step for effecting movement of the frame 33, is the upperside for the digits 1 to 5 and the underside for the digits 6 to 9.

For the digits 9 to 6 the sliding bar 36 is of two steps so arranged that while one engages the frame 33, the other engages the frame 34 only that in this latter the step is constant for all the digits 6, 7, 8 and 9 as the frame 34 must be lowered in any case by one space β only, so that the position of the steps with respect to the movement of the bar is such that it accomplishes first, or at least it begins first the movement of the frame 33 and then that of 34. It is obvious that in the normal position the rods of the multiplier keys do not prevent the movement of the frames 33 and 34 as also the rods 36 are situated in manner to permit free movement of the two frames.

From the above it is easy to understand the working of the machine. When the multiplicand is introduced into the keyboard as in all keyboard machines, each digit determines in the mechanism corresponding to its column of numeration the coupling between the frames 33 and 34 and the feeding-in elements 14, 18, 21 of the mechanism itself if greater than 5; but between the frames 33 and 34 and the elements 14 and 18 only if equal to or less than 5. When the number established is to be multiplied by another number the corresponding multiplier key is pressed down at the first digit on the left or the right of this number and the frames 33 and 34 controlled by the sliding bar 36 provoke the angular rotation of the sectors of the whole mechanism so that the discs 31 display all the digits of the number which represents the product of the number inserted into the keyboard for that multiplying figure. This number, in known manner is transferred to the totalizer. If the operation be commenced from the first digit on the left of the multiplier, the totalizer carriage is moved by one column to the left and the multiplier key corresponding to the second digit of the number is pressed down, thus obtaining the second partial product which is to be brought onto the totalizer in which it is added automatically to the number therein contained, which number owing to the displacement of the carriage is automatically multiplied by 10. If instead the operation be commenced with the first digit on the right of the multiplier the carriage after each partial product of a column should be moved to the right and the same result is obtained.

The totalizer carriage is moved from left to right or vice-versa as the case may be by any known means, and as such carriages and mechanisms for moving them are well known in the art, it has not been deemed necessary either to describe or illustrate them in this application. Examples thereof are to be found in United States Patents 996,523 and 1,566,650.

What I claim is:

1. Multiplying mechanism for calculating machines comprising multiplicand digit keys, mechanism operated by said keys for setting up the multiplicand digits employing ordinary positive magnitudes for those digits one to five and the complement to ten negatively for those over five, a totalizing counter for indicating the product, multiplier digit keys, and multiplier mechanism employing positive and negative magnitudes for the multiplier digits similar to those of the multiplicand and connected with the multiplicand setting up digit means so that when operated by said multiplier digit keys all the figures of the multiplicand are instantaneously and simultaneously multiplied by the multiplier digit and the final result is indicated upon the totalizing counter.

2. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; mechanism operated by said multiplier digit keys for simultaneously multipling each multiplicand digit by the multiplier digit, said mechanism consisting of means for forming the unit figure of each partial product, means for carrying the tens figure of each product of the digits up to 5×5, and compounding means for compounding and feeding in the tens figure of each product of digits one of which is or both of which are greater than 5, so that the final total product appears on the totalizing counter.

3. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; a first differential sector system for each denominational order of the multiplicand which work out the units figure of the partial product for that order, a second differential sector system for each denominational order of the multiplicand which compounds and feeds in the tens figure of the partial product for that order, means for carrying forward any value from the preceding multiplicand denominational order; and means for connecting each of the sector systems with the multiplier digit key so that upon operation of said key all the multiplicand digits are simultaneously multiplied by the multiplier digit and the final total product appears on the totalizing counter.

4. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; a first differential sector system for each denominational order of the multiplicand which works out the units figure of the partial product for that order; a second differential sector system for each denominational order of the multiplicand which compounds and feeds in the tens figure of the partial product for that order; means for carrying forward any value from the preceding multiplicand denominational order; means for connecting each first sector system to the multiplier digit key comprising a centrally pivoted lever, a driving sector rigidly carried by said lever and gearing with the sector system, pins upon said lever representing the multiplicand digit values of that position and located at distances from the lever pivot on each side thereof corresponding to the reciprocal value of the digits, a vertically reciprocable frame operated by the multiplier keys, links pivotally mounted upon said frame one for each digit 1–9 adapted to be engaged with their respective pins on the aforesaid lever, means connecting each link to its respective multiplicand digit key for effecting said engagement when said keys are operated; and means for connecting each second sector system with the multiplier digit key so that upon operation of said key all the multiplicand digits are simultaneously multiplied by the multiplier digit and the final total product appears on the totalizing counter.

5. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; a first differential sector system for each denomination order of the multiplicand which works out the units figure of the partial product for that order; a second differential sector system for each denominational order of the multiplicand which compounds and feeds in the tens figure of the partial product for that order; means for carrying forward any value from the preceding multiplicand denominational order; means for connecting each of the first sector systems with the multiplier digit key; means for connecting each of the second sector systems to the multiplier digit key comprising a lever pivoted adjacent one end thereof, a driving sector carried by said lever gearing with the second sector system, pins upon said lever the distances of which from the lever fulcrum are inversely proportional to their values, a vertically reciprocable frame operated by the multiplier keys, links pivotally mounted on said frame one for each digit 1–9 adapted to be engaged with their respective pins on the aforesaid lever, and means for connecting each link to its respective multiplicand digit key for effecting said engagement when said keys are operated.

6. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; a first differential sector system for each denominational order of the multiplicand which works out the units figure of the partial product for that order and comprises a

differential sector, an internally and externally geared quadrant, a satellite connecting the internal gear of the quadrant with the larger radius sector of the differential sector, a pinion engaging the external gear of the quadrant, and an indicating disc carried by said pinion; a second differential sector system for each denominational order of the multiplicand which compounds and feeds in the tens figure of the partial product for that order; means for carrying forward any value from the preceding multiplicand denominational order; and means for connecting each of the sector systems with the multiplier digit key so that upon operation of said key all the multiplicand digits are simultaneously multiplied by the multiplier digit and the final total product appears on the totalizing counter.

7. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; a first differential sector system for each denominational order of the multiplicand which works out the units figure of the partial product for that order; a second differential sector system for each denominational order of the multiplicand which compounds and feeds in the tens figure of the partial product for that order comprising a differential sector, an internally and externally geared quadrant, a satellite connecting the internal gear of the quadrant with the larger radius sector of the differential sector, a second internally geared quadrant, and a second satellite connecting the external gear of the first quadrant with the internal gear of the second quadrant; means for carrying forward any value from the preceding multiplicand denominational order, and means for connecting each of the sector systems with the multiplier digit key so that upon operation of said key all the multiplicand digits are simultaneously multiplied by the multiplier digit and the final total product appears on the totalizing counter.

8. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; a first differential sector system for each denominational order of the multiplicand which works out the units figure of the partial product for that order and comprises a differential sector, an internally and externally geared quadrant, a satellite connecting the internal gear of the quadrant with the larger radius sector of the differential sector, a pinion engaging the external gear of the quadrant, and an indicating disc carried by said pinion; a second differential sector system for each denominational order of the multiplicand which compounds and feeds in the tens figure of the partial product for that order comprising a differential sector, an internally and externally geared quadrant, a satellite connecting the internal gear of the quadrant with the larger radius sector of the differential sector, a second internally geared quadrant, and a second satellite connecting the external gear of the first quadrant with the internal gear of the second quadrant; means for carrying forward any value from the preceding multiplicand denominational order and means for connecting each of the sector systems with the multiplier digit key so that upon operation of said key all the multiplicand digits are simultaneously multiplied by the multiplier digit and the final total product appears on the totalizing counter.

9. Multiplier mechanism according to claim 4, wherein the vertically reciprocable frame is common to all the first sector systems.

10. Multiplier mechanism according to claim 5, wherein the vertically reciprocable frame is common to all the second sector systems.

11. Multiplying mechanism for calculating machines comprising means for setting up the multiplicand digits; a totalizing counter for indicating the final product; multiplier digit keys; a first differential sector system for each denominational order of the multiplicand which works out the units figure of the partial product for that order; a second differential sector system for each denominational order of the multiplicand which compounds and feeds in the tens figure of the partial product for that order; means for carrying forward any value from the preceding multiplicand denominational order; means for connecting each of the first sector systems with the multiplier digit key, said means including a vertically reciprocable frame operated by the multiplier keys; means for connecting each of the second sector systems to the multiplier digit key comprising a lever pivoted adjacent one end thereof, a driving sector carried by said lever gearing with the second sector system, pins upon said lever the distances of which from the lever fulcrum are inversely proportional to their values, a vertically reciprocable frame operated by the multiplier keys, links pivotally mounted on said frame one for each digit 1–9 adapted to be engaged with their respective pins on the aforesaid lever, means for connecting each link to its respective multiplicand digit key for effecting said engagement when said keys are operated, means for operating the vertically reciprocable frame of each first sector system a predetermined interval prior to the operation of the similar frame of the associated second sector system.

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