accumulator transmits an impulse through a diode or any other undirectional electronic tube associated with the said accumulator to a bus-bar J from which it is transmitted to the trigger electrode T^2_3 of the valve T_3 whereby the valve T_3 is rendered conductive. The further movement of the brush F bridges the contacts $B–B_1$ which applies a positive potential from the terminal M to the cathode T^1_3 of the valve T_3 thus rendering the valve T_3 nonconductive and the valve T_4 conductive. The valves T_3 and T_4 are so interconnected that when T_3 is switched off valve T_4 is switched on (under all other conditions T_3 and T_4 do not affect each other). It will therefore be observed that by the transfer of an impulse from one accumulator to the busbar J a potential is applied to the stud A associated with the commutator segment of the next higher order by virtue of the fact T_4 conducts and in consequence one is added into the accumulator of the next higher order before the brush F has commenced to sweep the key controlled studs associated with the said next higher order. It will be readily understood that when the valve T_4 was rendered conductive the valve T_9 was rendered nonconductive.

It will be further observed that after a transfer impulse has been transmitted from the valve T_4 and after the studs of the said next higher order have been swept by the brush F the valve T_4 is rendered nonconductive by the valve T_9 being rendered conductive as a result of the brush F bridging the contacts $C–C_1$ immediately following the said next higher order of studs.

Upon the further movement of the brush F the studs $B–B_1$ are bridged and the valve T_3 is cleared ready to receive a further transfer impulse even if such further impulse should be produced as a result of the brush F sweeping over the first stud of the next higher order and causing the accumulator of the said next higher order to register its maximum. It will be observed that the short circuiting by brush F of the studs $B–B_1$ which follow the order in which the accumulator reached zero not only turns on T_4 in order to effect a carry into the next higher order but also restores T_3 to nonconducting condition in which it can accept evidence of a further carry even if the accumulator of the said next higher order is brought to zero by the first carry pulse. The valve T_4 is only rendered conductive after the valve T_3 has been firstly rendered conductive by a transfer impulse from the busbar J and thereafter rendered nonconductive by an impulse from the studs $B–B_1$ being applied to the cathode thereof. The valves T_3 and T_4 therefore can be regarded as a two-stage transfer store which is common to the accumulators of all the orders of keys.

As hereinbefore stated the keys associated with any one order of keys are operable in such a manner that when a key of an order of keys is actuated the corresponding S pair of contacts is closed and the corresponding K pair of contacts is opened. Referring to the first order of keys it will be observed that if the third key thereof is actuated the contacts S^1_3 are closed and the contacts K^1_3 are opened and provided the common terminal CS^3_4 of the two-way switch CS_4 is making contact with the contact CS^2_4 a potential will be applied, after the brush F has bridged the contacts E—E, from the anode T^3_1 of the valve T_1 through the third pair of contacts S^1_3 and thereafter through the closed contacts K^1_1 and K^1_2 to the studs O_0, O_1 and O_2 which when swept by the brush F will transmit three impulses to the commutator segment O_9 and thence to the accumulator O_{10}, thereby registering upon the accumulator O_{10} the value of 3 if the reading of the said accumulator was previously zero.

If the common terminal of switch CS_4 is arranged in contact with the contact CS^1_4 it will be observed that the anode T^3_1 of the valve T_1 will be placed directly in circuit with the K pairs of contacts and not through the S pairs of contacts, and in consequence if a key is depressed, for example, the second key of the first order of keys, the switch K^1_2 will be opened and a potential will be applied to each of the last seven studs, namely the studs O_8 to O_2, thus ensuring that when the brush F sweeps over the said studs seven impulses will be transmitted to the commutator O_9 and thereafter into the accumulator O_{10}. In view of the fact that the first stud D of the series of studs associated with the first order of keys is energized from the same line as the seven studs O_8 to O_2 an additional impulse will have initially been transmitted to the accumulator O_{10} by the brush F sweeping over the contact D and the commutator segment O_9. In consequence the accumulator O_{10} will register 8 which is the tens complement of the numeral of the actuated key, if the said accumulator was previously registering zero. It will therefore be observed that by the setting of the switch CS_4 into one of two desired position, it is either possible to effect addition or subtraction without calling upon the operator when effecting subtraction to distinguish the keys which he has to actuate when effecting subtraction from the keys which he has to actuate when effecting addition. Further it will be readily observed that in the remaining orders is the nines complement and not the tens complement that is added into the accumulators when a calculation involving subtraction is being carried into effect.

With the benefit of the foregoing detailed description of the apparatus of FIG. 13 a summary of the operation of the calculating machine of the invention in the performance of addition and substraction may be given as follows:

For purposes of addition or subtraction the machine of the invention includes a plurality of orders of keys and an accumulator for each such order, and a further accumulator (H_1) for the storage of carries. The accumulators may take the form of multicathode tubes of the type sometimes called "Dekatrons," illustrated in FIG. 2. Associated with each order of keys there is provided a series of nine contacts, arranged to be bridged successively, via a commutator bar, to the input of the accumulator of that order by means of a pair of brushes F which successively bridge the contacts of each order with the commutator bar of that order, and thus scan all orders successively in the performance of a single addition or subtraction operation. When the machine is set for addition the actuation of a key in any order effects energization of contacts in that order to a number equal to the value of the key operated. When the machine is set for subtraction the operation of a key effects energization of contacts in its order to a number equal to the nines complement of the value of the key actuated.

When one or more keys have thus been actuated, the addtion or subtraction operation desired is effected by initiating motion of the brush, which, in sweeping over the contacts of all orders, applies to the accumulator of each order as many pulses as there are energized contacts in that order. Such a scanning of the contacts of all orders may be called a machine cycle, and upon its completion, in a case of addition or subtraction, the motor which drives the brush by which the scanning is effected is deenergized, and the machine comes to a stop. Addition of two numbers together is effected in two such machine cycles. Subtraction of one number from another is effected first by introducing the minuend into the accumulators (previously cleared) in an addition operation, followed by a machine cycle with the machine set for subtraction and with actuated keys representative of the subtrahend.

In both addition and subtraction the actuated keys are released at the end of the operation.

Means are provided for the transfer of a "carry" from the accumulator of each order but the highest into that of the next higher order, and from that of the highest order into the carry accumulator. These carry means comprise additional contacts between the contacts of adjacent orders, which are energized in appropriate fashion by trigger circuits responsive to output pulses developed in the accumulators of the orders of key orders when those accumulators reach their maximum setting,

e.g. a zero setting in a machine operating on the decimal system.

Referring to FIGS. 3 to 12, the machine there shown embodies the circuit of FIG. 13, and certain other apparatus hereinafter to be described in connection with FIG. 1. Specifically, in FIG. 3, there are shown nine orders or columns of nine keys each. Operation of any one of these keys closes, in its order, the S switch and opens the K switch of corresponding subscript. In addition, by means hereinafter explained in conjunction with FIGS. 4 and 5, it starts a motor which drives the brush F and it operates the one-shot device U. Switch CS_4 is set to the subtraction position shown in FIG. 1 by operation of a subtract key **88**, and it is set to the opposite position, for addition, by operation of an add key **87**. Each of the twelve orders of nine main keyboard keys has associated therewith a display device shown as a numeral wheel **70**, for indication of the contents of the accumulator O_{10} . . . Z_{10} of that order.

FIG. 1 is a circuit diagram of an electromechanical calculating machine according to the invention incorporating the apparatus of FIG. 13 and including in addition structure permitting performance of the operations of multiplication and division. In the apparatus of FIG. 1 (so far as concerns the performance of addition and subtraction) the control studs E—E and G—G are scanned by a separate brush F^1, mechanically coupled to the brush F, and in addition switches CS_5 and CS_9 in the circuits of those control studs are set to a common addition-subtraction position, by operation of either of keys **87** and **88** of FIG. 3.

To recapitulate therefore, for the performance of addition and subtraction the machine of FIGS. 1 and 2 to 12 or 13 and 2 to 12 includes, for each decimal order, a set of nine keys, nine pairs of S and K switches operable by those keys, nine studs or contacts (e.g. O_0 to O_8) selectively energizable by those keys, a carry stud or contact A, and an accumulator (e.g. O_{10}). The nine S switches including one switch from each pair are normally open and are connected in parallel between a bus (energizable when addition is to be performed) and the first of the nine studs (e.g. O_0). The other nine key-controlled switches K of each order are normally closed and are connected in series, with the remaining eight studs (e.g. O_1 to O_8) between them, between the first stud and a second bus, energizable when subtraction is to be performed. For each order, a commutator is provided, which serves as an input electrode to the accumulator, delivering to the latter pulses scanned from the energized ones of the nine studs of its order by a brush which traverses the studs of all orders successively in the performance of an addition or subtraction operation.

An extra accumulator may be provided to accept carries from the accumulator of highest order.

A carry bus accepts pulses from the other accumulators when they reach zero count. The voltage on the carry bus is employed, in a two-stage transfer store, to energize the carry stud of the next higher order, from which an extra pulse is then scanned into the accumulator of next higher order when the brush reaches that next higher order.

A flip flop (T_1, T_2) is reversed in conduction phase at the start of each addition or subtraction operation to energize a first bus, from which voltage is extended to one or the other of the first-named buses according to the setting of an add-subtract switch CS_4. The flip flop is reset at the completion of a scan by the brush. Operation of any one or more keys simultaneously (only one key in any one order) initiates a cycle of brush travel and reversal in conduction phase of the flip flop, so that the indicated addition or subtraction is performed. Such a cycle of brush travel, with the accompanying complete cycle of states for the flip flop, may be referred to as a machine cycle. Addition together of two numbers is effected in two such machine cycles.

For subtraction, an additional stud is provided in advance of the studs of the first order, which is connected to the subtraction bus and which effects addition into the accumulator of the first order of the tens rather than the nines complement of the number punched into the first order (1, in case no key is punched in the first order).

The brush or brushes (in FIG. 13 one brush F is shown for engagement with the control studs E—E and G—G as well as with the counting studs, while in FIG. 1 a separate brush F^1 is provided for the control studs E—E and G—G) are driven by the motor together and may stop in any position. When the motor is started up by operation of a key, by switch means not shown in FIG. 1, the brush or brushes rotate until control studs E—E are bridged. This starts the machine cycle, which is completed when control studs G—G are bridged.

On addition and subtraction, the motion of any main keyboard key slide due to operation of a key in such order will energise the motor which carries brushes F, F^1 and F^2 by engaging contacts **34** and **35** in FIG. 4.

On multiplication, such engagement is prevented, by element **41** as controlled from the multiplication function key **39** via element **43** (FIG. 3), until the slide of the order of multiplier keys is actuated by operation of a multiplier key therein.

On addition and subtraction, the one-shot device U is controlled by contacts **232** to **234** of FIG. 5, of which there is a set for each order of main keyboard keys. These contacts are shifted to deliver a striking voltage to the contacts E–E of FIG. 1 whenever any key of the main keyboard is operated. On multiplication and division, there are substituted for these contacts the contacts **417**, **418** and **424**, **425** on the key slide of the multiplier key column, wherein the "Divide" key **400** causes, on division, the extraction of a quotient digit. See FIG. 11. During multiplication operation of any one of these keys in this column effects a similar shift of contacts **417**, **418**, **424** and **425**, and during division operation of key **400** does so.

Instead of employing the three valves T_9, T_4 and T_3 only one pair of valves T_3 and T_4 need be employed in which case the valve T_9 can be disregarded but otherwise the circuit arrangement would be as illustrated in FIGURE 1. Such an arrangement ensures that the valve T_3 is available, at the shortest possible notice after it has received one impulse from the busbar J, to receive a further impulse in view of the fact that the duty of the first impulse has been taken over by the valve T_4.

The valve T_9 is of value as a means of rendering the valve T_4 nonconductive.

Thus it will be seen that according to the present invention there is provided an extremely simple means in an electronic calculating machine of transferring unity from one accumulator to the accumulator of the next higher order which involves the employment of not more than three electronic tubes but wherein even only two tubes could be employed to perform the function successfully.

In the employment of electronics considerable difficulty has hitherto been experienced in displaying the results stored in electronic devices upon accumulators, such, for example, as the numeral wheels of calculating machines, owing to the difficulty which arises both from the amount of energy consumed in the operation of any such mechanical devices and also due to the comparatively low speeds at which mechanically, or like operated devices, operate as compared with the high speeds of electronic actuation.

In practice, it has been found that if one wishes to ascertain a result of an electronic calculation during the course of said calculation, it becomes necessary eithter to stop the electronic actuation so as to allow a mechanical indicator to operate, or to slow down the electronic action to a speed commensurate with the speed of operation of a mechanical indicator.

An object of the accumulator hereinafter described is to provide means whereby the result of rapid electronic

actuation may be readily discernible without the necessity of involving the disadvantages referred to above.

One method of effecting the above result will be hereinafter described with reference to a stepping electronic tube operating at approximately 4,000 counts per second. In the main, according to the present invention, the fixed contacts of a rotary switch are connected to the cathodes of a stepping electronic tube, and the movable contact or contacts of the rotary switch is or are arranged to sweep continuously over the said contacts. The rotary switch is so designed that, if the glow remains on one cathode for a sufficient period of time, when the rotary contact makes contact with a fixed contact with which the glowing cathode is connected, an arresting relay connected in circuit with the said rotary contact is energised. The voltage received from the glowing cathode of the stepping electronic tube is amplified in order to effect the actuation of the arresting relay. The energisation of the arresting relay causes the movement of the switch to be arrested in the position in which it is in engagement with the contact connected to the glowing cathode until such time as the cathode ceases to glow, whereupon the arresting relay is deenergised and the rotary switch is released and resumes the rotary movement thereof whereupon the rotary contact or contacts of the rotary switch continue to hunt for another glowing cathode. This will continue until at least the rate of counting of the stepping electronic tube approaches a speed which the eye can follow.

It will be appreciated that if the stepping electronic tube is provided with 10 cathodes which are connected to 10 fixed contacts associated with a rotary switch, the rotary contact of the switch will be arrested upon the first "live" fixed contact connected to a glowing cathode which it encounters provided the glow persists for a sufficiently long period of time to ensure the actuation of the arresting relay. The rotary contact is connected to a flanged numeral wheel arranged to move therewith and having the numerals 0 to 9 arranged around the flanged face thereof and the numeral wheel is arranged behind the casing of the calculating machine which is provided with a suitable aperture. The numeral wheel is so arranged behind the casing that the number of the fixed contact upon which the rotary contact is arrested is displayed through the aperture in the said casing. In this way it will be observed that there is provided in accordance with the rotary contact operable as a result of energy emitted from the glowing cathode of a stepping electronic tube to cause the numeral associated with said cathode to be displayed by the numeral wheel hereinbefore referred to in a readily discernible manner.

The accumulator illustrated in FIGURES 3 and 4 comprises a numeral wheel **70** bearing the numbers **0** to **9** equally spaced around a circumferential flange **300** thereof (FIGURE 8). The numeral wheel **70** is mounted upon a continuously rotating spindle **301** which is driven by a belt **302** which extends firstly around a pulley **303** mounted upon the spindle **301** and thereafter around a pair of pulleys **28** carried upon a lay-shaft **29** and finally around a pulley **27** (FIGURE 4). The pulley **27** is mounted upon the upright spindle **25** of the motor **24** whereas the pulley **303** is mounted upon the spindle **301** which carries the thirteen numeral wheels required for a machine having twelve orders of keys. The numeral wheel **70** (FIGURE 8) is provided upon one side face thereof with a carrier disc **370** which is mounted on a boss **371** of the numeral wheel **70**. The carrier disc **370** is provided with a slot **372** (FIGURE 9) which engages with a pin **373** attached to an adjustment plate **342** clamped by a screw to the numeral wheel **70**. Mounted upon the carrier disc **370** are two pairs of interconnected contacts **311** and **312** and **314** and **315**. As the numeral wheel rotates the contact **311** is arranged to bear successively upon the contacts of a set of 10 fixed contacts **316** to **325** (FIGURE 10) arranged in a circle, upon a stationary panel **326** so that the contacts **316** to **325** are coaxial with the axis of the rotating spindle **301** of the numeral wheel **70** whilst the contact **312** is arranged to engage with a fixed circular commutator segment **327** extending around the face of the panel **326** so as to be coaxial with both the spindle **301** and the 10 contacts **316** to **325**. The second pair of contacts **314** and **315** are correspondingly mounted and bridge a second set of 10 contacts **328** to **337** and an associated commutator segment **338** mounted so as to be coaxial with the first set of contacts **316** to **325** and commutator segment **327**. Each of the 10 contacts of the two sets of contacts **316** to **325** and **328** to **337** hereinbefore referred to are arranged to be connected sequentially to the cathodes of a stepping electronic tube, whilst each of the commutator bars **327** and **338** is arranged to engage through an amplifier (not shown) with a relay **339** (FIGURE 7) mounted adjacent to each numeral wheel **70** of each order of keys (FIGURE 3). The relay **339** is provided with an armature **340** which, when the relay **339** is energised, is moved to engage with one of ten teeth **360** formed on an arrester wheel **341** mounted coaxially with the axis of the numeral wheel **70** and mounted in yielding relationship thereto in a manner hereinafter described.

The above arrangement is operable in such a manner that when a glowing cathode of the associated stepping electronic tube is connected to a contact on the fixed panel **326** and one pair of the interconnected contacts **311**, **312** or **314** and **315** carried upon the carrier disc **370** adjustably mounted upon the numeral wheel, short circuit the "live" contact and the associated circular commutator bar the relay **339** is energised and the arrester wheel **341** is arrested by the armature **340** of the relay **339** engaging with the appropriate tooth **360** on the arrester wheel **341** which corresponds to the glowing cathode of the stepping electronic tube. In this position the numeral on the numeral wheel which corresponds to the number of the "glowing" cathode of the stepping electronic tube will register within an aperture in the casing **320** (FIGURE 4) of the machine and so cause the number corresponding to the glowing cathode of the stepping electronic tube to be readily discernible.

The indicator described above shows an arrangement where the numeral wheel **70** is arranged to be continuously rotated and arrested when the speed of counting of the stepping electronic tube approaches a speed at which the impulses received from the cathode of the stepping electronic tube are slow enough to enable the relay **339** to be energized.

The drive between the numeral wheel **70** and the spindle **301** comprises a coil spring **350** (FIGURES 7 and 8) which normally binds tightly on the spindle **301** which is driven in an anticlockwise direction when viewed from the right-hand side of FIGURE 8. One limb **351** of the spring **350** is arranged to extend through a slot **352** (FIGURE 7) in the boss **353** of the numeral wheel **70** and to exert a turning force on the numeral wheel **70** causing it to rotate at the same sped as the spindle **301**.

The arrester wheel **341** is arranged as a sliding fit on a boss **354** (FIGURE 8) of the numeral wheel **70** and is provided with a slot **355** in its boss arranged to receive the second limb **325** so that it exerts a light turning movement on the arrester wheel **341** and causes it to rotate at the same speed and in the same direction as the spindle **301** and the numeral wheel **70**.

In order to arrest the numeral wheel **70** the armature **340** of the relay **339** must be energized by completing an electrical circuit by the contacts **311** and **312** or **314** and **315** sweeping over the associated fixed contacts and fixed commutator segments, until the armature **340** engages one of the teeth **360** on the arrester wheel **341** and stops its rotation. The arrest of the arrester wheel resists the turning movement of spring **350** causing it to unwind slightly and the driving force of the spindle **301** on the spring **350** is consequently relieved, and whilst the spindle **301** con-

tinues to rotate, the numeral wheel **70**, the arrestor wheel **341** and the spring **350** remain stationary.

When the electrical circuit which energises the relay **339** is broken the armature **340** disengages from tooth **360** thus allowing the spring **350** to resume its positive clutch on the spindle **301** and produce a turning movement on the numeral wheel, the arrester wheel **341** and the spring **350**.

A bush **361** is arranged as a free fit on the spindle **301** and has a clearance from the arrester wheel **341**, thus ensuring that the pressure of the contact points **311**, **312**, **314** and **315** on righthand side panel **326** does not create any friction between the arrester wheel **341** and the panel **326** and thereby restrict the freedom of the arrester wheel **341** to revolve.

Referring to FIGURE 2 of the drawings the counting device employed upon an office calculating machine constructed in accordance with the present invention comprises a multicathode stepping electronic tube which normally has ten cathodes L^1_0 to L^1_9 although a larger number of cathodes could, if desirable, be employed. A glow is maintainable between a single L^1_{10} and any one and only one of the above-mentioned cathodes L^1_0 to L^1_9.

The glow can be stepped from one cathode to another by providing a suitable series of pulses. By referring to the cathode as the No. **0** cathode L^1_0 and to the adjacent cathode L^1_1 as the No. **1** cathode and so on, up to any desired maximum, for example up to the cathode L^1_9 as the No. **9** cathode, it is possible to register in any notation according to the number of cathodes selected.

In a stepping electronic tube employed in connection with an office calculating machine constructed in accordance with the present invention two subsidiary electrodes L^1_{11} and L^1_{12} hereinafter referred to as guides **1** and **2**, are provided between each pair of adjacent cathodes. The electrodes L^1_{11} and L^1_{12} are only shown diagrammatically on the left hand side of the tube, the portions of these electrodes that are located between adjacent pairs of cathodes being omitted for the sake of clarity. It should be understood that, when "guide **1**" or "guide **2**" is hereinafter referred to as being made momentarily more negative than an adjacent cathode, this applies to each pair of guides **1** and **2** which are arranged between adjacent cathodes since all guides **1** are commoned and all guides **2** are commoned.

Normally the voltage difference between the cathodes L^1_0 and L^1_9 and the single anode L^1_{10} is kept greater than the voltage difference between the guides **1** and **2** and the anode L^1_{10}, thus ensuring that the glow rests on a predetermined cathode.

When it is desired to step the glow from one cathode to the next, for example, from cathode No. **8** to cathode No. **9**, the guide **1** adjacent to the No. **8** cathode is momentarily made more negative than the No. **8** cathode with the result that the glow steps to the said guide **1**. Thereupon, guide **2** is also made momentarily more negative than the No. **8** cathode, with the voltage on guides **1** and **2** being the same, thereby causing the glow to be shared by the said guides **1** and **2**. The voltage on guide **1** is then raised to normal, whereupon the whole glow transfers to guide **2** and finally, when the voltage on guide **2** is raised to normal, the glow which was resting on guide **2** steps to No. **9** cathode.

The pulses which are applied to guides **1** and **2** are derived by means of a single pulse which is applied directly to guide **1** through the resistor R_{10} and via an integrating circuit comprising resistors R_{10} and R_{11} and capacitor C_{10} to guide **2**, the delay necessary between switching off the pulses to guide **1** and guide **2** is provided by the charge stored in the capacitor C_{10}.

It will be appreciated that after the drive pulse has disappeared the glow will rest on guide **2** until such time as the charge on the capacitor C_{10} has dropped sufficiently to allow the glow to step to cathode No. **9**.

The mechanism employed for ensuring a delay in the release of a key of the main keyboard, hereinbefore referred to until at least the purpose for which the key has been actuated has been achieved will be hereinafter described with reference to FIGURES 3, 4, 5 and 6 and more particularly with reference to FIGURES 5 and 6. Each key stem **200** is provided, upon the end thereof remote from the key top **20**, with an extension **201** which is made from an insulating material, such, for example, as nylon, a bifurcated contact device **202** being secured to the said extension. The arrangement is such that each contact device bridges and connects electrically a pair of contacts **203** so long as the key associated with that contact device is not depressed, the electrical bridging being broken when the key is depressed. The stem **200** of each key is also provided with a laterally extending lug **204**. Each lug is so disposed as to engage, when the key with which it is associated is depressed, an inclined slot **205** formed in a key bar **37**, the downward travel of the lug **204** when engaged with the said inclined slot **205** causing the key bar to be moved towards the front of the machine (that is to the left when viewing FIGURES 4 and 6). The key bar **37** is pivotally mounted at the front thereof upon one limb of an inverted U-shaped stirrup **206** and at the rear thereof between the limbs of an upright U-shaped stirrup **209**.

Located at the front of each order of keys is a shaft **50**, connected through a dog clutch **53** to the pulley **51** which is driven at a constant speed from the vertical output spindle **25** of the motor **24**. The shaft **50** carries a fixed hub **210** which acts as an abutment piece and of which a segment is cut away. A ratchet wheel **211** is mounted on and rotates freely on the shaft **50** but is constrained to move generally with the hub **210** by means of a tension spring **212** one end of which is attached to the hub **210** and the other end of which is attached to a pin **213** on the ratchet wheel **211** in such a position that, if the ratchet wheel is restrained whilst the shaft **50** rotates, the tension spring **212** will stretch until the hub **210** abuts the pin **213**. Thereafter, the ratchet wheel **211** will again be turned by the shaft **50**.

It has been stated above that the key bar **37** is pivotally connected to and suspended from an inverted stirrup **206** at the front end thereof. The stirrup **206** and an inverted U-shaped secondary latch **214** are both mounted for pivotal movement about a spindle **215** which extends through all of the orders of the machine. The yoke of the stirrup **206** is extended downwardly and at an angle of approximately 45° towards the rear of the machine to form a toe **216** which acts as a stop for an arcuate, upwardly directed extension **217** of a lever **218** hereinafter described in greater detail. When the lever **218** and the arcuate extension **217** thereof are in the rest position thereof, the toe of the secondary latch **214** is held in contact with the rear edge of the arcuate extension **217** by means of a tension spring **219**. The toe **216** of the stirrup **206** makes contact with the forward edge of the toe of the secondary latch **214**, but the radius of the underside of the toe **216** of the stirrup **206** is slightly less than the radius of the underside of the toe of the secondary latch **214**, both radii being taken from the axis of the spindle **215** about which the two parts pivot, so that whilst the toe **216** of the stirrup **206** forms the stop for the arcuate extension **217** this extension in turn forms a forward stop for the toe of the secondary latch **214**.

Each lever **218** extends from a point adjacent the number "**1**" key of the order of keys with which it is associated towards the front of the machine to a point substantially vertically below the axis of the shaft **50**. At this point, each lever **218** is mounted for pivotal movement about a spindle **220** which extends through all of the orders of the machine and the lever **218** is urged in an anticlockwise direction about the axis of the spindle **220** by a spring. One end of another spring **221** is anchored to the lever **218** at about the mid-length thereof and the other end of the spring **221** is attached to a rearwardly directed arm of

a three-armed pawl 222 which is carried by the lever 218. The lever 218 is cranked at a point adjacent to the ratchet wheel 211 on the shaft 50 and the three-armed pawl 222 is pivotally mounted upon the lever 218 where the lever is cranked.

The three-armed pawl 222 has one rearwardly directed arm 223, a second and upwardly inclined arm 224 provided on the underside thereof with a tooth and a ramp 226 of which the purpose will be hereinafter explained, and a third and downwardly inclined arm 227 which is in line with the ratchet wheel.

A stirrup-shaped member 228, which is mounted for pivotal movement upon the same spindle 220 as that upon which the lever 218 is mounted, carries upon the yoke thereof a bifurcated electrical contact device 229, the contact device 229 is insulated from the stirrup-shaped member 228 and also is urged in an anticlockwise direction by the same spring that urges the lever 218 with the arcuate extension 217 in an anticlockwise direction. The upper edge of the yoke of the member 228 is extended upwardly and bent so as to provide a horizontal platform 230 whilst the lower edge of the said yoke is extended downwardly to form a stop arm 231 which, when it abuts one of the spacers 232, which are employed to space apart the frame plates of the machine, serves to limit the movement of the stirrup-shaped member 228.

There are provided three fixed contacts 232, 233 and 234 disposed one above the other, the middle and lowermost contacts 233 and 234 being bridged and electrically connected to one another by the bifurcated electrical contact device 229 when the said device is in the rest position thereof. However, the said contact device 229 is caused to bridge and connect electrically the uppermost and middle contacts 232 and 233 when the machine is set to effect a calculation. When the contact device 229 is bridging the uppermost and middle contacts 232 and 233 the stop arm 231 of the yoke of the stirrup-shaped member 228 which carries the contact device 229 is in contact with the frame spacer 232.

Another substantially U-shaped lever 250 is mounted on a spindle 251 extending through all the orders of the machine. The spindle 251 is located on the straight line extending between, the point of pivotal attachment of the key bar 37 to the inverted U-shaped stirrup 206 at the front of the machine and the spindle 220 about which pivots the lever 218 and the arcuate extension 217 thereof. One arm of this U-shaped lever 251 is arranged in contact with the pivot stud 252 by means of which the three-armed pawl 223 is pivotally secured to the lever 218 with the arcuate extension 217. The other arm 227 of the U-shaped lever 250 rests on the horizontal platform 230 which is formed from the extension of the upper edge of the yoke of the stirrup-shaped member 228 which is urged in an anticlockwise direction by a spring and which would be rotated in an anticlockwise direction but for the restraining influence of the arm 227 resting on the said horizontal platform 230.

The pairs of contacts 203 which are bridged by the contact devices 202 upon the key stems 200 in each order and the sets of three contacts 232, 233 and 234 disposed one above the other in the vicinity of the ratchet wheels 211 in each order are mounted in or on an insulating panel 253. Wiring or printed circuitry connects the contacts, which may also be printed, to the appropriate part of the calculating mechanism.

Having described the mechanism at rest, the action of the various parts during a quick key stroke and the release of a key, such as occurs during a normal adding operation will now be described:

When a key 20 is depressed, the lug 204 on the key stem 200 engages the inclined slot 205 in the key bar 37, urging the key bar towards the front of the machine (that is to the left when viewing FIGURES 4 and 6). The rear shoulder 254 of each pair of shoulders which define the opening of the inclined slot 205 move forwardly and beneath the lugs 204 on the key stems 200 of those keys which have not been depressed. Thus, once a key in any order has been depressed, it is not possible to depress another key in that order until the depressed key has been released and restored to the uppermost rest position thereof by spring action. Further, the depressed key is held depressed by interengagement of the lug 204 on the stem 200 of the depressed key with the inclined slot of the forwardly displaced key bar 37.

The inverted U-shaped stirrup 206 from one limb of which the front end of the key bar 37 is suspended, is moved about the pivot 215 thereof in a clockwise direction by the movement of the key bar 37, thereby causing the toe 216 of the said stirrup 206 to slide forwardly over the top surface of the arcuate extension 217. Whilst the toe 216 of the stirrup 206 still partially engages the arcuate extension 217 the bifurcated contact device 202 on the lower end of the key stem 200 will have been caused to slide off the contacts 203 normally bridged by the said device, thereby disconnecting them from the supply of voltage. Continued movement of the key bar and the toe 216 of the stirrup 206 will cause the toe 216 to disengage the arcuate extension 217, thereby permitting the lever 218 of which the arcuate extension 217 forms a part to move in an anticlockwise direction until arrested by the action of the three-armed pawl 223.

It will be appreciated that one arm of a substantially U-shaped lever 250 is caused to bear against the pivot stud 252, which connects the three-armed pawl 223 to the lever 218, under the influence of the spring which tends at all times to move in an anticlockwise direction the stirrup-shaped member 228 provided with the horizontal platform 230, the platform 230 being contacted by the arm 227 of the U-shaped lever. When therefore, the stirrup-shaped member 228 and the lever 218 with the arcuate extension 217 are freed for movement about the spindle 220 in an anticlockwise direction, the pivot rod 252 not only carries the three-armed pawl 223 forwardly but also allows the substantially U-shaped lever 250 to rotate in a clockwise direction about its pivot 251. Due to the proportions of the parts concerned this movement of the U-shaped lever 250 (which removes the restraining influence applied by the other arm 227 of the U-shaped lever 250 to the horizontal platform 230 hereinbefore referred to) ensures that the stirrup-shaped member 228 to which the bifurcated contact device 229 is connected is released rapidly, this rapid release in turn ensuring that the uppermost and middle fixed contacts 232 and 233 are electrically bridged with a snap action.

Continued movement of the lever 218 with the arcuate extension 217 will cause the downwardly directed arm 227 of the three-armed pawl 223 to abut the periphery of the ratchet wheel 211, so that movement of the pawl thereafter will cause anticlockwise rotation of the pawl 224 and tip the tooth 225 of the said pawl into engagement with a tooth of the ratchet wheel 211.

The arc through which the lever 218 with the arcuate extension 217 travels is limited by a lug 260 formed at the lower end of the arcuate extension 217 of the lever 218 abutting against the underside of the secondary latch 214. The lug 260 preferably forms an integral part of the lever 218 and projects rearwardly from the base of the arcuate extension 217.

When the tooth 225 of the three-armed pawl 223 engages a tooth of the ratchet wheel 211, the movement of the ratchet wheel 211 is arrested. However, in view of the fact that the ratchet wheel 211 is free to rotate on the shaft 50 when it is arrested, the shaft 50 continues to rotate without driving the ratchet wheel 211 until such time as the hub on the shaft (to which hub one end of a spring is attached) has completed an arc of movement of approximately 70° and abuts against a pin secured to the ratchet wheel (to which pin the other end of the said spring is attached). It will be appreciated that there is an interval of time between the arrest of the ratchet wheel

211 and the resumption of the drive thereof, this interval of time being essential for the correct working of the electronic apparatus. When the hub on the shaft **50** has abutted the pin on the ratchet wheel as aforesaid the drive between the shaft and the ratchet wheel will be solid and the three-armed pawl **222** will be pushed rearwardly (that is to the right when viewing FIGURES 4 and 6). This rearward movement of the pawl **222** is communicated to the lever **218** to which the pawl **222** is pivotally connected and is maintained until the ramp **226**, which is adjacent the tooth **225** of the pawl **224**, raises the tooth **225** of the pawl **224** out of engagement with the ratchet wheel **211** as a result of coming into contact with the teeth of the ratchet wheel **211**. The time taken to cause this disengagement to the tooth **225** of the pawl from the ratchet wheel **211** provides a further delay which supplements the delay already referred to.

At some time during the cycle so far described the key will have been released by the operator but it will be prevented from rising to the normal rest position thereof by virtue of the fact that the key bar is held in its forwardmost position by engagement of the arcuate extension **217** with the toe **216** of the inverted U-shaped stirrup **206**, the associated inclined slot in the key bar **200** trapping the lug **204** on the stem **200** of the key which has been depressed. Towards the end of the return movement, in a clockwise direction, of the lever **218** with the arcuate extension **217** the pivot **252** which connects the three-armed pawl **223** to the lever **218** abuts one arm of the substantially U-shaped lever **250** and moves the lever **250** in an anticlockwise direction about its pivot **251**. Such anticlockwise rotation of the substantially U-shaped lever **250** causes the other arm thereof to depress the horizontal platform **230** which forms a part of the assembly which includes the bifurcated contact device **229**, thereby causing the said device to move from the position in which the uppermost and middle contacts **232** and **233** of the three fixed contacts are bridged to the position in which the lowermost and middle contacts **234** and **233** are bridged. The final part of the arc of travel of the lever **218** with the arcuate extension **217** in a downward direction moves the top of the said arcuate extension **217** clear of the lowermost edges of the toe of the inverted U-shaped stirrup **216** and of the secondary latch **214**. The toe of the said stirrup thereupon snaps over the top of the arcuate extension **217**, thus restoring the key bar **37** to its rest position and releasing the depressed key. Furthermore, the rear end of the toe **216** of the said stirrup holds the toe of the secondary latch **214** clear of the arcuate extension **217** which, on release of the tooth **225** of the three-armed pawl **223** from the tooth **225** of the ratchet wheel **211**, settles with the uppermost surface of the arcuate extension **217** abutting the underside of the toe **216** of the inverted U-shaped stirrup **206**.

The above description of the operation of the various parts of the mechanism presupposes that the operator, having depressed a key, releases it quickly. Should, however, the operator hold the key depressed for a period of time in excess of the normal time of the cycle, the operation of certain parts at the end of the operating cycle is slightly different from that described above. The operating cycle under the new circumstances is the same as before up to the time when the arcuate extension **217** and the lever **218** of which it forms a part descend (that is when they rotate about the pivot **252** in a clockwise direction) due to the drive from the ratchet wheel **211** through the three-armed pawl **223**. When the drive from the ratchet wheel **211** has caused the top of the arcuate extension **217** to pass below the level of the toe **216** of the inverted U-shaped stirrup **206** the toe **216** will not, as before, snap over the top of the arcuate extension **217** because the key is still being held down by the operator and because the lug **204** on the key stem **200** holds the key bar **37** to which the inverted U-shaped stirrup **206** is connected against movement. Therefore, the tension spring **219** secured to the secondary latch **214** causes the said latch to snap across the top of the arcuate extension **217** until the said latch is arrested by contact with the edge face of the toe **216** of the inverted U-shaped stirrup **206**. In this position the secondary latch **214** will prevent further upward movement of the arcuate extension **217** which would otherwise automatically take place when the tooth **225** of the three-armed pawl **223** becomes disengaged from the ratchet wheel **211**.

When the operator releases the key, the key bar will move rearwardly, thereby causing the toe **216** of the inverted U-shaped stirrup **206** to push the toe of the secondary latch **214** off the top of the arcuate extension **217** so that the toe of the latch **214** will drop below and behind the top of the arcuate extension **217** and permit the arcuate extension **217** to rise by the small clearance distance between the face of the toe **216** and the face of the secondary latch **214** into contact with the underside of the toe **216** of the inverted U-shaped stirrup **206**.

The delay afforded by the mechanism hereinbefore described is at least $\frac{1}{10}$ second.

On addition and subtraction, this key delay apparatus insures completion of one addition or subtraction operation before insertion of other data into the main keyboard (comprising the twelve orders of keys **1** to **9** in FIG. 3), by preventing reoperation of the one-shot device U of FIG. 1 at contacts **232** until the keys involved in that addition or subtraction operation are restored.

For the case of multiplication the machine hereinbefore described is provided with means which are capable of producing electrically what has hitherto been effected mechanically by the transverse movement of the carriage which carries the accumulators. The means in their broadest aspect consist in transferring the contents of the accumulator of each order into the next higher order which when operating according to the decimal system has the effect of mutiplying the contents of the various accumulators of the different orders of keys by ten. This is achieved by adding impulses into a particular order sufficient to produce a transfer whereupon the remaining number of impulses are added into the next higher order. Thus, for example, if there exist in the accumulators associated with the first, second and third order of keys the numbers **4**, **1** and **3** respectively, the means hereinafter described achieves the result of transferring the numeral 3 from the third order into the fourth order, transferring the numeral 1 from the second order into the third order and transferring the numeral 4 from the first order into the second order, and thus the figures which are displayed upon the accumulators of the calculating machine will be 3 1 4 0.

Dealing more specifically with the arrangement for achieving the above result, an electromechanical calculating machine constructed in accordance with the present invention is provided, in addition to the arrangement hereinbefore described, with two additional sets of O to Z studs. The said two sets of studs are associated with a pair of valves T_7 and T_8 operable to apply alternatively a potential to one or other of the said sets of studs. Each batch of studs of the first added set of studs is associated via a brush F^1 with a commutator segment of a particular order of keys whilst the corresponding batch of studs of the second added set of studs is associated via a brush F^2 with the commutator segment of the next adjacent order of keys.

The brushes F^1 and F^2 rotate with the brush F. Thus, the brush F^1 associates with the first added set of studs a set of commutators O_9 to Z_9, in however the order of Z_9 to O_9, so that brush F^1 delivers pulses from the O order of studs in the first added set to a segment Z_9, from the P order in the first added set to a segment Y_9, and so on. The brush F^2 associates with the second added set of studs a set of commutator segments L, Z_9, Y_9, etc. to P_9. Thus the brush F^2 delivers pulses from

the O order of studs in the second added set to a segment L, from the P order of studs in the second added set to a segment Z_9, from the Q order of studs in the second added set to a segment Y_9, and so on, and lastly from the Z order in the second added set to a segment P_9. The commutator segments O_9 to Z_9 shown in FIG. 1 as engaged by the brushes F^1 and F^2 are short-circuited respectively to the similarly identified commutator segments of the series O_9 to Z_9 engaged by brush F. In addition there is provided a commutator segment L, engaged by the brush F^2 when sweeping the studs O_{22} to O_{30} of the first order in the second added set of studs. On multiplication this segment is connected through a switch CS_7 to the trigger electrode of the carry accumulator H_1. Further, for multiplication, the machine of FIG. 1 includes a counting tube L and a further pair of tubes T_5 and T_6. As will be further explained, the multiplying operation is controlled by a set of ten multiplier keys **0** through **9** seen at the right in FIG. 3. These keys control switches in the cathodes of the tube L.

On division, the commutator segment L connects through CS_7 to the stepping electrode of the counting tube L. Moreover, for multiplication and division the machine of FIG. 1 includes two additional pairs 3—3 and 4—4 of control studs, arranged like the studs E—E and G—G to be bridged by the brush F^1. The additional sets of studs and their associated commutator segments are preferably arranged upon a commutator plate in which both the studs and the commutator segments comprise either printed circuits or studs and bars embedded in suitable insulating material or in any other suitable manner. The brushes are mounted so as to rotate about the axis of the said commutator plate and bridge and short circuit one set of studs and their associated commutator segments.

Referring more specifically to FIGURE 1 of the accompanying drawings there is illustrated a circuit arrangement for effecting what will hereinafter be referred to as "multiplication by ten," although it is to be clearly understood that the system is not limited to a decimal system and is equally applicable to any system wherein the accumulators are capable of operating to a definite maximum, and wherein the accumulators all register to the same maximum. Assuming that the accumulators are all capable of registering up to a maximum of ten, the circuit arrangement comprises a first added set of ten studs associated with each order of keys and a further added set of nine studs associated with each order of keys. The first of the two sets of added studs comprises twelve batches each of ten studs, and will be hereinafter referred to as the O_{12} to O_{21}, P_{12} to P_{21}, Q_{12} to Q_{21}, R_{12} to R_{21} etc. up to Y_{12} to Y_{21}, and Z_{12} to Z_{21} batches of studs. The second added set of studs comprises twelve batches each of nine studs which will be hereinafter referred to as O_{22} to O_{30}, P_{22} to P_{30}, Q_{22} to Q_{30}, R_{22} to R_{30} and so on up to Y_{22} to Y_{30} and Z_{22} to Z_{30} batches of studs. Each of the studs O_{22}, P_{22}, Q_{13}, R_{22} and so on up to Y_{22} and Z_{22} of the second added set are disposed respectively in line with the studs O_{13}, P_{13}, Q_{13}, R_{13} and so on up to Y_{13} and Z_{13} of the first added set, assuming brushes F^1 and F^2 (and for good measure, brush F) to be abreast of each other. Moreover, in each order, the first stud of subscript 22 in the second added row of studs is aligned with the first or O-subscript stud of those engaged by brush F.

It will therefore be observed that the first stud of each batch of studs of the second added set of studs is always disposed in alignment with the second stud of each batch of studs of the first added set of studs as clearly illustrated in FIGURE 1 of the drawing. Arranged in advance of the first stud of each batch of studs of the first set of added studs, namely in advance of the studs O_{12}, P_{12}, Q_{12}, R_{12}, and so on until Y_{12} and Z_{12} is a stud E^0, and arranged in advance, that is to the right of each E^0 stud in each order, with the exception of the order of studs O_{12} to O_{21}, is a stud F^0.

The arrangement is such that when the brush F^1 sweeps over the studs P_{12}, Q_{12} and so on up to Y_{12} and Z_{12} of the first added set, it will first contact with an F^0 stud arranged in advance of each batch of studs. Further in its sweep over the various sets of studs F^1 will contact, in advance of each batch of studs, an E^0 stud associated with each of the batches of studs O_{12}, P_{12}, Q_{12}, R_{12}, etc. Associated with the O_{12}, P_{12} and so on up to Z_{12} batches of studs swept by brush F^1 are commutator segments Z_9, Y_9, X_9, etc., up to P_9 and O_9. Arranged in advance of each of the commutator segments Y_9, X_9, etc., up to P_9 and O_9 engaged by brush F^1 are studs E^0 and F^0 arranged in alignment with the corresponding E^0 and F^0 studs associated with the P_{12}, Q_{12}, R_{12}, etc., up to Y_{12} and Z_{12} studs of the first added set of studs. Similarly, arranged in advance of the segment Z_9 associated with brush F^1 there is a stud E^0 bridgeable by F^1 to the E^0 stud in advance of the O_{12} to O_{21} studs of the first added set. The E^0 studs associated with the O_{12}, P_{12}, Q_{12}, R_{12} up to Y_{12} and Z_{12} set of studs are connected to the trigger electrode T^1_8 of a valve T_8. The E^0 studs mounted in advance, (that is to the right when viewing FIGURE 1) of the commutator segments Z_9, Y_9, X_9, and so on up to P_9 and O_9 for brush F^1, are connected to the anode T^1_5 of a valve T_5. The batches of studs O_{12} to O_{21}, P_{12} to P_{21}, Q_{12} to Q_{21}, R_{12} to R_{21} and so on up to the studs Y_{12} to Y_{21} and Z_{12} to Z_{21} are connected to the anode T^2_8 of the valve T_8. The F^0 studs in advance of the segments Y_9 to O_9 for brush F^1 are connected to a source of positive potential, and the F^0 studs between the orders of −12 to −21 studs in the first added set are coupled to the cathodes of T_7 and T_8. The second row of studs O_{22} to O_{30}, P_{22} to P_{30}, Q_{22} to Q_{30}, R_{22} to R_{30}, up to Y_{22} to Y_3 and Z_{22} to Z_{30} are all connected during multiplication to the anode T^1_7 of a valve T_7, the cathode of which, like the cathode of T_8, is connected through a gate G_5 to the busbar J. The gate G_5 is operable in such a manner that when the valve T_5 is non-conducting the gate G_5 prevents any transfer impulse being applied to the trigger electrode T^2_3 of the valve T_3, but permits a transfer impulse to be applied to the cathodes of the valves T_7 and T_8.

The valves T_7 and T_8 are so interconnected that normally they are both maintained nonconductive when an impulse is fed through the gate G_5 to the cathodes of the valves T_7 and T_8 but if the valve T_8 has been rendered conductive prior to a transfer impulse being applied to the cathodes of the valves T_7 and T_8, the valve T_8 is rendered nonconductive and the valve T_7 conductive.

The valve T_5 hereinbefore referred to is so interconnected with the valve T_6 that when one of the valves is rendered conductive the other is rendered nonconductive, and further, when the machine is not being operated the valves T_2, T_5 and T_9 are all conductive and the valves T_1, T_3, T_4, T_7, T_8 and T_6 nonconductive.

The trigger electrode T^1_6 of the valve T_6 is connected through a contact CS^1_5 and a common terminal CS^2_5 of a two-way switch CS_5 to the "one shot device" in a manner more specifically described in connection with FIGURES 3 to 12. The two-way switch CS_5 in the alternative position thereof, with the common terminal CS^2_5 in engagement with the contact CS^3_5, connects the trigger electrode of the valve T_1 to the one shot device. Therefore in the case of calculations involving addition, division and subtraction the one shot device is connected to the trigger electrode T^1_1 of the valve T_1 whilst in the case where multiplication is to be effected the switch CS_5 connects the one shot device to the trigger electrode of the valve T_6. In order to effect multiplication there are provided six switches CS_3, CS_4, CS_5, CS_7, CS_8 and CS_9. The switches are shown with arithmetical signs indicating the positions to which they must be set in order to

effect multiplication. It will be observed that when set for multiplication the common terminal of the switch CS_3 is connected to the anode T^1_7 of the valve T_7 and the switch CS_4 connects the anode T^3_1 of the valve T_1 as for addition. The electrode H_2 of the accumulator H_1 is connected to the contact CS^1_7 of the switch CS_7 and to the commutator segment H. On multiplication the switch CS_5 connects the trigger electrode T^1_6 of the valve T_6, through the studs E—E to the one shot device U. The electrode L_{11} of the counter tube L is connected through the switch CS_8 and the studs 3—3 to the anode T^3_1 of the valve T_1. The switch CS_9 is arranged through the studs G—G to apply a positive pulse to the trigger electrode T^2_5 of the valve T_5 when the studs G—G are bridged and shorted by the brush F^1. The anode T^2_8 of the valve T_3 is connected as hereinbefore stated to the batches of studs O_{12} to O_{21}, P_{12} to P_{21}, Q_{12} to Q_{21}, R_{12} to R_{21}, and so on up to the studs Y_{12} to Y_{21} and Z_{12} to Z_{21} of the sets of studs which are swept by the brush F^1 and arranged to be bridged and short circuited successively by the brush F^1 with the commutator segments Z_9, Y_9 and so on up to P_9 and O_9. With the switches set for multiplication it will be observed that when the brush F_1 bridges the studs E—E with the one shot device in the position illustrated in the drawing, that is after any one key of a set of multiplier keys have been actuated, an impulse is transmitted from the one shot device through the contacts CS^1_5 and CS^2_5 of the switch CS_5 to the trigger electrode T^1_6 of the valve T_6 whereby the valve T_6 is rendered conductive and the valve T_5 nonconductive. The effect of the valve T_5 being rendered nonconductive is to place a zero voltage from the anode T^1_5 upon the studs E^0 associated with and in advance of each of the commutator segments Z_9, Y_9 and so on up to R_9, P_9 and O_9, and as the brush F^1 short circuits the said E^0 stud with the associated E^0 stud arranged in advance of each of the batch of studs O_{12} to O_{21}, P_{12} to P_{21}, Q_{12} to Q_{21}, R_{12} to R_{21} and so on up to Y_{12} to Y_{21} and Z_{12} to Z_{21}, zero potential is applied to the negative biassed trigger electrode T^1_8 of the valve T_8, which is thereupon rendered conductive and applies a potential to all the studs O_{12} to O_{21}, P_{12} to P_{21}, Q_{12} to Q_{21}, R_{12} to R_{21} and so on up to Y_{12} to Y_{21} and Z_{12} to Z_{21}. It will be observed that as the valve T_8 is rendered conductive the valve T_7 is nonconductive and therefore does not place a potential upon the studs O_{22} to O_{30}, P_{22} to P_{30}, Q_{22} to Q_{30}, R_{22} to R_{30}, and so on up to Y_{22} to Y_{30} and Z_{22} to Z_{30}. Consequently, if the brush F^1 is arranged to make one complete revolution and to sweep over all the studs of each batch of studs ten impulses will be transmitted from each batch of studs through the commutator segments associated with the said batches of studs and the accumulators connected to the said commutator segments. Each accumulator will be stepped up ten places.

It will be observed from FIGURE 1 that the studs O_{12} to O_{21}, P_{12} to P_{21}, Q_{12} to Q_{21} and so on up to the studs Y_{12} to Y_{21} and Z_{12} to Z_{21} are associated respectively with the commutator segments Z_9, Y_9, X_9, W_9 and so on up to P_9 and O_9 and that the studs O_{22} to O_{30}, P_{22} to P_{30}, Q_{22} to Q_{30}, R_{22} to R_{30} and so on up to Y_{22} to Y_{30} and Z_{22} to Z_{30} are associated respectively with the commutators L, Z_9, Y_9, X_9 and so on up to Q_9, P_9.

Assuming that the numerals 4, 1 and 3 are registered in the accumulators O_{10}, P_{10} and Q_{10} and the switches CS_3, CS_4, CS_5, CS_7, CS_8 and CS_9 are all set to multiplication, it will be readily appreciated that upon the brush F^1 bridging and short circuiting the contacts E—E an impulse will be sent from the one shot device U through the common terminal CS^2_5 of the two-way switch CS_5 to the contact CS^1_5 and thence to the trigger electrode T^1_6 of the valve T_6. The valve T_6 is rendered conductive and the valve T_5 nonconductive. The zero potential from the anode T^1_5 of the valve T_5 is applied to the contacts E^0 mounted in advance of the commutator segments Z_9, Y_9, X_9, W_9 and so on up to P_9 and O_9 and short circuited by the brush F^1 to the trigger electrode T^1_8 of the valve T_8 which will be rendered conductive and cause a potential from the anode T^2_8 to be applied to the studs O_{12} to O_{21}, P_{12} to P_{21}, Q_{12} to Q_{21}, R_{12} to R_{21} and so on up to Y_{12} to Y_{21} and Z_{12} to Z_{21}. The brush F^1 sweeping over the 0 contacts and the commutator Z_9 will send ten impulses from the O_{12} to O_{21} batch of studs to the accumulator Z_{10} and a transfer impulse will be sent from the accumulator Z_{10} through the diode or any other unidirectional electronic tube Z_{11} and the gate G_5 to the cathodes T^2_7 and T^3_8 of the valves T_7 and T_8, whereupon the valve T_8 will be rendered nonconductive and the valve T_7 conductive applying a potential from the valve T_7 to all the studs O_{22} to O_{30}, P_{22} to P_{30} and so on up to Y_{22} to Y_{30} and Z_{22} to Z_{30}. In view of the fact that when this occurs the brush F^2 has passed over the stud O_{30} and the commutator segment L nothing will result from the valve T_7 having been rendered conductive. Upon the brush F_1 reaching the pair of studs F^0—F^0 mounted in advance of P_{12} to P_{21} batch of studs and the commutator segment Y_9, a positive impulse will be transmitted to the cathodes T^3_8 and T^2_7 of the valves T_8 and T_7 which ensures that the valve T_7 is rendered nonconductive. When the brush F^1 bridges the studs E^0 mounted in advance of the P_{12} to P_{21} batch of studs and the associated commutator segment Y_9 a pulse is applied to the trigger electrode of the valve T_8 and this valve is made conductive. As a result, when the brush F^1 sweeps over the contacts P_{12} to P_{21}, ten impulses are transmitted to the accumulator Y_{10} which will record zero, but an impulse will be transmitted through the diode or any other unidirectional electronic tube Y_{11} through the gate G_5 to the valve T_8 which is again rendered nonconductive, and the valve T_7 conductive which in turn is rendered nonconductive by the bridging of the studs F^0—F^0 mounted in advance of the Q studs and X_9 commutator segment.

The above procedure will continue until the brush F^1 reaches the X_{12} X_{21} set of studs (not shown), whereupon impulses will be sent to the commutator segment Q_9 and thence to the accumulator Q_{10}. In view of the fact that the accumulator Q_{10} is recording 3 the brush F^1 will, after having swept over seven studs cause the accumulator Q_{10} to register zero and an impulse will be transmitted through the diode or any other unidirectional electronic tube Q_{11} to the cathode T^3_8 of the valve T_8 which will render the valve T_8 nonconductive and the valve T_7 conductive whereupon three impulses will be transmitted from the studs X_{28}, X_{29} and X_{30} (not shown) through the brush F^2 to the commutator R_9 (not shown) causing the accumulator R_{10} to read 3. As the brush F_1 sweeps over the remaining commutator segments P_9 and O_9 associated with the batches of studs Y_{12} to Y_{21} and Z_{12} to Z_{21}, ten impulses will be transmitted, in the manner indicated above from the Y_{12} to Y_{21} and Z_{12} to Z_{21} batches of studs to the accumulators P_{10} and O_{10} causing them successively to register zero and at the same time cause the valve T_8 to become nonconductive and the valve T_7 conductive with the result that the accumulators P_{10}, Q_{10} and R_{10} will register 4, 1 and 3 whilst the accumulator O_{10} will read zero. It will be observed that by the above operation the numerals originally registered in the accumulators O_{10}, P_{10} and Q_{10} have all been stepped up one order, thereby multiplying the quantity originally shown on the accumulators by ten.

A calculation involving multiplication is carried into effect upon the machine hereinbefore described with reference to the accompanying drawings by, firstly, setting the machine for multiplication and then actuating keys of selected orders of keys which correspond to the number of the multiplicand. Each key representing a number of the multiplicand upon being actuated is held in its actuated position by means of a key locking mechanism. The highest digit of the multiplier is then set up upon the counter tube L by the depression of the appropriate multi-

plier key. Upon the actuation of the multiplier key in the manner hereinafter described the "one shot device" is set with the contact U_1 of the two-way switch U in contact with the contact U_3. The brush F^1 being set in rotation by the actuation of a key marked "X," in a manner hereinafter described, makes a contact in its path over the commutator plate with the studs E—E, causing a potential from the one shot device U to be applied to the trigger electrode T^1_6 of the valve T_6, thereby rendering the valve T_6 conductive and the valve T_5 nonconductive. Upon the valve T_5 being rendered nonconductive zero potential is applied from the anode T^1_5 thereof to all the contacts E^0 disposed in advance of the commutator segments Z_9, Y_9 and so on up to Q_9, P_9 and O_9 engageable by brush F^1, with the result that zero potential is applied to the trigger electrode T^1_8 of the valve T_8 which thereby renders the same conductive. Upon the valve T_8 being rendered conductive a potential is applied from the anode T^2_8 thereof to the contacts O_{12} to O_{21}, P_{12} to P_{21}, and so on up to Y_{12} to Y_{21} and Z_{12} to Z_{21}, so that as the brush F_1 sweeps over the contacts O_{12} to O_{21} up to Z_{12} to Z_{21} impulses are transmitted to the commutator segments Z_9, Y_9 and so on up to the commutator segments R_9, Q_9, P_9 and O_9, and therefrom to the accumulators Z_{10}, Y_{10} and so on to R_{10}, Q_{10}, P_{10} and O_{10}.

More specifically, when the brush F^1 has swept over the studs O_{12} to O_{21} it bridges the stud F^0 arranged in advance of the studs P_{12} to P_{21} and also the stud F^0 arranged in advance of the commutator segment Y_9 causing a positive potential to be applied to the cathode T^3_8 of the valve T_8, thereby rendering the valve T_7 conductive.

Upon the brush F^1 sweeping over the studs E^0—E^0 arranged in advance of the studs P_{12} to P_{21}, a zero potential is once again applied to the trigger of the valve T_8 causing the valve T_7 to be nonconductive. By the further movement of the brush F^1 the studs P_{12} to P_{21} are bridged successively with the commutator segment Y_9 and ten impulses are transmitted to the numerator Y_{10}. The above sequence of operations is carried through the twelve orders leaving all the numerators reading zero, as they were at the start of the operation.

The continued movement of the brush F^1 will cause it to bridge the studs G—G with the result that a positive potential will be applied to the trigger electrode T^2_5 of the valve T_5, thereby rendering the valve T_5 conductive and the valve T_6 nonconductive.

When the valve T_6 is rendered nonconductive it applies zero potential from the anode T^2_6 to the trigger electrode T^1_1 of the valve T_1 rendering the valve T_1 conductive and the valve T_2 nonconductive.

The valve T_1 being rendered conductive applies potentials through the common terminals CS^3_4 and contact of the two-way switch CS_4 to the S pairs of contacts of the keys of the multiplicand which have been actuated and held actuated in the various orders of keys and also through the pairs of contacts K of the same keys to the studs of the various orders of keys. Thus, for example, if the multiplicand comprises the numeral 851 the stud O_0 of the first order of keys will have a potential applied to it, the studs P_0, P_1, P_2, P_3 and P_4 of the second order of keys will have a potential applied to them and the studs Q_0, Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, and Q_7 of the third order of keys will have a potential applied to them. As the brush F sweeps over the various studs of the first three orders of keys, it will transfer one pulse at each revolution into the accumulator Q_{10}, it will transmit five impulses into the accumulator P_{10}, and it will transmit eight impulses into the accumulator Q_{10}.

Assuming that the multiplier is 97 and the ninth multiplier key has been actuated, a glow will appear at the first cathode L^1_1 of the counter tube L.

Subsequent to the shift operation, after the brush F has completed one revolution over the various studs O_0 to O_8 up to Z_0 to Z_8 of the different orders of keys, the brush F^1 will have bridged the studs 3—3 and will have thereby caused an impulse from the anode of T_2 to be delivered through switch CS_8 to the driving electrode L_{11} so that the glow in the counter L will pass from the first cathode L^1_1 to the second cathode L^1_2. After the brush F has made two revolutions the accumulator P_{10} will read zero, having had ten impulses transmitted to it, and in consequence will have passed an impulse through the diode P_{11} and G_5 to the trigger electrode T^2_3 of the valve T_3. Upon the further movement of the brush F over the studs C B and C_1 B_1 the valve T_3 will be rendered nonconductive and the valve T_4 conductive, applying a potential to the stud A which thereupon applies an impulse to the commutator segment Q_9 of the accumulator Q_{10} which is therefore stepped up one before the brush F commences to step over the studs Q_0 to Q_9.

The movement of the brush F over the studs O_0 to O_8 up to Z_0 to Z_8 will continue until the counter tube L has stepped up nine steps, one step at a time, by the brush F^1 bridging the studs 3—3 at each revolution and applying a potential to the drive electrode L_{11}, whereupon an impulse will be transmitted from the electrode L^1_0 to the trigger electrode T^1_2 of the valve T_2 which thereupon renders the valve T_2 conductive and the valve T_1 nonconductive.

After the multiplicand has been introduced nine times into the accumulators O_{11}, P_{11}, Q_{11} and R_{11} the numerals in the various accumulators will come to rest whereupon the operator inserts the next highest numeral of the multiplier into the multiplier column whereupon the machine firstly moves all the numerals registered in the accumulators each into its next higher order, whereupon the multiplication by the next digit of the multiplier is effected in the manner hereinbefore described.

Thus to effect multiplication, the machine is first set for multiplication by operation of the multiplication key **39** of FIG. 3. Operation of this key sets the switches CS_3, CS_4, CS_5, CS_7, CS_8 and CS_9 to the positions indicated therefor in FIG. 1 by the multiplication sign. It also changes the machine from key responsive to key set operation, so that keys on the main keyboard once punched will remain depressed until a cancel key **89** or **90** is operated.

The multiplicand is thereafter inserted into the main keyboard, preferably with the lowest ordered digit thereof in the lowest order of keys. The multiplier key in column **38** corresponding to the digit of highest order in the multiplier is then operated. This starts the motor, operates the so-called one-shot device and closes a normally open switch connecting one of the cathodes of the multicathode counter tube L, which controls the number of addition cycles which will be automatically performed and initiates a shift operation. During this shift operation, beginning with the accumulator of highest order (except the carry accumulator H), the contents of each accumulator is shifted into the accumulator of next higher order, the contents of the accumulator of highest order being shifted into accumulator H. Assuming that the machine had been reset so that all accumulators read zero on insertion of the multiplicand into the main keyboard, as is desirable, this shift operation makes no change in the appearance of the accumulators. It is immediately followed, faster than the eye can perceive in practice, by addition of the multiplicand into the accumulators a number of times equal to the value of the operated multiplier key, the glow in counter tube L shifting one step towards the L^1_0 cathode on each such addition until it reaches the cathode L^1_0, whereupon the indicators come to rest.

The multiplier key corresponding to the multiplier digit of next lower order is then operated and the process is repeated. In this case however, since the accumulators are not initially at zero, the shift operation changes the status of the register, effectively multiplying its contents by ten. This shift operation is immediately followed, again before the numeral wheels **70** come to a stop, by addition into the register of the multiplicand a number of times

equal to the value of the operated multiplier key, representing the second multiplier digit.

In the machine of FIG. 1 which has been described, the "shift" operation which precedes the working out of each multiplier digit is a shift to the left. For this reason, the multiplier digits are employed successively beginning with the multiplier digit of highest order. Consistently with the invention it is possible to construct the machine to shift the partial products to the right instead of to the left. In such a machine, multiplication would start with the multiplier digit of lowest order.

To the apparatus of FIG. 1 thus far described, a number of further elements are added for the performance of division. These elements, shown in FIG. 1, will be further described hereafter. Essentially they comprise the following:

(1) In the first added set of studs, thirteenth and fourteenth batches of ten studs H_{12} to H_{21} and L_{12} to L_{21}, each of these batches being preceded by an E^0 and an F^0 stud. The studs H_{12} to H_{21} are connected, like the O through Z batches of studs in the first added set, to the plate of T_8. The studs L_{12} to L_{21} are connected to the plate of T_6. The E^0 and F^0 studs preceding the H_{12} to H_{21} and L_{12} to L_{21} batches are connected respectively, like the other E^0 and F^0 studs of the first added row, to T_8 grid and to the T_7, T_8 cathodes.

(2) In the second set of added studs, thirteenth and fourteenth batches of nine studs H_{22} to H_{30} and L_{22} to L_{30}.

(3) A connection via switch CS_3 whereby, in the second added set of studs, the batch O_{22} to O_{30} is connected to the plate of T_7, as in multiplication, whereas the remaining P through Z, H and L batches are connected instead to the plate of T_8.

(4) Thirteenth and fourteenth commutator segments H and L associable by brush F^1 with the studs H_{12} to H_{21} and L_{12} to L_{21}. These segments H and L are preceded by E^0 and F^0 studs aligned with the similarly identified studs preceding the H_{12} to H_{21} and L_{12} to L_{21} studs in the first added row and connected respectively to the plate of T_5 and to a source of positive potential.

(5) Thirteenth and fourteenth commutator segments O_9 and H associable by brush F^2 with the studs H_{22} to H_{30} and L_{22} to L_{30}.

(6) A connection from the 0 cathode of the carry accumulator H_1 to the carry bus J.

(7) A connection from the 0 cathode L^1_0 of the control tube to the bus J via the switch labelled in FIG. 1 "Closed in Division Only."

The commutator segments mentioned in the fourth and fifth numbered paragraphs immediately preceding are short-circuited to the commutator segments of like designation already described in connection with the application of the machine of FIG. 1 to addition, subtraction and multiplication.

The machine will be hereinafter described with reference to a calculation involving division and a method of effecting such a calculation.

Dealing more specifically with the arrangement for achieving division, a machine constructed in accordance with the present invention is provided in addition to the arrangement hereinbefore described, with two sets of studs L and H in addition to the O to Z studs. The said two sets of studs are associated with a valve operable to apply simultaneously or alternatively a potential to both of the said sets of studs. Each batch of studs of a set of studs is associated with a commutator segment of a particular order of keys whilst the corresponding batch of studs of the other set of studs is associated with the commutator segment of the next adjacent order of keys.

Each of the additional sets of studs and their associated commutator segments hereinbefore referred to are arranged to be swept by rotatable brushes F^1 and F^2. The additional sets of studs and their associated commutator segments are preferably arranged upon a commutator plate in which both the studs and the commutator segments comprise printed circuits or studs and commutator segments embedded in suitable material or in any other suitable manner. The brushes are mounted so as to rotate about the axis of the said commutator plate and bridge so as successively to short circuit each stud of a set of studs and the associated commutator segment.

In order to effect a calculation in division it is first necessary to set the machine for addition and, the register first having been cleared, to insert the dividend into the register with the most significant digit thereof in the highest order of keys, that is, in the example illustrated in FIGURE 1, in the twelfth order of keys. When the divident has been registered in the appropriate accumulators of the register the machine is set for division by operation of the key **93**. This sets switches CS_3, CS_4, CS_5, CS_7, CS_8 and CS_9 and the "Closed in Division Only" switch to the positions indicated therefor in FIG. 1 for division. It also sets the counting tube L with the glow therein at the cathode L^1_9. The divisor is then inserted into the main keyboard of the machine with the most significant numeral thereof in the highest order of keys, namely in the twelfth order of keys. The actuation of the key marked "DIVIDE" in FIG. 3 causes the one shot device U to operate and starts a division cycle.

Upon the actuation of the one shot device U an impulse is transmitted to the trigger electrode T^1_1 of the valve T_1 thereby rendering the same conductive and the valve T_2 nonconductive. Upon the valve T_1 being rendered conductive a potential is applied through the switch CS_4 and the K switches to the various orders of studs with the result that as the brush F sweeps over the stud O_0 to O_8, P_0 to P_8 and so on up to Y_0 to Y_8 and Z_0 to Z_8, the complement of the divisor is added into the dividend. If, as a result of the addition of the complement of the divisor to the dividend a transfer is effected from the accumulator Z_{10} to the accumulator H_1 the valve T_9 (of the transfer device comprising the arrangement of valves T_3, T_4, and T_9 hereinbefore described), will be rendered non-conductive and consequently zero potential will be applied from the anode $T_2{}^9$ to one stud **4** of the pair of studs **4—4** which when the studs **4—4** are bridged by the brush F^1 will cause a zero potential to be applied to the drive electrode L^{11} of the stepping electronic tube L and consequently the stepping electronic tube L is unaffected. The brushes then perform a second cycle in which the complement of the divisor is again added to the dividend, and this process continues until on such an addition no carry into H_1 is produced.

In that event the first quotient digit has been extracted (at H_1). This is followed without stopping of the brushes, by what may be called a shift and complement operation. The result of this operation, presently to be described in detail, is to transfer the content of each of the accumulators O_{10} to Y_{10} into the accumulator of next higher order and to replace it there by its nines complement, to transfer the content of Z_{10} in uncomplemented form into the control tube L and in nines complemented form into H_1, and the content of H_{10} in nines complemented form into O_{10}. The machine then comes to a stop, with the first quotient digit appearing in nines complemented form at O_{10}. Extraction of the second quotient digit is then initiated by a second operation of the DIVIDE key of FIG. 3, and when the indicator wheels **70** next come to a stop, at the end of the shift and complement operation which is the concluding effect of the second operation of that key, accumulators P_{10} and O_{10} contain respectively the first and second quotient digits, both in true form. Quotient digits are thus extracted in pairs.

To revert now to the explanation previously undertaken, when during the extraction of the first quotient digit an addition of the divisor complement does not effect a transfer or carry from the accumulator Z_{10} to the accumulator H_1, the valve T_9 will remain conductive and a potential of −150 volts will be applied as the brush F^1 bridges the studs **4—4**, to the drive electrode L^{11} of