made a mistake in supposing that the policy carried out by Sir George Clerk at an early date, or that of Sir Bartle Frere at a more recent date, were the policies of those distinguished servants of the Crown. Sir George Clerk went out to pursue a policy which had been resolved upon by the Government of this country, and he was spoken of throughout South Africa with respect, as having done a most unwise thing in a very able way; while the policy which Sir Bartle Frere was sent to carry out was an impossible one, and this ought to be borne in mind. For the purpose of any healthy discussion of the affairs of South Africa they must, however, shake themselves loose from personalities, and try to attain a stable footing for the consideration of the future of that important country.

THIRTEENTH ORDINARY MEETING.

Wednesday, March 3, 1886; Professor W. CAWTHORN UNWIN, M.Inst.C.E., in the chair.

The following candidates were proposed for election as members of the Society:—

Blythe, Herbert, Church, Lancashire.
Brookes, Thomas William, The Grange, Nightingale-lane, S.W.
Brown, William A., Cliff Lodge, Greenock.
Field, George W., 23, Park-street, Park-lane, W.
Peter, Otho Bathurst, Northernhaye, Launceston, Cornwall.
Tate, Edwin, 21, Mincing-lane, E.C.
Thompson, James Elliot, Thornhill-park, Sunderland.

The following candidates were balloted for and duly elected members of the Society:—

Bedford, Duke of, K.G., 81, Eaton-square, S.W.
Fletcher, Frederick W., 56, Hamilton-road, Highbury, N.
Forth, Henry, New Basford, Nottingham.
Knightley, Thomas Edward, 106, Cannon-street, E.C.
Peebles, Alexander, 23, Marlborough-road, St. John's-wood, N.W.
Spray, Henry John, 23, Arlington-square, N.

The paper read was—

CALCULATING MACHINES.

By C. V. Boys, A.R.S.M.

Among the philosophical instruments exhibited at the International Inventions Exhibition, so large a proportion might be classed under the heading calculating machines, and these attracted so much attention, that it was suggested that a paper on this subject alone would be suitable at the present time. At the invitation of the Council of the Society of Arts, I have therefore prepared a description of the various calculating machines which were exhibited. But as it seemed that it would not be right to exclude from this paper all account of similar or corresponding machines, because they did not happen to form part of the collection at South Kensington last year, I have attempted to make what I have to say more valuable, by including an account of other machines which serve a similar purpose to those exhibited. In doing so, however, I have of necessity widened the subject to such an extent that in many cases little more than bare mention of a machine is possible.

Of the simple arithmetical processes, counting is the first and most essential; in the same way among calculating machines, apparatus for counting is the essence of all depending on wheel-work. I do not intend to deal with the subject of counting machines, of which a very great number were exhibited, because counting is not calculating. I would, however, point out that there are two types of counting machines, the first a plain train of wheel-work, such as is generally used in gas meters, in which each arbor turns ten times as slowly as the one on its right. Here the wheels cannot fail to act, the record must be true, but this kind is subject to the objection that the numbers on view change gradually, so that it is not always possible to say what figure ought to be read unless the next one to the right be read first, and even then mistakes are sometimes made. They are, of course, unfit for printing a series of numbers. In the other type of counting machine each arbor is normally at rest, and only moves on one figure when the next to the right passes from 9 to 0. If the counting proceeds at as low rate, the mere friction opposing the motion of each wheel may be sufficient to hold it at rest, in which case any wheel can be moved by hand either way unless the next wheel to the right happens to be passing from 9 to 0. At such times only are the wheels locked. If the counting proceed at a high speed, the momentum would carry each counting wheel as liberated a little too far unless a strong click spring, an efficient brake, or some locking contrivance, were applied.

Addition and its converse, subtraction, are, next to counting, the most simple of all arithmetical operations, they are in fact so simple, that machines for adding a series of numbers, though easily made, do not serve any really useful purpose; for it would take, perhaps, longer to set all the numbers in a column of figures on to an adding machine than it would to add them without the machine; moreover, there is the possibility of setting a wrong figure which cannot be discovered afterwards, so that there is not even the recommendation that mistakes are impossible. No adding machines were exhibited at the Inventions Exhibition, that is if we except arithmometers, which in reality are adding machines of great power, or counting machines, which, of course, are only capable of continually adding 1. Adding machines were made more than 200 years ago, but, for the reasons stated, have not come into use. An early one, by Sir Samuel Morland, is exhibited at South Kensington, together with a book on the subject by the same author, dedicated to Charles II. A series of circles divided into 10 parts each, and three others divided into 20, 12, and 4 parts for shillings, pence, and farthings, are arranged on a block, so that when any one completes a turn it shows on an auxiliary circle that one has to be carried to the next circle to the left. Each circle is then moved through as many divisions as represent the number in the corresponding column to be added, a handle and stop being provided for the purpose, and so the total, at any period of the operation, can be read. I am able to show another of Sir Samuel Morland's adding machines belonging to General Babbage. In arithmometers and difference engines the adding is performed in precisely the same way, but the machine, instead of the hand, performs the operation of adding and carrying. In the *Scientific American* of August 29, 1885, there is an account of a recent adding machine invented by the late Mr. W. J. Macnider.

Passing on to the machines for multiplying and dividing, we find a great number. Here the length of the calculation is so great compared with the number of figures required in the setting, that a machine which will quickly perform the operation is well worth using. Of wheel-work multiplying machines two were exhibited at the Inventions Exhibition, one by Tate and the other by Edmondson, but as these machines are developments of much older ones, a few words on their origin may be desirable.

The earliest machine, if it can be so called, for simplifying the operation of multiplication, is due to Napier, the inventor of logarithms, and is known as Napier's bones. These are nothing more than a series of vertical slices from ordinary multiplication tables. When they are arranged so that the top figures are, in order, the figures of the multiplicand, the series of lines which must be added for the product can be read with great facility.

Viscount Mahon, afterwards Earl Stanhope, was the first to make practically useful machines for multiplying and dividing. He made four machines which still exist. I am able, through the kindness of General Babbage, to show two made in 1775 and 1777. He introduced that which is essential in a calculating machine, viz., the possibility of setting one factor so that at each turn of the handle as many teeth shall operate in the place of each digit, as each digit represents. Thus, if 7201 were to be set, then in the units place one tooth only would operate on the first of the set of dials on which the answer is read, and move it forward 1 at each turn. In the second place nothing would happen, in the third two teeth would act, and in the fourth 7. Thus, at every turn, the number 7201 would be added to whatever number happened to be on the machine. When the handle has been turned as many times as corresponds to the last figure of the other factor, say five times, the number set, 7201, has been added five times, or has been multiplied by five; the number which is set, together with the plate-wheels and appendages on which it is set, are then shifted one place to the left, or the recording dials one place to the right, and the handle turned as many times as corresponds with the last figure but one of the multiplier, and so on till the result is complete. In the 1777 machine, the figures are set upon a cylinder which, at a certain point of its revolution, shifts slightly along its axis, and throws out of gear all the teeth upon its surface which were operating upon the recording dials. In the 1775 machine, the stepped reckoner—a series of nine teeth increasing in length by steps from a short one to one nine times as long, a contrivance used in most modern arithmometers—was first employed. In this machine, however, the slides move longitudinally instead of turning in the operation.

In the 1851 Exhibition two instruments were awarded medals, the first by Staffel, a Russian, which has since been lost sight of, and the other by Thomas de Colmar, now extensively used in this country. This machine is so well known that more than a short description of it is unnecessary. The reversing motion of three bevel wheels, the eraser for clearing off all figures from the machine, and the use of quotient holes, which act as counters to show how many times the handle has been turned in each position of the number slides (and on which, therefore, one of the factors in multiplication becomes recorded, instead of being reduced to nothing, as in the Stanhope machine), are, I believe, due to de Colmar. The arrangement of this machine, of which I have a specimen on the table, is easily understood. There are eight (or more or less) parallel axes all in gear with a long shaft turned by bevel gearing by a handle. Each axis turns once for every turn of the handle. There is on each axis a "stepped reckoner," already described. To the left of each of these axes are eight auxiliary axes, carrying sliding spur-wheels, which may be set by thumb-pieces, so as to gear with one, two, three, or any number up to nine of the teeth on the stepped reckoner. Each auxiliary axis carries a pair of bevel wheels set facing one another, and between each of these pairs is a horizontal bevel, gearing with either the front or the back bevel. By moving a handle, all the pairs can be shifted so as to reverse the motion of the horizontal bevels. Each horizontal bevel carries a number disc. The part of the frame carrying the number discs can be raised and slid along so as to bring the middle one of the sixteen number discs over any one of the pairs of bevels. A series of counting wheels show the number of turns of the handle in each position of the moving slide, if the number does not exceed nine. To prevent overshooting, every auxiliary axis is supplied with a locking plate, so that it is suddenly stopped when the stepped reckoner has done its work. So far the machine can be employed for multiplication, or inversely for division, but unless each number disc were made to move on one tooth as soon as the next one to the right completed each turn, the answers given would not be correct. The mechanism for carrying the tens is always the most troublesome to arrange in a calculating machine. This cannot be done during the calculating part of the rotation for obvious reasons. It is necessary, then, for each dial to make a signal when a carriage is necessary. Again, all the carriages cannot be effected at the same time, for if the last only of a series of nines shows that a carriage is due, it only would change to zero if the carriages were effected simultaneously, while it is clear that all should change to zero. It is necessary, therefore, to perform the carriage of each one just before the next to the left. In the Stanhope machines on the table, this result is obtained by an ingenious contrivance which I cannot easily describe. In the de Colmar machine each number disc, when it completes its revolution, presses back a small lever, which pushes a tenth tooth into temporary gear on the reckoner of the next barrel to the left. Moreover, in passing from right to left each barrel lags one tooth behind the last, and can thus carry one if necessary.

Of the two machines exhibited last year, Tate's is, in its general appearance and working, identical with the de Colmar machine, and Edmondson's is but a step removed. As I had an opportunity of examining these machines very closely while the Exhibition was open, and, through the kindness of the inventors, I have lately had one of each and a de Colmar machine in frequent use, perhaps some remarks on the relations between these three machines may be of interest. I hope I shall succeed in treating this rather delicate matter without wounding the feelings of anyone in this room; I am sure those who are most concerned, to whom I am under deep obligations, will give me credit for being impartial. If I should give in any way a false impression, I hope that Mr. Edmondson or Mr. Tate, will remove that impression in the discussion.

I have said that Tate's machine is in appearance identical with the de Colmar machine. This refers to the general design and to the outside. When opened, at once a great difference is apparent, the most important being the substitution of the best English for what can hardly be considered the best foreign work. It is impossible to speak too highly of the beautiful finish, the accuracy of construction, or the excellent materials which are employed in every part. So far, Tate's machine might be nothing more than the French machine better made. There are, however, improvements in detail in the design. In the first place, the erasing mechanism is, in practice, far more convenient than in the French machine. In the place of a long rack which pulls each dial round until, in consequence of an absent tooth, it stops at 0, an operation performed by twisting a milled head against a spring for one set of dials, and another in the same way for the other set, it is merely necessary to jerk a handle one way to erase one set of numbers, and the other way to erase the other set. The dials are brought accurately to zero by a long steel rod, acting on cams, exactly in the same way that the second hand of a stop-watch is set back to sixty seconds. Another improvement, or change as it has been considered, is the removal of the stops, or cams and cam-guards, which prevent the dials and auxiliary arbors from overshooting their mark in obedience to their momentum. These guards, which act much in the same way that the Geneva stop prevents overwinding of a watch, suddenly bring the dials to rest. In place of these, Tate employs a series of springs under which these parts move stiffly. This, at first sight, seems inadequate, in view of the great speed at which the machines are run. I have done my best to try and make one of these overshoot, but without success. I thought it would be interesting to find how far the dial must really move before the spring brings it to rest. I therefore made the following measures (on the C.G.S. system). The moment of inertia of the dial and its attachments is 10·9, and of the secondary axis and wheels 6·7. If we take a working speed of four turns of the handle a second, we shall find that the angular velocity of these parts is in radian measure 16π or 50·4, and therefore the energy of motion is 22,370 units. The springs are adjusted until they resist a force equal to the weight of a kilog. applied to the teeth, which represents a turning moment of 784,800 units. These figures make the greatest possible amount of overshooting to be about $1\frac{1}{2}°$. Now as no error could be introduced unless an angle approaching 18° were reached, it is evident that the factor of safety is fully 10, and that any fears as to the efficiency of this brake are unfounded. The brake has been found an efficient means of checking the motion of heavier things than the wheels of a calculating machine.

Against this brake may be urged the fact that more mechanical work is spent in driving the machine, but this is so slight that it can hardly be urged with propriety. The remaining improvement relates to the method of holding the carrying arm in its working or its idle position. To what extent the old-fashioned double spring is likely to fail I am not in a position to say; I think I may safely say that the simple spring that takes the place of this double spring can never fail.

Edmondson's machine differs from that of de Colmar, first in its general form. It is not a straight but a circular machine. The line of product holes is as it were bent round so as to make a circle of twenty holes. Outside this, at the back, are a series of radial slides for the setting of numbers. Some of the product holes also serve for quotient holes, there being no special row of dials to count the revolution of the handle. The combination of stepped reckoners, of reversing bevels and number wheels, is identical with that in the de Colmar machine, the only apparent difference depending on their radial arrangement. The locking apparatus is more perfect, for at no part of the revolution can any one of the number wheels be ever moved except by the machine, whereas in the de Colmar machine each number wheel, after being stopped, is for a short time free. The number of turns of the handle may or may not be counted at pleasure, and a choice of three positions is given on the circle of holes on which to make this record. This record may be either forwards or backwards, and so the multiplier may either be worked on to the machine, as in the de Colmar or Tate machine, or if it is already on the machine, as the result of a previous operation, it can—by making the counting proceed backwards—be worked off and leave nothing. The same is true of the dividend in division. This is peculiar to Edmondson's machine, and is a certain advance, for it takes as long to set figures on a machine as it does to make the calculation, and such setting introduces the possibility of error on the operator's part.

The eraser is the same in principle as that in the de Colmar machine, but its application is peculiar on account of the circular form. On lifting up the erasing handle, the central disc on which are all the number wheels is raised out of gear; it can then be rotated, and each disc in turn is set to zero. Here, again, is something peculiar to the machine. Any of the numbers may be erased or left as they were at will. I understand from Mr. Tate that Mr. Edmondson was not the first to make a circular machine, but that Hahn, of Stuttgart, made one 77 years ago, and that that form was then discarded. I know nothing of this other machine, nor is there any evidence that the peculiarities of Edmondson's machine—the locking, the possibility of working on or off, the absence of quotient holes and the eraser are not entirely original. I have more than once heard it urged against Edmondson's machines as made (this of course does not refer to the design or invention, but to the manufacture), that it is roughly made. This is true in so far as the surfaces which do nothing are concerned, for the castings in these places have not even been filed smooth. In this respect I think Mr. Edmondson sets an example which instrument makers would do well to follow. If the care and time which are devoted to the finishing of parts which have nothing to do with the working of an instrument were spent instead in more carefully fitting and adjusting the working parts, we who use them would certainly be better off, but then the purchasing public would not be so well satisfied. Instrument makers to whom I have occasionally made this complaint, assure me that they cannot trust their workmen to do any work accurately unless every part is highly finished, for it seems these men cannot understand that what they call an unfinished instrument can be fit for anything but second rate work. Here, surely, is an opportunity for the technical educationist. Edmondson has finished only the working parts, but these are done sufficiently well to work correctly. In the finish of the working parts and in the material, I should say that Tate's machine is not equalled by any. Against the superiority in this respect of Tate's machine must be set the fact that the cost is exactly double. On the other hand, against the increased powers of Edmondson's machine must be set the fact that Tate's machine has a slight advantage over Edmondson's on account of the slope of the surface towards the operator, the straight rows of holes, and the fact that the number slides are nearest the operator, and are parallel, as in the original de Colmar machine.

I think that what I have said is sufficient to show that each machine is in some respects better than the other, and that both are superior to the arithmometers originally made by de Colmar.

Of other calculating machines I have but little to say. A circular machine, by Wiberg, of Sweden, was exhibited in the Exhibition of 1862, together with a difference engine by the same inventor, also with a circular arrangement.

There is another machine, by Grant, of which there is a specimen on the table, in use in the United States, which, in the cylindrical arrangement of the setting and recording discs, might seem to be developed from the 1777 Stanhope machine.

Passing from arithmometers to machines of another class, we come to one highly specialised. It does one thing only, and that it does well. I refer to an entirely novel instrument, invented by Hartmann, for calculating interest. It is certainly surprising that it attracted so little attention, and seems so little known. It consists essentially of tables, calculated by Hartmann with great labour, arranged as follows:— First, there are a pair of corresponding primary tables. The bottom line of the upper one contains the series of values 1d., 2d., 3d., 4d. and so on, the figure in each column being one penny more than in the one to the left. In the line above this are the values 2d., 4d., 6d., 8d., &c., in the next line 3d., 6d., 9d., 1s., &c., and so on for 183 lines. This, then, is a multiplication table in which the unit 1d. is at the bottom left hand corner. In corresponding columns in the table below are the capital sums which, at various rates of interest from 1 to 10 per cent., increasing by eights, will yield as interest the 1d., 2d., 3d., &c., per day, which is tabulated in the bottom line of the upper table. Thus, if we take any row in the lower table representing any desired rate per cent., and find any sum marked in one of the vertical columns, the amount found in the bottom line of the upper table immediately above this will show the interest per day, the tenth line will show the interest for ten days, and so on for any number of days or any rate per cent. So far, I have described a special multiplication table rather than a machine, and this it would still be, in spite of the mechanical mounting of the tables whereby the required squares can be almost immediately pointed out, if it were not for the graphical table attached. It is evident that the capital sums in the lower table must differ from square to square by considerable amounts, and not only this but the sums tabulated cannot be even amounts if they produce the 1d. a day exactly. The next lowest even amount is written in the table, and by the side a correction. As the sum on which we may require to calculate interest is not likely to be exactly found in the table, means have to be provided to find the interest due to any differences. This is the part of the machine which is specially ingenious. A second or graphical pair of tables is prepared with a horizontal line corresponding to each horizontal line in the two tables already described. Each of these lines is divided into a series of equal parts, such that the number of parts is equal to the difference between any pair of numbers in the primary tables. Thus in the lower part of the graphical table are capital sums, and in the upper part are pence, shillings and pence, or pounds shillings and pence, which are corresponding amounts of interest. This table is mounted on a cylinder, while the first being longer is mounted on a pair of cylinders. Two sliders are provided, one to be set to the rate per cent., and the other to the number of days. To find the interest on any sum the lower slider is set to the rate, the next lower capital amount than that given is set opposite to the pointer. The difference and correction are set opposite the other end of the same pointer on the graphic table. The upper pointer is set against the number of days. On the one side is the interest on the chief amount, and on the other the interest on the difference and correction combined correct to a farthing. The time occupied is less than would be spent in looking over tables in the usual way, or in calculating by a machine. A pair of horizontal lines are specially divided for the calculation of brokerage and commission. I am able to show a complete machine and the tables separately amounted.

I have also an instrument by Detallanté for the calculation of interest. This only calculates at 5 and 6 per cent. Interest at other rates must be found by a simple proportion sum.

Machines for solving equations were represented by only one example, that for cubic equations shown by Mr. Cunynghame. Equation machines may be divided into three classes, those for solving simultaneous equations, those for equations of any order involving one unknown quantity, and those for solving certain forms of differential equation. The first and last class are almost beyond the scope of this paper, I can, therefore, do no more than merely refer to them. The only machines with which I am acquainted are the invention of Sir William Thomson. In his simultaneous equation machine there are as many pivoted pulley frames as there are unknown bodies, and as many pulleys on each as there are pulley frames. The positions depend upon the co-efficients. There are as many cords passing over one pulley on each frame as there are frames. On pulling the cords the frames are inclined in certain directions, and the angles when measured give the value of the unknown quantities. It is worthy of note that the same machine can be employed to recalculate and correct for any slight errors it makes.

Machines for solving differential equations involve the use of integrating machines, a class of machine which, for reasons stated later, I am reluctantly compelled to pass over.

Of machines for solving equations of a high order, involving only one unknown quantity, there are very few. Mr. A. B. Kempe, whose work on linkages is well known, has shown how to apply linkwork to solve these equations. He employs a series of bars hinged on one another, and jointed by linkwork, or otherwise, in such a manner that each one makes the same angle with the one on either side of it, and the same angle that the first makes with the axis of x on which the first hinges. The equation is put through a trigonometrical transformation, and the new coefficients determine the lengths of the bars When the first bar is rotated, the end of the last passes over the axis of y every time that a root is indicated, and the value can be determined by transforming the new equation back to its original form. Mr. Kempe has shown me the simplest solution of a cubic equation by linkage, which is published in the "Messenger of Mathematics," vol. v., as an extract from the "Comptes Rendus" of 1874, due to M. Saint-Loup. This involves the use of only four links, forming one quadrilateral. When this is deformed, the point of intersection of two opposite sides continued passes a certain point, and then the value of a root may be found by measure.

Mr. Kempe has also sent me a paper by Mr. Freeland, published at Philadelphia, where it is shown that this problem may be solved mechanically by an adaptation of Sir William Thomson's simultaneous equation machine, in which the several pulley frames are connected by linkages, to move through angles successively, which are a series of powers of that moved through by the first. An appendix to this paper gives a history of the problem beginning with a geometrical solution adapted for a machine by Clairaut. Reference is next made to what is perhaps the most interesting possible method. Among the innumerable feats of the analytical engine of Charles Babbage was that of deliberately calculating the value y in the expression $y = a + bx + cx^2 +$ &c., as x increases from nothing through small steps for ever. Whenever the value of y became nothing, the machine would ring a bell and stop, so as to call attention to one value of x which it had found to be a root of the equation.

I am not aware that any of the contrivances mentioned are practically convenient or suitable for the solution of equators. Mr. Cunynghame's machine, at any rate, has this merit, that the only thing that it does it does at once and accurately. This one thing is the solution of an equation of the form $x^n + bx + c = 0$. A cubical parabola is drawn upon a large board, and the points marked for which y has certain values as 1, 2, 3, &c., up to 1,000. A protractor divided so that the divisions and numbers engraved are co-tangents is to be applied to the curve, so that the readings on the axis of x and the co-tangent scale are the coefficients of the equation, then the point or points where the straight edge cuts the curve are roots of the equation. Any cubic equation can be solved by the machine, for by Cardan's rule it can be made to want its second term. It is curious that if two of the roots are impossible, by a second application of the protractor, their value (in impossible measure of course) can be found.

There is also a machine for solving equations of any degree, which I designed some ten years ago, of which I have a model. If the machine is to solve an equation of the nth degree $n + 1$ beams are employed. These are each provided with a pair of pans marked + and —. Alternate beams are always opposite one another. Each beam is connected with that in front of it by a sliding joint. Weights equal to the coefficients of the several terms are put into the pans in order, on to the + or — side, according to the sign. Then one set of beams is made to slide along. In certain positions of the slide the first beam leans over to the other side, and may be made to ring a bell. The reading on the slides is then a root of the equation. If there are not more than two impossible roots they also may be found by the machine. This machine and Mr. Cunynghame's are described in this month's "Philosophical Magazine."

Though the tide-predicting machine, invented by Mr. E. Roberts, F.R.A.S., and made by A. Légé and Co., does not do more than draw a curved line, it may certainly be included as a calculating machine, since in only two hours it will find the height not only of high water, but the level at every intermediate time throughout a year for any place for which the constants have been determined, taking into account twenty different tide components, an amount of work which would take an immense time when worked out any other way. It might seem at first that such a machine must be so complicated that it would be impossible to make clear the principle of its action in a short time, but this is not so, as I hope to show. If the tides were due to a single attracting body in the plane of the equator always at the same distance from the earth—say the sun or moon alone—then the tides would be perfectly regular, and would follow an harmonic law. Their motion would be similar to the motion of a pendulum, or as Sir George Airy has expressed it, the rise and fall of the water would be the same as that of a point moving at a uniform rate round a circle, of which the diameter is equal to the total rise of the water. Now, there are two tide-producing bodies, each of which gives rise to its own effect, so the resulting tide is the sum or difference of that due to either body separately. But this is not all. Neither the sun nor the moon remains in the plane of the equator. They journey north and south, nor do their distances remain constant; they approach and recede from the earth. In consequence, the actual height of the water is not to be expressed by any such simple law as already indicated, but, as is well known, it can be represented as the algebraic sum of the heights of a great number of tides of various amplitudes and periods. Supposing these tide components are known for any place, then the machine can be adjusted, and will calculate the resulting tides as I shall now explain. I have a model which shows how a bob tied to a string passing over a pulley carried by a crank, moves up and down harmonically as the crank is turned. The same string passes under a second pulley, and when that is turned the bob again moves harmonically; but the period and excursion depend on the rate of motion and throw of the second crank. If both cranks are turned simultaneously, the bob has a compound motion, which is the algebraic sum of the motions which either crank would have produced. If a third pulley and crank were introduced, the motion would be still more complex, and so on as the number increased. In the machine exhibited by Légé, there are twenty of these cranks, so connected by gearing that these periods have the same ratio as the periods of the twenty most important components of the tides due to the sun and moon. These periods are the same all over the world, and, therefore, this part cannot be altered; but the different components have different values in different localities, and so the pulleys are moved by cranks, of which the throws can be adjusted by micrometer screws. In the first machine, now at the South Kensington Museum, there were only ten of these pulleys, and they were carried directly by the cranks, and so the parts of the chain joining the upper and lower pulleys did not always remain truly vertical. In the new machine with twenty pullies, each is carried by a geometric slide, and thus moves vertically only, while the pin of the crank is allowed to move horizontally in an adjustable steel slide. The bob which hangs from a fine steel wire consists of an ink bottle moving in a vertical geometric slide, carrying a pen which draws the required curve on a travelling band of paper. Mr. Roberts has lent this year's curve for Singapore, a portion of which I have enlarged.

Such a machine requires the constants of any port to be given to it. These constants, depending so much on the accidents of the situation, can only be obtained by calculation from curves previously found for the same place for a year or more by a tide recorder. These calculations even can be made by a machine called an harmonic analyser, invented by Sir William Thomson. A row of eleven of Prof. James Thomson's integrators are connected as follows:—The y of each instrument is made to follow the curve given by observation. The first merely integrates $y\,dx$, the disc of this having a uniform motion. The discs of the remainder are given a harmonic motion of oscillation depending on the periods of the several components. From the integral shown by each, the numerical value of the corresponding components may be determined.

The same curve is again passed through the machine, but on a drum of half the size, whereby all the discs move twice as often, and thus the values of the first harmonics or octaves of the same components are determined.

It may, perhaps, seem presumptuous in me to make any suggestion on this subject in view of the fact that the harmonic analyser is the work of the greatest mathematical-mechanical genius of the present day. I would, however, suggest that for this special purpose my disc-cylinder integrator is even more fitted than that of Professor James Thomson.

I now pass on to a subject on which I am believed not to be able to speak reasonably. The slide rule is an instrument which makes all who are really familiar with it wonder at the ignorance and apathy of those who are not, that is of nearly the whole community, who neither know what labour they might save by its use, nor care to take the little trouble that would enable them to join the wondering few. I am convinced that if only those who are responsible for the subjects taught in our technical colleges knew how to use this instrument themselves, it would at once become a compulsory subject, and its use would become general in every room and workshop in the land, as I am told it nearly is in Germany and France. The calculating machines already described enable one to obtain answers containing sixteen figures correct to the last figure. This represents a degree of accuracy far beyond anything that is required in ordinary experimental or commercial work. If the data on which the calculation is to be made are liable to a possible error of one per cent., it is useless to insist on what is called perfect accuracy. After the first three or four figures of such a result have been obtained, all subsequent ones have no meaning whatever, they may be ornamental.

Few observations are made in which an error of 1-1000 of the whole may not creep in (I am not speaking here of the most exact scientific work or of some commercial work where far greater accuracy may be obtained); in all such cases, provided the calculation is carried out with a degree of accuracy well exceeding that with which the primary figures are found, the result obtained will be just as good as if long rows of ornamental figures, such as students especially delight in copying from tables of logarithms, had been put on at the end. The question then is what is the quickest and the most convenient way of making those numerous calculations where the term absolute accuracy has no meaning. The very commonest slide rule used by carpenters can be trusted to give results with an accuracy of ½ per cent., while the most accurate instrument of the kind I know, Prof. Fuller's helical rule, gives results trustworthy to a ten thousandth part.

Addition, or subtraction, may be performed by the use of two scales of equal parts which, by way of distinction, may be called A and B. If the zero of one scale A, be placed opposite any number p on B, opposite any other number q on B will be found $p + q$ on A. What I have said about machines for adding applies equally to rules for adding, they are not worth using. There is one exception in the slide rule which was exhibited by Mr. W. Heath, in which the scales, though each of equal parts, are not on the same scale. By the use of this instrument, the correction to be applied to mean solar to convert it into sidereal time, or the reverse, may be found at once, with a possible error of not more than 1-50th second.

What slide rules do is to add quantities but not the numbers which are written upon them. The series of numbers which lie between 1 and 10 are placed at distances proportional not to these numbers but to their logarithms, and these, when added, as is well known, give the logarithm of the product. This is well shown on this large rule, 18 ft. long. The mark numbered 2 is $\frac{301}{1000}$ of the distance between 1 and 10, ·301 being the log. of 2. The same is true of each of the 190 marks between 1 and 10 on the lower line marked D, as is clear from the scale of equal parts adjoining. In this particular instrument, which is an enlarged copy of the ordinary engineer's rule, there are four divided lines, two on the rule and two on the slide, distinguished by the letters A, B, C, and D. The first three lines, A, B, and C, are identical, and of these the two halves are identical. Wherever the slide may be placed, the numbers opposite one another on A and B are in the same proportion, that is, have a common quotient. If the slide is inserted upside down, the numbers opposite one another have a common product. The lower line, D, is on double the scale, and as by doubling the logarithm of a number we find the logarithm of its square, it is evident that when the slide is in its normal position, a table of squares is exhibited. Moreover, however the slide is placed, the squares of any numbers on D are in the same proportion as the numbers opposite them on C; they have a common quotient. If the slide be inverted so that the B line is opposite the D line, they then have a common product. These are all the lines on the rules most usually sold. With these all calculations of ordinary arithmetic may be instantly made, and it makes no difference in the labour if the squares or square roots of any numbers are involved instead of the numbers themselves, for they need only be set upon the proper line. I am not able to show, for want of time, the thousand and one purposes for which these lines may be profitably employed. I will merely give one instance of frequent application. If the length of a square or round bar found on B is set against a certain number on A, opposite the side or diameter on D will be found the weight or volume on C according to the number set on A. Besides the lines mentioned, other lines are sometimes supplied either on the back of the slide or on separate slides. One of one-third of the scale of the D line makes it possible at once to find proportions in which the cubes or square roots of cubes of numbers are involved. A line in which the distance from 1 to 10 (called the radius) of the D line is divided into equal parts enables one to find logarithms directly. One, in which the distances are proportional to the log sines or log tangents of the angles marked, supply at once a table of sines or tangents, or make the results of proportions in which these functions are involved as easily and directly ascertainable as those of simple proportion.

As may be expected, the number of forms in which the slide rule is found is almost indefinite. Any attempt to give a description of every instrument would of necessity fail. There are, however, certain broad principles of construction. In the first place, all rules may be divided into two classes, those in which two lines logarithmically divided slide against one another, and those in which there is only one line, or possibly several independent lines, and a pair of indices, which may be set to measure the angular or linear distance between any pairs of numbers, and be then transferred to any other part of the scale, when another pair, either themselves, or whose squares, cubes, roots, sines, or tangents, as the case may be, will be found in the same proportion. Of the first class, great length, and therefore proportional accuracy, is sometimes obtained by the use of many parallel bars like a gridiron, on each of which part of the scale is engraved. I have, as examples of such rules, one of Professor Everett's in card, one of General Hannyngton's in wood, and one made for Mr. Walford of the same kind, but the largest I have seen. It would make an elegant top for a tea table. There is on the table a rule of this class, where great accuracy is obtained by another method devised by Mr. Beauchamp Tower. In this there are two endless bands, each with a half twist in them, mounted on pulleys side by side. Both sides of the bands are thus available for the scale, and the instrument becomes equivalent in openness of scale to an ordinary straight rule eight times as long. The power of a rule may be extended by the addition of slides working against one another, numbered the same way when division, or opposite ways when multiplication is to be performed. Of rules of this class, I may especially refer to some made by Stanley. Again, instead of scales generally applicable, rules are marked specially for certain trades. As an instance, I would mention one for the iron and steel trades, made by Aston and Mander.

Of plain straight rules there is no limit, and I have not attempted to obtain many. I have, I am glad to say, through the energy of Mr. Fairer, of Leeds, their English agent, a complete set of more than twenty of the rules made by Gravét, of Paris. I am sorry that it is not possible to obtain rules of English make that will compare with these for general convenience and accuracy. It is impossible to describe them all. I have a large model of the ordinary Gravét rule which shows the leading features. The four lines at first seen are the same as those of the engineer's rule, except that the third or C line is the same as the fourth or D line. This is in someways convenient, and in some inconvenient. The back of the slide is divided for sines, tangents, and logarithms, all of which can be read at the back through special openings, without removing the slide. Or the slide may be reversed, and these lines read against the A or D lines for introducing trigonometrical quantities into a proportion without the necessity of first finding their value. A sliding index is provided which adds materially to the power of the instrument. Of all slide rules that I have ever seen, none compare in accuracy, portability, and universality with the ordinary rule of Gravét. I have so far said nothing about circular rules. These are generally of the single line and index class. I have on the table several instruments of this class. There is the most portable rule made, in the form of a watch, by Bouchet, which will do all that the Gravét rule is capable of, but less accurately; two circular rules, by Haas and Hurter, and Professor Fuller; two circular instruments by T. Dixon, one, for simple proportion and logarithms, equivalent to a straight rule 50 ft. long, and the other for trigonometrical work; and the most accurate of all the helical instrument of Professor Fuller.

There is another kind of line, invented first by the late Dr. Roget for finding fractional powers of numbers. A line so divided is called the P line. Here the distances are logarithms of logarithms. A straight and a circular rule of this kind were exhibited by Lieutenant J. H. Thomson, who re-invented the method.

The subject of integrating machines on which, if I had consulted my own inclination, I could have found much to say, I am obliged to pass by, and this I can do with the greater propriety, as Professor Hele Shaw only last year read before the Institute of Civil Engineers a paper on the subject so complete that nothing more need as yet be said. At the Exhibition the most important instruments of this class were the new precision planimeters by Coradi, and Professor Hele Shaw's beautiful spherical integrators. Unfortunately, Amsler's mechanical integrator and planimeter were not on view. Two instruments of mine represented that class of integrators depending on the tangent principle which has been independently discovered by Professor Abdank and myself. Other machines by Rev. F. J. Smith, Mr. Walter Baily, and Messrs. Ashton and Storey, were exhibited. I might add that integrators are the only machines, except certain linkages, which multiply directly and continuously.

It is impossible to conclude a paper on calculating machines without referring shortly to the difference engine of the late Charles Babbage. In the history of calculating machines there seem to be only three great steps, the first was made by the Earl of Stanhope, who put arithmometers into a practicable form; the second by Babbage, when he invented the difference engine; and the third by Babbage, when he invented the analytical engine. The difference engine calculates and prints tables of any kind whatever; once being started it continues to calculate and print without the possibility of error. Unlike the semi-automatic machines, it only requires to be driven by a boy or a donkey-engine.

It depends on this principle; if in a table of any kind, whether of powers of a series of numbers, of sines or tangents, of logarithms, of the value of lives or joint lives, or of anything else whatever, if each number is subtracted from the one above or below it, a table of first differences will be formed; from these a table of second differences, and of third or fourth differences, and so on to any extent, can be formed. Now, in general, after a time it is found that a difference becomes constant, in which case the next one is zero Thus in the table of cubes on the wall, the first differences are 1, 7, 19, &c., the second differences 6, 12, 18, &c., the third differences 6, 6, 6, &c., and the fourth difference is 0. As these columns are obtained by subtraction from the first, it is clear that the first can be formed by addition from the others, and that each of the others can be formed by addition from those to the right. Thus if the first row of figures only are given 0, 1, 6, 6, 0, by addition only a table of cubes may be formed. The diagram on the wall shows how a table of fourth powers is produced by the Schutz difference engine. Any kind of table may be thus formed if only enough differences are introduced. In the difference engine these additions are made mechanically, after each result has been found, type wheels are set automatically, and the result printed on a stereotype mould. I cannot enter into the mechanical details of the Babbage machine. It is well known that the machine was never completed. Small parts have been put together. General Babbage has been good enough to lend one of these pieces, which shows that no work done in these days can excel either in accuracy, excellence of material, finish, or in the substantial character of the work, that which was being put into the Babbage engine. On the wall are drawings of the complete machine, lent by the South Kensington Museum. While this machine was in progress, a printer in Sweden, named Schutz, read a magazine article on the Babbage engine, and he and his son, inspired by this, invented a machine to do exactly the same thing. They put their ideas into metal, and completed a difference engine on a less magnificent scale than that of Babbage. Ultimately a Schutz machine was made for the British Government by Bryan Donkin, and Co., which is now at Somerset House. This machine was employed to calculate and print among other things the well-known life tables of Dr. Farr. The Registrar-General has lent some moulds and casts made by this machine. One of them is part of a table of joint lives, male and female, interest 4 per cent. There is on the table a model by Mr. Edmondson, showing in a general way how the additions are performed in the Schutz machine. As to the details of this and the Babbage machine, and to the methods employed for carrying the tens, it is impossible to enter into them. Though no one would grudge one spark of the honour justly due to a poor foreign printer for the splendid result which he has achieved, it must be a matter of the most profound regret that means were not forthcoming to complete the most magnificent work of the human brain, begun at enormous expense, and that money alone should have prevented the richest country in the world from possessing a monument of its native genius unrivalled in the civilised world.

I am indebted to the following gentlemen and institutions for the loan of the series of instruments as given in the following list. I am also under an especial obligation to Mr. Edmondson, who has enabled me to obtain a large amount of information, and for the very large number of instruments, models, and diagrams which he has lent. Also to Mr. A. B. Kempe for papers on kindred subjects, and to General Babbage for the invaluable instruments which he has enabled me to show you.

Thing Exhibited.	Lent by
Model showing principle of adding machine	Mr. Edmondson.
Adding machine, 1666. Sir Samuel Morland	General Babbage.
Old set of Napier's bones..	General Babbage.
Diagram of Napier's bones	Physical Laboratory, South Kensington.
1775 Stanhope machine ..	General Babbage.
1777 Stanhope machine ..	General Babbage.
Thomas de Colmar machine	Mr. Edmondson.
Tate's machine	Messrs. C. & E. Layton.
Separate parts of Tate's machine, showing stepped reckoner and carrying apparatus..............	Messrs. C. & E. Layton.
Edmondson's machine	Mr. Edmondson.
Grant's machine..........	Mr. Theodore Jones.
Hartmann's interest calculating machine. Also the tables used, separately mounted	Hedicke & Co.
Détallantés interest machine	South Kensington Museum.
Model of Saint-Loup's equation solver.	Physical Laboratory, South Kensington.
Cunynghame's machine for cubic equations.	Mr. H. H. Cunynghame.
C. V. Boys' machine for an equation of any degree.	Physical Laboratory, South Kensington.
Model showing action of tide-predicting machine.	Physical Laboratory, South Kensington.
Curve drawn by machine ..	Mr. E. Roberts, F.R.A.S.
Drawing of machine	Messrs. A. Légé & Co.
18 foot slide rule, and other large scales.	Physical Laboratory, South Kensington.
Professor Everett's proportion table..............	Mr. C. V. Boys.
General Hannyngton's rule.	Messrs. Aston and Mander.
Mr. Walford's rule........	Mr. Walford.
Hudson's, Ganga Ram's, and other rules, made by Stanley................	Mr. W. F. Stanley.
Rule for iron and steel	Messrs. Aston and Mander.
Tower's rule	Mr. Beauchamp Tower.
Set of Gravét rules........	Mr. W. Farrer.
Large model Gravét rule ..	Physical Laboratory, South Kensington.
Bonchet calculating circle	Physical Laboratory, South Kensington.
Haas and Hurter circular rule	General Babbage.
Prof. Fuller's circular rule	Mr. F. S. Hunwicke.
Dixon's circular instruments	Prof. Unwin.
Prof. Fuller's helical rule ..	Physical Laboratory, South Kensington.
Dr. Roget's rule for involution	South Kensington Museum.
Part of difference engine ..	General Babbage.
Drawings of Babbage's difference engine	South Kensington Museum.
Model of part of Schutz difference engine	Mr. Edmondson.
Stereotype and moulds made by Schutz difference engine	The Registrar-General.
Diagram showing process of working of Schutz machine	Mr. Edmondson.

DISCUSSION.

Mr. TATE said that since he first took up the improvement of the calculating machine, over six years ago, his main object had been to simplify it, and at the same time make it thoroughly durable and accurate. He had sent his machines all over the world, and had never had any complaint with regard to them.

Mr. BEAUCHAMP TOWER said he was a very great advocate for the slide rule. His instrument gave results accurate to 1 part in 5,000, which was equivalent to one minute in a week, or one foot in a mile; and when that could be so easily attained, he did not see the necessity for complicated machines, going to a great many places of decimals. The slide rule gave a uniform degree of accuracy, the distance between 90 and 100 being nearly the same as between 9 and 10. If there were an inaccuracy of one per cent. in one part, it would be the same right through the scale.

Mr. A. J. ELLIS, F.R.S., said he had used the slide rule to a considerable extent, and the only trouble he found with it was the difficulty of seeing when the lines did coincide; he found that so exceedingly trying to the eyes that he gave it up some years ago, and found that with a table of logarithms he did the work more easily. Still, he had no doubt that, for mechanical purposes, the slide rule would be more easy to manipulate than tables of logarithms, which he had been accustomed to all his life. In calculating machines, in which you had to set the numbers, he had always found the great difficulty was that you were apt to make a mistake in the number; and you could not find it out. You got a wrong result, but did not know where the error arose. He was a bad calculator, and always had to verify his figures, but he liked to have them before him, in preference to using something which he might make a mistake in manipulating. Still, he hoped he was a bad specimen, and that others might use the machines with more confidence. He agreed with Mr. Tower that it was quite enough for most purposes to go to three places of decimals, but you sometimes wanted to go to a fourth to verify the third, and that was not always possible with the slide rule.

Mr. W. H. MASSEY had used slide rules since he was a lad, and was pleased to find that some people at South Kensington had at last taken them up. It was a curious coincidence that Mr. Farrer, of Leeds, was now introducing Gravet's rules into the town where he took the first one twenty-five years ago. He had given away dozens of them during the last twenty years, and he was glad that they were now easily procurable, as he should save money thereby. He could not think how an engineer could get on without a slide rule.

Mr. ACKLAND said he bought the first arithmometer exhibited by Thomas in 1851, and had used it so much that it was fairly worn out. It gave him great satisfaction, and saved him many hours in calculation. The use of the slide rule ought to be taught in every school, for commercial purposes, calculating interest, &c., and even for checking logarithmic results; for mistakes were often made, not only in the third or fourth decimal, but in the whole numbers. If he did anything by logarithms in a hurry, he always checked it by the slide rule, which frequently discovered an error that might have been unnoticed. He had no experience of any machine but Thomas's, but certainly the improvements introduced by Mr. Tate must add much to the durability, and the indices were so well held by the spring, that it could be operated much more readily than the old Thomas de Colmar machine. It was a credit to Englishmen to turn out a machine so far superior to the French.

Mr. E. WALFORD said his attention was drawn to the slide rule a few years ago, and since then he had studied it thoroughly, and he quite agreed that its use ought to be taught in every Board school. Whatever might be a man's trade or profession, he would find it useful, it would save him hours of work; and the more he studied it the more he would discover its capabilities, and the better would he be able to apply it to his special needs. In his own office one of the clerks used to do three quarters of an hour's work every day in working out certain exchange operations, but by means of the slide rule these were now done in ten minutes.

Mr. STANLEY said a table of logarithms furnished a very exact method of making calculations, and it was very convenient when you were sitting at a table and had it before you, but the value of the slide rule was that it formed a sort of pocket logarithmic table by which all small matters could be readily calculated. Mechanics in Germany, and some of the best in France, generally carried them, much more so than was the case in England. One point which had not been alluded to was the use which might be made of the slide rule by means of gauge points. If there were a particular multiplier which suited your business, say 112 lbs., you could set the point to that, and you had a whole series of numbers calculated out for you. That occurred in engineering works particularly, but it was also applicable in every trade, and he felt confident that the slide rule only wanted to be better known to be much more employed. On the table there were some special ones by Mr. Hudson, of Glasgow, by means of which all the proportions of a steam-engine, the size of cylinder, length of stroke, and every point of importance could be seen at a glance. Some large firms, such as Kitson's, and Armstrong's, presented all their draftsmen and assistants with one of these rules. It was in these particular applications that the slide rule showed to most advantage, but the ordinary slide rule, especially if fitted with gauge points, might be adapted to any business. With regard to Edmondson's machine, he had had a good many in his hands lately, and having gone through the work very carefully, he could bear testimony that it was perfect in all essential parts, though rough elsewhere. Both this and Mr. Tate's were exceedingly good machines.

Mr. HEDICKE, as a friend of Mr. Hartmann, wished to point out the advantages of his interest calculating machine. The table contained nearly 400,000 numbers, and in order to have them correct they were first drawn out on a very large scale, and then reduced by photography. The great advantage of the machine was its accuracy. If you were calculating interest on a large amount at one-eighth per cent. it was a laborious operation, and might involve adding four, five, or six amounts together, each of which might be slightly inaccurate, and when added together, the error might be appreciable. With this instrument you were sure of accuracy, and saved a great deal of labour as well.

Mr. COFFIN said it was suggested to him at Washington by the International Bureau of Weights and Measures, that the greater use of the slide rule in France than in England might be due to the decimal system. Mr. Boys's opinion on that point would be valuable.

Mr. THOMAS ACKLAND said he was familiar with some of these machines, but others were quite new to him. It was of course impossible for Mr. Boys to deal with all the powers and functions of any one machine, but he was rather surprised that in dealing with the Thomas, Tate, and Edmondson machines, he had not referred to what he considered its greatest power, namely, that if you took any three numbers, call them A, B, and C, you could so arrange the slides as to obtain A + B × C at one operation. That was of great value in calculations involving continuous results, such as actuaries and other mathematicians had to employ in calculating tables. Mr. Peter Gray was the first to point out this power of the machine, and it had been about thirty years before the public before this was discovered. He believed the Edmondson machine had other powers still undiscovered. The working off the result from the circular plate, as distinguished from working it on, with the other two machines was a very remarkable function, and he believed it would be discovered in time that the computation of continuous values in tables was very much facilitated by this remarkable power.

The CHAIRMAN said he had had to his sorrow, rather an exceptional amount of arithmetic to do, and he had probably used all the aids to arithmetic which had been introduced. He was still inclined to think that the one machine which Mr. Boys had not mentioned was the most useful of all, viz., a small table of logarithms. At the same time, no doubt all of these appliances had their use, and many of them he was much dependent on from day to day. Some ten years ago he first saw a Gravét slide rule in Switzerland, and brought one home with him which had been his companion ever since, as there were certain kinds of calculations to which it lent itself very readily; but there were two difficulties which he always found with it; one was that it was always tempting you on to try and be a little more accurate than was easily possible with it, and the other was that there was always a slight difficulty about the numeration. The dodge by which the latter was got over was to think of the characteristics of the logarithms which would express the numbers you were using, but still it was a slight drawback, that you had to spend a little time thinking over what the numeration of the answer was. About twelve years ago he obtained one of the French calculating machines, and had used it occasionally a good deal; recently Mr. Tate had been kind enough to add some of his improvements to it, and he should probably use it for some time to come. It was extremely useful for its particular kind of calculations, and saved an immense deal of trouble; you might have absolute confidence in it, and he had never found occasion to verify the calculations. He had a very good test of that. Some time ago, they used to have an exceedingly heavy task in adding up a complicated table of examination marks to get the total of each candidate, but for seven or eight years he had used this machine to add up the three figure numbers in the table, and, with the sharpest possible critics, a mistake had never been discovered.

Mr. BOYS, in reply, said he had been obliged to omit a great deal for lack of time, but some of the deficiencies which had been mentioned would be found in the printed paper. For instance, he had omitted to mention the sliding index, or cursor, on the Gravet slide rule, by which its powers were enormously increased, and many difficulties in the use of a slide rule eliminated. Dr. Coffin had referred to the greater use of the rule in France as being due to the decimal system, but there were two sides to the question. It was true that you read off at once (if it were a money calculation) the answer in francs and centimes. The French was a rational system, which the English was not, but he might remark that if an English foot rule were divided on the edge into hundredths of a foot, and also into inches divided into eighths, tenths, and twelfths, you could read off at once pence as decimals of a shilling, or other measures decimally in the same way. But the very complexity of the English system rendered the use of the rule more needful for calculation. He had not mentioned the particular point to which Mr. Thomas Ackland had referred, because there were so many other special points in these machines which he was obliged to pass over; but it was quite true that the addition of a number before or after the multiplication could be effected by the arithmometer at once. As Mr. Edmondson was not present, he might perhaps insist still further on the advantage of "working off" figures on that machine. If you had to make a calculation, and the only thing to be done was simply to multiply one number by another, and possibly add a third, the arithmometer, as originally made, was perfect, and was, possibly, preferable to Edmondson's; if, however, you were working out a long fraction in which there might be half a dozen factors in the numerator and in the denominator, as you went on multiplying and dividing, you always had to transfer your result as found to the number slide for the next operation. Whereas in the Edmondson machine you could, as it was worked on, use it as a multiplier and work it off, getting a new answer, which you could again use as a multiplier or which you could divide, always leaving a place for the new result. In reply to the Chairman, he could only say that he did not mention logarithm tables partly because they were not machines, and also because he supposed everybody was familiar with them. As to the slide rule, he had not said all he could against it, but he had certainly not said all he could in its favour, He agreed that one was apt to push the accuracy of the instrument too far, and possibly Gravet's rules—which were by far the best, taking them all round—had this defect, that you might use a lens and strain your eyes in trying to obtain the most accurate readings possible, and the instrument would bear the test, whereas with the majority of English instruments the errors were obvious to the naked eye. He referred to the older instruments; amongst the modern ones many of them were beautifully accurate. The number of figures that should appear in the answer was also a difficulty, especially to beginners. If the answer came out 548, they were not always sure whether that was the real answer or whether it was 5,480,000. But as a matter of fact, there were rules for finding the number of figures in the answer. If you multiplied 2 by 7 there were as many figures in the answer as in the two factors together, whilst 2×4 made 8, or one figure less. One rule was, that if the first figure of the product was greater than that of either multiplier, the number of figures in the product was one less than the sum of the number of figures; if less, the number would be equal. There were other rules depending on the manipulation of the instrument, but in practice he had never had occasion to apply these rules. If the calculation was an individual one, it did not take long to run over the figures in your mind, and arrive at a result near enough to guide you; but if you had a number of calculations all on the same pattern, then it was that the slide rule became an instrument of the most enormous utility, you need not trouble about the numbers in the answers; they were sure to steadily increase or diminish, and you only need find out the significant numbers and put in the decimal points at pleasure.

The CHAIRMAN then proposed a vote of thanks to Mr. Boys, which was carried unanimously, and the meeting adjourned.

Miscellaneous.

COLONIAL AND INDIAN EXHIBITION.

A conference between the Lord Mayor and the masters and clerks of the various Livery Companies of the City of London was held at the Mansion House, on Monday, 1st inst., in reference to the forthcoming Colonial and Indian Exhibition. The Lord Mayor presided, and there was a large attendance of the representatives of the Guilds. The proceedings were private, but it may be stated that the following letter from the Prince of Wales was read:—

"Marlborough-house, Pall-mall, S.W.,
"Jan. 12.

"My Lord,—As a member of the Royal Commission for the Colonial and Indian Exhibition to be held in London this year, I have no doubt your Lordship is fully conversant with its general objects, and I need hardly say that my position as Executive President is an assurance of the warm interest I personally take in its anticipated usefulness and desired success.

"The intimate association of very many of the Guilds with the products and resources of our Colonial and Indian Empire, encourages me to ask your Lordship to use your influence with the Livery Companies of London, with the view of inducing those bodies to kindly accord support to the guarantee and donation funds of the Exhibition, which I have every confidence will result in more firmly cementing the ties existing between the mother country and its distant dependencies.

"I have the honour to be, my Lord, your obedient servant,

(Signed) ALBERT EDWARD P.

"To the Right Honourable John Staples, F.S.A.,
"Lord Mayor, Mansion-house, E.C."

The Lord Mayor stated that the Corporation of London had promised £10,000 to the guarantee fund for the expenses of the Exhibition, and the total amount subscribed by the other guarantors—including the Colonial and Indian Governments and private firms—exceeded £200,000. The Master of the Mercers' Company, Mr. Watney, said his Court had guaranteed £1,000, and the Prime Warden of the Goldsmiths' Company, Mr. Stephen Smith, stated that a similar vote would be proposed to his company at their next meeting. The other representatives said they would lay the matter before their respective Courts at the first opportunity.