SCHEUTZ' DIFFERENCE ENGINE, AND BABBAGE'S MECHANICAL NOTATION.

Mr. HENRY P. BABBAGE exhibited some detailed diagrams, to illustrate the Difference Engine of Messrs. Scheutz, of Stockholm, as an example of the 'Mechanical Notation' of Mr. Babbage, showing, that even the most complicated machinery might be described by a method at once so clear, concise, and easy of reference, as to render any written description unnecessary.

Diagram No. 1, exhibited the principal groups of the machine, and their relative connexion.

Diagram No. 2, gave these groups more in detail, and a very complete outline of the machine, without entering into minute mechanical details.

Diagram No. 3, contained the full details of the whole machine, of which it was, in fact, a complete description. Each single Piece of the machine was indicated by a capital letter: every working Point was indicated by a small letter. The motion of every Piece might be traced back, through any number of Pieces, to the first mover; or forward, to show how it contributed to the final result. To give a full description of this diagram, would be to give a full description of the machine itself, and would occupy a volume of some bulk, as in this Difference Engine, there were about four hundred separate Pieces, and about two thousand working Points. Any one acquainted with the Mechanical Notation, would be able to refer, at once, to any part of the machine, and to understand its action quickly. Those conversant with descriptions of machinery, written in ordinary language, could say how laborious it was to wade through them, even when aided by a good index, and would, therefore, be able to appreciate this facility of reference. It had been observed by different persons who had examined these Notations, that the machine would be understood more quickly, by studying the Notations, than by examining the machine itself; for in the Notations were seen, at once, everything that affected each Piece, and everything which it acted upon; whereas it was well known, that by looking at a machine at rest, this was almost impossible, and it was necessary to watch a machine in motion, for some time, in order to obtain the same information.

Diagram No. 4, contained that part of the Notation which was called the 'Cycles,' and related entirely to the time of motion of the Pieces, (expressed by capital letters,) and to the time of action of the working Points, (expressed by small letters). Each Piece

Minutes of the Proceedings of the Institution of Civil Engineers 1856.15:497-514.

had a vertical column for itself; and an arrow in its column denoted the times and duration of motion of that Piece. On the left hand of each column for a Piece, there was a column for each of its driven Points; and on the right hand, a column for each of its driving Points. The arrows in these columns gave the times and duration of action of each working Point; sometimes the action of a working Point was simultaneous with the motion of its Piece; sometimes a Point was acting whilst its Piece was at rest. The Cycle for any machine, was the time during which one complete operation was performed, after which all its motions recurred in the same order, (in this instance, it was one calculation made, and punched on the lead); and the Cycle might be divided into any number. In this machine, the Cycle was divided into ninety-six parts, because one of the wheels having ninety-six teeth, made one revolution during each operation, and it was convenient to count by it. By simply looking along the horizontal lines, it could be ascertained, at a glance, what Pieces were in motion, and what working Points were acting, at any instant.

The other illustrations consisted:—

1.—Of a plan and elevation of a small part of the 'Analytical Engine,' to give an idea of the system of lettering employed in the Notation.

2.—A copy of the trains of the printing part of the Analytical Engine. This was a description of machinery, no part of which had yet been made.

3.—Signs of Motion employed in the Notation.

4.—Signs of Form employed in the Notation.

Mr. BABBAGE expressed his regret, at the absence of the very beautiful calculating engine, which had been invented and executed by Messrs. Scheutz, and which his Son, Mr. H. P. Babbage, had described by the diagrams. He regretted it the more, because there was no Institution in the world in which mechanical ingenuity was better appreciated, or in which more sympathy would be felt with the genius of the inventor. He was, however, happy to add, that when the instrument was in this country, and also when in Paris, very important assistance had been rendered by Mr. Gravatt, (M. Inst., C.E.,) who took considerable pains to explain the structure of the machine, and to make its merits known to the scientific world.

Before explaining the Mechanical Notation, he would detain the Meeting for a few moments, to render that justice to Messrs. Scheutz which he did not think had yet been accorded them, at least to the extent which they really merited. It had been said, that their machine was, in a great measure, copied from, or suggested by his own; but if the two engines were placed in juxtaposition, the difference between them would be immediately manifest. In the

Minutes of the Proceedings of the Institution of Civil Engineers 1856.15:497-514.

absence of the machines themselves, the diagrams would serve to illustrate the few remarks which he intended to offer.

He wished, in the first place, to call attention to a point which was the most important in machinery for making calculations of any kind: the method of adding number to number. It was not difficult to contrive machinery for that purpose: it had already been done in numerous instances. The simple addition of number to number was easy. The great difficulty was the carriage. In Messrs. Scheutz' machine, there was a very beautiful contrivance to effect it, which, fortunately, admitted of description without drawings.

In that instrument, when fifteen figures were added to other fifteen, a carriage might occur at any one, or more of fourteen figures. There was, in this case, a certain analogy to a railway having fifteen stations. Messrs. Scheutz had contrived a travelling arm with a roller. When the pillar to which that arm was attached, advanced, the roller ran along a railway from one end of the machine to the other. In the same way, a train travelling over fifteen stations, only stopped when the telegraph signal denoted, that a passenger had to be taken up. In the machine, this travelling arm ran along the railway, until a signal, that a carriage was wanted, was made by a point being turned on the rail. The arm now went into a siding,—took up its passenger without stopping,—then re-entered the main line, and pursued its course until another point determined another carriage. The ingenuity of this contrivance would, he conceived, be universally admired.

He would mention only one other point of difference between the two machines, viz., the printing part. Mr. H. P. Babbage had given, on one of the diagrams, an analysis of the printing part of Messrs. Scheutz' machine; and Mr. Babbage had placed by its side, another diagram, explanatory of the printing part of his own apparatus, by way of showing the striking difference between the respective works. He had mentioned a few of these decided contrasts, in order to do justice to the originality of an inventor who had, he believed, had as great difficulties to contend with, as those Mr. Babbage had himself encountered.

In the remarks he had addressed to the President and Fellows of the Royal Society, on the occasion of the delivery of the Medals at the last Anniversary of that Society, he had made the following observations on this subject:—

"There is, however, an instrument to which we have given hospitality during many months in these apartments, which I think highly deserving of a Medal; and I had hoped, that on the present occasion, it might, at least, have been considered worthy of being placed among the list of candidates for that honour. I allude to the admirable Machine for Calculating and Printing Tables by

Minutes of the Proceedings of the Institution of Civil Engineers 1856.15:497-514.

Differences, and producing a mould for the stereotyped plates, to print the computed results,—an instrument we owe to the genius and persevering labour of Mr. Scheutz, of Stockholm. A Committee of the Royal Society has already reported upon the machine, and I can myself bear testimony to the care and attention which our Secretary bestowed upon that valuable Report. But as some misapprehension exists in the public mind, respecting the originality displayed in that invention, I trust, that having, as is well known, given much attention to the subject, I may be permitted briefly to explain some of its principles, and thus render justice to its Author.

"The principle of Calculation by differences is common to Mr. Scheutz's engine and to my own, and is so obviously the only principle, at once extensive in its grasp and simple in its mechanical application, that I have little doubt it will be found to have been suggested by more than one antecedent writer.

"Mr. Scheutz's engine consists of two parts,—the Calculating and the Printing; the former being again divided into two,—the Adding and the Carrying parts.

"With respect to the Adding, its structure is entirely different from my own, nor does it even resemble any one of those in my drawings. The very ingenious mechanism for Carrying the tens is also quite different from my own.

"The Printing part will, on inspection, be pronounced altogether unlike that represented in my drawings; which, it must also be remembered, were entirely unknown to Mr. Scheutz.

"The contrivance by which the computed results are conveyed to the printing apparatus, is the same in both our engines: and it is well known, in the striking part of the common eight-day clock which is called 'the snail.'

"About 1834, or 1836, Mr. Scheutz, himself a Member of no Academy, a Professor at no University, but simply an eminent printer at Stockholm, first learnt, through the 'Edinburgh Review,' the existence of that Difference Engine, a small portion of which is now placed in one of the rooms of the adjoining building, (the Museum of King's College).

"Unfortunately for himself, Mr. Scheutz was fascinated by the subject, and was impelled by an irresistible desire to construct an engine for the same purposes. He has always avowed, in the most open and honourable manner, the origin of his idea; but his finished work contains undoubted proofs of great originality, and shows, that little beyond the principle could have been borrowed from my previous work. Having formed the project, Mr. Scheutz immediately began to work upon it. After four years of labour and difficulties, which cost him a large portion of his fortune, he produced the first model. This, however, did not satisfy his wishes:

Minutes of the Proceedings of the Institution of Civil Engineers 1856.15:497-514.

but far from being disheartened, he immediately recommenced his experiments with renewed energy, expending on them all the remaining savings of an industrious life, as well as the whole of the time he could snatch from the labours on which the support of his family depended.

" His Son, also, after completing his studies with great credit at the Technological School of Stockholm, was anxious to assist his Father in this difficult task ; and for that purpose, abandoned the career he had previously chosen.

" The Father and Son now worked together for several years, and at last produced a machine, in which were united all the requisite conditions of a Difference Engine. But the severe economy they had been compelled to use in the purchase of materials and tools, and probably, the absence in Sweden of those precious but expensive machine-tools, which constitute the power of modern workshops, rendered this new model unsatisfactory in its operations, although perfectly correct in principle.

" Exhausted by the sacrifices thus made, yet convinced, that with better workmanship, a more perfect instrument was within their reach, Mr. Scheutz determined to apply for assistance to the Diet of Sweden.

" The Diet, with difficulty, consented to advance about £280, on certain conditions and with a stipulated guarantee. This guarantee was as great a difficulty as the construction of the machine.

" Fortunately, however, amongst the Professors of the Academy of Stockholm, enlightened men were found, capable of sympathising with moral and intellectual worth. To the enduring honour of the Swedish Academy, a numerous list was soon formed, in which each name became responsible for a part of the guarantee.

" Messrs. Scheutz, confident in ultimate success, further pledged their own credit, and after working night and day, with indefatigable industry, the last day of the allotted year saw the completion of their long-cherished hopes.

" Sweden has thus secured for herself the glory of having been the first nation, practically to produce a machine for Calculating Mathematical Tables by Differences, and printing the results. Wealthier and more powerful nations will regret, that the country of Berzelius should thus have anticipated them, in giving effect to an invention which requires for its perfection, the tools of nations more highly advanced in mechanical science. But there is still left to them the honour of acknowledging the services of a foreigner, from which the richest and most commercial countries will derive the greatest advantage.

" The machine was conveyed to Paris, and placed in the Great Exposition, and the Jury to which it was referred, after full examination, concurred with their distinguished colleague, (M. Mathieu, Member of the Institute,) in unanimously awarding to it the Gold Medal.

"The Emperor Napoleon, true to the inspirations of his own genius and to the policy of his dynasty, caused the Swedish engine to be deposited in the Imperial Observatory of Paris, and to be placed at the disposal of the Members of the Board of Longitude.

"Your Lordship is aware, that previously to awarding any of our medals, each Member of the Council may place one, or more names, on the list of candidates whose claims are to be discussed. I regret that, (perhaps through inadvertence,) the name of Mr. Scheutz was not placed upon that list, and I cannot, my Lord, sit down, without expressing a hope, that the Council of the ensuing year may more than repair the omission."

The Difference Engine of Messrs. Scheutz had supplied an excellent subject for illustrating the power of the language he had contrived, for the purpose of describing machinery of all kinds. He had himself used the Mechanical Notation during the last thirty years. He was driven to contrive it, because he found himself completely stopped by the complexity of the movements necessary to be combined in the original Difference Engine. The language itself had been adapted to, and found sufficient for, all the most complicated requirements of the Analytical Engine, and it was, in his opinion, capable of being applied to the description of every kind of machinery. When it became more generally known, he had little doubt, that it would be adopted as the ordinary language for all machinery; because by its means, even the most complicated mechanism could be easily understood, without the aid of any written description. The signs themselves expressed everything without difficulty. As a proof of this, he might state, that he had, at various periods, at least half-a-dozen draughtsmen working for him, who, after a short time, had each been able to use it with facility.

Machinery was usually represented by geometrical drawings. These gave the exact shape of every part, and the relative position of all the pieces. The art of mechanical drawing was of old date; but its principles had not yet been sufficiently discussed. By the use of a few simple rules to which the necessities of the Analytical Engine had given rise, its power of expressing machinery had been greatly augmented.

Mechanical Notation.

With respect to the Mechanical Notation there were three sections to which he wished particularly to direct attention. In order to explain the construction and action of machinery, they were all essentially necessary.

Section 1. The forms and exact magnitude of the whole machine and of all its separate parts. This was accomplished by the art of mechanical drawing.

Section 2. The connection between the first mover and the final results, including the courses through which each Piece received its various motions and transmitted them to others. The diagrams to be used for this purpose, he had called the Trains.

Section 3. The time of motion of every Piece and the time of action of every working Point: every successive time of motion, or rest of each Piece must be shown, and the cotemporaneous action of every Piece at every instant of time. The diagrams which conveyed this information, he had called the Cycles.

The three great elements of the description of machinery were then:—Form, represented by the Drawings. Directive power, expressed by the Trains. Times of motion and of action, expressed by the Cycles.

Section I. Of Form.

The most important addition he had made to mechanical drawing consisted, in having established rules for the use of letters. Hitherto, letters had only been employed for indicating certain points on the drawing. He had proposed, by a proper choice of various classes of letters, to convey other meanings, informing the observer by the nature of the letter itself, of certain characters belonging to the object it represented.

Thus the first great divisions of parts in every machine was into, 1st. Frame-work by which it was supported; 2nd. Moveable Pieces which acted and were acted upon. He proposed to mark all frame-work by upright letters; and to indicate all moveable parts, or Pieces, by inclined letters. The two classes would, at once, be distinguished from each other upon all drawings; and the attention might be entirely confined to that class which the student wished to consider.

Every working part, or single Piece of a machine might be considered either by itself as a whole, or as having Points and surfaces capable of acting and of being acted upon by those of other Pieces. Frame-work also might be viewed in the same light: it had its working Points, such as the supports of axes and slides: also Points against which Pieces were thrust. The rules he had proposed were first, that all working Points should be represented by small letters; and secondly, that all frame-work and every Piece should be represented by capital letters. The working Points of machines were very numerous; and a portion only of the small letters of the Roman and Italic alphabets were convenient for use.

It was, therefore, necessary to distinguish the small letters from each other, and also to connect every small letter belonging to a Piece, with the capital letter which represented it as a whole. For this purpose, he had established an index of identity, according to the following rules:—

1. A number placed on the upper left-hand corner of any letter, was called its index of identity.

2. The same index of identity which distinguished the letter denoting a Piece, must be applied to all small Italic letters denoting its working Points.

3. In Frame-work, (indicated by upright letters,) there were also working Points, such as the bearings of axes, &c. These might be marked by small printed letters, which were always upright letters.

4. Every working Point must be marked by the same small letter, as that of the working Point of the Piece on which it acted.

5. No two adjacent moveable pieces could have the same index of identity, unless they were permanently fixed to each other.

6. No two adjacent parts of frame-work could have the same index of identity.

7. In lettering drawings, the axes were to be commenced with.

8. Axes must be marked by inclined capital letters of either of the six alphabets, hereafter mentioned.

9. Dead centres, (being in fact frame-work,) must be indicated by upright letters.

10. Whenever the wheels, arms, &c. of any two, or more axes crossed each other, those axes must not be denoted by letters of the same alphabet.

11. No axis which had a Piece crossing any other Piece belonging to an adjacent axis, must have the same identity as that axis.

It was frequently necessary to refer from one drawing to another, in order to understand the relative position of the parts. Thus in examining a plan, any axis having attached to it a considerable number of fixed, or unfixed Pieces; it was very difficult and in many cases, impossible to know the order of their superposition, without referring to the elevation, or the end view. But this order might be made evident by a simple law of lettering. By first lettering the elevation, and marking the lowest Piece on the axis, by the letter *A*, the next above by the letter *B*, and so on; then when these letters were respectively transferred to the plan, they would render the order of their superposition evident upon that plan. This system would, however, unnecessarily restrict the use of letters, and would cause an inconvenient frequency of occurrence of the earlier letters of the alphabet. The course proposed to be pursued was, therefore, to mark the lowest Piece upon an axis, with any convenient letter. Then to place on the next Piece any subsequent letter of the alphabet, and so on : always observing, that no letter earlier than the one last used, could be applied to any Piece above it. This gave rise to the following rules:—

1. In lettering Pieces, to begin with the lowest, if on plan, or with the most remote, if in elevations, or end view.

2. To place any letter on each Piece, provided the alphabetic order of the letters was never inverted.

On the drawings, it often happened, that several contiguous axes had upon them wheels, arms, &c., which spread over other wheels, arms, &c., belonging to other adjacent axes. In this case, it was sometimes difficult to trace the pieces up to the axes with which they were connected. The index of identity would assist, in most cases, in tracing their origin, but it compelled an examination in detail of each Piece. The difficulty was much more readily solved by taking advantage of different forms of alphabets. He had found the following six alphabets to be quite sufficient for the purpose:—The Egyptian, the Roman and the writing capital letters inclined in the usual direction, namely, from left to right:—

A, B, . . . *A, B,* . . . *A, B,*

and the same alphabets, with the letters inclined in the opposite direction.

These were to be used according to the following rules:—

1. In assigning letters to the axes represented by circles in any drawing, never to allow any two adjacent axes, nor any two axes, whose arms, levers, &c., interfered with each other, to have letters of the same alphabet.

2. The capital letters thus possessed peculiar characters, arising from their belonging to the Egyptian, Roman, or writing alphabets, inclined in the usual, or in the opposite direction. The rule adopted for lettering the Pieces belonging to, or connected with each axis, was this:—Whatever might be the character of letter which had been used for the axis or slide, letters of the same character, or alphabet, must be used for every Piece whether fixed or loose upon it.

It sometimes occurred, that a boss, or other piece of matter, had several different arms forming part of it, which were placed at different heights upon it. It might be desirable to distinguish these projections from each other, and also from the Piece itself as a whole.

When this was necessary, it might be effected by the two following rules:—

1. Whenever it was necessary to distinguish the arms or parts of a Piece which projected from it, the same capital letter, with the same index of identity, must be used. But then, to that letter on

the right-hand lower corner, an index of linear position must be added.

2. The lowest projection, or that which was most remote from the eye, must be marked by the index 1, the next lowest by 2, &c.

Under similar circumstances, if the various arms were placed in different angular positions, then the indices must be placed in the right-hand upper corner, which was reserved for the index of circular position.

By the use of both indices, it was possible to distinguish the circular, as well as the linear position of every arm of any Piece. These two indices were indeed rarely wanted, but he had found them very useful in describing an axis with projecting arms placed spirally, which occurred in several of his drawings, as part of a means of carrying the tens.

In any drawing lettered according to this system, it was possible to distinguish at a glance,—Frame-work from moveable Pieces;—the outlines of every Piece;—all the Pieces connected with each axis;—the order of superposition of each Piece upon its own axis;—the order, both in elevation and angular position, of all the arms belonging to each Piece;—the working points which acted and reacted on each other.

Section II. Of Trains.

In this section of the Mechanical Notation, he proposed to show, almost at a glance, all the connections between the first mover and final result, and also the action which every working Point throughout the whole machine, either gave, or received. In very simple machines, it was not difficult to effect this object; but when it was attempted, by means of the drawings, for any machine of moderate complexity, the impossibility soon became apparent. He had given the general term of Trains, to the system of signs he had employed for this purpose. Pieces and working Points had already been defined. The former, as represented by inclined capital letters; the latter, as denoted by small inclined letters, if belonging to Pieces, and small printed letters, if part of frame-work. He would give an illustration. Supposing that ${}^2B$ represented a Piece, and *a*, *e*, *n*, *t*, *v*, were its working Points; that of these, *a* and *n* were Points by which ${}^2B$ was driven,—*e* and *t*, Points by which it drove, or acted on other Pieces; and that the working Point *v* sometimes acted as a driving, and at other times as a driven Point: then the Piece ${}^2B$ might be represented thus:—

$$\left.\begin{matrix} a \\ n \\ v \end{matrix}\right\} {}^2B \left\{\begin{matrix} e \\ t \\ v \end{matrix}\right.$$

He had proposed the following rules for the construction of the Trains:—

1. The object of Trains was to show the courses through which power was received and transmitted by every Piece.

2. Each axis must be taken in succession as it occurred in the machine, or as represented on the drawing, by its proper inclined capital letter, and its index of identity. This letter should then be placed between two inverted parentheses, thus:—

$$\left.\vphantom{\begin{matrix}a\\b\\c\end{matrix}}\right\}\,{}^3P\,\left\{\vphantom{\begin{matrix}a\\b\\c\end{matrix}}\right.$$

3. Every Piece belonging to this axis which received motion, must have its capital letter placed next the left-hand side of the first bracket.

4. Every Piece which gave motion, must have its letter, with its identity, placed on the right-hand of the second bracket.

5. When such Pieces were both acted and acted upon, their letter, with its index, must appear in both brackets, thus—

$$\left.\begin{matrix}{}^3B\\ \\ \end{matrix}\right\}\,{}^3P\,\left\{\begin{matrix}{}^3D\\ \\ {}^3B\end{matrix}\right.$$

${}^3B$ might represent a bevel wheel fixed to the axis ${}^3P$, by which that axis was driven. This bevel wheel itself also drove some other wheel. ${}^3D$ might represent a spur wheel, higher up on the axis than ${}^3B$, which gave motion to some other Piece. In this case, the two wheels and their axis having the same index of identity, must act as one piece of matter, and the expression would be more conveniently expressed thus:—

$${}^3B\ {}^3P\left\{\begin{matrix}{}^3B\\ \\ {}^3D\end{matrix}\right.$$

If the identity of the spur and bevel wheels were different from that of the axis, as ${}^2D$ and ${}^2B$, they would then form one piece of matter loose upon their axis ${}^3P$. If the wheels themselves had different identities, then each, separately, would be loose on the axis; the two cases would be thus represented:—

$${}^2B\ ({}^3P)\left\{\begin{matrix}{}^2B\\ \\ {}^2D\end{matrix}\right. \qquad\qquad {}^2B\ ({}^3P)\left\{\begin{matrix}{}^2B\\ \\ {}^5D\end{matrix}\right.$$

The parenthesis ( ) in which the axis was included, was so placed in consequence of the following rule:—Whenever all the

Pieces belonging to an axis were loose upon it, the axis itself might be enclosed in parentheses.

The next step was to attach their working Points to these expressions. For this purpose, the following rules must be observed:—

1. All working Points which were acted upon, or driven by others, must be written on the left hand of the letter representing the Piece to which they belonged.

2. If any working Point was acted upon by several different working Points, it must appear on its proper side, as often as might be required.

3. All working Points which acted upon, or drove others, must be placed on the right hand of the Piece to which they belonged.

4. In Trains, it was not necessary to put the index of identity to each working Point, because its juxta-position to its own Piece, sufficiently indicated its identity.

Resuming the first case of the three Pieces having the same identity. Supposing that the bevel wheel ${}^3B$ received motion from two different sources, and communicated motion to one Piece; and also, that the spur wheel ${}^3D$ communicated motion to two other Pieces: then the small letters indicating the working Points, must be thus placed:—

$$\left.\begin{array}{l} a \\ \\ a \end{array}\right\} {}^3B\,({}^3P) \left\{\begin{array}{l} {}^3B\,a \\ \\ {}^3D \left\{\begin{array}{l} v \\ \\ v \end{array}\right. \end{array}\right.$$

The other two cases would be thus represented:—

$$a\,{}^2B\,({}^3P) \left\{\begin{array}{l} {}^2B\,a \\ \\ {}^2D \left\{\begin{array}{l} v \\ \\ v \end{array}\right. \end{array}\right. \qquad \left.\begin{array}{r} \left.\begin{array}{l} a \\ a \end{array}\right\} {}^2B \\ \\ v\,{}^5D \end{array}\right\} ({}^3P) \left\{\begin{array}{l} {}^2B\,a \\ \\ {}^5D \left\{\begin{array}{l} v \\ \\ v \end{array}\right. \end{array}\right.$$

When every axis, slide, &c., throughout a machine, had been thus represented, the whole of these expressions, each of which was called a Term, could be combined. This must be done according to the following rules:—

1. To write down the letter which represented the first mover, with its proper identity, and all its driving Points. To connect each of its driving Points by an arrow-headed line, with the Point it drove, that being a small letter the same as itself.

2. These small letters would each be found on a Piece connected with some adjacent axis. The term expressing that Piece, should

Minutes of the Proceedings of the Institution of Civil Engineers 1856.15:497-514.

be written down in such a manner, that the driving Point of the first mover, should be joined with the proper driven Point of the Term.

3. Each term so written down would have its driving Points, and must be treated in the same manner, until every Term had been placed on the paper.

It would then, probably, be found, that several of the driven Points remained without a driver. On further examination, their drivers would be discovered, and arrows must be placed to connect them. When it was found, that every driving Point throughout the machine, had been connected by an arrow, with the driven Points on which it acted, the work of constructing the Trains was accomplished. The paper, it was true, would probably present a mass of letters irregularly grouped, and connected together by curved arrow-headed lines, crossing each other in every direction. This might be considered as the first edition of the Trains. The next step was by altering the positions of a few of the Terms, and consequently, of the connecting arrows, to bring nearer to each other those Terms which were most intimately connected, and thus to diminish the number of intersecting arrows. Without attempting to carry this process too far, it was best to make a rough copy, perhaps in ink, with these improvements. The same process must be repeated on each edition, until a tolerably clear and symmetrical representation had been obtained. It had not been an uncommon event, in respect to some of the Trains he had made, that they had passed through above a dozen editions. He believed the intimate knowledge gained by such a tedious process was, however, invaluable in enabling the inventor to effect improvements.

It would have been observed, that mechanical drawings were the pictures of things, and that by the aid of lettering, those drawings had been rendered, as it were, transparent. It would also have been noticed, that through the same system of lettering, the constant reference from plan to elevation, section, or end view, had been very greatly abridged. In constructing the Trains, the letters of the drawings had been used as the signs, not as the pictures of things. The consequence of this was, that in preparing the Trains, an almost constant reference became necessary to the drawings themselves, and thus much time was consumed. Moreover, when the Trains themselves were studied, it was often difficult to find a letter on the drawing, because the letter itself conveyed no notion of the form, or shape of the Piece it represented. In order to remedy this inconvenience, he devised a new system of signs, which he had called the Alphabet of Form. It consisted of a series of certain very simple signs to be placed above the letters, in order to express the species, but not the exact shape, or magnitude of the Pieces they represented. That Alphabet would be difficult to ex-

Minutes of the Proceedings of the Institution of Civil Engineers 1856.15:497-514.

plain in print, until special type had been cast for it. It might, however, be sufficient to state, that he had endeavoured to make each sign, directly, or constructively, resemble the Piece it represented. Thus:—a small hollow circle above a letter, represented a hollow axis; a circular dot of the same magnitude, denoted a solid axis; $^4\mathring{N}$ was a hollow axis; $^3\dot{P}$ was a solid axis. Another source of delay arose from the frequent necessity of referring from the Trains to the drawings, in order to ascertain the nature of the motions communicated to each Piece. To remove this difficulty, he adopted another Alphabet, that of Motion, which consisted of about ten signs. These were placed under the letter which received the motion. When a Piece had two, or more motions, it must have as many signs of motion, under the capital letter representing it. In such cases, the letter representing each working Point, must have under it, the sign of that motion which was communicated through it, to its own Piece. In other cases, the signs of motion were rarely required for the working Points.

The Trains were specially intended to represent the transmission of motion; but by placing the signs of Form above the letters, frequent references to the drawings would be saved. By placing signs of motion below these letters, a further economy of reference would be produced.

A still greater power of explanation might be given to the Trains, by adding to them information relative to the times of action of the working Points, which would afterwards be found in the Cycles. Under the arrow connecting each pair of working Points, the numbers in the Cycle at which the driving Point began its actions, must be written. Above the arrow, and immediately over each time of commencing action, the number of units during which that action continued, must be written. With these additions, the Trains alone contain every information relating to the working parts of a machine, except the exact form and position which drawings were alone competent to afford.

Section III.—Of Cycles.

The first section had explained the external form of machinery; the second had explained the whole sequence of its actions. In this, the third section, he proposed to represent every circumstance relating to the time of action of all its parts.

In the motion of machinery, two cases must be distinguished. 1st. The time during which a Piece moved. 2nd. The time during which it acted upon another Piece. An axis having arms and wheels attached to it, might move continuously, or at intervals; but it need not, necessarily, be giving motion to other Pieces, during the whole of that time. On the other hand, a Piece at rest might be the cause of relative motion to an arm pressed against it. The times of motion belonged naturally to the Pieces themselves, or to the capital letters which represented them. The times of action were determined by the position of the working Points, therefore, the signs which indicated them must refer to those Points. In almost every machine, there was a Cycle of actions which recommenced and repeated themselves at certain fixed intervals. In the machine of Messrs. Scheutz, after the calculation of the tabular number, and its differences, had been completed and stereotyped, a similar process recommenced. The length of this cycle depended on the nature of the machine; it was usually measured by the number of rotations of some axis, or by the number of teeth in some wheel. Having decided into how many units of time it was convenient to divide this period, or cycle, a number of horizontal parallel lines must be ruled, at equal distances, on a large sheet of paper. The number of spaces between the lines, must be a few more than the number of units in the intended cycle. These horizontal lines must be crossed by other lines at right angles to them, thus forming vertical columns, which must be equal in number to the sum of all the working Points added to the number of all the Pieces in the Trains. The horizontal divisions of units must be numbered from the top downwards.

With the Trains for a guide, the number of driven Points possessed by the first Term, and also the number of Points by which it drove, must be ascertained; then, as many of the headings of the first columns, as there were driven Points, must be filled up with the small letters by which they were indicated. In the heading of the next columns, the principal capital letter with which those working Points were connected, must be written; and as many vertical columns must be used for the Piece, as it had separate kinds of motion. In the heading of the columns which immediately followed this capital letter, all the small letters indicating its driving Points must be written. The vertical lines at the commencement and end of these headings, must be made darker than the intermediate lines, or they might be drawn with red ink.

Between these dark vertical lines, there was now the principal letter of the first term of the Trains, with all its driven Points in columns on its left side, and all its driving Points on the right side, each being indicated by its own small letter. Every succeeding capital letter occurring in the Trains, with each of its driven and driving Points, must, in succession, be inserted in the remaining columns. When two or more connected Pieces had different letters, with the same index of identity, it was not necessary to assign a vertical column, to more than one of those capital letters. Commencing on the left-hand vertical column, just above the letters thus placed, the natural numbers must be successively written: these were necessary for reference. The verticals which represented each Term of the Trains must now be connected together, just above the numbers, by a horizontal bracket. Above this bracket the Term itself must be written, just as it appeared in the Trains. Commencing with the first mover, the number of units of time each Piece moved, must now be ascertained from the structure of the machine itself. In the vertical column headed by the capital letter indicating each Piece, a thick arrow must be drawn vertically, through those units during which it moved. If the Piece itself sometimes moved in one direction, and sometimes in the opposite, this must be indicated by placing the heads of the arrows in opposite directions. As soon as the time of working of each Piece had been entered in its proper column, the time of action, or of receiving action, of each working Point must be ascertained, and must be entered with a fainter arrow, in its proper vertical column.

When this process had been gone through for every working Point and Piece in the machine, the Cycles were complete. All the possible successive motions of each, would have been registered in the vertical columns. All the cotemporaneous motions at any part of the Cycle might be immediately known, by inspecting the horizontal divisions indicating the point of time for which that information was required. Above the headings of the vertical columns, extracts from the Trains were placed, in order to exhibit the relative position of the larger divisions of the machine, and also to assist in directing attention to any required Point. The number of the principal letter of each term in the Cycles, might be placed in red ink just above the term itself in the Trains, thus affording easy reference from each illustration to the other.

One of the greatest advantages which arose from the Mechanical Notation, was the power it gave of looking at any machine in its most general conception, or in its most minute detail, and even at any intermediate degree of generality.

Three different degrees of generality of the Trains of the Swedish machine, prepared by Mr. H. P. Babbage, were exhibited in the diagrams. In the first illustration there was a handle which showed, by two arrows proceeding from it, that the machine consisted essentially of two parts. One of these, a mangle-wheel, governed the calculating portion, and conveyed the computed table to certain steel punches. The other, by means of cams, governed the counting apparatus, conveyed the counted number to other steel punches, and then pressed a leaden plate up to the punches, which thus received a stereotype impression. Such, probably, would have been the first conception of the Swedish engine in the inventor's mind, and such was its shortest and most popular description. The third illustration of the Trains descended to the minutest information as to the directive power. The immediate cause of every movement throughout the whole cycle of its operations, appeared on that paper. Every channel by which power was conveyed might be immediately traced out, either back to its original source, or onward to the ultimate result. The second illustration of the trains was made merely to show, that any intermediate degrees of generality thought desirable, might be attained. The largest illustration of the Cycles was nearly five yards long. It contained the answer to every question relating to the time of action, or of motion, of about six hundred Pieces, and nearly two thousand working Points.

The three sections of the Mechanical Notation which he had now described, were, in his opinion, sufficient for all the present wants of machinery. For the contrivance of the Analytical Engine, they were, however, found insufficient. They would, perhaps, also be insufficient for working out the construction of certain automatic machines, capable of playing games of skill and chance, which the structure of the Analytical Engine led him to imagine. These new difficulties had been surmounted by other sections of the Mechanical Notation, to which he had alluded in addressing another Institution.[1] But he abstained from further remark upon them, because they had not that practical and every-day utility, which so eminently characterised the discussions of the Institution of Civil Engineers. During a long use of this language, he had had opportunities of observing the facility with which it could be acquired. In one instance, having himself made the Trains, and also a rough sketch of an imaginary machine, he placed the Trains alone in the hands of two of his draughtsmen, and desired each, without communicating with the other, to make a pencil sketch of the machine. On comparing the three sketches, they were found to be identical in principle. Of course as no drawing had been given, the magnitudes and relative positions of the wheels, cranks, &c., were not the same; but the ultimate effect was, in all three cases, arrived at through the same chain of intermediate means.

As an illustration of the practical effect on the mind, of these illustrations of the Swedish engine, he might mention the fact, that two gentlemen, both highly conversant with mechanical art, had, at separate times, each observed that, although he had never seen the Swedish machine, he thought he understood more of it from those illustrations, than he should have done by inspecting the engine itself. He attributed this to several concurring causes.

[1] *Vide* "Sur la Machine de M. Scheutz." Académie des Sciences: Comptes-rendus. Tome xli. October 1855.

The relations and subordination of the great sections of the instrument, as exhibited on those illustrations, were distinctly visible at a distance; whilst all the minuter details were indistinct. The consciousness that, on a closer examination, even the minutest action of each Piece, throughout the whole machine, would become immediately apparent.

Again, in examining a machine, it was scarcely ever possible to see all the parts and their connections, at one view. The time of action of the various parts of the machine itself, could only be observed in succession, and during their motion; but the Mechanical Notation revealed even its most fleeting movements. It had, as it were, photographed the footsteps of time; and with power more enduring than electric fire, it had conferred fixity and permanence on the swiftest motion. In thus making public those laws which he had framed for the description of machinery by a new and universal language, he might be permitted to observe that, however desirable it might be, in his opinion, that the whole should at once be introduced, yet it was quite possible to divide the subject into, at least, four distinct stages:—

1st. The art of lettering drawings.
2nd. The Trains.
3rd. The Alphabets of Form and Motion.
4th. The Cycles.

Whatever course might be chosen, he left it with the fullest confidence, in the hands of a Society whose object was essentially progressive.

May 27, 1856.

The Session was concluded by a CONVERSAZIONE, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.

Minutes of the Proceedings of the Institution of Civil Engineers 1856.15:497-514.