

*Account of the Invention of the Pantograph, and a Description of the Eidograph, a Copying Instrument invented by WILLIAM WALLACE, A. M., F. R. S. Edin., F. R. A. S., Memb. Cam. Phil. Soc., &c., Professor of Mathematics in the University of Edinburgh.*

(Read 13th January 1831.)

THE power of making such a representation of any object, as shall give a distinct idea of its form, is a faculty which artists possess in different degrees of perfection. The principal difficulty is, to get a first delineation of any subject; from this a copy may be made in various ways, with less exertion of talent than was required for the composition of the original.

Various geometrical and optical inventions have been proposed to assist the artist in making an outline of an object which he wishes to represent. The *Reticulated Square* and other contrivances, for placing every point of the thing to be represented in its proper place in the picture, belong to the first class; the *Camera Obscura* and the *Camera Lucida* to the second. When a design is to be *copied*, a different kind of contrivances will in general be more convenient. It is only of these that I propose to treat here.

In making a copy, the assistance the artist seeks from mechanical invention is, the power of forming a correct outline. In many cases, as in the formation of maps and some architectural designs, this is all that is wanted: the gradations of light and shade must, in general, be given by the imitative skill which the artist exerts by the eye alone.

There are various well known contrivances by which a copy of any design may be made, when it is to be exactly the size of

the original. Of these, a sheet of semi-transparent tracing paper laid on the subject to be copied, is one of the most simple and elegant. On this, the engraver may make an outline of a subject which he means to transfer to his copperplate. If he set no value on the original design, he may dispense with the transparent paper; and having made a trace with black lead along the lines to be copied, he may render them visible on the copper by the pressure of the rolling-press.

Another elegant way of making a copy is by means of a tracing glass. This, fixed in a frame, is placed in a sloping direction like a writing desk: the sheet to be copied is laid on the glass, and the paper on which the copy is to be made above it: a strong light, either natural or artificial, is directed upwards through the glass, while the surface on which the copy is to be made is skreened from the light. The lines to be copied are thus made visible through the two sheets, and a trace is made on the uppermost by carrying a point over them.

If a subject is to be diminished or enlarged, none of these methods will apply. Now this is by far the most common case at the present time, when numberless Encyclopædias, Atlases, and other works illustrated by figures, are in progress of publication, the materials of which are, for the most part, taken from writers of established eminence.

It may be supposed that attempts must long ago have been made to furnish the various classes of artists with instrumental aid. In investigating this subject, however, I did not find that the mechanical contrivances for copying on an enlarged or reduced scale, had been numerous or considerably different, or that their application can be traced to a very remote period. There is a well known instrument called the PANTOGRAPH: this appearing to have been the earliest, and that from which all the others have been imitated, I was induced to look into its history; I found it figured and described by various writers, who yet have given no indication of its inventor. In a work called “ Geome-

trical and Graphical Essays," by GEORGE ADAMS, printed in 1791, I found it described under the name of a *Pantographer*. ADAMS says, " I have not been able to ascertain who was the inventor of this useful instrument. The earliest account I find is that of the Jesuit SCHEINER, in a small tract entitled, *Pantographice, sive ars nova delineandi*."

ADAMS must either never have looked into SCHEINER's book, or assuredly must have forgotten what is in it : MONTUCLA, in his *Histoire des Mathematiques*, says expressly that SCHEINER was the inventor. In enumerating this learned Jesuit's writings, he mentions his work called *Pantographia*, in which, he says, the construction and use of the Pantograph is described ; and he adds, " that, independently of his other writings (which MONTUCLA did not highly esteem), the invention of this instrument alone ought to have given immortality to his name."

Besides this notice of MONTUCLA, and SCHEINER's own book, I have met with no other recorded testimony that he had the merit of being the inventor of the Pantograph, although such may exist.

There is an instrument, exactly the same as SCHEINER's, described and figured in a folio work on Geometry and Perspective (of which there were various editions), by SAMUEL MAROLOIS, who must have been his contemporary. There is also a figure and description of a like instrument in a small book called *Thaumaturgus Mathematicus*, printed in 1651 ; but in neither are we told who was the inventor, nor is even a name given to the instrument, although I have no doubt it was that of SCHEINER's invention.

I see it described in BION's treatise on Mathematical Instruments (edit. 1723), where it is called the *Pentagraph* : and again, in the History of the Academy of Sciences for 1793, where it is called the *Pantograph* ; still the inventor is not named. In this last mentioned work, some defects in its construction are pointed out, and improvements suggested by LANGLOIS, Engineer to the

King and the Academy. In this state it was taken up by ADAMS (the father of GEORGE) the English Instrument-maker, who gave it nearly the form it has at the present day. MONTUCLA having said that the preface to SCHEINER's book is very curious, I was desirous to see the work. It must be rare, for I could not find a copy in any of our Edinburgh public libraries. At length I found one in the Catalogue of the University Library of St Andrew's, from which, by courtesy, it was lent to me. I found the preface, or rather the first chapter, very curious indeed. I have shewn to several friends, members of this Society, a translation of it, who entertain the same opinion ; and it has been suggested, that in this communication, in which I propose to describe an instrument for a like purpose, I may not improperly give the most interesting part of SCHEINER's own account of his invention.

*Translation of a part of the first Chapter of Scheiner's work, entitled "Pantographice, seu Ars delineandi res quaslibet per Parallelogramum lineare seu Cavum, Mechanicum, mobile," &c.*

"Being, in the year 1603, a professor in the celebrated German Academy at Dillingen, where I taught in general polite literature, but sometimes also mathematical science, I contracted a friendship with an excellent painter named GEORGIUS, a man lame and deformed, from whom I learned some secrets of the arts and of nature, and communicated some discoveries of my own in return.

"This person boasted to me of possessing an admirable invention, namely, a compendious method of delineating any object, most easy, sure, and speedy to practise ; so that whoever would take a drawing from any original, did it by regarding the original alone, without needing to look at the copy he made, and yet without erring in his delineation by one hair's-breadth. He de-

clared farther, that in the drawing of any figure whatsoever, he was so assured of accuracy, that he could pass at once from forming the feet to represent the nose ; then, after producing the hands, he could pass from them to delineate the eyes, or any other part. All these copies he asserted he could make either equal to, greater, or less than the original ; which alone required to be seen, but always most exactly true : he never looking at the copy he made, although he could point out and designate any part of it he pleased.

“ Upon hearing these particulars, and many more like them which he told me, being inflamed with a desire to learn his invention, I asked him to communicate it, promising to recompense the benefit by disclosing to him some similar and equivalent discoveries in the art of painting, which I thought were not commonly known. He replied, that he valued his invention so highly, that so far from thinking that any thing comparable with it existed, he did not believe that such could be even imagined ; in fact, that it was not a human so much as a divine invention, which he thought had been brought and disclosed to him by no human efforts, but rather by some celestial genius. Therefore he declared that he could not bring his mind to barter a secret of that nature for any others whatsoever.

“ I begged that at least he would give me some specimen of his art, by copying a picture before me. He replied, that to exercise his art before a bystander, was the same thing as teaching it, for he that saw it practised could not fail to learn to imitate it.

“ Confounded beyond belief at this assertion, I asked him seriously if he was advancing fables or facts, hyperboles or the naked truth ? He declared that he said even less than truth warranted.

“ Upon this I, more full of admiration than ever, again inquired, how, if the artist was guided by seeing the original only, he could direct the copying pen or pencil without error ? He

replied, that the nature of the thing was such, that accuracy ensued infallibly, and as it were spontaneously : so that it was impossible to err without design. I inquired whether the effect was wrought by the drawing of lines, or by the help of a material instrument ? Here he began to hesitate, and to speak evasively, avoiding a clear answer, and hiding a thing, dark and unintelligible in itself, in obscure language. This alone he admitted, that the thing was done by the help of compasses depending upon a firm centre. I asked him to shew me these compasses : he refused, upon the plea that whoever saw them would at once comprehend the whole mystery. At length I earnestly entreated that he would make a disclosure to me under the seal of secrecy, and a pledge of keeping silence, promising to reveal it to none without his knowledge or against his will ; to all which he gave a round denial. Seeing that I talked to one deaf to importunity, I changed my style ; telling him that I trusted to discover the thing by the blessing of God, who would, according to my desire, communicate the invention to me in his own good time, while he might chafe and fret in vain. He laughed at my threats, saying, that the invention surpassed the power even of the Devil himself ! These things happened in the beginning of the year 1603, at which period, turning my attention to the investigation, I laboured with all my might. I tried the thing at first with a cord, which I imagined fixed at one end (for I formed the whole in my mind only, and in thought, until I had attained a true knowledge, along with a clear demonstration) ; then taking the other end in my fingers, I moved it round on imaginary paper, there being upon it two small spheres acting as cursors, to mark out points and proportional lines. These, indeed, I saw, might be formed about a fixed centre ; but then, neither was there any motion to or from the centre by means of the flexible thread, nor did the cursors change their positions upon it, which yet was necessary to increase or diminish the motion proportionally. Dismissing, therefore, lines formed by threads,

I had recourse to iron rods. These, however, it was difficult to get of the requisite straightness, while to connect them by joints convenient for motion seemed impossible. I consequently put them away, and betook me to rods of wood.

“Placing one of these before my thoughts, I supposed it perforated at certain distances, and hollowed out ; with this, so fitted for use, I found out something regarding the motion *round* the centre, but with regard to that *to* and *from* the centre, it proved to little purpose. Next I joined two rods, using their common junction as a moving centre, and assuming a point, which might be in either, as a fixed centre ; but neither in this way did I attain my object. At length, making an attempt with four rods, forming a gnomon round a small parallelogram, I began to conceive better hopes of success. However, owing to placing the tracer and drawing pen almost always on the same rod, or in a position deviating beyond the straight line, I did not reach the desired end on the first day that I entered on the inquiry. The object of this invention related to the producing a copy broader than the original, but in what manner to perform correspondingly what referred to the height greatly perplexed me. I had, indeed, learned how to go round the fixed centre, but I was uncertain as to the method either of receding from, or approaching to it. However, I did not despair, but after some consideration, I resumed the design of accomplishing the work at the hours and days of my leisure ; telling nothing to any one of my attempt, but sedulously commending it to God and my guardian genius.

“These at last were not wanting to my arduous efforts, but most graciously imparted a knowledge of the whole secret, along with its scientific principles, on that same night which precedes the day sacred to Saints Fabian and Sebastian. In this revelation, the form itself of the instrument was so represented to my mind, its practice, and a demonstration of the whole shewn, as it were, at one glance, as if I had seen all things with my bodily eyes, and was receiving the lesson of a master

guiding and teaching me. This impression upon my mind was so strong, that after twenty-seven years it appears as of yesterday. Immediately on arising, giving thanks to God and my tutelary angel, and being full of joy, I exclaimed often within myself, 'ευρηκα, ευρηκα !' Then having fitted together four wooden rods by means of needles, I took a picture of St Ignatius, and drew it on paper, the copy being of like form, but on a larger scale ; also, around this, and from the same picture, I carefully drew others of a distorted proportion. All these, along with the instrument I had invented, I sent to the before mentioned painter, by the hands of a certain novice, MELCHIOR SCHENCK, at present Father of our Society, who was commissioned, along with fifty other young men of my jurisdiction in the Monastery of St Jerome, to ask and interrogate him, 1. Whether he knew or had ever seen this kind of instrument ? 2. Whether he knew the use of it, and could assign, at pleasure, points for the fixed centre, for the tracer, and for the drawing pen ? 3. Whether from a given picture he could draw an unlike distorted one ? 4. Whether from a distorted picture he could restore the symmetrical one ? 5. Whether the picture shewn to him corresponded to its original ? 6. Whether he believed that this invention was made by Master SCHEINER ?

“ The painter on seeing the drawings and instrument, stood, as they told me, mute and astonished for a quarter of an hour. At length, recovering himself, he replied, That he had never seen a similar instrument, nor knew its use : That the drawing pen, the point of the tracer, and fixed centre in his compasses, were connected with certain holes, besides which, he could not assign others. He allowed that he had never seen distorted pictures, being neither able to produce a distorted copy from a symmetrical original, nor from such a copy to reproduce the original. He admitted that the figure of the saint in the middle of the copy shewn to him, corresponded most exactly with the picture. He declared, lastly, his doubt if Mr SCHEINER, without his previous



instruction, would ever have made so illustrious a discovery, which in his opinion should have been kept secret, and not promulgated to be trodden under the feet of the vulgar.

“He that had the commission from Mr SCHEINER then returned thanks in his name to the painter, for having, by so industriously concealing his small invention, given occasion for the discovery of a much greater ; and by denying a little gem, having paved the way to lay open a concealed treasure : and also, that whereas at one time he might, by the doing of a small good office, have bound his friend to him for ever, so by his refusal he had raised him to the dignity of being a benefactor to the whole world. He added farther, that the inventor would take care that this divine blessing should not fall into contempt, by too promiscuous an imparting of it.

“After this I gave instructions to some friends and pupils upon the subject, and having, after teaching of Humanity for four years at Dillingen, returned to Ingoldstadt to pursue Theology, I there also communicated the art to some others. At this time, WILLIAM Duke of Bavaria, a person well skilled in the art of painting, hearing of the fame of my instrument, invited me to Munich to exhibit it before him ; and so wonderfully was he pleased with its niceness, its sureness, and facility of execution, that he desired me to write a short description of the instrument itself, and the manner of drawing a figure.

“In requital of this service he paid me the compliment of making known to me that curious artifice by which water is raised and projected upward. In this method the air is extracted by means of two wheels closely connected, and by the suction thus produced, the water is first raised and afterwards impelled ; the *rationale* of the experiment being nature’s dread of a vacuum, and the impenetrability of bodies.

“Having now returned from Munich to Ingolstadt, I went through the prescribed course of Theology and published my thesis. Being then requested by my superiors to teach Mathematics, I was sufficiently liberal in communicating a knowledge

of my parallelogram ; for both publicly in school did I deliver to my pupils precepts in the art of delineating objects on a plane, along with sound demonstrations, and at home also, privately, I revealed to many the abstruser doctrines of the science. By this means it happened that a general knowledge of the art got abroad. I made, however, a more free communication to those who were going into the Spains, and thence about to traverse the eastern and western worlds for the dissemination of the Catholic faith, that they might have by this means a more ready access to conciliate the benevolence of mankind, and thence instil more easily truths of deeper moment into minds thus prepared to receive them.”\*

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The Pantograph has no defect in its geometrical principles, but, considered as an instrument for practice, it is by no means perfect. It is composed of metallic bars, which turn on five centres ; it is supported on six rollers turning also on centres, and continually changing their direction while they move along the paper ; and when the instrument is used, the force which changes its figure is in some positions applied obliquely, and thus acts at a disadvantage. On all these accounts, its excellence as a working machine is by no means equal to the perfection of its geometrical theory. Land-surveyors sometimes use it from necessity, in reducing or enlarging plans, but the engraver hardly ever employs it ; indeed, in his more delicate work, he can derive from it very little assistance.

In the summer of the year 1821, my attention was directed to copying instruments. I found that the Pantograph was then the only one used, and I formed the resolution of attempting to invent a new instrument, which should be free from its imperfections.

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\* The remainder of SCHEINER's first chapter contains nothing now particularly interesting ; it is therefore needless to continue the extract farther.

About the middle of July I shewed my friend Mr JARDINE my first essay, a rough model made of wood. His favourable opinion encouraged me to persevere, and I succeeded in contriving an instrument, which gave reason to expect that, when properly made, by its use any plan could be copied, of the same or a smaller size, or even larger than the original, with as much accuracy as a tracing point can be carried along a line. To distinguish the instrument from others designed for a like purpose, I have called it an EIDOGRAPH, from the two Greek words, εἶδος, *a form*, and γράφω, *I write*.

I next attempted to contrive another instrument that should make a reversed copy, that is, such as would be shewn by the reflection of the original from a mirror. In this also I succeeded. but the construction was more complicated than that of the other. The object of the reversing instrument was to make a trace, at once, on copper, with a view to the etching of any subject on a varnished ground. An engraver whom I consulted did not think this form so necessary and likely to be so useful as the other, and therefore the invention has not been followed out beyond the rough model; which, however, serves to shew that the thing is quite possible. By this second construction, which may be applied also to make a *direct* copy, an instrument might be made, by which a person sitting in one room may write at a considerable distance in another, notwithstanding intervening walls or floors. I mention this, because cases may be imagined in which it might be useful for persons in different parts of an establishment to have the power of holding intercourse by writing, without moving from their places.

I shall not trouble the Society with a detail of the pains I have taken to improve the Eidograph, and of my experience of that law of the human mind, by which it tenaciously adheres to old habits and methods to which it has been accustomed, and refuses to adopt new ones, although more perfect. My object in this paper is to prevent an useful invention from being lost, by having it recorded. Indeed, its utility is now pretty generally

known ; for besides occasional applications to the construction of enlarged maps and scientific diagrams, exhibited in the meetings of this Society, and to other purposes of public utility, it has been extensively employed by some engravers in constructing drawings for the plates of literary undertakings, and in particular, the seventh edition of the *Encyclopædia Britannica*, now in course of publication ; to the anatomical engravings of which, as well as to those of other works of a like kind published in Edinburgh, it has given a degree of perfection much beyond what could have been attained without its aid.

I am sorry to have reason to say, that at least one imitation of my instrument has been pressed on public attention, in opposition to mine, which, for an obvious reason, has been disparaged by comparison with the imitation. I possess, however, in writing the testimony of competent judges that the defects alleged to be in my instrument really did not exist. In fact, the imitation is a modification of the first form that occurred to me, but which was abandoned for a better. My case, however, is no worse than that of many inventors : their labours have frequently been imitated after they have been at great pains and expense in bringing them to some degree of perfection.

The Eidograph has been shewn to every ingenious person who has visited me since 1821, amongst whom have been many foreigners. This has been done in order to spread a knowledge of the invention, and to make it, if possible, useful to society ; and I have had the satisfaction of knowing that an imitation of it has been publicly exhibited amongst works of ingenuity in Russia by a British officer, who, however, had the candour to acknowledge to my friend who saw it, that it really was an imitation of my instrument.

I shall now state some of the advantages which the graphic art may derive from the Eidograph.

1. The instrument is applicable to the copying and reducing of very nice works of design ; for example, the lineaments of a portrait. Indeed, it has actually been applied to the tracing re-

ductions of a subject, of various sizes, on an etching ground on copper, and the process afterwards completed by an acid in the usual way, and impressions printed from the plate.\* Of course the figure is reversed in respect of the original. This limits the application, except the copy be made by a reversing instrument; but in many cases this is a matter of no moment. I know of no attempt to do any thing of the same kind by the Pantograph.

2. In estimating the value of the instrument, the economy of time by its use is important. This will vary according to the intricacy of the design to be copied. I have been assured by a skilful engraver who had used the instrument, that in ordinary cases the saving may be three-fourths of the time required by the methods used before its invention; and that, in more intricate subjects, the saving may be nine parts out of ten.

3. Another advantage is, that a youth whose labour costs little, may be taught in a few days to accomplish what would require years of practice, by the eye alone, in the ordinary way.

4. In the last place, the work may be better done. In the old methods, its accuracy could only stand the test of the unassisted eye; but if done by the Eidograph, it will bear an examination by measurement on a scale.

The principle which has directed the construction of the Pantograph and Eidograph is the same: it is taken from geometry, and may be stated thus: "If two points move on a plane, so that the straight line which joins them passes always through a fixed point as a pole; while in every position the distances of the moving points from the fixed point have to each other the same invariable proportion: then if, by any means, one of the points is carried along any line, the other shall trace a line exactly similar; the parts of the two lines passed over by any change of position of the points, having always to each other the invariable proportion of their distances from the fixed point."

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\* Specimens of these etchings were deposited in the library of the Society some years ago.

Or, generally, and more briefly, thus :

“ If, from a given point, two straight lines be drawn, containing a given angle, and having to each other a given ratio ; and if one of them terminate in a line of any kind given in position, the other terminates in a similar line, which is also given in position.”

The proposition in this second form gives great latitude in the construction of the instrument. I have, however, only employed the principle as first enunciated.

In applying the principle, the object to be accomplished was, to connect by mechanism two material points, which should move with perfect freedom, subject to the specified conditions of the abstract proposition ; or so that one of them, a tracing point, being carried along the lines of any proposed design, the other, a copying point, should trace on paper a true copy of the design in any given proportion. This has been effected by the instrument now to be described.

Its general appearance is shewn in Plate XIV. Fig. 1, which is a projection of it on the plane of the surface on which the design and its copy are placed. The beam *aa* is a square prism of brass ; it passes through a socket *cc*, in which it may slide either way. The socket is supported by, and turns on an axis rising out of a base *dd*, which is a brass cylinder. There are two wheels *f, f*, having equal diameters, below the beam ; these have vertical axes fixed in them, which turn in bored tubes attached to its extremities. The wheels are connected by a metallic band *fg, fg*, which passes round them, and is fixed at a point in the circumference of each, so that it cannot slide along their edges.

Two arms *Pb, Tb*, pass through sockets (in which they may slide), under the centres of the wheels, and turn along with them in a plane parallel to that on which the instrument stands. By the equality of the wheels, and their connection by the band, the arms when once placed parallel continue so, although the wheels are turned about their centres. A tracer with a steel

Fig. 1.

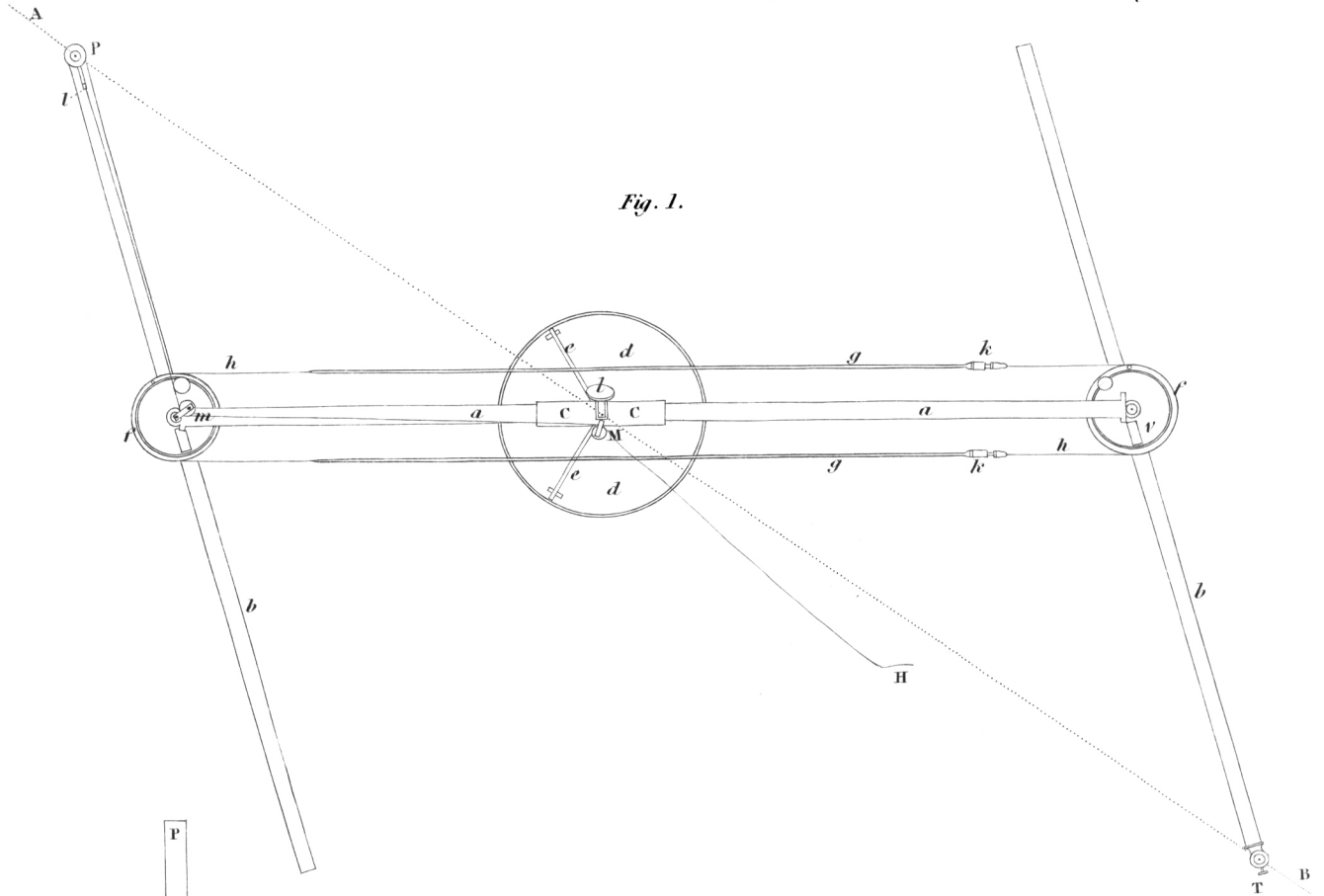


Fig. 3.

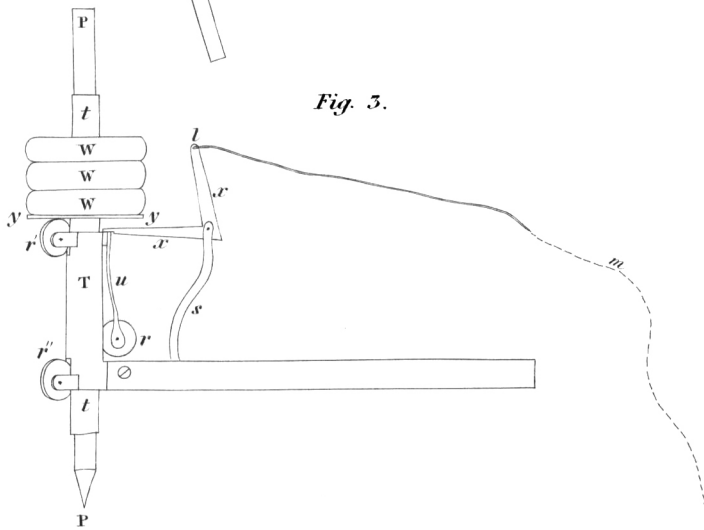


Fig. 2.

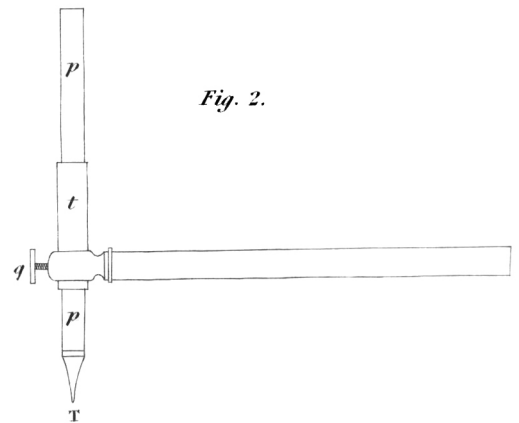


Fig. 4.

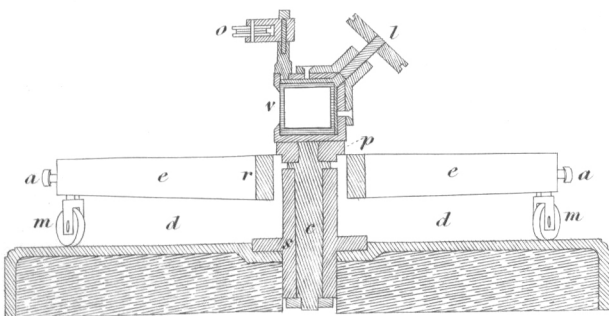
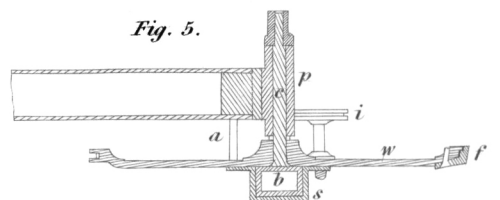


Fig. 5.



point is fixed at T, the extremity of one arm, and a black lead pencil, which serves as a copying point, at P, the extremity of the other arm on the opposite side of the beam. The distances of these points from the centres of the wheels are in every case equal to the distances of the latter from the centre of the beam, whatever proportion these have to each other. By this disposition of the members of the instrument, a straight line joining the tracing and copying points passes through the axis of motion of the beam, and is there divided into two parts, which have to each other the proportion of the distances between the centres of the wheels and the centre of the beam. Thus the conditions required by the mathematical theory are satisfied.

Having described the instrument generally, I shall now notice its parts, particularly, in detail.

THE BEAM *a a*, for the sake of lightness and stiffness, is hollow ; it is about thirty inches long, but may be of any required length ; its cross section is a square, about nine-sixteenths of an inch in the side. There is a SCALE of 200 equal parts engraved on one of its vertical faces. The length of the scale is the exact distance between the centres of the axes of the wheels, and each division is  $\frac{1}{200}$ th part of this length. The division at the middle of the beam is 0 (zero), and the scale is numbered both ways ; the extreme divisions would be 100, if they were numbered so far, but they go only to about 70, no more being ever required.

THE SOCKET *c c*, in which the beam slides, is four inches long ; it has an opening on one side, through which the divisions on the scale appear, and there is an index engraved on it, against which the zero division is set, when the middle of the beam is exactly over the centre of the vertical axis on which the socket turns. Fig. 4. is a vertical cross section, through the centre of the beam socket, of half the actual size. The opening for viewing the scale is at *v* ; *c* is a steel conical axis, fixed into a strong plate *p*, screwed into the bottom of the socket, and turning in the bored tube *s*, which is screwed to *d d*, the base of the instrument.



THE BASE is a cylinder, externally of brass, but filled with lead to give it stability ; two finger-screws pass through it, so that, if thought necessary, it may be fixed to the table on which the instrument stands when the instrument is used ; or the ends of the screws may have each a sharp steel point, which may just enter the wood, and keep the instrument from sliding on the table. The shaded part of the section is a ring, to which the short *arms e e* are fixed ; there are three of these, making equal angles round the centre : only two, however, are seen, as in Fig. 1, the third being under the beam, and screwed to a strong plate which connects the socket and beam. From the extremities of these arms vertical *rollers* descend, Fig. 4. (*m, m*, are two of them), which turn on their centres by the motion of the instrument, and press on the upper surface of the base *d d*. Their use is to prevent flexion of the main axis *c*, when the middle point of the beam is on one side of its support, as happens in making a reduced or an enlarged copy. There are *adjustments a a*, by which the weight of the moveable part of the instrument is made to bear equally on the three rollers, which thus transfer the weight from the axis to the base. There is a screw in the lower end of the axis which serves to give it greater or less tightness in the conical tube in which it turns. Returning to the socket of the beam, *l* is a finger screw which passes diagonally through one of its angles. It acts on a spring interposed between two sides of the beam (the upper, and that opposite to the scale), and clamps it by pressing it into the opposite angle formed by the other two.

By drawing the beam along in the socket, its parts on each side of the centre may have any assigned proportion to each other ; and this is indicated by the *scale* on its side. Thus, when the division 1 on the scale is placed opposite to the index on the socket, one part of the beam has to the other the proportion of 99 to 101 ; and when 5 is opposite, the proportion is that of 95 to 105, or of 19 to 21, and so on. The rule to find the number on the scale, which shall give a proposed proportion, is this :

“ Annex two ciphers to the difference of the numbers which express the proportion, and divide the result by their sum ; the quotient is the number on the scale which must be set opposite to the index on the socket.” Thus, to give the proportion of 3 to 2, the difference of which, with two ciphers annexed, is 100, divide 100 by 5 ; the quotient 20 on the scale must be set opposite to the index. If the proportion be that of 5 to 3, we have for the dividend 200, and for the divisor 8 ; this gives 25 for the division to be set at the index ; and so on. In general, the quotient is a fraction, but the nearest whole number is accurate enough in practice. Thus, if a design is to be reduced in the proportion of 8 to 5, the sum being 13, and the difference, with two ciphers annexed, 300 ; the number on the scale to be set to the index is  $\frac{300}{13} = 23$ , nearly. In some instruments a vernier scale has been engraved on the socket, by which each half of the beam was actually divided into 1000 equal parts ; and then, between the proportion of equality and that of 6 to 1, there might be interposed  $\frac{5000}{7} = 714$  different ratios, namely, those of 1001 to 999, of 1002 to 998, &c.

THE WHEELS *ff*. These turn on steel axes which pass through vertical bored tubes fixed to the ends of the beam. The diameter of each is about four inches, and they ought to be exactly equal, because on this the accuracy of the instrument mainly depends.

There is a portion of each wheel, about a third of an inch in breadth from its circumference, which is thicker than the part within it. This is shewn in Fig. 5, which is a section of a wheel through its centre *c* and a part of the beam, of half the actual size. The upper surface of this bounding ring rises higher than the surface it incloses ; and the lower surface also rises higher than the lower central surface. Thus, additional space is given for the groove in the circumference in which the band lies, and the band thus raised is kept quite clear of the arms which pass freely below it.

THE BAND is composed partly of very thin and narrow watch-springs  $fh, fh$ , and partly of steel wires  $gg$ ; of course, the former only can be applied to the circumferences, but neither wheel requires to be turned more than about half a revolution; and there are *stop-pins* fixed vertically in them, which come against the beam and prevent them from turning farther. Hence the spring parts of the bands need not be much longer than the arcs on which they are applied, and each is attached by soldering to a piece of brass screwed to the wheel, so that it cannot slide along the convex surface. The stops prevent the soldered points from ever being detached from the wheel. The bottoms of the grooves to which the band is applied ought to be truly cylindric surfaces, of exactly the same diameter, and concentric with their axes. The springs are connected by steel wires, the junctions are made by swivel screws  $k, k$ , by which the band may be tightened, or one wheel turned round a little, while the other is at rest; this last motion is required in the adjustment of the instrument.

THE ARMS. These are represented by  $Pb, Tb$ , Fig. 1; they are hollow four-sided prisms of brass; their upper and lower faces are half an inch broad, and their other sides a quarter of an inch; their length is about twenty-eight inches; they fit into SOCKETS which are directly under the centre of the wheels, and go quite across them, so that the direction of the sliding motion of an arm in its socket is in a vertical plane, which should pass always along the same diameter of the wheel. When the instrument is used, each arm is firmly fixed to its wheel by a *clamping screw*. In Fig. 5,  $b$  is the socket of an arm, and  $i$  the head of its clamping screw. The sockets are *slit* and *sprung*, to allow the arms to enter and pass freely along them. The *tracer*  $T$ , the point of which is of steel, is fixed at the extremity of one arm, and the *copying pencil*  $P$  (the point is of black lead) at the extremity of the other arm. Figs. 2. and 3. represent the tracer and copying pencil of half their actual size. The tracer  $pp$ , Fig. 2, passes through a tube  $t$ , in which it slides, and there is a finger screw in the side of the tube to fix it at the proper height in

working. Fig. 3. shews the copying point, and its apparatus; P P is a black lead pencil, *t t* a tubular case into which the pencil is fitted tightly: these, when the instrument is not used, are detached from the arm and kept apart. The pencil-case has a *flanch y y*, which surrounds it like a collar; the part *t* of the case above the flanch, may be called its *neck*: W, W, W, are round discs of metal (three are shewn in the figure); each has a hole in it, through which the neck of the pencil-case may be passed; one or more of these are placed on the neck when the instrument is used, they serve by their weight to bring down the copying point when raised in working, and also to give the proper degree of shade to the pencil line traced on the paper. There is a bent LEVER *x x*, the arms of which are nearly perpendicular to each other. It is supported at its angle by the fulcrum *s*, which stands on the arm of the instrument. The use of the lever is to raise the copying point from the paper by lifting the pencil-case in the tube T. For this purpose, there is a silk line *l m n H*, Fig. 1. (of which *l m*, Fig. 3, is a part), fixed to it at *l*; this passes over the wheels of two small pulleys, one, *m*, supported on the beam over the centre of the wheel, Fig. 1, and another, *n*, fixed to the socket *c*, over its centre. The end H of the silk line is held in the *operator's* left hand while he works; by drawing it he turns the lever about its centre. By this angular motion, the arm under the flanch raises the pencil in the tube; by slackening the line he allows it to descend, until its point again reaches the paper.

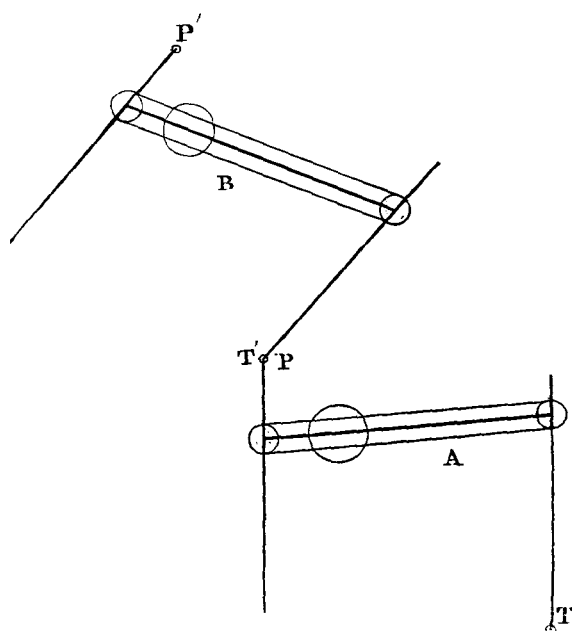
The *pencil-case*, when it is put into the tube T, does not come into absolute contact with its inside, but is held firmly in an upright position, by pressure on the convex surfaces of five *friction rollers* which enter the tube, and project a little beyond its inner surface. Two of these are at the top of the tube and two at its bottom, directly under the former (only one of each pair, viz. *r' r''*, are seen in the figure); the fifth, *r*, is on the opposite side of the tube, towards the wheel, so that its pressure may be opposed to that resulting from the combined pressure of

the other four. The rollers at the top and bottom of the tube T, turn on axes fixed in short projections, which form a part of it, as shewn in the figure. There is a *spring*, *u*, passing along the side of the tube, which is fixed to it at the upper end, and loose at the lower. On this, the axis of the fifth roller turns when it is pressed upon by the pencil-case, which is thus acted on by three pressures in directions making equal angles round the axis. In this way the pencil is held steady while tracing on the paper, and little force is required to raise or depress it, because the rollers revolve on their centres by the pencil passing along their round surfaces, and the only material friction generated is that on their axes, which is but little in comparison of what it would be, if the pencil-case moved with equal freedom from shake in the tube T.

There is a *SCALE* of equal parts on the upper surface of each arm, exactly like that on the beam, the divisions on all the three being of the same length, and numbered both ways from 0. Part of each scale is seen through an oblong opening in the wheels. There is an index engraved on a side of each opening, and the divisions are so numbered, that when the distances between the axes of the tracer and copying pencil and the centres of motion of the wheels are each equal to one hundred divisions; then the zero divisions on the scales are opposite to the indices. There are vernier scales on the wheels exactly the same as that on the beam. The artist in constructing the instrument, takes care that the planes which pass along the axes of the tracer and copying points and the axes of motion of their wheels, be truly parallel; when they are nearly so, he completes this adjustment by the swivel screws in the band. If the parallelism be disturbed by any accident, it may be restored in the same way. There is a mass of lead belonging to the instrument, which may be put on the shorter portion of the beam, as a *saddle*, when its centre is on one side of its point of support, as happens in making a considerably reduced copy. This acts as a counterpoise, and restores in some measure the equilibrium of the instrument on its base.

The instrument has these two properties, by which its accuracy may be verified : When the zero divisions on the scales are at their indices, in which case, a copy made would be exactly the size of the original ; if two corresponding dots be marked anywhere on a surface, one by the tracer and the other by the copying pencil, and the point of the tracer be carried round and put on the mark made by the copying pencil, the latter should fall exactly on the dot marked at first with the tracer. Of course some allowance must be made for the impossibility of perfect workmanship in this as in other instruments. 2. If a straight line be drawn on paper, and there be laid off on it any number of equal parts ; then if an enlarged trace of the line, in some known proportion, be made by running the tracer along a ruler, and the divisions of the original be marked on the copy ; this last ought to be sensibly straight, the divisions equal, and the original and copy ought to have the prescribed proportion.

For obvious reasons, there is a limit not very remote to the power of making an enlarged copy ; that of making a reduced



copy has, however, more scope. For two instruments, A and B, adjusted so as to make each a reduced copy, may be united by

passing an axis through the tubes of P the copying point of A, and T' the tracing point of B. If this axis contained a copying pencil, it would make a reduced copy of the original, and P', the copying point of B, would at the same time make a copy of this first copy; if the intermediate copy be not wanted, it need not be made. If each instrument were adjusted so as to make a copy, reduced in the proportion of five to one, the copy made at P' would be one twenty-fifth of the original. It is evident that two or even more reduced copies might be made at the same time from one original, by using several instruments. I have not, however, made more than one at a time by two instruments. It was in this way that some of the etchings on copper referred to in this paper were made; their sizes were  $\frac{1}{5}$ ,  $\frac{1}{6}$ ,  $\frac{1}{9}$ , and  $\frac{1}{12}$  of the original. The place of the copying pencil was supplied by a steel point, which just cut through the varnish of the etching ground; this was all that was required to allow the acid to act on the copper.