A SYSTEM OF APPARATUS

FOR THE USE OF

LECTURERS AND EXPERIMENTERS

IN

MECHANICAL PHILOSOPHY,

ESPECIALLY IN THOSE BRANCHES WHICH ARE CONNECTED WITH MECHANISM.

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CONTENTS.

LIST OF FIGURES.

A SYSTEM OF PHILOSOPHICAL APPARATUS.

INTRODUCTORY REMARKS.

(1.) In the year 1813, the Rev. William Farish was elected to the office of Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge, and soon after commenced a Course of Lectures on Arts and Manufactures, which he repeated yearly until his death in 1837. The plan of this Course included the exhibition of models of almost all the more important machines which were then in use in the manufactures of Britain. This led him to conceive the possibility of devising a system of mechanical apparatus consisting of the separate parts of which machines are made, so adapted to each other, that they might admit of being put together at pleasure in the form of any machine that might be required. Thus the models required for one day's Lecture could be afterwards taken to pieces and the parts built up again in a totally different manner, so as to form the models required for the next; and thus the bulk and expense of a collection of separate models, which must always oppose great obstacles to the teaching of this subject, would be removed. This happy thought he carried into practice, and was thereby enabled to furnish a most attractive and original Course of Lectures. The forms and constructions of manufacturing mechanism underwent so total a change after this Course had been arranged, that it is no disparagement to its ingenious author to say, that his apparatus, framed in accordance with the methods used in this country in 1813, became useless long before 1837, as a representation of British machinery, to say nothing of the various defects of contrivance, in his system, incidental to the first attempt to carry out an original conception.

When I had the honor to succeed to the chair in 1837, I was compelled, on these grounds, to reject the apparatus of my predecessor. But it appeared to me that his idea of a Protean mechanism was capable of being carried out in a different and more complete manner, so as to be of great practical utility, and of a much more extensive application to philosophical apparatus in general. Availing myself of the facilities which the improved state of machine-making afforded, I endeavoured to carry my own plans into execution, and have found the result so far satisfactory during the fourteen years that I have held the Professorship, as to embolden me to lay my system before the public, in the hope that it may, in some of its parts at least, be found useful to my professorial brethren and to experimental philosophers in general. It must be understood that this system has nothing in common with that of my predecessor, excepting its universal properties. Its forms and details, and their entire system of connexion, are totally different.

In describing my apparatus, it will be observed that I have given the dimensions and scantlings of every part where required, so as to enable it to be constructed by any persons for themselves, or by the hands of their accustomed workmen. These dimensions have been settled with great care, and in many cases after much trial and alteration.

I have also given a distinct name to every part: such a nomenclature is necessary in a system of this kind, to enable directions to be given to assistants, as well as for describing arrangements in writing.

The figures in the plates are all drawn to scale, and most of them in isometrical perspective.

CHAPTER I.

ON THE WHEELS AND STUD-SOCKETS.

(2.) THE system about to be described consists of certain definite parts, including the principal forms which occur in the moving portions of trains of mechanism, the shapes and dimensions of which parts are so arranged as to allow them to be fitted together in a great number of different ways, and thus to compose various machines, with the assistance of a general system of frame-work, which similarly admits of being built up and composed of a few parts so contrived as to permit them to be united in various combinations. Especial pieces are added when required, as will presently appear.

Now every train of mechanism is composed of a series of moveable pieces,[1] each of which is so connected with the frame-work, that when in motion every point of it is constrained to move in a certain path. In by far the greater part of these pieces the path is a circle, or, in other words, the pieces revolve; and under this head also are included nearly all the pieces that are susceptible of being applied in common to a variety of combinations; that is, toothed-wheels, pulleys, or riggers, shafts, lever arms for link-work, and so on. Sliding pieces (in which the path is rectilinear) are usually formed with an especial object (excepting racks), and occur in such a manner that I have never found it advantageous to give them a place in the general system: this will be admitted when the nature of that system has been explained. Still less is it required to provide for pieces that move in curvilinear paths other than circular.

(3.) Toothed-wheels may be obtained of cast iron, and those which are fit for our purpose are of the kind employed in the construction of the smaller parts of manufacturing mechanism. Spur-wheels may be had in sets of selected numbers of

[1] See 'Principles of Mechanism,' p. 28. As this work was written by me expressly as a text-book for that part of my Lectures which relates to mechanism, I shall be necessarily compelled to refer to it repeatedly in the course of these pages.

teeth, and all of the same pitch, so that any two will work together. The quantity of these wheels, their pitch and numbers of teeth, must of course be determined by the nature of the machinery or models to which the system in question is intended to be applied. A few pairs of small bevel-wheels and mitre-wheels may be also provided, and ratchet-wheels, as well as a set of worm-wheels of different numbers of teeth, all of the same pitch, with worms to match. Pulleys, or 'riggers,' for belts or ropes, may be made of wood; but if tolerably large, as from 8 inches diameter upwards, are better, and look lighter, of cast iron, and may be procured at a moderate expense. (I have given more particulars of my own apparatus in the note.[1]) Every one of these revolving pieces must be accurately bored with a hole *one inch* in diameter, having a key-groove, and the boss faced in the lathe on both sides so as to reduce the thickness to *one inch*. The size of the hole must be exactly the same in all, because they may each be required in turn to take their place upon any one of a certain number of pieces, hereafter to be described, which are exactly

[1] The wheels that I employ were furnished to me by the well-known firm of Sharp, Roberts, & Co., of Manchester. These gentlemen have an extensive assortment of patterns for small wheels, and will, I believe, for scientific purposes furnish castings of any that may be required. Their most complete set of numbers belongs to the size which they denominate *ten-pitch* (see 'Principles of Mechanism,' p. 59), in the peculiar nomenclature introduced by Mr. Roberts. This is equivalent to a pitch of $\frac{5}{16}''$ in the ordinary language of millwrights. Of this size, a set of wheels may be had containing every number from 12 to 100 inclusive, with the addition of 110, 112, 120, 127, 134, 138, 144, 156, 180, 200, and possibly some others.

Twelve-pitch and *sixteen-pitch* wheels (*i. e.* $\frac{1}{4}''$ and $\frac{3}{16}''$) may also be procured. The size of the former is exceedingly good for the construction of models, and perhaps better than the ten-pitch, because lighter; but unfortunately very few numbers of this size have been made (namely, 15 to 20, 24, 28, 34, 54, 59, 60, 108, 120); whereas the *ten-pitch* set is abundantly complete. The *sixteen-pitch* set includes wheels of all numbers from 16 to 60 inclusive, also 64, 68, 70, 72, 80, 90, 96, 120. These teeth are too small for the general purpose of lecture mechanism, but make very convenient wheels for some especial purposes. On the whole, the *ten-pitch*, although somewhat heavy, are by far the best, for they are strong enough to drive machines doing work, such as small lathes for turning metal, and the teeth are just large enough to be seen at a distance. The proportions of my framework are all adapted to carry ten-pitch wheels.

If the apparatus be intended merely to furnish the means of putting together certain examples of wheel-work trains previously selected and arranged for a given Course of Lectures, it will be obviously unnecessary to procure more than the actual wheels required for these machines; and the number of these wheels may be reduced to a very few by exercising a little skill in setting out the trains so that the same wheels may, as far as possible, be employed in different machines on successive days. But a complete apparatus should be prepared to meet any cases that may arise in the trial of new combinations and fresh machinery, and in the arrangement of change-wheel systems for actual work. To do this, at least one full set of the ten-pitch wheels, with duplicates of the most frequently recurring numbers (as 30, 60, 120), is required, to which should be added similar sets of the twelve-pitch and of the sixteen-pitch.

one inch in diameter.[1] The exact thickness of one inch is not so imperatively necessary. It is convenient in the set of spur-wheels, but in the others the thickness may vary according to their nature, within the limits determined by the length of the pieces which are to receive them.

(4.) Key-grooves are always made with their *sides* parallel; but the bottom of the groove may be either *parallel* to the axis or *inclined*. The first form is usually employed when the wheel is to be retained by a feather or pin projecting from the shaft or other piece to which it is to be attached. But when the wheel is to be secured to its shaft by a wedge, key, or *cotter*, as it is termed, the bottom of the key-groove must be inclined to the axis at the same angle as the wedge. As an inclined groove does not unfit the wheel for being used with a feather, provided the latter is not too prominent for the shallow end of the groove, it is better for our purpose to have the wheels furnished with inclined grooves, as they will then suit either method of fixing, as the case may be.

(5.) For mounting the above wheels, &c. on axes, to adapt them for use, I always prefer *stud-sockets*, if admissible. Fig. 8 (Plate I.) shows a section of the simplest form of stud-socket, of the dimensions adapted to the present purpose.[2]

The socket A B is of brass, one inch in diameter, to receive the wheels; it is provided with a shoulder (A) ($1\frac{1}{2}''$ diameter) at one end, and with a strong screw (B) and octagon nut at the other. It is three inches and a half long, and the plain part a little shorter than two inches; so that when two wheels are placed on it, the nut will screw them tight against the shoulder (the wheels being each an inch thick). A feather of the exact width of the key-groove is screwed against the plain part.

When only a single wheel is fixed on the socket, the brass collar, fig. 12, must be placed before or behind it, to enable the nut to act upon it. This collar is split, to allow it to pass the feather. The collars may be made of hardwood instead of brass, in which case they should be of larger diameter, to allow of a groove for the feather; and an assortment of such wooden collars of various thicknesses must be provided, for the stud-sockets are also required to receive wooden pulleys of various thicknesses, mahogany cam-plates, sheet-iron disks of various forms, &c.,

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[1] Machine-makers are so much in the habit of making the parts of their machines in great numbers, and also of replacing broken portions, that their arrangements are now successfully directed to making pieces so accurately bored alike that they may fit any one of a number of other pieces. Wheels that are too small to receive an inch hole must be bored with similar accuracy, with a hole $\frac{3}{4}$ inch in diameter, or $\frac{1}{2}$ inch, so as to fit pieces of those diameters respectively.

[2] Stud-sockets of various proportions are largely employed in manufacturing mechanism. I have merely put them into the forms most suitable to my own object.

any of which may be fixed by such collars, and at any distance from the shoulder A, by placing collars of proper size before and behind.

The socket revolves upon a stout stud C D, $\frac{5}{8}$ inch in diameter, with a shoulder or flanch C, at the back, of the same diameter as the base of the socket, and the stud is furnished with a strong screw and nut (E), behind, the screw being rather more than $1\frac{1}{2}$ inch long, so as to allow it to be fixed in a hole in a bar or other piece of frame-work to be presently described, the thickness of which is a full inch. The plain part of the screw close to the shoulder must be $\frac{5}{8}$ inch in diameter.

The front end (D) of the stud is pierced with a hole in which a pin is inserted to keep the socket in its place. As these sockets are continually removed and replaced on their studs, as well in the process of fitting up the apparatus as during the lecture, whenever it is necessary to take the wheels off, or otherwise separate the parts to facilitate the explanation of them, spring-pins (fig. 15) should be used. These are easily removed and replaced, are never liable to drop out, and will fit any hole.

The length of these sockets is quite sufficient for all ordinary purposes; but as in some cases rollers or wheels are required of greater projection, it is convenient to have one or two stud-sockets *six inches long*, and of the same dimensions as the above in every other respect.[1]

Rollers and other pieces, longer than the stud-sockets, may be mounted as shown in fig. 10. In this figure the stud and socket are precisely the

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[1] The sixteen-pitch wheels and the small pinions of the ten-pitch set, below 20 teeth, do not allow of an inch hole. They must be bored $\frac{3}{4}$ inch, and they are full $\frac{3}{4}$ inch thick. It is necessary, when these wheels are used, to provide stud-sockets for them differing from the above only in dimensions. These sockets are $2\frac{1}{2}$ inches long; diameter of studs $\frac{7}{16}$ths; diameter and length of the screw the same as for the larger studs, because they are required to fit the same holes in the frame-work.

The length of the socket allows one of the small wheels to be paired with one of the inch-bored wheels. But a loose collar (like fig. 12), $\frac{3}{4}$ inch bore and 1 inch external diameter, must be placed on the socket to receive it. One or two of these $\frac{3}{4}$-inch sockets may be made $4\frac{1}{8}$ inches long, and others $1\frac{1}{8}$ long. The latter are especially useful for wooden disks, levers, and other light pieces that would be preposterously mounted upon the inch-sockets.

But, for the purpose of combining small pinions with large wheels, I have sometimes found it necessary to employ a stud-socket of the form (fig. 9), because the stud, if made small enough to carry a pinion bored only $\frac{1}{2}$ inch, is too weak to sustain the great wheel. This stud-socket was made for a train of clock-work, in which class of mechanism the pinions are always small and the wheels large. In this case the wheel had 138 teeth, and the pinion only 12, both of ten-pitch; the pinion admitted only of a bore of half an inch, and a stud small enough for a stud-socket of this diameter was manifestly too weak to carry the wheel, which was 14 inches in diameter.

same as that shown in fig. 8; but the socket is placed in the reverse position, having its nut downwards,[1] and the roller and other piece (A A) is turned with a hollow (C) at the top, sufficient to allow the spring-pin to be inserted in its hole: B B is a pinion (or any other wheel, &c.) by which motion is communicated to the roller from the rest of the mechanism.

(6.) There are several pieces, however, the forms of which do not readily allow of this expedient, and for which, if placed upon the socket in the position of fig. 1, the projecting nut and stud would be an equal impediment. Such, for example, is a handle which may be required to give motion to the first wheel of the train; a disk, the upper surface of which is required to be completely at liberty; or an arm with an excentric pin, &c. Although such pieces may be screwed to the top of a block similar to A (fig. 10), after it has been placed on the stud, it is better to employ the socket represented in fig. 13. This socket has the shoulder F F in the middle; the part below the shoulder is formed exactly like the previous sockets in the reverse position (fig. 10); but the part G, above the shoulder, is perfectly plain.[2]

This plain portion will receive any piece that is provided with a lateral binding-screw, such as the handle, fig. 34 (Plate II.), the flanch, fig. 32, which is made to carry excentrics or disks, or the coupling, fig. 37, which will serve to grasp any odd-shaped piece that can neither be bored with a central hole nor screwed against a flanch. These pieces are more fully described below. (See Arts. 30, 31.)

(7.) Another variety of stud-socket is shown in fig. 11. In this the stud is considerably shorter than the socket, and the latter is kept in its place during its revolution by a screw *a*, tapped into its shoulder, the end of which is engaged in a groove turned at the bottom of the stud. This allows the socket to revolve, but not to come off. Any piece which is of such a form as to allow of a short stem behind it can be fixed to this socket by inserting the stem in the vacant hollow above the stud, and securing it by a screw *b b*. Thus in the figure, a piece L is so shown, which is a section of a pinion so small as to forbid a hole being conveniently bored through it, in the direction of its axis, to fit it upon the various sockets already described. The pinion is therefore

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[1] It is convenient that all the sockets should be fitted to their studs with cylindrical holes, instead of slightly conical holes. This allows the sockets to be placed with either end outwards at pleasure.

[2] The projection of the end of the stud may be reduced by the construction shown in fig. 14, namely, by substituting a flat screw and washer for the spring-pin. But this plan is more expensive, and does not allow of dismounting during lectures.

furnished with a stem M, which fits the bore of the stud-socket, and the stem, being inserted in the upper part of the socket, is secured by the screw *b b*.

Any wheel required to connect this small pinion with the train must be previously placed on the socket close to the shoulder, and also a collar between it and the nut.[1] This collar must have a hole bored in its side to admit of the subsequent insertion of the screw *b b*; for it is clear that the pinion or other piece (L, M) must be fixed in its place after the wheel has been secured to the socket by its nut.

Pieces that do not admit of being mounted for revolution on stud-sockets require other devices, which are explained in Chapter III. I shall in the next Chapter proceed to the frame-work by which the studs, as well as the whole of the machinery, are connected and supported.

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[1] This nut is not shown in the drawing, but is precisely similar to B in figure 8, and the screw-thread of the socket is seen just above *b b*.

CHAPTER II.

ON THE FRAME-WORK AND GUIDE-PULLEYS.

(8.) It will in the next place be convenient to show the nature of the frame-work by which the socket-studs described in the last chapter can be fixed in their proper relative positions, so as to cause the wheels, pulleys, or other pieces which revolve upon them, to gear properly together and form machines.

In arranging the parts of mechanism, it will be found that their axes of rotation may be required to be fixed in every possible position, whether horizontal, vertical, or inclined at any intermediate angle. Accordingly, when our rotating pieces have been mounted on stud-sockets, we must provide the means of fixing their studs in any of these positions, as the case may require, and also at the proper distances.

The most obvious way is to make a wooden frame for each especial machine, and to bore holes in the frame for the reception of the studs; care being taken to design the frame so that the rails of which it is composed shall present themselves at the proper angles and distances to receive the holes.[1]

This method I adopt when the machine in question is frequently wanted for use, or when its construction is so complex that the putting together of its frame by the more general system about to be described would consume too much time, and require too many pieces, to make the attempt worth while.

But even this simple method has a great advantage over ordinary models; for after the machine has been exhibited, the stud-sockets, wheels, and other parts of general use, can be removed, leaving the *peculiar*[2] parts by which most machines are characterized, and which may remain undisturbed, upon the frame-

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[1] See Art. 43, and fig. 43, Plate II., for an example.

[2] Throughout this Essay I use the epithet *peculiar* to characterize all pieces and frames which are constructed for one object or model only, in contradistinction to those pieces or frames which are shaped to adapt themselves to a great many objects or models in turn.

work; and if the holes for the studs are carefully made, these, with their wheels, can be readily replaced when the machine is again required. But the quantity of such frames, if they were employed for every machine, would lead to serious inconvenience from their bulk, and they will be found perfectly unnecessary for the greater number of cases. In many examples, machines may be contrived in which the complex parts may be thus mounted in a small peculiar frame, and the simpler portions, together with this peculiar frame, be fixed upon a frame built up upon the general system. Thus we obtain a machine which, when put together for use, is large, and its acting parts spread forth so as to be distinctly visible to an audience; but which admits of being separated so that its peculiar frame and pieces may be stowed away for the next year's Lecture, while its general parts are available during the entire Course, as required.

(9.) The advantages of mounting the revolving pieces upon studs are various. When wheels are fixed to axes that are supported at or near each end, the frame-work becomes more complex; and if the wheels or any other parts lie between the two halves of the frame, they are liable to be concealed thereby. But when stud-sockets are used, the supporting piece of the frame is wholly behind or beneath, and thus leaves the revolving piece fully exposed to view; and the latter can also be readily taken off and replaced, if required in the course of the explanation. Again, the steadiness of rotation depends wholly upon the stud and its socket, and not at all upon the frame; and the stud-socket, which requires good workmanship, will serve for many machines, but the frame may be a mere deal board with holes in it, or other simple form, which, being of comparatively small cost, may be cut up or altered at pleasure.

(10.) I will now proceed to a system of framing which is built up of parts capable of being combined in various ways, so as to make frames for the support of the studs and other pieces in any relative position at pleasure. This may be called the *general system* of framing, in opposition to the *especial frames* above described. In the first place, for the purpose of carrying the studs firmly, and of readily fixing them in the various relative positions required, cast-iron *brackets* of six different forms are provided. These are all shown in Plate I., and are there indicated respectively as No. 1, No. 2, and so on. They will also be described in the following pages as Bracket No. 1, Bracket No. 2, &c.

Each bracket has a *head* A (see No. 1), bored with a hole $\frac{5}{8}$ inch diameter, and thus fitted to receive the screw (E, fig. 8) of any of the studs, which, as already mentioned, are of the above diameter at the shoulder; also a *sole* B, in the middle of which is a slit, full $\frac{3}{8}$ inch wide (or rather $\frac{1}{2}$ inch), to receive the bolt or bolts by which the bracket is attached to the wooden or iron frame-work.[1]

The brackets differ from each other, as well in the direction in which the stud is fixed with respect to the sole as in the height of the stud above it. In No. 1, No. 2, and No. 3, the stud stands parallel to the slit of the sole, and its axis is at heights of 8, 5, and $1\frac{1}{2}$ inches respectively above the lower surface. In No. 4 and No. 5 the stud stands also parallel to the plane of the sole, but is at right angles to the direction of its slit, and at heights of 5 and $1\frac{1}{2}$ inches respectively. In No. 6 the stud stands perpendicularly to the plane of the sole.[2]

In each of these forms the stud may be fixed with its shoulder either on one side or other of the head of the bracket.

The higher brackets (Nos. 1, 2, and 4) are also provided with bolt-slits in the upright face, for the convenience of fixing other pieces, as will presently appear.

(11.) The brackets are fitted up for use, as follows, by fixing them to wooden or iron stands or frames. For the purpose of uniting the brackets to these frames, as well as the parts of the frames to each other, I employ bolts of the kind termed *coach-bolts*. These have a circular and convex head, below which the shank is made square for a short distance, and then continued as a strong screw with a square nut. The shank is $\frac{3}{8}$ inch square, and the slits in the brackets are adapted to receive it: a washer must be placed under the nut, and if the head of the bolt bears against a wooden frame, another large washer must be also placed under this head, but is unnecessary if the head bear upon the sole of the bracket. A key or spanner must be provided, to screw up the nuts. Thumb-screws, or fly-nuts, as they are called, may be employed,[3] but I greatly prefer the plain nut for its simplicity and firmness, and because it looks neater and more engine-like, and is besides cheaper, as the coach-bolts can be had ready-

[1] A mathematician will perceive that I have so designed these brackets, that supposing their soles to be fixed on a plane horizontal or vertical surface, with the slits parallel to each other, the different forms give the power of placing the studs parallel to the three axes of co-ordinates.

[2] The dimensions of the brackets are,—sole, $6'' \times 2\frac{1}{2}''$; diameter of head, $1\frac{1}{2}$ inch; thickness of head, $\frac{9}{10}$ inch; thickness of sole, $\frac{3}{8}$ inch; thickness of upright, $\frac{1}{2}$ inch. The patterns of these brackets and of the rectangle (Art. 15) are in the hands of Messrs. Holtzapffel, 127, Long Acre.

[3] Bolts with fly-nuts are employed in fig. 45, Plate III. (Art. 45,) to fasten the two No. 3 brackets to the bridge. But the position of these brackets, from the nature of the apparatus, may require to be changed, to adjust their distance for different proportions of the curves; and whenever such adjustments are required, fly-nuts are of course convenient and appropriate.

made in the shops. An assortment must be kept of various lengths, which I will indicate as their uses occur.[1]

(12.) The wooden frames which constitute the bases of the machinery are of various kinds, but all constructed on the principle of providing a number of slits, $\frac{3}{8}$ inch wide, for the reception of the bolts by which the soles of the brackets are attached to them. Fig. 16 (Plate II.), which I term a *slit table,* is the simplest form: it consists of four bars of deal, each 2 feet long, $1\frac{1}{4}$ inch broad on the upper face, and $2\frac{1}{2}$ inches deep, arranged so as to leave a space of full $\frac{3}{8}$ inch between each. It is supported on two feet, so as to raise the bars a convenient height, for access to the nuts below, and allow room for overhanging wheels, &c. Each foot is, as the drawing shows, notched on the upper edge to keep the bars in their places, and united to them by a single bolt, which passes through the whole. Thus we have a table about $6\frac{1}{2}$ inches wide and 2 feet long, upon which the brackets may be set so as to bring their studs into any required relative position; and the soles of the brackets being laid transversely to the slits, the slit of the sole is sure to intersect one or more of the slits in the table, so as to allow a bolt, or two if required, to be passed through and secured, the nut being placed upwards or downwards, as convenience may dictate. The 'slit table' is shown in use in fig. 42 (described below in Art. 42).

The mode of arranging a simple train of wheel-work, consisting of wheels and pinions with parallel axes, will be understood from the following diagram, in which A, B, C, are the wheels, *a, b, c,* the pinions with which they respec-

[1] Bolts unite pieces more firmly than the clamps which are most commonly resorted to for apparatus; but bolts require holes or slits to be provided in the pieces which they must necessarily pass through. On the contrary, clamps unite pieces that are not so pierced. Occasionally, therefore, clamps must be employed. Fig. 7 represents a form that I have adopted, which has the advantage of not bruising the pieces to which it is applied. It consists of an L-shaped piece (H), the long leg of which is formed into a strong screw, and provided with a large fly-nut. The nut acts upon another L-shaped piece (K M), which has a hole through which the screw passes *freely,* so as to allow this piece to take its bearing firmly by the leg M upon the thing to be clamped, and by the other leg K upon the back of the first piece H. I employ two sizes of these clamps, differing only in the extent to which the jaws H M may be opened. The jaws and flat part of the backs are $\frac{1}{4}$ inch thick and $\frac{5}{8}$ inch wide; screw about $\frac{4}{10}$ inch diameter. The range of motion is of course determined by the length of the plain part and of the screw. In the smaller size the opening of the jaws ranges from $1\frac{1}{2}$ to 3 inches, and in the larger from 3 to 6 inches. The inside length of the jaw H is 2 inches. A diminutive form of this clamp is also very useful for clamping paste-boards to thin frame-work, or drawing-paper on drawing-boards. Its opening ranges from $\frac{1}{2}$ to 1 inch. It is $\frac{1}{10}$ inch thick and $\frac{4}{10}$ inch wide, and the inside length of H is $\frac{4}{10}$ inch. Besides the plain coach-bolts, hook-bolts and T-bolts are sometimes required, as well as a few fly-nutted bolts. (See Arts. 32 and 46, and figs. 48, 49, Plate III.)

tively gear; the wheel and pinion that occupy the same stud-socket being set in the same horizontal line, and the characters =o indicating the place of the bracket-sole and head respectively. The diagram thus represents a plan of the relative positions of the mechanism upon the slit table.

The 1st stud carries a pinion *a*, which gears into a great wheel A, fixed on the 2nd stud; and as the pinion and the wheel should be set close to the shoulders of their respective stud-sockets, the two brackets will stand with their faces in the same line. But the pinion *b*, in front of it, gears with the great wheel B, which is close to the shoulder of the 3rd socket, and thus the 3rd bracket will be set a little in advance of the 2nd bracket. Similarly the 4th bracket will be a little in advance of the 3rd, and thus all the brackets, except the first, will be set in a slanting direction. Their great wheels will be as close as possible to the head of the bracket, thus laying the least strain upon the stud; and as each stud is mounted upon an independent bracket, it can be shifted about and set in any relative position to the others that will best suit the pitching of the wheels, or the nature and thickness of any other revolving pieces that may also be mounted upon the stud-sockets. As the wheels are all placed behind the pinions, they do not conceal them.

1st stud =o *a*
2nd stud =o A *b*
3rd stud =o B *c*
4th stud =o C

(13.) The choice of heights at which the studs may be fixed, given by the different forms of the brackets, is not always sufficient to suit all arrangements; therefore an assortment of wooden blocks is required, termed *sole-blocks* (fig. 17). These are of various thicknesses, and their breadth, width, and slit correspond exactly to those of the bracket-soles. Thus the height of every bracket may be adjusted as required.[1]

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[1] The thicknesses provided should be ¼", ½", ¾", 1", 2", 3", and 4". In practice, it will be rarely found necessary to employ sole-blocks; the choice of heights given by the brackets and adjustable frame-work is usually sufficient, as the smaller adjustments required for pitching toothed-wheels or for stretching bands can all be effected by the changes of horizontal position which the nature of the frame-work admits of almost indefinitely.

It may at first appear that the different heights of the studs might be adjusted by forming the bracket-head with a slit instead of a hole for the reception of the screw of the stud. But I find that if a stud-screw be inserted in a slit, the last turn of the nut in securing it is sure to disturb it from its position by the wriggling motion which it gives to the screw. The shank of the screw being of course made square (or at least flattened on opposite sides) to fit the slit, must necessarily have a little play to allow of sliding the stud into the required positions, and this play permits sufficient torsion to produce the effect above described, which is exceedingly vexatious. For example, if a toothed-wheel be mounted on a stud, and the stud placed in a

(14.) Slit tables of similar construction to fig. 16 may be made, if required, of different dimensions and numbers of bars; but I find the actual form and dimensions of this example the most convenient; and for machines that require larger or more comprehensive frames, the following more general system is better.

A set of wooden bars is in the first place provided, which are screwed together in pairs, as in fig. 20. The bars of each pair are united by strong screws passing also through small blocks of hardwood (*a* and *b*), which fix the bars at full $\frac{3}{8}$ inch asunder, so as to allow the coach-bolts to pass between them. Such a pair of bars I term a 'bed,' from its similarity to the bed of a lathe, which in like manner consists of two parallel cheeks of wood, between which the bolts pass by which the poppet-heads are secured. The bars of my beds are all of the same depth, namely, $2\frac{1}{2}$ inches, and their breadth varies from $1\frac{1}{8}$ to $1\frac{1}{2}$ inch, according to their length. The beds are of the various lengths of 1′ 6″, 2′, 3′, 4′, 5′, 6′, and 10′.[1] It is convenient to have four or more of the three first lengths and two each of the remainder. I make these beds and frames of deal for cheapness and lightness, but possibly beech or birch might be better, as the repeated screwing and unscrewing of the bolts is apt to indent the soft fibres of the deal. This is diminished by using large washers.

It may sometimes be necessary to employ triple instead of double bars for the beds, in cases where two bolts are required to hold a piece the slit of which lies transverse to the slits of the bed, and which happens to be liable to great strains.

(15.) Fig. 19 represents a cast-iron 'rectangle' employed for supporting and connecting the beds. Its faces are $2\frac{1}{2}$ inches broad (the same as the bracket-soles), their length 6 and 9 inches respectively, and thickness $\frac{5}{8}$ inch. Each face has a bolt-slit, as shown. Three or more pairs of these rectangles should be provided, for they are not only applicable to the support of the beds, as shown in figs. 27 and 39, but are useful in forming stands to which brackets or other pieces may be fixed, and also in constructing other parts of frame-work, as shown in fig. 47 (Art. 46).

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slit in the proper position for pitching with another wheel, this small disturbance of position destroys the pitch. The same effect does not take place when two slit pieces, such as the sole of a bracket and the slit table, are united by a bolt; for the position of the two pieces is secured by the contact of their surfaces, and the wriggling above described only affects the bolt. It will be seen too that the surfaces in contact are much greater than when the shoulder of the stud rests upon the edges of a slit, as in the former case.

[1] In the following descriptions, for conciseness sake, a bed 2 feet long is termed a *two-feet* bed, and so on.

(16.) The beds may be bolted upon a pair of rectangles, or otherwise combined in various ways, so as to form frames suitable for receiving the brackets with their studs, or other pieces of apparatus in every useful position; and they are heavy enough to be very steady on the table. Commonly a single bed of 3 or 4 feet long is sufficient, but in many cases the frame may require two or more beds, sometimes of different lengths, or beds in an upright position.

Various examples of frames, composed of beds and rectangles, are given in the subsequent figures, the machines which they carry being described below. Thus fig. 27 (Art. 52) shows a frame the basis of which is a 3-feet bed, bolted on two rectangles, and the upright faces of the latter serve to support the uprights of a lighter frame for small apparatus.

Fig. 39 (Art. 25) is similarly combined, but the rectangles also carry each a No. 3 bracket on their vertical faces.

Fig. 40 (Art. 34) has a bed sustained by two wooden feet, also employed in fig. 41 (Art. 37). These wooden feet, the form of which is sufficiently shown in these figures, are very convenient when a single bed is used as a frame. Each has three bolt-holes to allow of giving different positions to the bed, which, when the machinery hangs over one side of it, as in fig. 41, requires the feet to be longer on that side than on the other.

Lastly, the machine shown in fig. 46 (Plate III.) (Art. 47) is built upon a rectangular frame, made by bolting two beds, one 2 feet and the other 3 feet long, across a pair of 18-inch beds. In this case the rounded heads of the bolts that unite these beds, being downwards, furnish four points upon which the frame rests. The rectangles may also be used, without beds, in combination with each other, or with brackets, to receive stud-sockets, to support models, or in various ways to form the nucleus of the frames of smaller mechanism. When a single bracket or rectangle is sufficient, it should be attached to a small *base-board* (fig. 18). This is a plain board, about 9 inches by 6, with a short bolt inserted in the middle, by which to secure it to the sole of the bracket or rectangle. It serves to give extension to the base of the machine.

(17.) The stands and frames just described are adapted to rest on the lecture table; but larger machines and more extended combinations require to rest on the floor, and for this purpose the beds, rectangles, brackets, and other elements of frame-work, may be attached to the *stool* shown in fig. 24.

This is a strong frame, constructed, like the smaller ones already described, upon the principle of providing slits for the reception of the $\frac{3}{8}$-inch coach-bolts. It consists of two double frames, A B C D, E F G H, connected by two stout rails, I and K, placed near the ground.[1] The halves of each double frame are connected at the upper angles (B, C, F, G) by iron plates, one of which is shown detached from the angle F at fig. 26. This angle shows the appearance of the stool when the plate is removed. In using this stool it is frequently necessary to fix a bed transversely on the upper surface of its top rails; and to allow this to be placed as close to their extremities as possible, the following arrangement is adopted.

Fig. 25 shows one of the bolts furnished with an oblong washer, *k*.[2] One of these bolts is passed through the slit of B C, and another through F G, and both also through the slit of the bed which lies transversely across, the nuts being uppermost. To enable the bed to be shifted, if necessary, close to the angles B and F, grooves are cut in the top of the posts (shown at *a*, near F), of sufficient width and depth to allow the rectangular washer of the bolt-head to be moved close to the iron plate. Without these grooves, it is clear that the washer of the bolt could not be shifted beyond the inner angle of F, and thus the bed could not be fixed close to the extremities B and F of the frame.

Similar grooves (shown at *b*, near F,) are cut vertically, which are employed when a bed is bolted against the vertical faces of the legs. A bed in this position is shown at S, in fig. 47. When a bed is thus bolted to the legs of the stool, the soles of brackets fixed to it become vertical; but this is of no consequence, for the forms of brackets can always be selected so as to place their studs in a horizontal position, if required.[3]

The frame, fig. 23, is employed by bolting its vertical rails against the legs of the stool, for which purpose these rails have two or more holes bored in them, slits being in this case unnecessary, as the slits in the stool-legs furnish the means of fixing the rails at any height required. The rails carry a 3-feet bed, the inner face of which is flush with that of the rails, as shown. Thus the bed may be fixed either below or above the level of the top of the stool at pleasure. A similar bed, with longer vertical rails, may be provided to give the means of raising the bed still higher.

The frame is shown in use in fig. 45, Plate III., where it is bolted to the back of the stool, in order to support a drawing-board in an inclined position. (See

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[1] The frames are 2 feet 6 inches high and 1 foot 9 inches broad, and their outer surfaces 2 feet 6 inches asunder; so that the extreme horizontal dimensions of the stool are 2′ 6″ × 1′ 9″.

[2] $3\frac{1}{2}$ inches long, $1\frac{1}{2}$ broad, and $\frac{1}{8}$ thick, of iron plate.

[3] The same happens when beds or brackets are bolted against the vertical faces of the iron rectangles (fig. 39).

Art. 45.) This stool allows beds of various lengths, from 3 feet upwards, to be bolted on the horizontal surface of its rails or against its legs, in various relative positions: they may also, as required, be fixed either against the inner or outer surfaces. The beds may be bolted vertically against the fronts of the legs, so as to form posts which may similarly be set up against the sides. For the latter purpose the double rails (D, H) at the sides are provided,[1] and the post must be secured to the upper rails by a hook-bolt (shown detached in fig. 48). A bed may also be bolted upon one of the double top rails in their own direction (as at F, fig. 47), instead of lying transversely upon the two double top rails. By these different arrangements, employed singly or in combination, as required, large and substantial frames may be set up, not only for the reception of revolving mechanism, but for the exhibition of numerous other experimental arrangements which are required for the elucidation of mechanical or physical science, and which are frequently omitted on account of the bulk and expense of frame-work when constructed expressly for such purposes. (Two examples of frames thus built upon the stool are given in figs. 45 and 47.) But it will also be seen in these figures, that in many cases the brackets, rectangles, &c. may be bolted to the frame of the stool without the intervention of the beds, or in combination with them, so as to increase the comprehensiveness of the arrangement.

(18.) If a bed like fig. 20, about 6 feet long, be set upright and permanently fixed to a wooden or iron foot, it forms a convenient *post* to which various contrivances may be attached; or two such may be set at a convenient distance on the floor, and one or more long horizontal rails or beds be bolted to them,

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[1] The scantlings of the parts of the stool are as follows: The legs and horizontal top rails, $3'' \times 2\frac{1}{8}''$; the bottom front rail, 3″ wide and 4″ deep. The double side rails (D, H) are $1\frac{3}{4}''$ thick, being made thinner than the legs into which they are mortised, in order to allow the washers of the bolts to pass behind them. They may be $2\frac{1}{2}''$ deep. The slits of course to be full $\frac{3}{8}''$ wide throughout.

The frame (fig. 23) has its upper bed of the same scantling as fig. 20, and its vertical legs 3″ thick, to allow their upper ends to pass between the rails of the bed: the lower rail only serves to keep the legs together, and may be slighter.

It is useful to provide a set of single bars of wood, 3 feet long and 3 or 4 inches wide, each with a bolt-hole near each end, countersunk to receive the head of the bolt or nut. These bars being fixed close together across the top rails of the stool, convert it into a table, with this property, that a slit may be had at any part of it by there setting the bars apart, or any *peculiar* bar be inserted in the series, as required. The outer bars must be secured by square-headed bolts like bed-screws, with the heads uppermost, the nuts being of the form of the washer *k*, fig. 25, the place of which they occupy.

so as to constitute a very useful frame for suspending drawings or many kinds of Lecture-Room devices.

(19.) The connexion of lighter pieces than those which are usually carried by the stud-sockets, or than the cast-iron brackets, may be effected by wrought-iron loops, of which I employ the three several forms shown in fig. 22, A, B, C. They are made of $\frac{3}{8}$-inch square iron, the slit being, as before, a full $\frac{3}{8}$ inch wide, or rather, in this case, nearly half inch, as the workmanship may be rough: A is straight and 8 inches long; B and C have upright branches 4 inches long, and differing in this respect from each other,—that a plane passing through the horizontal loop would in B also pass through its upright loop, but in C would be perpendicular to a second plane passing through its upright loop. These loops are useful in a great number of ways,—for carrying light pieces of frame-work and connecting them with the frames already described, supporting the fulcra of levers or clicks, assisting in clamping, and various other purposes that will readily suggest themselves as occasion arises.

(20.) To return to the brackets, which, as I have already stated, are intended to supply the means of fixing the studs in any required angular positions. If the first five forms of bracket be fixed upon a horizontal surface, it is plain that their studs admit of being set in any relative angular positions in the horizontal direction, and that the bracket No. 6 provides for the vertical direction. If any other angular directions be required, they may be obtained by fixing the sole of the bracket to a vertical surface of the frame-work, or by combining the brackets. For example,—let the stud be fixed in the head of bracket No. 3. If this be attached to the vertical face of bracket No. 1 by a bolt passing through the slit of the former and the head of the latter, the stud may be set at any angle in the vertical plane parallel to the face of the latter bracket. Any one of the first five forms carrying a stud may be thus combined together; but it would be useless to combine No. 6 with the others, because its stud (being parallel to the bolt) would remain parallel to the direction of one fixed in the head of the lower bracket: such a combination will, however, sometimes serve to hold a stud over other pieces. In fig. 45, brackets (D, E) are seen in combination, not for the purpose of holding studs, but for fixing a bed in an angular position.

(21.) These angular positions are seldom required but for bevel-wheels or guide-pulleys. Guide-pulleys are so often wanted, that although they can be mounted very well upon stud-sockets and set in any angular position in the above manner, it is more convenient to fit them to studs of their own. But the most complete guide-pulley is shown in fig. 38 (in the left-hand lower corner of Plate II). This pulley, $4\frac{3}{4}$ inches in diameter, runs upon a stud which is carried by a piece C, tapped to suit the screw of an iron looped piece A B (about a foot long). The latter has a loop, $\frac{3}{8}$ inch wide and 6 inches long, at the end A, for the reception of a coach-bolt: the other end (B) is formed into a screw upon which the piece C is placed, and flanked by a pair of binding-nuts, so as to secure it in any angular position. The loop may be bolted against the face of a bracket (as shown at D), or to any other convenient part of the frame-work, as at R in fig. 47.

By combining the angular motion round the head of the bracket-bolt with the motion about the screw-tail of the loop, the axis of the pulley may be set into any required position, so as to make its plane coincide with the directions of any band which it is required to guide.[1]

When brackets are combined in the way above described, or wrought-iron pieces screwed against them, the gripe of the bolt is much assisted by interposing a thin leaden washer between the two.

(22.) The machines are sometimes required to be set in motion by a hand-wheel at some distance from them. In this case the band may be conveniently guided by the '*tripod-stretcher*,' the construction of which was suggested to me by the late Mr. Holtzapffel, and carried out with some improvements for the purpose of giving motion to a cutting-engine which I contrived in the year 1835.[2] This tripod is a three-legged frame of wrought iron, the lower ends of whose legs are 2 feet apart. They converge upwards and unite at a point 3 feet above the ground, from which point arises a looped upright bar adapted to receive my $\frac{3}{8}$-inch bolts.

Against the vertical side of this bar the loops of two guide-pulley frames, like that represented in fig. 38, can be bolted so as to place their respective pulleys in any required angular position. Two of the legs of the frame terminate below in points; the third is loaded with a heavy adjustable weight, made up of one fixed lump of a hemispherical form which rests on the ground, and of twelve shifting pieces (each $4\frac{1}{2}$ inches diameter and 1 inch thick), made, as usual for adjustable weights, in the form of disks, slit so as to allow them to be placed in any number at pleasure upon the bottom lump. Their whole collective weight is 50 lbs.

When this tripod is set on a floor, the two pointed legs take sufficient hold of the latter to allow the machine to revolve, without slipping, upon the points, and thus to lift the third or weighted leg a few inches above the floor.

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[1] See 'Principles of Mechanism,' p. 177.

[2] The tripod-stretcher and the cutting-engine are manufactured by Messrs. Holtzapffel.

The position of the pulleys and of the whole tripod must be so chosen that the band passing from the great hand-wheel to the machine which is to be driven may be properly guided, and that the weight may be held up by it, as above described. Thus the band will be stretched by the effort of the weight to turn the tripod about the line passing through the points of the two legs that rest on the floor; for as the pulleys are fixed at the top of the machine, and the weight at the lower end of one leg, the rotation of the other legs about their pointed extremities produces a vertical motion of the weight and a nearly horizontal motion of the pulleys. Thus the band is kept tight, for the hand-wheel and the wheel to be driven are usually very nearly at the same level. The convenience of this stretcher is, that it can be set down in any part of the room required, without any previous fixing, and the pulleys will even move sufficiently to accommodate themselves to the band, when the driven wheel is mounted on a travelling carriage so as to shift its position during its action, as, for example, is generally the case in cutting or drilling machinery.

CHAPTER III.

ON THE SHAFTS AND TUBE-FITTINGS.

(23.) HAVING now explained the principal parts of the frame-work, I will return to the arrangements of the revolving mechanism.

I have already stated the advantages of mounting these parts for exhibition, as far as possible, upon studs; this, with a little contrivance, may be done to a very great extent. No doubt a long stud is liable to bend, and its diameter being necessarily greater than those of the pivots of an axis or shaft supported at the ends, introduces greater friction. But the forces and resistances of the machines we have to deal with in the Lecture-Room are rarely of sufficient magnitude to occasion inconvenience on this score. Nevertheless there are combinations in which shafts must be employed, and I will now explain the manner in which I have arranged them, in conformity with the system of frame-work.

When the pivots or necks of shafts are sustained by two 'plummer-blocks,' 'pedestals,' or other supports independently attached to the frame of a machine as usual, great inconvenience necessarily arises from the difficulty of fixing these pedestals so that the axes of their holes shall coincide with the direction of the shaft; for as every practical mechanist knows, the holes in the pedestals which receive the pivots or journals may separately fit the latter perfectly, and yet it will be found that when the pedestals are to be screwed to the frame, a great deal of careful fitting and adjustment is required in putting them together; otherwise the direction of their holes will be twisted, so as to set the shaft perfectly fast, and require the insertion of wedges or bits of paste-board, or careful filing of the seats against which they are fixed. Processes of this kind are plainly out of the question in putting lecture-machinery together.

Such shafts as are wanted must therefore be fitted each in its own carriage to which the pedestals or bearing-holes are permanently fixed, so that this carriage may be bolted to the frames already described when the shaft is required to take its place in a train of machinery; or else the pieces which sustain the ends or necks of the shafts must be so contrived as to obviate the necessity of the above-described troublesome adjustments.

(24.) Fig. 35 represents a cast-iron carriage adapted to our system. It carries a short shaft, 1 inch in diameter, and 5 inches long between the bearings. The latter are fitted with caps, with binding-screws, and oil-ways, so that the shaft is very steadily mounted in the most complete manner. The shaft is not intended to receive revolving pieces between the bearings, and therefore does not require to be dismounted. But the ends upon which the wheels, &c. are to be fixed project, the one 2 inches and the other 3 inches. A flat fillet is filed upon these plain parts, and thus any large wheel or rigger, provided with a binding-screw in its boss, or any other piece similarly fitted with binding-screws, as the handle (fig. 34), or the flanch (fig. 32),[1] may be attached to the shaft. But the toothed-wheels and pulleys described above (Art. 3), which are all bored with an inch hole with key-grooves, do not readily admit of the addition of a binding-screw. For these the 'lengthener' (shown in section, fig. 36) is provided. This is made of iron, and has a socket with a binding-screw by which it can be fixed to the end of the shaft. Its left-hand portion is 1 inch diameter, and has a feather or a pin to suit the key-groove of the wheel, and a screw and nut by which to fix it in its place against the shoulder.

The 'coupler,' fig. 37, is also intended to fix short pieces of inch-shaft to the ends of the carriage shaft, in order to lengthen them, if required, and will also serve to attach disks or other pieces that admit of a short neck or stem of hardwood, 1 inch diameter, being fixed to their backs.[2]

The cast-iron carriage has four bolt-slits, two of which are seen in figure 35. It may either be bolted to the beds, &c., or directly to the stool at any part most convenient. It is strong enough to carry a small fly-wheel of 2 feet diameter, like those employed for five-inch lathes. In this case the carriage may be bolted to one of the top beds of the stool; for example, midway between B and C, fig. 24: the

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[1] See Arts. 30, 31, for the description and use of these.

[2] The most complete way of arranging the end of the carriage shaft is to cut a square-threaded screw upon it which does not interfere with its cylindrical form, and therefore allows an inch-bored wheel, or two, to be fitted steadily upon it, and pressed against its shoulder by the nut. There may be a flat place filed upon this screw, which will not disturb its action; or better, a groove sunk in it for the reception of a feather that will thus adapt itself to the key-grooved wheels, and may be removed if it be required to fix a wheel which is simply bored and fitted with a binding side-screw. The square-threaded screw should stop short of the shoulder, to leave a plain part for the binding-screws to act upon, which might otherwise bruise the thread. When a shaft is thus provided with screws and nuts, its shoulders must be both outside, not both together as in the figure. One carriage may be fitted up with this kind of shaft, and another with the plain shaft.

fly-wheel, which must be provided with a strong binding-screw, should be placed on the inner end of the shaft, so as to revolve within the stool. The handle (fig. 34) being then fixed on the outer end of the shaft, will be at a convenient height for the hand, and a useful hand-wheel is thus arranged, by which motion may be given by an assistant to the larger class of machines, which are built upon the stool or fixed on a separate frame; or a treadle may be fixed below, the link of which may act upon a shorter handle-arm. If more convenient, the wheel may revolve outside the stool, and the handle or crank-arm within it.

One or two shafts in carriages of this description are necessary for strong work, and are applicable to all cases in which the limited length of the shaft is no inconvenience. But the most comprehensive method of arranging shafts is that which is described in the next Article.

(25.) The shafts, in this general method, are plain turned iron rods of the several diameters of 1″, $\frac{3}{4}$″, $\frac{5}{8}$″, $\frac{1}{2}$″. For simplicity, however, I will at first confine the description of the arrangements and appendages to the $\frac{3}{4}$-inch diameter, and apply them to the other diameters afterwards. The lengths of these may be 3′, 2′, 1′, and 7″. By way of pedestals to support and guide them in their rotations, I employ pieces termed *tube-fittings*.

The *tube-fitting* (fig. 29) I make of gun-metal or brass, in one piece. It consists of a tube M N, 2 inches in length, bored to fit the $\frac{3}{4}$-inch shaft, and $1\frac{1}{4}$ inch in external diameter. The back of this tube presents a flat surface parallel to the bore, from which projects a stem P, $\frac{5}{8}$ inch diameter and 2 inches long, having a strong screw upon it, provided with a nut (omitted in the drawing). This stem and nut serve to fix the tube to the heads of the brackets, which, it will be remembered, are bored with a $\frac{5}{8}$-inch hole, and the direction of the tube may thus be fixed at any required angle in the plane parallel to the face of the bracket. Also, the bracket can be shifted round the bolt which fixes its sole to the frame, and the axis of this motion is perpendicular to the stem of the tube; so that, by combining the two motions, the tube can be fixed in any required direction.[1]

Fig. 39 is intended to show the manner in which shafts may be mounted upon this system. It represents a frame carrying two shafts, the lower of which (A) is horizontal and parallel to the bed, and the upper (B) inclined both horizontally and vertically. Each shaft is carried by a pair of tube-fittings in brackets. The frame is composed of a 3-feet bed (C) upon rectangles (D, E). The tube-fittings of the lower shaft are carried by No. 3 brackets (F, G), bolted to the upright faces of the rectangles. Thus each tube can swivel about its *vertical* stem and the *horizontal* bolt of the bracket, and the troublesome adjustment described in Article 23 is

[1] See 'Principles of Mechanism,' p. 280.

wholly avoided; for when the shaft is in its place, and the nuts of the stems and bolts moderately fast, the tubes of themselves are compelled to take their places in the line of direction of the shafts, and the nuts may be then screwed fast.

The upper shaft (B) shows how an inclined position may be given. In this instance the higher end of the shaft has its tube-fitting attached to a single No. 1 bracket (K), and that of the lower end to a No. 3 bracket (H), and these brackets are also so disposed as to place the shaft across the direction of the bed horizontally. In similar ways any required angular position may be given to a shaft with respect to the frame, and the tube-fittings will always accommodate themselves to the line of the shaft, as above explained.[1]

In selecting the proper brackets for any required position, it must be remembered that the adjustability of the *tube to the line of the shaft* depends upon the former having two axes of adjustment (namely, its stem and the bolt which fixes the bracket-sole), which must not be parallel to each other, neither must the shaft be parallel to the bolt.

It follows, therefore, that the bracket No. 6 is not applicable to the support of a tube-fitting, because its bolt would be parallel to the stem of the tube. Also, no form of bracket can be applied to the support of a vertical shaft, if its sole be placed horizontally, because thus the bolt and shaft become parallel. Therefore, when it is required to support a vertical shaft by a tube-fitting, the frame must be so arranged as to place the bracket-sole vertically.

(26.) To prevent the endlong motion of the shafts, which are mere plain cylinders unprovided with shoulders or necks, rings must be employed. This device is usual in manufacturing mechanism when a shaft requires to be often taken out for cleaning or adjustment. Two rings, fitting the shaft accurately, and secured upon it by binding-screws, are attached on each side of one or other of the pedestals, or tubes, if the latter be employed; or, if more convenient, they may be fixed either close to the inner sides of the tube, or to the outer sides.[2] It is plain that in either

[1] The tube-fitting was suggested to me by a somewhat similar method of supporting shafts in some machines at Manchester. In these the shaft passed through a short cylindrical tube of metal or hard-wood. The tube was inserted in an iron ring which had a tail attached to it, tapped with a screw and nutted. This tail being passed through a slit in the frame-work, and the nut put on and screwed up, the tube was grasped and pressed against the frame, and the slit allowed sufficient play to enable the tube to settle itself in the direction of the shaft, but by no means the universal adjustment afforded by the form I have been led to adopt.

[2] *a*. O. *b*. *c*. P. *d*.

In this diagram, if the line represent a shaft, and O P the place of the tubes, it is clear that we have the choice of four positions for the two rings; namely, (1) at *a b*, (2) at *c d*, (3) at *b c*, (4) at *a d*.

of these four manners the shaft will be free to revolve, but prevented from sliding endlong. If a wheel or other piece be fixed on the shaft close to either tube, it will manifestly render one of the rings unnecessary.

It will be seen that the system of mounting shafts just described is well adapted to our purpose, because it leaves us at liberty to place the bearings at any convenient distance, and to choose any required projection of the free ends of the shaft. A narrow flat fillet may be filed along the shaft, to receive the pressure of the binding-screws by which the rings and the other pieces about to be described are attached to it. This fillet will not impede the rotation of the shaft in the tubes, and it serves to receive the small burrs or bruises which the screws are apt to produce when repeatedly applied, and which would disturb the smoothness of the rotation if allowed to be impressed on the cylindrical surface.

(27.) Some or all of these shafts should have deep conical centre-holes at their ends.[1] This will enable them to be mounted occasionally to run between *centre-points,*—a method which has much less friction than the tube, and is also useful for vertical shafts. In the latter case the lower end of the shaft may rest upon a point, and the upper be supported by a tube-fitting, especially if the upper end be required to run free,—to sustain a disk, for example. (In fig. 47, Plate III., such a vertical shaft is shown at A.)

One or more pairs of pointed centre-screws of steel must be therefore provided, each having two nuts, and the external diameter of the screw being $\frac{5}{8}$ inch. The screw will thus fit the holes in the heads of the brackets, and may be secured by a nut on each side of the head. This obviates the necessity of tapping the hole to fit the screw. The head of the screw should also have a conical sunk recess to receive the point of a revolving shaft, if required; in which case it must be placed in the bracket so as to present the head to the shaft. A pair of brackets thus provided with centres must be bolted to a bed or to any convenient frame-work, so as to receive the shaft, and the screws may be adjusted by turning the two nuts simultaneously, until the shaft is found to revolve with proper freedom.[2]

(28.) The toothed-wheels, pulleys, &c., which, as above described, are bored with an inch hole, are fixed to the shafts by the intervention of a piece termed an *adapter,* shown in section in fig. 33. This is bored with a $\frac{3}{4}$-inch hole to fit the shaft, upon any part of which it can be secured by the binding-screw. Its external diameter is one inch, and it has a shoulder below, through which the binding-screw

[1] If each shaft is turned in a single length between centres in the lathe, the original centre-holes will answer the purpose; but if they are cut from one long rod, the centre-holes must be made afterwards.

[2] In fig. 46 the shaft H of the swing-frame is supported by centre-screws of this kind. If it be required to support a shaft which has small pivots at the end, a pair of small tube-fittings may be used.

is tapped, and a nut and screw at the opposite end. Its length is sufficient to receive one wheel. To prevent the wheel from slipping round, a feather may be fixed to the adapter; but as one wheel only is placed upon it, the feather need not be prolonged as in the stud-socket, upon which two wheels are usually mounted; and, in fact, a pin of sufficient diameter, driven tight through a hole bored in the shoulder of the adapter, is sufficient, and is simpler.[1] Three or four of these adapters are required, some of which should be longer than the above, to receive pulleys or riggers that may be thicker than one inch, or two wheels, if need be.

(29.) Long rollers or cylinders, however, are better secured to the shaft by boring a ¾-inch hole through them which will fit the shaft. The roller must then be placed upon the shaft between two shaft-rings, one or both of which has one or two stout pins fixed into its edge, so as to lie parallel to the shaft (as shown in fig. 30). These pins being inserted into corresponding holes in the roller, and the shaft-rings secured to the shaft by their binding-screws, the roller will plainly be completely united to the latter.

(30.) The *flanch*, fig. 32 (shown in section at A and in front at B), is useful to fix pieces to the shaft in cases where the nut and shoulder of the adapter, by projecting on each side, may be in the way. This is especially the case at the free extremity of a shaft. The flanch is made of cast iron or of brass; it is bored to fit the shaft, and has a projecting boss behind, with a strong binding-screw to secure it thereon: the face is turned flat, and about 3 inches diameter. Three holes are bored at equal angular distances near its margin, and a fourth opposite to one of the former, as shown in the figure. These four holes are tapped to receive strong screws.

Small excentric pins, for giving motion to the rods of link-work, &c. may be attached to the flanch by these screws, as is shown in the figure. The pin *k* is carried by a slit piece *l m*, which admits of an adjustment that may give it any desired excentricity, from zero to a radius a little greater than that of the disk. For greater distances another pin may be provided, fixed to the extremity of a longer looped piece.

By means of these screws also, pieces of wood, such as large disks, cam-plates, riggers, excentrics, and so on, may be fixed to the flanch, and thus to the shaft. Generally the *three* holes will be preferred for this purpose. The *two* opposite holes are adapted to fix bars carrying excentric pins, or any similar contrivances.

[1] I sometimes employ a screw tapped into the side of the adapter, the head of which is filed square to fit the key-groove of the wheel. This has the advantage that it may be removed if the wheel be required to slip round. A similar screw, with an oblong head, may be used for the stud-sockets; if tapped into the plain part of the socket, with its centre one inch from the shoulder, it will catch both the lower and upper wheel.

If the projection of the screw-heads be objectionable, they may be sunk below the surface of the wooden disk; but if the latter be required to be attached to the extreme end of a shaft in such a manner as to leave its outer surface perfectly unbroken and smooth, three pins must be fixed to its inner surface, so as to pass through the three holes in the flanch; and the pins being tapped at their extremities, nuts and washers will attach the disk to the flanch. Such a disk is sometimes required to receive drawing-paper in mechanism for tracing curves, and in such cases screw-holes or other disturbances of the surface would interfere with its action. A disk may also be fixed to the end of a shaft by a stem fitted to the coupler, fig. 37, as explained in Art. 24.

(31.) The *lever arm*, fig. 34, has a boss at one extremity, bored to fit the shaft, and having a binding-screw. The arm is bored with several holes, or else made with a slit. It is intended to receive either a wooden handle (B), as in the figure, which converts it into a winch for giving motion to the models, or else pins (A or C) for link-work motions. The connecting-rods of the latter may be made of wood. The long pin (C) combines the office of a handle and of an excentric pin, as will be more apparent below, in the explanation of fig. 40, in which these lever arms are shown in use.

The flanch and its appendages (fig. 32), the lever arm (fig. 34), the adapter (fig. 33), the lengthener (fig. 36), and the coupling-tube (fig. 37), may all be employed in the stud-socket system by fixing them to the stud-socket, fig. 13, as already mentioned above (Art. 6). But for this application they will require to be bored with an inch hole, if the stud-socket be of an inch diameter; whereas the set of apparatus just described is adapted for $\frac{3}{4}$-inch shafts, and therefore bored with $\frac{3}{4}$-inch holes.

(32.) Here it may be remarked, once for all, that in any system of pieces which are required to fit together in various combinations, it will necessarily follow that the larger machines will appear too light and the smaller too heavy; for as the transverse sections of all the pieces of the same kind in a common system must be the same, to allow of mutual fitting, while the lengths may be and are different, the longer pieces will of course tend to a light and weak proportion, and the shorter to a clumsy and stronger proportion.

This objection is not a very serious one in the ordinary purposes to which the plan is applied; for the parts of all machines, whether they be originally small or large,—watches, mouse-traps, or steam engines,—require all to be constructed and exhibited upon a scale that will make them visible at a distance, in the same manner as the draughtsman delineates the small parts of mechanism on an enlarged scale, and reduces the larger ones. But in a complete apparatus the proper remedy is to establish two or three definite sizes, in every one of which a set of the parts above described must be made. These sizes I have, in fact, already indicated. Thus there should be an *inch set,* in which the wheels are bored with an inch hole; the stud-sockets an inch diameter; the shafts $\frac{3}{4}$ inch diameter, with their tube-fittings and apparatus to suit, as in the description given above: also a $\frac{3}{4}$-*inch set,* in which the wheels being bored $\frac{3}{4}$ inch, the stud-sockets are $\frac{3}{4}$ inch diameter, and the shafts $\frac{1}{2}$ inch diameter, with their proper apparatus. These two sizes are sufficient for most purposes. A still smaller set, adapted to thin wheels cut in brass plate, might be sometimes useful.

For some machines of the larger class the inch-bored wheels may require to be *keyed* upon shafts 1 inch diameter for greater *strength,* instead of being fixed by means of adapters upon $\frac{3}{4}$-inch shafts; and therefore a shaft or two of 4 feet and 3 feet length, with rings and tube-fittings, should be provided. Larger diameters of shafts than these are beyond the requirements of the system; but short shafts of $\frac{5}{8}$ inch diameter are useful, because they fit the $\frac{5}{8}$-inch holes of the bracket-heads, and are otherwise of a good proportion.

Thus we have the four diameters of shafts mentioned at the beginning of Art. 25; namely, $1''$, $\frac{3}{4}''$, $\frac{5}{8}''$, $\frac{1}{2}''$, in each of which sizes an assortment of lengths must be kept, and one or more pairs of tube-fittings, shaft-rings, and adapters, to each size, and there must also be a handle to each. Separate flanches are not so necessary: a flanch bored one inch will fit the stud-socket, fig. 13, or an inch shaft, and may also be fixed to $\frac{3}{4}$ inch diameters by means of a split collar (fig. 12) which is thin enough to yield to the binding-screw, and enable it to grasp the shaft. Similarly, a flanch bored $\frac{5}{8}$ inch will also suit a half-inch shaft by means of a split collar.

With respect to the frame-work, it will be seen that I have provided cast-iron brackets for the larger pieces and wrought-iron loops for the lighter pieces. The beds must necessarily be of the same depth in all the various lengths, in order to preserve the level of their surfaces when two or more of different lengths are employed side by side. But to diminish the clumsiness of the short ones, or weakness of the long ones, their thickness is varied from an inch and an eighth to an inch and a half, according to their length. Also, the lighter form, shown in fig. 27, is employed for small pulleys, rods, levers, or other matters that do not require the cast-iron brackets.[1] A set of beds of

[1] These small beds are 4 feet long, $\frac{3}{4}$ inch thick, and each bar of the pair $1\frac{1}{8}$ inch on the face, and $\frac{1}{4}$ inch apart; small bolts being kept for the purpose of connecting them. The intermediate size may have their bars $1\frac{1}{8}$ inch thick and $1\frac{3}{4}$ inch deep, being in other respects exactly like fig. 20, and of the lengths 2′, 3′, 4′.

an intermediate section may be made, if thought necessary. Bolts also must be kept assorted in sizes, they being the universal implements of connexion in this system.[1]

(33.) There are many cases in the fitting up of machinery in which it is required that the two ends of a shaft should be free to receive revolving pieces, but for which a long shaft supported on two bearings is not necessary. A short shaft supported by a single tube-fitting fixed in the head of a bracket may be used for these purposes; but the pressure of the nut of the stem is not always sufficiently powerful to prevent the stem from slipping round in the head of the bracket, so as to disturb the position of the shaft. It is therefore necessary to have a binding-screw in the head of the bracket, (as shown in No. 6, Plate I.) which effectually secures the stem from this twisting. One or two of the brackets of each form should be thus provided with stout binding-screws[2] in the head, which are also useful for fixing cylinders or other pieces in the hole, as shown in fig. 41. (See Art. 37.)

(34.) An example of the employment of short shafts in single tube-fittings is given in fig. 40. This represents a model of the arrangement of link-work

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[1] I have already stated (Art. 11) that the principal frame-pieces of the system are all to be united by coach-bolts $\frac{3}{8}$ inch square. Having now explained these frame-pieces separately, I will give some useful details respecting the different *lengths* of bolts required, which are of course determined by the respective thicknesses of the pieces they have to pass through. Now the bolts are employed to unite, (1st,) brackets to rectangles or other brackets; (2nd,) brackets or rectangles to beds or stools; (3rd,) beds to stools. The actual thicknesses of each of these several combinations are, (1st,) $1\frac{1}{2}$ inch; (2nd,) from $3\frac{1}{4}$ to $3\frac{3}{4}$ inches; (3rd,) $5\frac{1}{2}$ inches. Thus about four lengths of bolts are necessary, in each of which the bolt must be so long as to allow of a washer at each end and a good projection of the screw. Occasionally longer bolts than the above are required; and for putting together smaller sized frame-work an assortment of bolts with smaller shanks than the $\frac{3}{8}$-inch coach-bolts are exceedingly useful: for example, they may be $\frac{1}{4}''$, $\frac{1}{8}''$, and $\frac{1}{10}''$ square, and (the smallest especially) may be provided with fly-nuts.

Messrs. Fenn, of Newgate Street, now keep for sale a very useful kind of small steel and brass bolts, the former $\frac{1}{16}''$ diameter, the latter $\frac{1}{8}''$ diameter, of various lengths, and with hexagon heads and nuts. I have been for many years in the habit of keeping ready for use steel and brass screws of two or three of such small sizes, some having slit heads for the screw-driver, others milled heads and nuts to suit, and also taps to suit when the screws are used for connecting pieces that require a tapped hole. Much time is in this way saved in the construction or alteration of experimental apparatus. As a general principle in designing apparatus, it is better to connect parts by bolts and nuts than by screws tapped into holes, especially if the parts have to be frequently taken to pieces or are likely to be altered.

[2] I prefer inserting *two* binding-screws in the bracket-head, at an angle of about 60° apart, because two screws will gripe a piece of considerably less diameter than the hole, which one screw will not do, unless the opposite side of the hole be filed into the form of a V trough.

by which two parallel axes can be so connected as to revolve simultaneously. It is the element of mechanism which I have explained at p. 187 of my 'Principles of Mechanism.' Two No. 1 brackets are bolted to a 3-feet bed, which is sustained by feet. Each bracket carries a *tube-fitting* with a short shaft, $\frac{3}{4}$ inch diameter (or less, if such be provided), and 5 inches long. A lever arm (like fig. 34) is screwed to each end of each shaft, care being taken that the corresponding arms are of exactly the same length. I employ a pair of $6\frac{1}{2}$ inches long on one side, and a pair of $4\frac{1}{2}$ inches on the other. These arms are set at right angles to each other, or nearly so, and a pin (like A, fig. 34) is screwed into three of them, and a longer pin (C, fig. 34) into the fourth. Two wooden rods are provided with a hole at each end, to suit these pins, and bored at *exactly the same distance*, which may be about 2 feet 6 inches. The brackets are fixed so that the axes of the tubes shall also be set at the same distance as these holes. When the rods are in their places, as shown in the figure, the final adjustment of this distance is very easily made, as a few trials readily point out the necessary changes.

The long pin serves as a handle to give motion to the machine. When the two rods are in place, the motion is smooth; but by taking off one of them, it can be shown that the system is then capable of two kinds of motion (as shown in my 'Principles of Mechanism'), and that the change from one to the other can only be made at the dead points, &c.

(35.) Another way of arranging these short shafts is to have brackets like No. 2, Plate I., but in which the head is larger, so as to admit of an inch hole being bored through it. Thus an adapter can be fixed in this hole by its nut, and a short $\frac{3}{4}$-inch shaft will revolve in it, and may have wheels, levers, &c. fixed to its free ends at pleasure.[1]

The wrought-iron piece, fig. 21, is also useful for this object and similar ones. It is made $\frac{3}{8}$ inch thick, has a hole one inch diameter at the end, and a slit, $4\frac{1}{2}$ inches long and $\frac{5}{8}$ths broad, to receive the bolts by which it may be attached either to the wooden frame-work or to bracket-heads, &c. The inch hole is destined to receive an adapter of an inch external diameter, which may be screwed fast to the iron by its nut, by interposing a collar of wood or brass of sufficient length. As the adapters are bored of the sizes of the shafts, we have thus a convenient tube within which a short

[1] If the holes in the head of the ordinary form of bracket were carefully and cylindrically bored, $\frac{5}{8}$-inch shafts would revolve in them for this purpose; but holes in metal are usually made slightly taper or conical by the action of the rimer which is employed to enlarge the hole made by the drill and adjust it to the proper size. The holes are thus rendered unfit for the steady rotation of a short shaft.

shaft can revolve, being retained endlong, as above, by rings or any piece that may be fixed to it, and the iron can be bolted to the frame-work in any required position.[1]

(36.) It may happen that a number of pieces are required to turn freely about a single axis, as in the case of *epicyclic trains*,[2] in which a frame containing mechanism is made to revolve round a shaft, and the mechanism receives its motion from a wheel or wheels which are either fixed to the shaft or turn about it in various ways. Such motions may be mounted by means of a series of adapters, put on the shaft in sufficient numbers, and either screwed fast to it by their binding-screws, or left free to revolve, as the case may require; and if the shaft itself be required to be fixed, it must be a $\frac{5}{8}$-inch shaft, secured to the head of a bracket by a binding-screw.

(37.) As an example of the way of building up epicyclic trains, fig. 41 shows a model of Ferguson's paradox.[3] A, the bed in section; B, one of its feet; C, a No. 6 bracket, the head of which grasps a short $\frac{5}{8}$-inch shaft in a vertical position; D E, a bar of wood, which can be made to revolve freely and steadily about this shaft by means of an adapter fixed by its nut into a hole bored in the bar, and having its binding-screw loosened or removed. Above this adapter, another is placed on the shaft, and screwed fast to it by its binding-screw. The latter adapter receives the central wheel (F) of the system, and thus fixes it to the shaft. Two common stud-sockets, G, H, are fixed at the proper distances in holes bored in the bar, and thus the train is completed. The central wheel may be of 60 teeth, the intermediate wheel of 50; and for the outer stud-socket (H), three wheels (of 59, 60, 61) must be laid out, either of which can be employed. These are so nearly alike, that if the stud be fixed so as to allow the largest to gear without being pitched too deep, the others will act sufficiently well. The wheel of 60 being first placed on the stud-socket, and a chalk-mark made on its circumference, the frame may be turned, and the chalk-mark will continually point in the same direction. Then the wheels of 59 and of 61 being substituted in turn, they will slowly revolve when the frame is turned, the one in the same direction as the frame, the other in the reverse. This apparatus is very useful to explain the first principles of epicyclic trains.

(38.) It would require a greater number of figures than the plan of this work would admit, to show all the various methods of building up apparatus of

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[1] A stud-socket will often answer the same purpose as the adapter, and the revolving piece may then be screwed to the stud by its nut. The stud may require to be made of a somewhat different form; but as the stud-socket is bored $\frac{5}{8}$ inch, a short $\frac{5}{8}$-inch shaft may be substituted for the stud.

[2] 'Principles of Mechanism,' p. 361.

[3] Ibid. p. 371.

which the system is capable; but the few examples which I shall give below will serve to suggest many others, and will show the general nature and appearance of the machines when set up. With a little practice no difficulty will be found in devising other arrangements to suit any case that may arise. Every combination that proves to be useful must be sketched before it is taken to pieces.[1] Thus the trouble of contriving the same thing over and over every year is saved. The most complex parts may be simplified by having *peculiar* frames or pieces made for the express purpose; but this should only be done after the combination has been tried; for one of the advantages of the system is that it enables us to try various mechanical arrangements, and to reject or improve them as the case may be, without incurring the expense and loss of time consequent upon making frames and pieces on purpose.

(39.) To recapitulate: revolving pieces are, whenever they admit of it, supported by *stud-sockets,* the studs of which are carried by *brackets,* which are supported either on *base-boards, slit tables, rectangles,* or by compound frames built up of *beds* and *rectangles,* combined with *feet, stools,* or *posts.* All these parts are connected by *coach-bolts.* Other revolving pieces are attached to *shafts* by means of *adapters, flanches,* or *pinned rings,* and the shafts are supported either in *carriages,* or by *tube-fittings* or *centre-screws* carried by brackets and by the system of frame-work above described. The shafts are guided endlong by *rings.* The terms in italics, with the addition of *split collars, lever-arms, loops,* and *sole-blocks,* include all the "definite parts" alluded to in Art. 2.

It is perhaps needless to say that drawers with proper compartments should be provided to receive the separate parts of the system, every one of which should

[1] It was for this purpose that my ingenious predecessor, Professor Farish, developed the system of Isometrical Perspective now so commonly employed. This method, however, had been previously used, but, I believe, never explained: for example, in volume v. of the 'Machines Approuvées' of the French Academy, 1728, p. 52, there is a large and carefully executed engraving of a machine for milling lead, isometrically projected to scale. The leading lines of the horizontal planes, however, instead of being placed at an angle of 120°, are rectangular, making angles of 45° with the vertical. Thus the distortion of the plan is avoided. (See also tom. vii. p. 126.) I have already stated that the system I have endeavoured to explain has little in common with that of my predecessor, except the idea of employing the same parts in the construction of different combinations of mechanism. In his system, the parts were on a much smaller scale; the toothed-wheels were all of brass, and their pitch five to the inch, which is nearly as small as the Manchester *sixteen-pitch,* the ten-pitch which I employ being about three to the inch. All his revolving pieces were mounted on shafts, and these were made of an *octagon* section, $\frac{3}{4}$ inch diameter. The wheels, &c. were fixed to them by *adapters* (the only feature, in fact, common to our two systems); and to guide this octagon shaft in its revolution, and at the same time to prevent its endlong motion, two rings were fixed to it at the proper points by binding-screws: each ring was $\frac{3}{4}$ inch thick, and consisted of a plain part, 1 inch diameter and $\frac{3}{8}''$ wide, which revolved in a hole of these dimensions in the frame-work; and of a flanch, or shoulder,

be carefully put away in its proper receptacle when the machines are taken to pieces. The bolts, washers, &c. should also be placed in drawers, each form having its own cell. The brackets, rectangles, and sole-blocks are best arranged on shelves.

$1\frac{1}{2}$ inch diameter and $\frac{3}{8}''$ thick, which received the binding-screw and also governed the endlong motion. Thus the neck of the shaft was larger than its own diameter. Some of the shafts had pivots turned at one end. There was no provision to prevent the shafts from binding or jamming in their guide-holes, which were made sufficiently loose to obviate this inconvenience. The frame-work was built up of bars of iron, $\frac{3}{4}$ inch square, of which an assortment was provided of various lengths, some straight, some bent into the shape of an L, some in other forms. These were united by *clamps* of a peculiar form, with thumb-screws. The entire plan, into the details of which I cannot further enter, had the merit of great simplicity and ingenuity, but the machines were apt to appear somewhat embarrassed and complicated by the variety of clamps and junctions of the frame-work. It is to be regretted that the ingenious inventor of this mechanism did not draw up a detailed account of his system. The general appearance of his models may be gathered from the sketch of an optical grinding engine appended to his Paper on Isometrical Perspective, in the first volume of the 'Cambridge Philosophical Transactions,' which has also been copied in Gregory's 'Mechanics for Practical Men.'

CHAPTER IV.

ON THE APPLICATIONS OF THE SYSTEM.

(40.) The purposes to which I have found my system applicable may be classed under four heads: (1,) the formation of models of the Elementary Combinations described in my work entitled 'Principles of Mechanism,' and other similar ones; (2,) the construction of such machines as I select as examples, either of the principles of mechanism or of the processes employed in manufactures; (3,) the construction and arrangement of apparatus for Experimental Philosophy in general; (4,) the trial of new combinations and original research.

(41.) I will now endeavour to explain more at length, and in order, these several applications of the system; and first, the *Elementary Combinations*, nearly the whole of which I am thus enabled to exhibit; whereas, if each were constructed, as usual in such cases, as a separate model complete on its own foot or stand, the expense and bulk of such a collection would render it impossible.

Many of these combinations consist of pieces of peculiar forms which admit of being made of wood, and in which the axis of motion does not even require a stud-socket. For example, large models to illustrate the forms and action of the teeth of wheels may be cut out of mahogany, with the teeth on a large proportional scale, as in the diagrams given in my work, and such wheels will turn very well upon strong ordinary joiners' screws. In this case I generally mount the two pieces of which such combinations usually consist upon a bar of wood, and fix this bar, when wanted for exhibition, by means of a bolt to one of the posts (Art. 18) or to an iron rectangle (fig. 19), which serves to hold it up or enable it to stand on the table during the explanation.

In other cases a little more building is required; thus, if the action of ratchets, clicks, and detents is to be shown, a cast-iron ratchet-wheel is mounted on a stud-socket, the stud of which is fixed in a hole in a board, on which board is also properly mounted an arm for the clicks, a detent, &c., and the board bolted to the front of an iron rectangle or bracket. Here the rectangle, the ratchet-wheel, and the stud-socket and stud, are general pieces removed after the lecture, to serve for other purposes: the board with its clicks is *peculiar*, and reserved for this purpose alone.

Elementary trains of spur-wheels, of bevels, and mitres, are mounted wholly by means of the general system of parts. Thus, according to the nature of the combination we desire to represent, we must either employ a peculiar construction, frame or pieces, or build it up entirely of the general forms; or, finally, employ such a mixture of the two methods as may suit our convenience.

(42.) Fig. 42 may serve as a specimen of an elementary combination. This is known as Roëmer's wheels, ('Principles of Mechanism,' p. 257,) and was invented by him to effect the varying motion of planetary machines, but will also serve in any case where a rotation of varying velocity is required to be produced from a uniformly revolving shaft. In the figure, the shaft, to which a handle F is attached, is the uniformly revolving shaft, and upon it is fixed a cone A, fluted into sixteen regular and equidistant teeth, like those of an ordinary bevel-wheel, but occupying the surface of a much thicker frustum of the cone than usual. Opposite to this cone is placed, upon a parallel axis, a smooth frustum of another cone B, of the same angle, but set with its smaller end in the reverse direction to the first cone, so that its surface lies parallel to the teeth of the latter, and so close as just to escape contact. Upon the surface of B are planted a series of pins (of brass wire driven into it), and so arranged as to fall in succession between the teeth of A, when the latter is made to revolve. As this series is so placed as to be in some parts at the small end, and at others in the middle or at the large end, the velocity which B receives from A continually varies; for A and B are about the same diameter at the remote ends, and at the other ends the diameter of B is considerably greater than that of A. Thus, when the pins that are engaged in the teeth of A happen to lie opposite its small end, as in the figure, B revolves much more slowly than A. When the pins are opposite the large end, the velocities of the two are nearly equal, and between these two extremes the passage from one velocity to the other may be made gradual or abrupt, according to the path upon which the pins are placed. To mount this apparatus, a *slit table* (fig. 16) is employed for the base. The cone A, made of hardwood, is bored with a $\frac{1}{2}$-inch hole, and is fixed on a $\frac{1}{2}$-inch shaft by pinned rings (fig. 30). The shaft is carried by tube-fittings upon No. 2 brackets (C, D), and the endlong motion of it prevented by the handle F at one end, and by a shaft-ring at the other end. The frustum B is also made of wood, and bored with an inch hole, so as to be mounted on a long stud-socket which is carried by a No. 2 bracket, E.

In this model the only *peculiar parts* are the two cones, every thing else being derived from the general system. I have already described two other specimens of this class; namely, the link-work, fig. 40 (Art. 34), and Ferguson's Paradox, fig. 41 (Art. 37).

(43.) The second purpose to which this system is applied is the construction of models of such machines as I select as exemplifications either of the principles of mechanism or of the processes employed in preparing and working raw material.

A model of a machine is generally constructed for one or other of the following purposes,—to explain the use and contrivance of the machine, or its actual form and construction. If the latter be the object, the model must necessarily resemble the original as nearly as possible, and differ from it only in material or magnitude; as, for example, when a large model is made of a small machine, as a clock scapement, to make its various minute parts more clear; or *vice versâ*, when a small model is made of a large steam engine. When the purpose is to explain and teach the arrangement (or '*packing*') of the different parts, and the form and mode of putting together the frame-work, no deviation from the original, or simplification of it, can be permitted, with this exception, that as the model is not subjected to the strains which the work of the original throws upon its various parts, wood may be used instead of brass or iron.

The case is very different, however, when the object of the model is to explain the motions and mechanism of the original.

Real machines consist of a number of parts of various sizes, packed together in a *cubical form* in a frame-work contrived so as to support the pieces in the best manner, and to reduce the machine to the smallest possible compass consistent with the proper access to the parts for oiling, cleaning, &c. In such machines it is difficult even for an experienced observer to see all the parts, without looking on all sides, or even removing some of them, because they are placed without any reference to the display of their motions, which are often hidden by the frame-work and by other portions of the mechanism.

In preparing a representation of the action of such a machine for the Lecture-Room, it is necessary to alter its arrangement by displaying the parts as much as possible on a *plane* system, instead of a *cubical one*, so that one piece may not conceal another. Instead of ingenious *packing* of the parts, we must have them *unpacked* and laid out, as it were, for inspection, without interfering with their connexion and action. Moreover, the frame-work must be kept out of the way as much as possible. Again, the small parts must be made larger in proportion, to render them visible at a distance, and the larger parts may often be reduced in scale. All this may, by judicious care, be effected without disturbing the connexion of the trains of mechanism, or destroying the individual character of the machine. When a machine contains a repetition of working parts, as in spinning, weaving, &c., a few such parts will do better for our purpose. Two or three *real spindles* set in a frame, with their proper drawing rollers above, may be set in motion by a combination built up of the general pieces above described, and will enable a clearer and better idea to be given of the action of these machines than if the Lecturer was provided with a complete throstle-frame. Many subsidiary contrivances also, which are necessary for adjustments or other secondary objects, and not essential to the primary work of a machine, may be dispensed with in an explanatory model, or explained subsequently by a model made on purpose.

(44.) As an example of the manner in which the parts of a machine may be arranged for Lecture-Room exhibition and explanation, I will take the striking part of a clock on the repeating principle (fig. 43). This model contains so many peculiar parts, and is so complex, that a peculiar frame is provided for it.[1] (The drawing is made to scale.) The frame consists of a base-board with two feet (A, B), and two upright pillars (C and D) of inch deal are attached to the base, as shown in the figure. The left-hand pillar (C) is 8 inches broad and 2 feet 7 inches high, and serves to carry the studs upon which the train of wheel-work is mounted, and also the hammer F, and bell E. The right-hand pillar D, 5½ inches broad and 2 inches higher than the other, carries the snail N, the rack M, and the detent L. This pillar stands 2 inches in advance of the other, and the pieces which it carries are all made of wood and mounted on strong screws, which are quite sufficient for the motion required by these parts, although they would not answer for the wheels, &c. on the other pillar. The snail and the rack have bosses behind, which set them at the proper distances from the pillar; for from the nature of the machine the detent lies behind the rack, and the rack behind the snail. The rack has a projecting knob at the lower extremity, which rests upon the step of the snail when it falls. The detent here is of the simplest construction, consisting merely of an arm turning freely on the screw at the upper end, and having a projecting pin at the lower end, which lies in the teeth of the rack. It is unnecessary to introduce a *lifting-piece* or any other contrivance for the *warning*, because this device is fully explained by a similar large model which I have, of the count-wheel striking train, which it is convenient to exhibit pre-

[1] See Art. 8.

viously to the present one. Also the snail (N) is so mounted as to turn on its axis by stiff friction, and can therefore be set by hand to the proper positions required for the different hours. The rack (M) turns freely on its centre, and therefore, when the train is discharged by raising the detent (L), it falls on the snail by its own weight.[1]

The train is mounted on three stud-sockets, and is furnished with cast-iron wheels and pinions of the *twelve-pitch* size.[2] The lowest stud-socket carries a wheel of 120 teeth, and a barrel of hardwood, 6 inches in diameter and an inch thick, to the front of which is screwed an annular plate of iron (G), provided with six pins for the hammer-tail.

The hammer (F) turns on a stud which is fixed to a block of sufficient projection to bring the hammer-tail in front of the plate: to the same block are fixed the hammer-springs (not shown in the drawing); the bell (E) is also mounted on a block; a slender cord (P) is coiled round the barrel, to give motion to the train, and passes through a notch in the base-board. The machine, when in use, is set upon a stool or other open-legged frame that will allow the string to hang down, and motion may be given to the machine during the explanation of its action by pulling the string by hand. After the action of the parts has been demonstrated, a weight may be hung to the string, for the purpose of still better showing the effect, by allowing the machine its proper self-action.

It is unnecessary to employ a ratchet for winding up; for by drawing the hammer-tail sideways, so as to clear the plate G, the string may be wound upon the barrel.

The wheel of 120, behind G, gears with a pinion of 20 fixed to the next stud-socket, H. This socket carries in front of the pinion a wheel of 108, and also the gathering pallet and its hook.

It is required that this gathering pallet stand visibly at the end of the socket, and for this purpose it is better to employ a stud-socket of the form fig. 11 or fig. 13, Plate I. (Arts. 6, 7), or to make a stud-socket expressly for the machine in question, in which the pallet and hook are permanently attached to the front of the socket, but from which the wheel and pinion can be removed for other purposes, when the machine is not in use.

The fly K is carried by a third stud at the top of the pillar C, the peculiar

[1] In this description I assume that my reader is already acquainted with the mechanism of the contrivance, the description of which may be found in any treatise on clock-work. My object is only to show the actual construction of the Lecture-Room model.

[2] For simplicity sake, the *teeth* of the wheels are not introduced into the figure.

arrangement of which is shown in fig. 44, which is a view of the fly, &c. seen from above: *a b* is the pillar; *c*, a block screwed to it, to which is also fixed a long stud (5 inches long). The stud carries two separate sockets; the first, which lies next to the block, is a short socket of the common form, $\frac{3}{4}$ inch in diameter, upon which a pinion (*d*) of 12 is fixed, and gears with the wheel of 108.

In front of this is placed a socket with two branches, to which the fly *h* (of sheet iron) is riveted. This fly, 10 inches wide and $4\frac{1}{2}$ broad, projects so far as to enable it to revolve clear of the other mechanism. It has a semi-circular opening, which allows the end of the stud to project and receive a pin which keeps the sockets in their place. The socket has two springs (*e* and *f*) riveted to it, which are bent backwards, as shown, so as to press upon the shoulder of the pinion socket, which may be notched. Thus, when the pinion turns, the pressure of the springs enables it to carry the fly along with it; but when the train is checked by the tail of the gathering pallet striking the pin of the rack, the fly can proceed alone in the usual manner.

By the peculiar disposition of the parts of this model, every motion is visible during the action of the machine. I have also constructed large models of the same kind, representing the going part of a clock and the count-wheel striking part.

The above machine is an example of the first method of frame-work, which I have explained in Art. 8. Every model thus constructed has an analogy with a section of the machine made by a draughtsman, or rather with a machine in which, by the common artifice of representation, the front plate or some other part is supposed to be removed, to show the machinery. Fig. 43 may be considered as a drawing of a clock, in which the frame consists as usual of two plates connected by pillars. In such a clock the wheel-work on the left-hand deal post (c) would be contained between the plates, and the detent, rack, and snail would be attached to the outside of the front plate. The draughtsman would describe this drawing as made under the supposition that a part of the left-hand portion of the front plate was removed to show the machinery. In the model, the employment of stud-sockets enables this part of the plate to be dispensed with, without disturbing the arrangement or action of the machine or destroying its identity.

A great number of machines, therefore, in which the framing consists of two parallel and similar frames, connected by transverse pillars or braces, and supporting shafts or other axes, may be modelled under this system without materially altering their general appearance, by making one only of these frames of the same shape as in the original engine, and substituting studs for the axes. The employment of the general system of framing with beds, stools, brackets, &c. necessarily alters the appearance of the machine, and is therefore not to be employed when the actual form and construction of the real machine does not allow of much modification, or is part of the object of the Lecture.

(45.) Fig. 45 is a machine to describe the curves that belong to parallel motions under various proportions of the radius rods and link, and different positions of the describing point upon the latter. I select this as an example of the employment of the stool (fig. 24), the brackets, &c. to the fitting up of a lighter class of mechanism than the cast-iron machinery hitherto described.

A drawing-board inclined forwards, to make it more visible to the audience, is fixed to the stool, as shown. The back edge rests on the frame (fig. 23), which is bolted behind the stool, and it is kept in its place by looped squares (like B, fig. 20), bolted to the front legs,[1] and by a hook-bolt not visible in the figure, which is passed through the slit of the back frame, these fixing pieces being lodged in notches cut in the drawing-board.

The instrument which it is the object of the frame to support requires to be suspended, as it were, over the board, so that its arms may be perfectly free to revolve, and that their action may be as little concealed as possible. A parallel motion (see 'Principles of Mechanism,' page 399, &c.) consists of two radius rods connected by a link: a pencil is attached to this link, and when the rods are made to turn about their fixed centres of motion, the pencil describes a curve, which, under certain proportions between the lengths of the rods, link, &c., possesses the property that a part of its length is so nearly rectilinear, that in practice it may be employed as if it were a true right line. The radius rods of the machine we are considering are made of sheet iron or brass, with a slit towards one end and a rivet-joint at the other, by which they are united to the link: *a b*, *c d* are the radius rods, and *c b e* the link to which they are jointed at *b* and *c*: *e* is the place of the describing point or pencil.

The axis of motion of each rod is provided by taking the tube-fitting of a ½-inch shaft (fig. 29), and turning a piece of hardwood with a shoulder at one end, and of such a length as will just project beyond the tube when it is placed within it. The diameter must just allow it to turn freely and steadily in the tube. It is bored to receive a small bolt with a fly-nut. Let the bolt

[1] One of these is shown in its place at B, but is omitted on the opposite side at C, in order to show the notch in the drawing-board.

be now passed through the slit of the radius rod, and then through the wooden axis just described, placed so that the shoulder may be downwards and in contact with the radius rod. The wooden axis must now be inserted into the tube, and a washer put on the upper end of the bolt, and the whole secured by the fly-nut. The nut will, of course, bind the radius rod fast to its wooden axis, and the length of the rod can be adjusted before the last turn is given, by means of its slit. But as the axis is a little longer than the tube, the washer of the bolt is not pressed upon the tube, and thus the axis is free to turn within the tube, and the radius rod becomes capable of a steady rotation.

A bed 3 feet long is fixed as a bridge over the drawing-board, in the manner shown in the figure. By combining at each end a No. 1 bracket (D) with a No. 3 bracket (E), and bolting the latter to the bed, we obtain the means of inclining this bed so that its lower surface becomes parallel with that of the inclined board. To the lower side of the bed are bolted two No. 3 brackets (F, G), which carry the tube-fittings. Thus the axes of the radius rods are firmly supported, and yet the frame is kept so high and so far backwards as not to conceal the action of the rods and pencil.

I have not thought it worth while to enter into the minutiæ of the construction of the link and pencil carriage, which are so contrived as to allow of ready changes of length and of the position of the pencil. In the positions shown in the figure, the curve, which is usually a distorted figure of eight, has two isolated branches, *m n p* and *q r s*, of which the portions *m n* and *q r* are nearly rectilinear. By gradually altering the proportions of the machine, the curves respectively drawn in each adjustment are seen gradually to approach each other, and finally to unite into the single figure of eight.

Other varieties of the curve, corresponding to different combinations of the parallel motion, are obtained by fixing the pencil to a transverse bar which can be clamped fast to the link, so that the pencil is no longer situated in the right line which passes through the joints of the link. Thus we get curves that belong to such arrangements as that given at page 411 of my 'Principles of Mechanism.'

In this apparatus, the only peculiar parts are the radius rods and link, with the wooden axes that turn in the tube-fittings: the whole of the frame is built from the parts of the general system.

In a similar manner may be mounted the machine termed a 'geometrical pen,' or 'Suardi's pen,' which I have constructed with *sixteen-pitch wheels*, for showing to an audience the mechanical description of epicycloids and hypocycloids on a large scale.

(46.) Fig. 47 represents an arrangement for the exhibition or trial of various regulators for mechanism moved by weight.

The regulator, which is shown in operation, is of the class usually employed for the clock-work which is attached to equatorial telescopes, and is similar in its mode of action to that description of these regulators which was first introduced by Mr. Sheepshanks,[1] but differs in the manner of carrying out the principle, which I have endeavoured to simplify as much as possible.

As my purpose in giving these examples is not so much to describe peculiar contrivances as to illustrate the method of building up frame-work and machinery out of the parts of my general system, I shall very briefly describe this revolving regulator, which is, in the present example, the only *peculiar part* required.

A vertical spindle A is supported below by a centre-point screwed to a No. 6 bracket (B); the upper end of the spindle is guided in its revolutions by a *tube-fitting* carried by a bar of wood C D, which is bolted to a pillar formed of two *rectangles:* the bracket and the lower rectangle are bolted to the *stool* as shown in the drawing.

The spindle has a small bar *m* pinned to it near its upper end, and a longer bar of wood *p q*, pinned to it below. The upper bar serves to suspend the pendulum rod *k q*, which, as the figure shows, terminates upwards in a fork which embraces the bar, and is pierced so as to swing on a steel wire fixed to the bar. The lower end of the rod carries a heavy ball, and rests, when the machine stands still, against one end of the lower bar at *q*: the other end (*p*) of this bar carries a similar ball to counterpoise that of the pendulum rod. The details of the upper part of the spindle are best seen in fig. 50, where they are exhibited on a larger scale.

Between the upper short bar *f*, fig. 50, and the tube-fitting *c d*, there is a metal collar *e*, upon the spindle, which can travel freely upon it vertically, but is compelled to revolve with it by its connexion with a lever *f g*, the fulcrum of which is carried by the end of the bar at *f*. This lever expands into a loop which presses against the collar at two opposite points, and beyond it terminates in a single arm *e g*, which rests upon a short branch *h*, projecting from the pendulum rod just below its fork.

When the spindle revolves, and its speed is accelerated, the ball and rod are carried outwards by the centrifugal force, and the branch (*h*) thus raising the long arm (*g*) of the lever, the collar (*e*) is pressed upwards against the lower surface of the tube *c*: thus a friction is produced which retards the spindle, and prevents its velocity from increasing.

To the lower part of the spindle, beneath the long bar *p q*, fig. 47, is screwed an *adapter*, which carries a small wooden pulley, and a larger cast-iron one, E; the former to receive the band which sets the spindle in motion, the latter to act as a

[1] See a Paper on these Regulators by the Astronomer Royal, Mem. Astron. Soc. vol. xi. p. 251.

fly-wheel. The spindle, with its bars, balls, pendulum rod, lever, &c. are *peculiar parts*, and are therefore not taken to pieces; the *adapter*, &c. are *general parts*, applied for the occasion only.

To keep this spindle in motion, and thus to exhibit its action, the following mechanism is built up. A *two-feet bed* (F) is bolted to the opposite side of the stool to that which supports the pendulum frame; upon it two No. 1 brackets (G, H), with tube-fittings, carry a ¾-shaft (T) 18 inches long: upon this shaft will be perceived a drum Q (of wood), a ratchet-wheel, and a large iron band-wheel, 14 inches diameter. The wooden drum is fixed fast to the shaft by an adapter; the ratchet and wheel are mounted on a second adapter, which is left loose on the shaft; but a click is fixed to the side of the drum, which engages the teeth of the ratchet.

A high post (10 or 12 feet high) is secured to the stool by a bolt, the head of which is seen below at K, and by a *hook-bolt* (shown separate at fig. 48),[1] which engages the lower side of the upper rail of the stool (behind L). To the upper end of this post is fixed a No. 3 bracket (M), carrying a *guide-pulley* N, and a loop O (like B, fig. 22), to which the end of a cord is tied: this cord passes (as shown in the figure) downwards and over a pulley P, to which a weight is suspended, then upwards and over the guide-pulley N, thence downwards to the drum Q. As the drum is fixed to the shaft, a handle (fig. 34), applied to either free extremity of it, will wind up the weight, which in its descent gives motion to the revolving pendulum by means of an endless band from the large wheel. This band passes over a guide-pulley R, similar to fig. 38, Plate II.

To receive this pulley and other mechanism, a 3-feet bed (S) is bolted against the front legs of the stool.

It may be required to exhibit the action of other regulators,—flys, for example, like fig. 44, or with longer arms and surfaces capable of being set at different angles.

For this purpose a No. 6 bracket may be bolted at the back of the bed S, into which bracket the stud of the fly may be screwed, which will thus project horizontally forward. A pulley must be used instead of the pinion *d* (of fig. 44), and a band provided of proper length to suit the great wheel.

The fly may be taken off its stud and laid by, so as not to interfere with the action of the pendulum, and the bracket must be fixed in such a position that its

[1] The upright branch of the hook-bolt is placed in the slit of the top rail of the stool, and the tapped end passed through the post, and the nut secured. Thus the post is firmly fixed against the inside of the top rail. The crooked form of the shank is adopted to give a firm central bearing to the upright branch; but in some relative positions of the post and stool (as, for example, when the post is to be bolted against the outside of the leg A B, fig. 24, the hook being inserted in the vertical slit of the leg), this bent form is inadmissible, and the straight hook, fig. 49, must be used.

stud may not interfere with the band of the pendulum. When the latter has been exhibited and explained, the fly can be readily put into gear. I mention these details by way of showing the advantage of the stud-socket system in readily allowing the parts of machinery to be dismounted or replaced before an audience, by which the explanations and arrangements of a Lecture are greatly facilitated.

If it be desired to prolong the motion of the machine, an additional axis may be introduced into the train by bolting a No. 6 bracket with a stud-socket at the back of S. A toothed-wheel must be placed upon the adapter which carries the ratchet, instead of the band-wheel, and the band-wheel must be transferred to the stud-socket, which must also carry a pinion to gear with the toothed-wheel. The bracket may be either fixed between H and B, or on the prolongation of the bed S, at its left-hand extremity beyond H; and if more room is wanted, a 4-feet bed must be substituted for the 3-feet bed S.

(47.) Fig. 46 is a machine to elucidate the laws of friction.

The frame of this machine is built up of four beds, bolted to each other as already explained above (Art. 16). A $\frac{3}{4}$-shaft, 18 inches long, having a handle (K) screwed to one end of it, is mounted in a pair of tube-fittings carried by No. 3 brackets, one of which only is seen in the drawing. To this shaft a cylinder of hardwood (A) is fixed, in the manner already explained (Art. 29), by means of pinned shaft-rings. The cylinder is 6 inches in diameter and in length, and is turned very true and smooth.

Above this cylinder is seen a smaller one, B (4 inches diameter and $4\frac{1}{2}$ long); this revolves upon the points of a pair of steel centre-screws, inserted into the ends of an iron frame, which itself swings upon another pair of steel centre-screws inserted in the heads of the two No. 1 brackets (C, D), which are bolted at the remote ends of the wooden frame: a transverse board is fixed to the iron frame, upon which a 7 ℔. weight is resting in the drawing.

A bar of wood (E) is placed between the two cylinders: this bar, 2 feet long and 3 inches broad, is made flat on its lower surface, but the edges of the upper surface are chamfered off so as to leave only a narrow fillet. The bar rests upon the lower cylinder, and is pressed into contact with it by the weight of the iron frame and upper cylinder, assisted by the 7 ℔. weight. The upper cylinder being, as before stated, mounted in a swing-frame, is at liberty to press upon the bar. The far end of the bar rests upon a roller F, the stud of which is carried by a No. 3 bracket, bolted to the bed between those which carry the centre of the swing-frame and the tube-fitting of the shaft of the great cylinder. The bracket in question is, however, raised to the requisite height by a *sole-block* (Art. 13).

One of the beds of the frame is longer than the other, to enable it to support a Marriott's Spring Dynamometer (G): the latter is furnished with a larger dial-plate than usual (1 foot in diameter), and will indicate pressures up to 25 ℔s. This dynamometer has a bolt at the back, by which it can be attached to any frame (it being a very useful piece of apparatus for various purposes). In the present machine the bolt attaches it to a No. 2 bracket, bolted to the projecting end of the long bed: the sole of this bracket is just visible in the drawing behind the dial; the bar of wood is linked to the dynamometer.

The action of the machine is as follows: the pressure exerted by the upper cylinder and swing-frame on the bar, without the 7 ℔. weight, but estimated at the point where the centre of that weight is to be placed, is 7 ℔s.; consequently the addition of one or more 7 ℔. weights enables us to double or triple the pressure.[1]

If the handle be turned, the bar E is drawn between the cylinders, extending the dynamometer spring as it goes until the resistance of this spring becomes so great as to balance the friction of the bar upon the lower cylinder. At this point the bar stops, and the cylinder may be turned, without otherwise disturbing the index than by the slight variations of friction at one part or other of the circumference of the cylinder. The weight indicated by the index is plainly the measure of the friction of the materials of which the lower cylinder and bar are made, under the pressure exerted by the swing-frame and upper cylinder. Accordingly, when no additional weight is put on, the index stands at about $1\frac{1}{2}$ ℔. The addition of 7 ℔s., as in the drawing, raises the index to 3 ℔s.; of 14 ℔s. to $4\frac{1}{2}$, and so on; thus exemplifying the law of friction which declares it to be proportional to the pressure.

But it will be found, under any of these pressures, that the index remains stationary at its proper point, whether the cylinder be turned slowly or rapidly; that is, that the amount of friction is unaffected by the velocity with which the rubbing surfaces move in contact. Thus another law of friction is shown, which it is impossible to exhibit to an audience in the usual manner in which experiments have been made to examine it.[2]

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[1] This pressure can be easily and conveniently measured, and shown to an audience by attaching the hook of a portable spring dynamometer to the swing-frame, and raising the latter thereby.

[2] The law is usually experimented on by observing the motion of a sledge along a long horizontal bar, for the purpose of ascertaining whether or no its motion be uniformly accelerated,—a result which can only be accurately attained by a strictly level bar, and an apparatus constructed in a solid and exact manner wholly incompatible with the arrangements of a Lecture-Room, to say nothing of the care required in observing the law of motion of the sledge.

In accurately determining the pressures of the above apparatus, the friction of the upper cylinder

Lastly, if the bar be reversed so as to place the narrow fillet in contact with the lower cylinder instead of the broad lower surface, the friction under each pressure will be found to remain the same as before. Thus the remaining law of friction is exemplified, namely, that it is independent of the quantity of surface in contact.

By this apparatus, therefore, the three principal laws may be rapidly exemplified.

(48.) Many machines occur so peculiar in forms and arrangements as not to admit of or require the employment of the stud-sockets, frames, or other parts of the general system, but in which the general principles above explained may still be brought into play; namely, of so modifying the frames and relative scale of the parts, simplifying their forms, and separating them, as to make every part and action of the machine, as far as possible, visible at once. The sectional models of steam engines which are now so generally employed may be quoted as examples; but I have applied the same principles to the construction of many other machines, of which I will mention only two or three in illustration of the manner in which I conceive Lectures on Mechanism should be illustrated.

(49.) *A loom* with four treadles and corresponding parts is built upon a single light frame (4 feet long and 5 feet 6 inches high): the rollers, or *beams*, as they are termed, are of mahogany (9 inches long and 3 inches diameter), and turn on stout studs fixed 2 feet 9 inches from the ground: the warp (5 inches broad) is formed of 40 threads of stout white round bobbin, so as to be visible at a distance; the *heddles* are formed of *brass wire*, with a hole drilled in the middle of each wire, and the *treadles* with their levers and apparatus mounted on a cross frame, so arranged as to interfere in the least possible manner with the view of their action. The *lay* consists of a single bar swinging on a stud at the top, and having a rail projecting at right angles at the bottom, to carry the *reed*, &c. In lieu of a shuttle I employ a wooden needle, like that used for netting. This machine enables me to exhibit the first principles of weaving, tweeling, diapering, &c. None of its parts are applicable to general

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on its pivots, and its rolling friction on the bar, must be taken into account; but these are so small as not to affect the result sensibly.

The rubbing friction shown by this engine is not that of two plane surfaces, but that of a plane rubbing tangentially upon a cylinder, the contact taking place along a *line* instead of a *plane*. But these frictions follow the same law, as is indeed evident, seeing that the amount of rubbing friction is unaffected by the extent of surface in contact under a given pressure, and is therefore the same whether it be a plane or a line. Plane surfaces might be exhibited in frictional contact by means of a revolving horizontal disk of wood, upon which a small plane surface, loaded with weights and supported by a radial bar, swinging round the vertical axis of the disk, might rest, the surface being linked to a dynamometer.

purposes, and it therefore remains undisturbed from one Course of Lectures to another. It may be considered as an example of the kind of models described at the end of Art. 44, in which the general appearance of the original is not materially interfered with. I have constructed a large similar model of the Jacquard loom, the whole mounted upon the stud principle, and the parts of the Jacquard apparatus on a highly magnified scale, with a group of few wires, so as to make the action of the successive cards perfectly visible.[1] To this also belongs a model of the machine used for piercing the cards, and several others.

(50.) For rope-making I have also made models of the registering machine and laying machine, in which the frame-work is constructed in skeleton, and the machinery mounted, as far as practicable, on the stud system, so as to make the entire action of these complex and beautiful contrivances visible.[2] These models, although constructed with the same kind of cast-iron wheels that are employed in the general system, are so complicated and peculiar that it would be absurd to take out the wheels for other purposes. The strands are formed of soft worsted, and each of a different colour, to make their progress through the mechanism more visible, while the material opposes little resistance to the skeleton frame-work. The result, therefore, resembles a bell-rope about half an inch in diameter. The actual machines must be seen for themselves, and will be easily intelligible after a sight of the dissected models, the object of which is to exhibit the principles and action of the mechanism.

(51.) Lastly, I may mention a large sectional model of a complete organ, with three rows of keys, pedals, and all the usual stops,[3] together with the whole of the usual couplings and combination pedal-work. The system upon which this is contrived is the following: The model includes two keys and two pedals, and may be supposed to be a slice taken out of the heart of the machine by two parallel planes, the distance of which is sufficient to include the two keys and all that belongs to them. It is true that it seldom happens that all the appendages in question really lie in the same vertical plane, but they may be brought into that relative position, and in the present case are supposed to be, exactly as they would be in a section of the instrument made by a mechanical draughtsman. In

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[1] This model is 8 feet 9 inches high from the ground: the prism of the Jacquard apparatus is 5 inches square and 8 inches projection, and each face has four rows only of large holes, six in a row. Four in a row would be sufficient.

[2] The whole of the machinery for rope-making is described, with many plates, in the 'Professional Papers of the Royal Engineers,' vol. v.

[3] Including eleven stops for the great organ, and seven each for choir and swell; the latter having a proper swell-box with shutters.

fact, the model is an acting section on the full scale: but of these two keys, &c., the front one of each key-board has its pipes made of wood painted and represented in section; the wind-channels, pallets, and all other matters also in section where required, and thus serving to show how the depression of the central key draws down the pallet of the great organ wind-chest,—how the wind-passage, thus opened, may be made to communicate with the pipes of one stop or other, by drawing the stop-sliders,—how the other key-boards and pallets are connected, and how they may all be linked and combined at pleasure by the couplings, levers, &c., all of which are mounted on studs; and lastly, how the draw-stops may be grouped by the combination pedals.

But the back key of each key-board acts upon a real pallet, in a proper wind-channel supplied by real bellows, and the pipes of this hinder system are the actual pipes that would be employed in such an organ, including a complete set of one of each stop of Great, Choir, and Swell organ for middle c, together with a great pedal-pipe. The wind-channels and pallets of this real system lie exactly behind their sectional representations, and their levers, couplings, &c. are of course mounted on the same studs and standards as those of the front keys.

Thus the front keys show the visible action of the machine,—the hind keys, the audible action; the front pipes exhibit the interior form and sections of the different stops,—the hinder pipes produce their real sounds.

To separate more distinctly the interwoven mechanism of the three key-boards and the pedals, different colours are employed.[1] The cut parts and connecting links of the great organ are painted blue; of the choir, yellow; of the swell, red; and of the pedal, green.

By this machine, which is, when mounted for exhibition, very large (13 feet long and 8 feet 6 inches high), I am enabled to explain this most curious instrument mechanically and acoustically; to show the qualities of the different stops, their harmonic relations, their combinations, and the use and arrangement of every part of the instrument.

A single-key system might be used, in which the wind-channels might be faced with glass, to show the motion of the pallets; but this is not so perfect a representation of their action and of the distribution of the condensed air as by the double system I have adopted. In all models of the kind above described, the acting parts should be, where practicable, made exactly as if for

[1] This plan is useful in many cases; for example, in a large sectional steam engine I have painted all that belongs to the steam, grey; to the condenser, yellow; to the warm water, blue; and to the cold water, green.

real use. Thus the set of pipes were made for me by Gray, and my audience are thereby assured that their forms and voicing are genuine. So also real shuttles, spindles, reeds, &c. should be obtained from the proper makers, in illustration of the processes to which they belong, as well as specimens of the products in various stages of preparation and of the raw materials.

(52.) The third application of the system is to the construction and arrangement of apparatus for elucidating the principles of Statics, Dynamics, or other branches of Natural and Experimental Philosophy. For this subject a great quantity of apparatus exists ready-made in the shops of the mathematical instrument makers, the accumulation of many centuries' work of contriving philosophers. But by the application of the system described above, I am enabled greatly to reduce the stowage space required for such apparatus, principally by dispensing with the frame-work, which, in the common forms, is usually made expressly for each machine. On the contrary, by building up frames for this purpose, I am enabled to display such combinations on a much larger scale than usual, and of course in greater number and variety. In apparatus of this class, however, the peculiar moving parts require to be made light, and with as little friction as possible; and the frame-work often requires posts and gallows-frames, as for suspending pulley systems, collision balls, strings with weights, often led over pulleys in different directions, and so on. The guide-pulleys which I use for machinery are too coarse for this purpose, and I therefore employ pulleys of the form represented in fig. 31. This pulley, of brass (made under my directions by Watkins and Hill), is $2\frac{1}{2}$ inches diameter, $\frac{1}{4}$ inch thick, as light as possible, and running with very little friction on a small steel pivot-screw, and is mounted in a brass frame provided at the back with a clamp-screw, the opening of which is sufficient to enable it to grasp a piece of frame-work a full inch thick. The posts and beds already described being too clumsy for this class of apparatus, lighter supports for the pulleys and strings are provided, one of which is shown in fig. 28, which consists of a bar of wood 1 inch thick and 2 inches wide, attached to a block similar in form and dimensions to the sole of the cast-iron brackets. Supposing this sole to be horizontal, the flat sides of the bar are vertical; but it is inclined slightly, as shown in the figure, so that when a weight is suspended from one of the pulleys, which may be clamped to any part of it, this weight may hang freely downwards.[1]

[1] The weights used with this class of apparatus for statical experiments are usually cylindrical, and rarely greater than 24 oz., which are nearly 2 inches in diameter. A silk line passed over the pulley in the drawing stands only half an inch from the surface of the post to which the clamp is fixed, and therefore, without inclining the post in the manner shown, the large weights would not hang free. The clamp might be crooked so as to throw the pulley at a greater distance from the post, but its form is then more clumsy. I have several pulleys of this kind, in which, instead of the clamp behind, a

This machine I term a *pulley-post*, and I have some inclined to the right, and some to the left, and others perfectly vertical. They are employed by being bolted to the beds, rectangles, or stools of the usual frame-work, which, as it will easily be seen, enables frames to be mounted so as to convey strings, weights, &c. in any of the varied directions required for apparatus to elucidate the laws of statics, the mechanical powers, &c. For the latter purpose they merely require the addition of an inclined plane, a wedge, &c., which being bolted to the same frames, the pulley-posts must be adjusted upon these frames so as to place the pulleys in proper relative positions.

Fig. 27 is an example of a frame convenient for suspending various pieces of light apparatus. This consists of two *iron rectangles*, connected and kept at the proper distance asunder by a *bed* 4 feet long, or more, if necessary. The uprights and transverse piece are made lighter; they each consist of two bars of wood (see Art. 32), screwed together with two blocks between in the form of a light *bed*, so as to leave a slit for a small bolt with a fly-nut. Such bolts are sufficiently strong for this class of apparatus, and are employed to connect the horizontal and vertical bars of the frame, and also to connect the latter with the rectangles below. Many other combinations will, of course, readily suggest themselves to any experienced Lecturer.

(53.) In contriving apparatus, I have had frequent occasion to employ paste-board where lightness and stiffness are required, and especially where it is necessary to combine diagrams, coloured figures, and letters of reference, or any kind of drawing or writing, with the moving parts of the mechanism. The paste-board should be of the stout kind which is termed sixteen-sheet paste-board (a full $\frac{1}{16}''$ in thickness and $24'' \times 19''$ surface), and is covered on each face with a white, or rather light grey, smooth paper which will take ink and even water-colour, so as to admit of diagrams being drawn upon it, or letters of reference.[1] The thickness makes it unmanageable with scissors or knives, but it can be readily cut with a small pair of tinman's shears, mounted in the manner described in the next Article, and mortises or apertures can be cut through it easily with joiners' chisels or gouges and a mallet, or with gun-punches. Its thickness enables it to be used for small tablets upon which to fix light specimens of seeds or other small objects of natural history, or impressions of seals, &c. in the drawers of a cabinet. When used in combination

stem is fixed, which is tapped with a strong screw, and has a nut. Thus the pulley-frame can be fixed in a bracket-head, or carried by one of the loops, fig. 22. But the clamp-pulley will also grasp the bracket-heads and loops, and will answer the same purpose.

[1] I have always procured this material of Messrs. Wilson, Richard, and Co., 26, St. Martin's Court, Leicester Square. For finer work, the thickest Bristol-board may be substituted, as its colour and surface enable any kind of graduations or colours to be applied to it.

with the other mechanism described in the foregoing pages, as for dial-plates, scales, or diagrams, the pieces of paste-board may be fixed to the frames by small bolts or clamps uniting them to the iron loops (fig. 22), or to the pulley-posts (fig. 28), or in any similar manner, as the case in question may require; and if the pieces of paste-board are to revolve, they may be mounted upon the smaller stud-sockets, adapters, or other contrivances.

But paste-boards may be combined in the form of various solids, exceedingly convenient for the illustration of many subjects, and the parts of these solids so connected that the component pieces may be separated and laid flat, thus allowing them to be kept in portfolios. Thus models may be built up, representing complex architectural structures in section and elevation, combined with the plan; also, solids bounded by vertical planes, and showing the relations of strata for geological purposes, the dispositions of mines, the arrangement of complex frame-work, and a variety of other cases in which drawing can be combined with solid representation. If much drawing and bright colours are required, I usually employ stout Bristol-board in combination with the paste-board, and my general method is to draw the plan of the structure in question, be it a building, a section of ground, or a frame, upon one or more sheets of the paste-board, which are then united together, and at the same time raised an inch and a half above the table by being secured to a pair of wooden bars[1] by small bolts with thumb-nuts. Usually a part only of the object to be shown is given in solid, and the rest in plan; as, for example, when a building is explained by making a transverse section and supposing one half to be removed. The half-plan that is exposed is carefully delineated; the solid part of the building constructed of vertical sheets of Bristol-board, with proper pieces for the roof, as the case may be; long narrow mortises are cut through the base-board, and the vertical pieces are provided with corresponding tenons, which are passed through and secured each with a pin beneath.[2] The edges of these pieces are either connected in the same way, or, if possible, merely hinged in the common manner by cutting the

[1] The bolts are $\frac{1}{16}$ inch diameter, and have thin square heads, $\frac{5}{8}$ inch square. The bars are an inch and a half high and an inch and a quarter broad, and have a flat shallow groove sunk along their lower surface, $\frac{5}{8}$ inch wide, which receives the heads of the bolts and prevents them from twisting. Holes are bored through the bars at regular intervals of 4 inches, and of these bars there are provided several pairs of five different lengths, from 2 feet to 5 feet. Two bars serve for each paste-board plan, and they may be set at the distance required by the nature of each model, and the holes for the bolts punched through the paste-boards accordingly. Some models require no such foundation, as they may be hinged to a flat base, and turned up like a box, or be supported in other ways that will readily occur.

[2] The base-boards are raised above the table, to allow of these tenons being passed through the mortises.

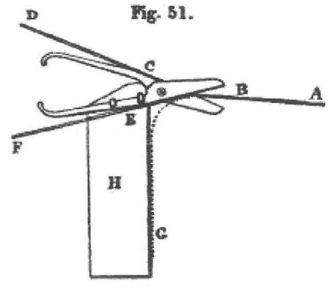
Bristol-board half through, or by pasting cloth slips along the joints, so as to allow the model to be unfolded and laid flat when out of use. A solid being thus built up in the form of the block of the building, the details of the sectional sides and of the elevations can be supplied by drawing; and thus we obtain a model which shows the relation of the several parts of the structure to each other and to the plan. Shifting pieces may be employed to show varieties, or to assist in the dissection of the structure.

A simple parallelopipedon put together in this manner[1] may be supposed to represent a block cut out of the ground by four vertical planes, its upper surface being the surface of the ground (and therefore inclined, if necessary). By proper painting of the four sides we convert it into a geological model to show the intricacies of strata, or into the model of a mine to illustrate the shafts and galleries, in which case the raised part of the model should be combined with a portion of the plan, as in the manner described above for a building.

The paste-boards may be sometimes united by means of little hook-bolts made of brass wire with nuts, instead of the mortises and pins. The nuts may be made like those used by piano-forte makers and organ builders. These are of thick sole-leather, cut out by a centre-bit, of which the chisel part has been filed away. With such a bit, the little roundels may be cut out of a sheet of leather with great rapidity. The centre-pin of the bit must be a little reduced and sharpened, and the hole which it makes serves for the wire. The wire must be tapped with a coarse sharp thread, and will cut its own way into the nut. These hooks save the trouble of cutting the mortises and tenons, as each hook requires only a hole in each of the two pieces which it serves to join. Many other modes of connexion will occur, which I will not weary my reader by detailing.

(54.) The shears will be much more manageable if mounted in the way represented in fig. 51. This shows a pair of hand-shears, as they are termed, one foot long: such shears are usually fixed in a vice when wanted. Now, from the nature of this implement, any thin material, as A B, submitted to its action, is, as fast as it is cut, slightly diverted from its course. The half which is on the remote side of the figure is turned upwards in the direction C D, and the

Fig. 51.



[1] Many of my readers may recollect the models of this kind which served for the illustration of my Lectures on Ecclesiastical Architecture, at the Royal Institution, Albemarle Street, in 1846 and 1847.

nearest half downwards in the direction E F. If the shears are fixed in a vice, this lower half encounters the upright side of the vice, and is turned abruptly downwards into the course indicated by the dotted line B G. This bruises the paste-board, and soils it so as to make it useless, so that card-makers usually employ shears the blades of which are long enough to extend completely over the sheet. But this effect may be got rid of by fixing the shears as shown in the figure. A wooden bar (H) is provided, about 1 foot long, 4 inches wide, and 1 inch thick, which may be fixed in a vice, or to the side of a table, or even held between the knees. The fixed leg of the shears is clamped against the upper part of the bar by two hook-bolts, the nuts of which are on the remote side, and a shallow groove is sunk in the face of the bar, to receive the leg and keep it steady. Thus the shears can be readily removed when their edges require grinding. As by this disposition the face (H) of the bar lies a little behind the vertical plane which passes through the edges of the shears, it is plain that the lower half (E F) of the separated material no longer encounters any obstacle, and is at liberty to travel onwards in the direction E F, which it receives from the shears. The upper half glides over the hand of the operator.[1] With this arrangement a pair of shears the blade of which is but 3 inches long will readily cut a sheet of paste-board or mill-board 2 feet or more in length.

(55.) Fourthly and lastly, I have often applied the parts of my system to the construction or trial of new mechanical combinations, or of apparatus required for original research. It will easily be seen that the revolving contrivances described above are only necessary in such cases as may require machinery; whereas the system of frame-work is very generally applicable to philosophical apparatus in which mechanism often forms no part, and in which the principal portions must be of peculiar forms, but require solid frame-work to keep them in their relative positions.

Every experimental philosopher must have experienced the vexation of delays in his researches occasioned by the difficulty of getting apparatus made for trials, and of altering it when trial has suggested change and improvements. To obviate this impediment to research, apparatus should be designed in the most general manner possible; the parts that require peculiar forms be brought within the narrowest limits; the connexions and frame-work made by pieces that will serve for various purposes, and which may therefore be provided be-

[1] If used for tin plate, it would probably cut the hand instead of gliding. This may be obviated by fixing a transverse handle to the shears, either horizontally or vertically.

fore-hand, and kept ready for use. Those parts that require good workmanship should be carefully distinguished from those that do not, and may therefore be constructed by an inferior and less expensive class of workmen; and although in this manner the resulting machine will often turn out somewhat clumsy, at least this advantage is secured,—that if it prove successful, small changes may be made and tried, and finally a complete and especial frame may be, if necessary, designed with confidence after experience has shown what is really required. On the other hand, if unsuccessful, the parts will mostly be ready to be employed again for other purposes.

The system which I have endeavoured to explain in the preceding pages offers many examples of such constructions and of universal methods of uniting and generalizing the forms of framing, and of various parts of apparatus. It would occupy too much space were I to pursue the subject by describing at length other machines which I have from time to time constructed, in which the same general principles have been kept in view.

In the present work I have confined myself to those details which I have found of the most universal application; and I trust that it will be of service by furnishing suggestions for the improvement of Mechanical Apparatus, and thus facilitating the important researches that depend thereon, and contributing to further the great work of Education by supplying new implements of instruction.

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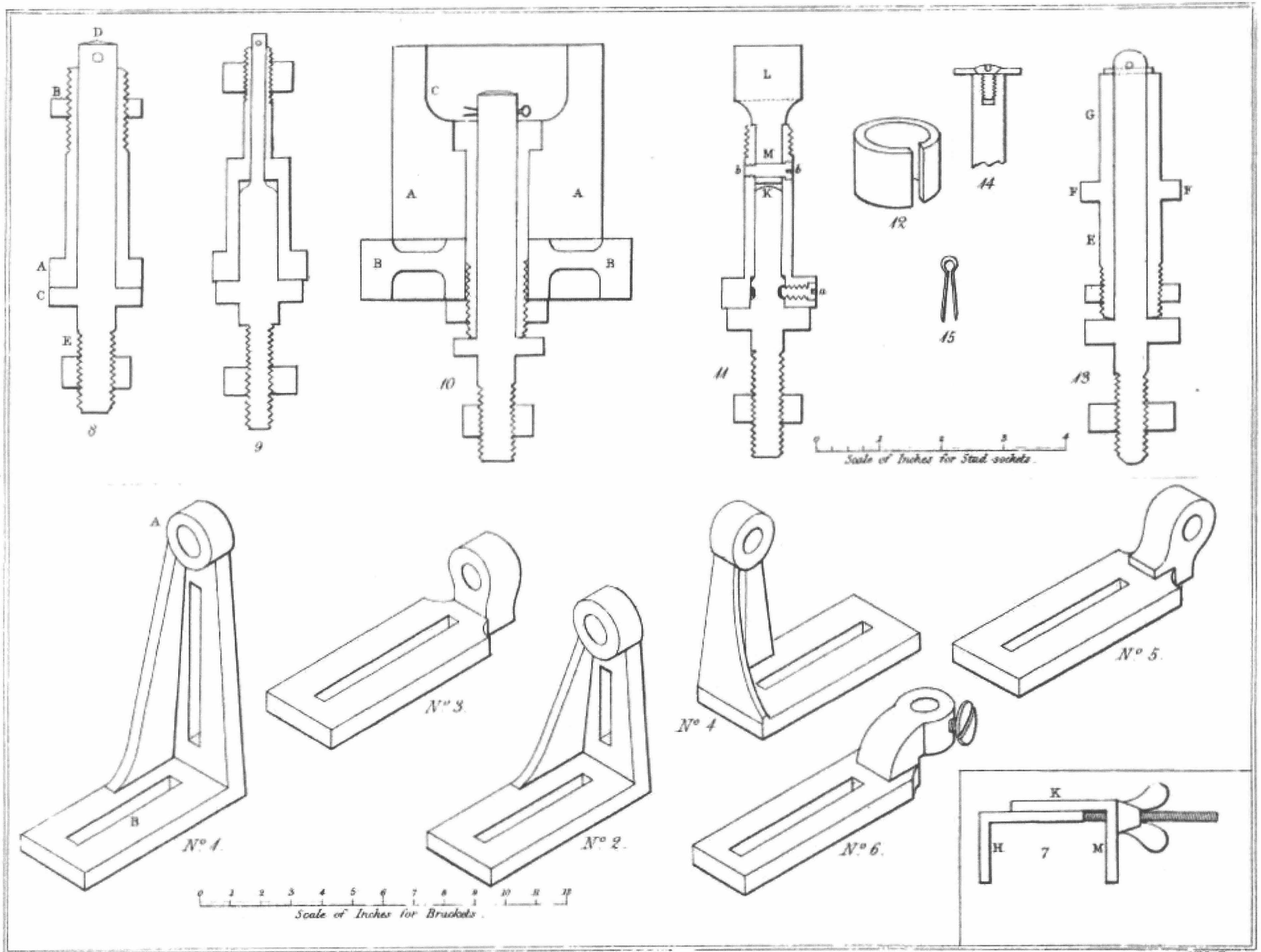

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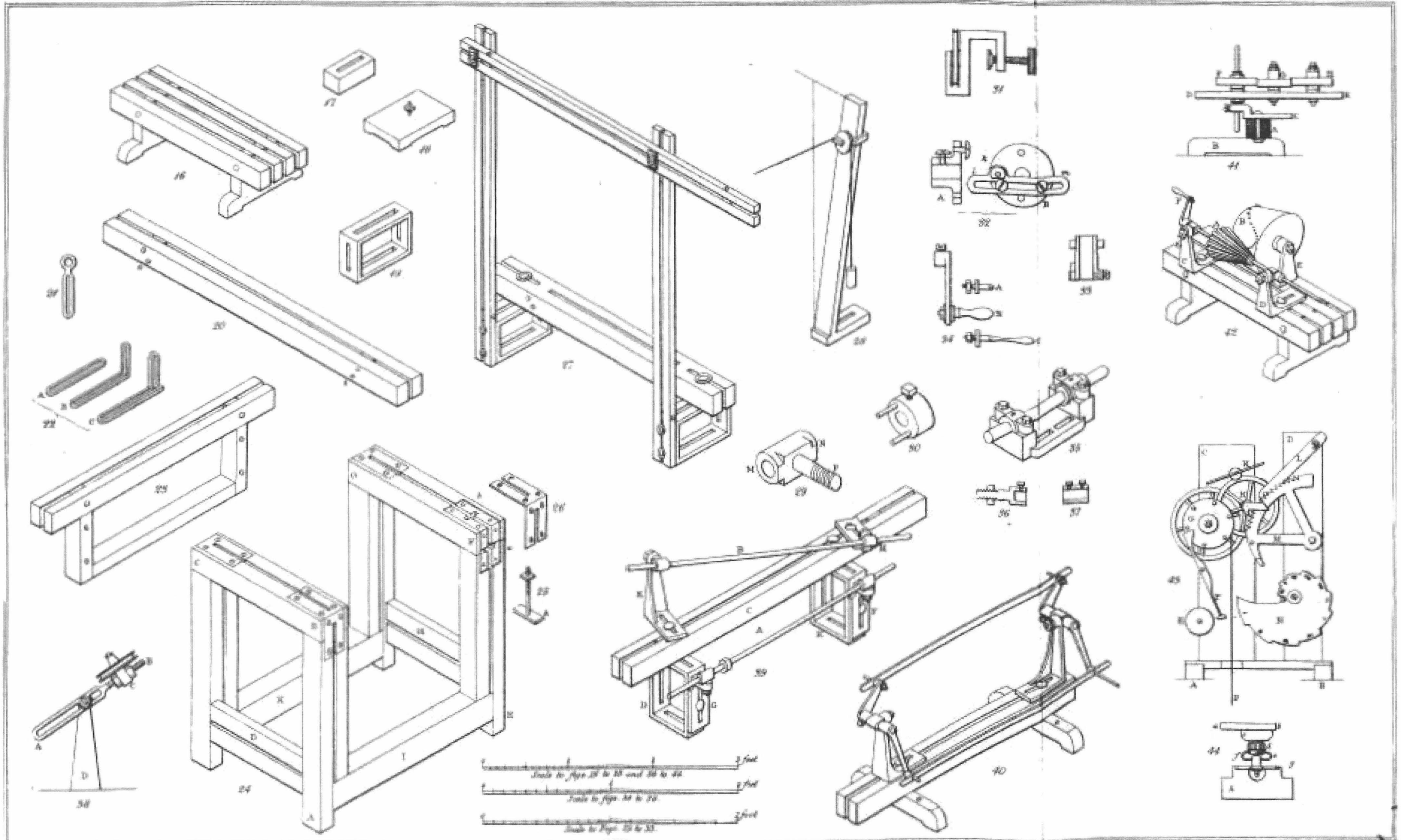

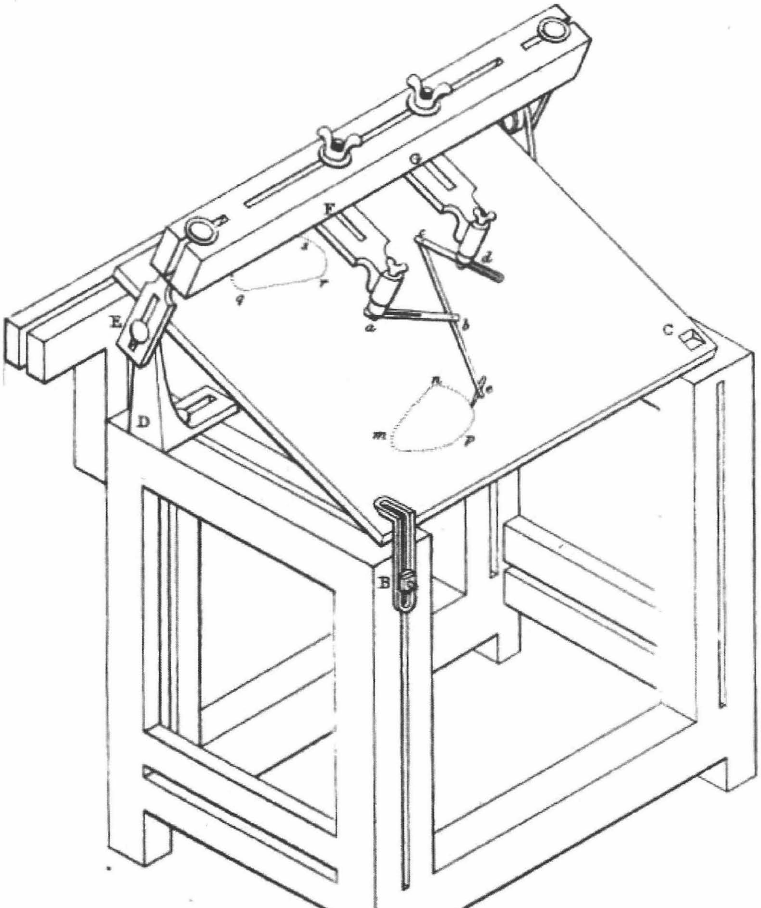

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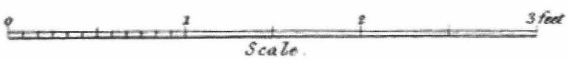

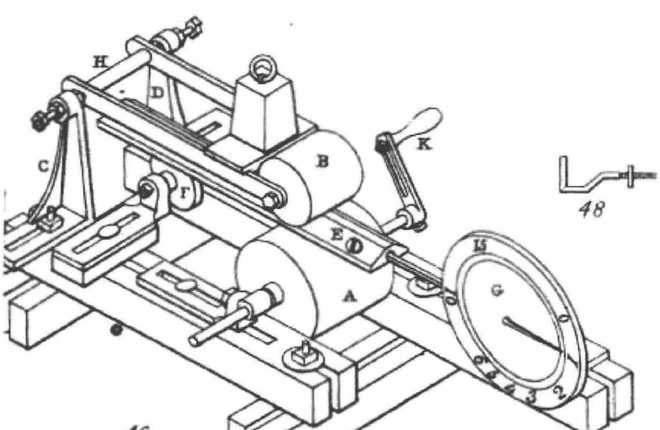

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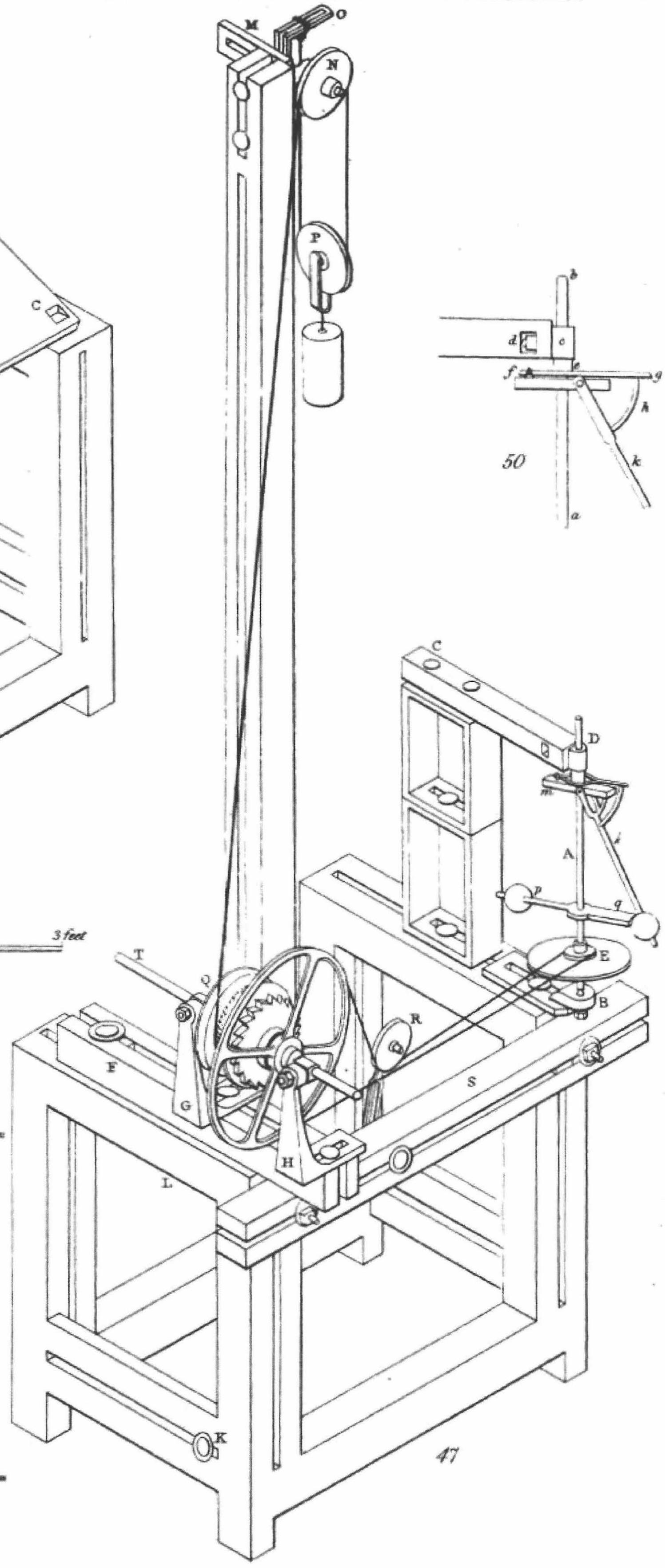

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