# PAPERS.

## I. *Description of a Machine for Polishing Specula, &c., with Directions for its Use; together with Remarks upon the Art of Casting and Grinding Specula, and a Description of a Twenty-foot Newtonian Telescope equatoreally mounted at Starfield, near Liverpool.* By WILLIAM LASSELL, Esq. F.R.S. F.R.A.S., &c.

Read December 8, 1848.

THE twelfth volume of the *Memoirs of the Royal Astronomical Society* contains a description of a Newtonian reflecting telescope of 9 inches aperture and 112 inches focus, equatoreally mounted in a revolving dome of $14\frac{1}{2}$ feet diameter.

Several years' experience in the use of this instrument so well convinced me of its general efficiency, and especially of the convenience and stability of its mounting, that I determined, two or three years ago, to carry out precisely the same principle on a much larger scale.

With a view of informing myself what degree of perfection is attainable in figuring surfaces of larger mirrors than can be wrought by hand, and also of ascertaining the smallest proportion of aperture to focus which it would be desirable to adopt, I visited Birr Castle; and, by the kindness of the Earl of ROSSE, enjoyed the opportunity of two nights' observations with the 3-foot telescope erected by his Lordship.

I was also favoured with an examination of the whole of the machinery employed in grinding and polishing the great speculum; and I returned so well satisfied with all I had seen, that I very shortly resolved to cast a speculum of 2 feet diameter and 20 feet focus — a proportion of aperture to focus, however, somewhat less than what Lord ROSSE had successfully adopted.

The mode of casting the large speculum which I employed involved the principle, so happily adopted by Lord Rosse, of casting the speculum on what is technically called a *chill, i. e.* an iron base, slightly warmed, which causes the speculum to cool upwards in horizontal strata and gives greater solidity to the lower surface of the metal.*

Principally, however, from the difficulty of forming it, I did not employ a base constructed with iron hoops placed edgewise and turned to the guage, as Lord Rosse recommends, but, instead of it, a *disk* of cast-iron, with its upper surface convex, according to the required radius of curvature, and a rebate formed on the edge of its upper surface, which, receiving a stout iron hoop, equal in breadth to the thickness of the speculum, formed an iron mould, and dispensed altogether with the use of sand in the casting. The disk does not require to be *turned*, but if cast from a well-made wooden pattern, will be sufficiently true; neither do I think turning the hoop essential, though it might be well to turn the inside surface and the edges, if the means of doing so were at hand.

As it is necessary that the pouring should be pretty quick, in order that there may not be time for the base to solidify any portion of the metal before it is completely covered, I inclined the base a little, pouring on the lowest side, in order that the fluid might rise in one compact wave; and when the disk was nearly covered, it was restored to a truly horizontal position, and the pouring continued, until the mould was sufficiently filled, namely, to the depth of about $2\frac{3}{4}$ inches. The hoop was about 3 inches broad, and having been turned parallel, the mould was in the first instance placed horizontal by a spirit-level being placed upon its edge. The inclination was produced by the application of a lever, which, when withdrawn, restored the base to its horizontal position, and insured the equable thickness of the speculum at every part of its circumference. The only disadvantage of this mode of casting is that the back being necessarily flat, the face and back cannot be parallel: I have not, however, in practice, found any evil which I could trace to this cause.

Not being able to procure a crucible large enough to contain the requisite

* Professor Potter, of University College, has requested me to refer to a paper of his in the fourth volume of the new series of Brewster's *Edinburgh Journal of Science*, page 18, where he gives an account of his casting some specula on an old steel speculum with perfect success, after many failures in casting on the plan he formerly employed.

quantity of metal, I was obliged to resort to another mode of casting. Messrs. PRESTON and ROSS, brassfounders, of this town, were kind enough to allow me to make use of their blast-furnace, technically termed a "cupola," such as is commonly used for running iron for castings. As in this mode of melting, the metal is in contact with the fuel, and when melted flows into a receptacle at the bottom whence it is drawn off by withdrawing a clay plug, it is evident that speculum-metal so treated would be exposed to great injury from oxidation; I therefore employed the cupola for the purpose of melting the *copper* only, and proceeded thus:—

A large scale beam was suspended from the crane used in the foundry, and the ladle to be used in pouring was suspended from one end, and counterpoised. Weights equal to 136 lbs. were then put in the opposite scale, and the equilibrium restored by pouring into the ladle melted grain tin from another ladle. By the motion of the crane, the ladle containing the melted tin was brought under the plug of the cupola which contained the copper in a fluid state. Weights equal to 295 lbs. were now put into the opposite scale and the plug of the cupola drawn. The moment the equilibrium was restored the plug was replaced. The ladle now contained 431 lbs. of alloy, in the proportion of 32 lbs. of copper to $14\frac{3}{4}$ lbs. of tin. Eighteen pounds of white arsenic of commerce was then added, and the compound well stirred with an iron rod. The composition was now assayed by taking out a quantity in a small ladle, cooling it instantly in water, and examining the fracture as to whiteness and brilliancy. This was repeated two or three times, small portions of tin which had been previously weighed being thrown in after each trial. These additions brought up the proportion of tin to 15·09 lbs., and the composition was then considered to be as brilliant as possible. It is best always to have the copper somewhat in excess in the first mixing, as it is much easier to add tin than copper, and the exact saturation of the copper by the tin, which produces the greatest brilliancy, is best judged of by ocular examination of the fracture. The requisite degree of experience in this matter is not difficult of attainment. Copper bolts of ships, either new or old, and the best grain tin, produce a most excellent composition. The time consumed in this stirring and assaying process reduces the metal to a proper temperature for pouring; for it should not be poured into the mould at a greater heat than will insure its perfect fluidity.

Lord ROSSE's directions for ascertaining the pouring heat cannot, I think, be improved, only the fluid metal must not be stirred much below the surface with the wooden rod, or it will be driven about in all directions.

In casting the second speculum, I availed myself of a plan adopted by my friend Mr. Nasmyth, which consists in cutting a small pouring hole out of the lower edge of the hoop in contact with the iron base, and attaching a cylindrical reservoir of sheet-iron lined with loam.

This reservoir extends about two inches below the lower edge of the hoop and rises as much above the upper edge. The metal is poured into this reservoir, and as it rises, flows steadily through the hole in the hoop into the mould.

The advantage of this plan is, that the reservoir, receiving the first *splash* of the metal, avoids the risk of small portions being scattered over the iron base and becoming solid, before its surface is covered. I deem this method to be, on the whole, an improvement, though I did not succeed quite so well with it as with the other; I believe principally because the metal requires to be poured at a somewhat higher temperature to insure its remaining fluid until the surface of the base is covered. It is obvious that in this mode of casting, a *failure* must not be calculated upon, as the composition could not be remelted in the cupola without injury.

As soon as the metal had become solid, it was conveyed by the crane (mould and all) into an annealing oven or furnace in a state of strong ignition. All draught to the furnace was then completely stopped, by luting up, and the metal and mould were covered with ignited cinders, closing the whole up ultimately with a tight cover. At the end of three weeks the speculum was taken out, and had not even then become perfectly cold. I very much doubt, however, whether this slow annealing process is absolutely necessary in specula cast on this plan.

This speculum was ground and polished on a machine almost precisely the same as that described by Lord Rosse, in his Lordship's very interesting paper published in the second part of the *Philosophical Transactions* for 1840.

I found, however, the grinding process much facilitated by interposing a piece of sheet lead about a tenth or twelfth of an inch thick between the speculum and the iron grinding tool. This saved the rapid wearing down of the tool, and also cut the metal much faster, as the softness of the lead suffered the particles of emery to imbed themselves into it, and thus form a very keen grinding surface. When the lead, fully charged with the emery, had become smooth, it was exchanged for a fresh piece. When an entire surface had been obtained upon the speculum, the smoothing and perfecting of the surface previous to polishing was produced by the iron tool and the finest washed emery.

The speculum was polished many times on the same machine, following, as nearly as practicable, the directions given by Lord ROSSE; but, after several months' trial, I did not succeed in obtaining a figure which satisfied me; the best I got being very inferior to the surfaces I had obtained by hand on specula of various sizes, up to 9 inches diameter. In despair of success by this process, I ultimately contrived a machine, in which I endeavoured to represent as closely as possible the evolutions of the hand by which I had been accustomed to produce very satisfactory surfaces on smaller specula. I at first erected this machine over the revolving spindle which carries the speculum in Lord ROSSE's machine; but having had occasion in my earlier experiments to alter it in some of its details, I found it ultimately much too weak and deficient in stability for the duty it had to perform. I found it, therefore, necessary to reconstruct it completely, and availed myself of the offer of my friend Mr. NASMYTH, the eminent engineer (who is also enthusiastically fond of the art of making reflectors), to construct for me a firm and compact machine on the principle of that which I had made.

Mr. NASMYTH also further favoured me by sending me the very beautiful drawing of the complete machine which accompanies this paper, and which I now proceed to describe.

Figs. I. and II. are opposite side views, and Fig. III. a front view of the machine complete and in operation. It consists mainly of two cast-iron brackets A and B attached to a cast-iron wall-plate C C by eight bolts, four of which are seen at *d d*, &c. The wall-plate is bolted to a firm wall by the bolts *e e* (Fig. II.), thus securing the firmness and integrity of the whole machine.

The lower bracket A carries a stout vertical spindle, which, by means of the toothed wheel of 77 teeth *f* and tangent-screw *g*, makes 0·81 of a revolution per minute.* On the upper end of this spindle rests a cast-

* Of course this is dependent upon the speed of the prime mover. I have generally used one or other of two driving pulleys, which give to the upper horizontal shaft of the machine speeds of 132 and 230 revolutions per minute respectively: it is the latter of these which gives to the speculum 0·81 of a revolution per minute.

iron basin or dish within which the speculum is placed, and intended, if necessary, to contain water for preserving the equable temperature of the speculum during polishing, as practised by Lord Rosse. I have, however, rarely used the water, except when polishing in the hottest weather. This basin can be attached or removed at pleasure, as it is fixed by the three bolts *h h h* (Fig. IV.) and *h* (Fig. I.) to three studs cast upon the toothed wheel *f*, which is keyed on to the vertical spindle. When the basin is not employed, a triangular plate supplies its place and receives the three ultimate points of the three plates which support the speculum, otherwise inserted in a plate resting on the bottom of the basin.

The manner in which the speculum is supported to prevent bending is the same in principle, and I believe very nearly the same in construction, as that employed by Lord Rosse in supporting his 3-foot speculum: indeed this spindle and its apparatus scarcely differ from the main spindle of his Lordship's machine.

As, however, the equable support of the speculum is a matter of the highest moment, it may not be amiss briefly to describe the way in which it is effected. Fig. IV. shews this in plan, and Fig. I. in section.

As the machine is intended to polish all sizes of specula, from 3 or 4 inches diameter up to 2 feet, there are attached to the bottom of the basin three radial grooved bars carrying a bracket, and a tightening and levelling screw, shewn at *i*, *k*, and *l* (Figs. I. and IV.). The brackets, being moved along the grooves *m*, can be fastened at any required distance from the centre by the screw *k*. The levelling screws *l* are tapped into a circular wrought-iron plate of a stoutness and diameter suitable to the size of the speculum, which can by their means be placed truly horizontal. This plate, shewn at *n* (Figs. I. and IV.), receives the three screws *o* supporting the centres of the three triangular plates loosely, so as to permit a *small* quantity of motion with the most perfect freedom.

To the upper surfaces of these plates, at the corners *p*, are cemented small circular bits of *felt*, on which the speculum reposes in perfect equilibrium; at least, the nine places of contact being so disposed as to bear severally, on the lever principle, a ninth part of its weight, no distortion by bending can take place; unless, indeed, it should be conceived that the metal should sink down between any two contiguous disks of support.

The exact places of the points, the centres of the disks, *p*, &c., for any speculum whose diameter is given, may be found as follows:—The two exterior points of each triangular plate are six equidistant points in the circumference of a circle whose radius is 0·77, the radius of the speculum being supposed unity. The interior points of the plates are three, equidistant in the circumference of a circle whose radius is 0·315, and, at the extremities of those radii which produced, become perpendiculars to the lines joining the exterior points of each plate.

The positions of *o*, the points of support *under* the triangular plates, are *in* those perpendiculars or radii, and distant 0·54 from the centre of the speculum. The triangular plates have each a piece of stout wire screwed into them (seen at *q*), which, *loosely* fitting a hole in the supporting-plate *n*, prevents their being deranged by turning round on the central pin.

In the system of plates supporting the 2-foot speculum, I have increased the points of equal support to eighteen, by introducing short levers whose centres are respectively over the nine points of the speculum, the *felt* disks being of course placed between the speculum and the levers, instead of on the surfaces of the triangular plates.

Views of the upper bracket B, similar to those of A which have been described, are also given in the first three figures. The essential and peculiar principles of this machine mainly consist in the movements emanating from this bracket. The tangent-screw *r* and toothed wheel *s* are precisely similar in form, and in position, to those in the lower bracket previously described. Near the end, however, of the shaft which carries the tangent-screw in this bracket are placed a fast and loose pulley to receive a driving-belt from a steam-engine or other prime mover; and at the ends of the tangent-screw shafts of both brackets are placed complementary cone pulleys whose extreme diameters are about 2·3 and 9·45 inches. By means of these pulleys motion is communicated from the upper horizontal shaft to the lower, and thence to the vertical spindle carrying the speculum, which is the only motion contained in the lower bracket.* The toothed wheel *s*, which receives its motion from the upper tangent-screw, is keyed on to a vertical shaft *t*, which, passing through collars in the upper and lower portions of the bracket, has keyed on to its lower end the casting *u*, the form

* I have always used that combination of these cone pulleys which gives the slowest motion to the speculum.

of which, though not very easy to represent by a drawing, will, I hope, be understood by a comparison of its appearance in the first three figures, in addition to the supplementary sketch in Fig. VI. Immediately above where the casting is keyed on to the spindle, it passes through a stout wheel of 72 teeth, *v*, which is bolted fast to the lower side or bottom of the bracket, and has no motion whatever.

The form of this casting, seen in section at Fig. I., consists of two cylinders, a larger and a smaller, connected together by a stout arm; the larger receives the end of the vertical spindle *t*, but is not bored through, there being cast to the lower part of it a circular arc whose radius is nearly equal to the distance between the two cylinders, or, more strictly, equal to the sum of the radii of the wheel and pinion, *x* and *y*.

The underside of this arc contains a circular ╥-shaped groove, best seen in perspective at *w*, Fig. II. A small spindle, having a head which nearly fits this groove, and a tightening screw by which it can be secured in any part of it, receives on its lower and cylindrical part or shaft, and freely turning upon it, the pinion *y*, of 16 teeth. This pinion has a rim firmly attached to its upper surface, which, extending a small distance over the teeth of the wheel with which it is engaged, forms the only support of the pinion, and prevents its dropping off in revolution. To the lower side of this pinion is firmly attached a rectangular casting, *z*, the side of which is seen in Fig. II., and the end in Fig. III. It contains a ╥-shaped groove, similar to that in the casting *u*, excepting that it is straight instead of being curved; it receives a similar though smaller spindle *c*, which enters a hole in a brass-plate in the centre of the polisher *b*. The smaller cylinder of the casting *u* is bored, and receives, turning freely within it, a short spindle, on the upper end of which is keyed the pinion *a*, and on the lower the wheel *x*. The wheels *v* and *x*, and the pinions *y* and *a*, are respectively alike, the former having 72 and the latter 16 teeth.

It will be evident that if the vertical spindle *t* be put in motion, it will carry with it the casting *u*, and the smaller cylinder will revolve round the larger one. Also, that as the pinion *a* is engaged with the *fixed* wheel *v*, motion must be thereby communicated to the lower wheel *x*, and through it to the pinion *y*, the axis of which, being movable in an arched groove concentric with the wheel *x*, can be made to revolve either centrally under the vertical shaft, or at any required distance from it not greater than four or five inches. Again, the small spindle or pin *c*, which enters the back of the polisher, can be fixed by its tightening screw in any part of its groove, either under the centre of the pinion or at any distance from it not greater than three or four inches.

If the pinion *y* be fixed in its groove centrally under the vertical shaft *t*, and the pin *c* also fixed under the centre of the pinion *y*, the pin *c* will merely turn round upon its axis, and, though the machine may be moving, no motion will be communicated to the polisher. But if the pin *c* be removed along the groove to any distance from the centre of the pinion, it will cause the centre of the polisher to revolve round the centre of the speculum in a circle whose radius is equal to that distance.

Again, if the pinion *y* be removed to any distance from the centre of the vertical shaft, it will cause the pin and centre of the polisher to describe a circle, not round the centre of the speculum, but round a continually advancing point in the circumference of a circle, whose centre is in the speculum, and whose radius is equal to the removal of the pinion from the vertical shaft. By means of these two adjustments of the pinion *y* and central pin *c* the powers of the machine in producing the parabolic figure with different proportions of focus to aperture are mainly developed.

The size, however, of the polisher has a material effect. When the proportion of aperture to focus is large, the polisher must be large: the extreme sizes I have found it necessary to use are 0·83 and 1·1, the diameter of the speculum being unity.

In order still more to facilitate the perfect apprehension of the principle and mode of working of the machine, I send a perspective sketch of it, also from the pencil of my friend Mr. Nasmyth, in which I have introduced some letters* corresponding in position with those on the other drawings.

The polisher should possess as much stiffness as is compatible with the requisite lightness, and I have found these qualities best combined by making it of white American deal in two strata, well united by glue and a few screws, with the direction of the grain at right angles, the wood well seasoned, and, if possible, cut out of the same board. The polisher for the 2-foot speculum is made out of $1\frac{1}{8}$-inch board, and has, for symmetry, both the upper and under surfaces convex, to fit the speculum. It is about 2 inches thick at

* In the plate these letters, not being deemed essential, have been omitted in order to preserve its beauty.

the circumference, $20\frac{1}{2}$ inches diameter, and weighs about 12 lbs. with the pitch surface upon it.

One of the greatest desiderata in the processes of polishing I have found to be the coating of the polisher with a surface of pitch with the requisite uniformity, and divided, as it must be very symmetrically, into a number of squares by rectangular grooves. The method which in the end I found to be most convenient and efficacious I will endeavour to describe, as in experimenting it is a process which must often be repeated.

Procure any ordinary tin or copper can which will contain one-third more than the quantity of pitch required, and let there be two or three straight spouts fixed in the side close to the bottom, of different diameters, from about two-tenths to four-tenths of an inch, which may be stopped with common corks. The pitch should be slowly melted, over a circular gas-burner if at hand; and when the pitch is of the consistence of tar or thick treacle, withdraw one of the corks, and by beginning at the centre of the polisher and giving the can a slow circular motion, increasing in diameter, the disk may be covered very uniformly with pitch to the thickness of about the eighth of an inch.

The disk should have a slip of thin tin or zinc extemporaneously bent round the edge, to prevent the pitch running over. If the internal surface of the hoop be lightly smeared with polishing powder and water, the pitch will not adhere to it, and as soon as the pouring is over it may be instantly withdrawn. One or two trials may perhaps be required before the exact temperature of the pitch can be known which pours best and gives the most even surface. Before the pitch surface has time to cool materially, it must be divided into squares, for a 2-foot speculum, not exceeding one inch in size. This I accomplished conveniently by joining together two similar pieces of wood, 26 inches long, 2 inches broad, and half an inch thick, each having one of its edges tapered down to the thickness of an eighth of an inch, and formed concave like the speculum. The pieces of wood were not in contact, but united by an intermediate piece, which separated their concave edges to the distance of one inch, forming a sort of double concave guage, the uniting piece of wood not coming up to the front or concave edges by half an inch. This mould, being dipped in water or wetted with a sponge and pressed upon the pitch surface, divided it quickly and symmetrically into inch squares. The exact coincidence of the polisher and speculum is to be brought about by laying the polisher upon the speculum while the pitch is moderately soft, to take its exact form; and in order to do this safely, the speculum should be slightly wetted with cold water. If the pitch becomes too hard before being perfectly figured, the best way of softening it again is by dipping it in clean warm water, which process may be repeated as often as necessary. The pitch must be made to touch all over pretty uniformly before any powder is used, or the process cannot go on well. Also for each successive polishing the pitch must be *fresh*, at least the surface, or the lustre will not advance quickly and well. To save myself the trouble of making a new polisher, which at best is an irksome occupation, I have sometimes scraped the surface of an old tool with a well-sharpened dinner-knife, which may be done with facility under water, or with water flowing over the pitch. I do not, however, much recommend this expedient, nor should it be repeated in any instance on the same tool.

The pitch should be most carefully attempered to the heat of the air in the apartment where the process is carried on; and if a considerable change takes place in this temperature during the interval between the making and use of the polisher, the process will, in some measure, be vitiated. To convey in writing a distinct idea of the requisite temperament of the pitch, it occurred to me to place a new sovereign of the present reign in a frame, so that it might rest edgewise, with its full weight on a surface of pitch that I had ascertained to be of the proper hardness, and I found that in $10\frac{1}{2}$ minutes it had left the impression of five strokes of the milled rim on the pitch. If there should be *six* well-defined impressions, the pitch will, probably, be rather soft, unless the speculum required to be polished be of very short focus; and if only four impressions are made, it will be too hard. The trial is best made under water, as it prevents the sovereign adhering to the pitch, and also keeps the pitch of uniform temperature; I believe this test to be sufficiently accurate, although apparently rude.

In polishing a speculum of 24 inches aperture and 20 feet focus, I generally proceed thus: the adjustment of the pinion $y$ I usually term, for brevity, S, and that of the pin $c$ I term Q. Having put the driving-belt on that pulley of the shaft, which gives a speed of 34 revolutions to the pin $c$, and having set Q to a radius of 1·4 inches, and S to a radius of 1·7 inches, the machine is ready for action.

I use the red powder known in the shops by the name of rouge, and have obtained the best quality from Mr. Fox of Saffron Hill.

Having smeared the surface of the speculum with a mixture of this powder and water, of the consistence of thin cream, I gently warm the surface of the pitch (in however a slight degree) and place the polisher, $20\frac{1}{2}$ inches in diameter, upon the speculum, and set the machine in motion. It is desirable, after fifteen or twenty minutes, even if the process seems to be going on perfectly well, to take off the polisher and examine the surface, which will indicate at once whether the contact is uniform. If it is not so, the polishing must be arrested, and by warming or other means a perfect contact must be secured. But it is best not to employ any powder until this perfect coincidence is obtained, and then the process, almost invariably, will go on well.

The whole time occupied in obtaining the requisite lustre varies from about one hour to three, and it ought to be steadily advancing throughout.

A good idea may be formed of the quality of the operation as it proceeds by watching the motion of the tool. It should be regular and uniform, without any apparent labouring or inequality of speed, and the spontaneous motion which the tool has upon the pin as a centre should be slow and regular. No firm adhesion is ever to be allowed between the tool and speculum: this will take place if a due and regular supply of water be not afforded.

A second application of powder will rarely be required, and never in any quantity, but many applications of water probably will, and the more rapidly the polish is advancing the more frequently will water be required. It is best applied through a hole in the back of the polisher, as near the centre as is convenient, which may, perhaps, be at about the distance of one-third of the radius. But care should be taken not to give the water in excess. The speculum must never be *dry*, but there must be no superfluous water. It is very conveniently applied with a flat camel's-hair brush, half or three quarters of an inch broad; but as much as the brush would take up would generally be too much for one application. Towards the last, the water should be added more sparingly, and, if needful, more frequently, going as near to dryness as may be, but *never reaching it*.

The lustre in this state of the process advances most rapidly. If the process has gone on well, the powder will have become almost black at the close. The machine having been stopped, the tool is to be carefully taken off by sliding motion, and the speculum may then be either wiped with a soft linen cloth or leather, or it may be washed with a soft sponge and water, and then dried, and ultimately rubbed lightly with some very soft wash-leather. If the polishing has apparently wrought smoothly, and the aspect of the tool when taken off, both during the process and at its close, is everywhere of even texture, when viewed by an oblique light; the speculum will most likely have a *uniform* curve of some description, whether parabolic or not, for it is a characteristic quality of this machine generally to produce a uniform curve. The quality of the curve is best examined by placing the mirror in its tube, and, by means of diaphragms, exposing separate portions of the mirror of equal area, from the centre to the circumference. Of course the figure is not perfect if, when a focus has been obtained of the rays from any one portion, that focus has to be deranged to suit the rays from any other portion. If the focal point of rays from near the circumference of the mirror is *nearer* to the mirror than the focal point of rays from the central portion, the figure is spherical; if *further* off, the figure is hyperbolic. I believe that with the machine adjusted as here given, no figure but a close approximation to the parabola would be obtained, and the process might, therefore, be repeated almost *ad infinitum* with the same effect; but if the proportions were altered,—for instance, the focus materially shortened with the same aperture, the figure would then be spherical, and it would be necessary to increase the size of the polisher and the softness of the pitch; to increase the throw of the crank S, and diminish that of Q.

For a speculum of 10 inches aperture and 80 inches focus, I found that the following adjustments produced an admirable figure. Diameter of polisher 9·2 inches, S radius = 1·4 inches, Q radius = 0·9 inch: and a speculum of 10 inches diameter and 110 inches focus received a fine figure with a tool of 9·2 inches diameter; radius of S 0·8 inch, and radius of Q 0·7 inch.

If the manner of operation of these settings be considered, I think it will be evident that they are calculated, as the focus is shortened in proportion to the aperture, to flatten down the curvature of the circumferential part of the speculum *more* in proportion to that of the central, which is precisely the thing required to be done. I believe it quite possible for an experienced eye to pronounce upon the character of a speculum by means of these diaphragms, when the telescope is directed to a well-defined object, such as the enamelled figures of a watch-dial, or some bold, well-contrasted letter-press; but the *experimentum crucis* of all telescopes is the definition of a fixed star, and the appearance it puts on when out of focus. If the penumbræ of a bright star are not precisely the same on both sides of the focus, and if they are oval or irregular and distorted in outline, or otherwise than perfectly round and equal all over in brightness (except the central black spot occasioned by the blocking out of the central rays by the small speculum), there is a fault somewhere, either in the intrinsic form of the curve, or some deflection from that curve occasioned temporarily by unequal support or constraint.

To this description I may, perhaps, without offence, subjoin my own estimate of the practical value of the machine. I have been accustomed to produce by hand surfaces of, I believe, great excellence, on various sized specula up to 9 inches diameter, of which I may instance my 9-foot equatoreal, which enabled me to discover independently (for I did not previously know of its existence) the sixth star in the trapezium of *Orion*, and with which also the observations of a second division of the ring of *Saturn* were made (See *Monthly Notices of the R. A. Soc.*, vol. vi. page 11.) Such surfaces as these were, however, produced with some degree of anxiety, much manual labour, and, perhaps, some admixture of accident, especially in the union of a perfectly parabolic curve with regularity of surface. The superiority of the machine in these respects is so striking as almost to put comparison out of the question.

If driven by a steam-engine, the manual labour is, of course, annihilated. The control over the machine is such, by the setting of the cranks (at least, with all foci, not less than eight diameters of the speculum), that the curve can be changed almost at pleasure from the spherical side to the hyperbolic side of the parabola, and *vice versâ*, the alterations of the curve being, *cæteris paribus*, almost exactly commensurate with the adjustments of the cranks. In fact, one of the most anxious and laborious operations is by this machine converted into an intensely interesting amusement. With moderate care and a little experience a *bad* figure never need to be feared, though it may require two or three successive trials to satisfy the fastidiousness of a cultivated and long-practised eye. The lustre of polish transcends even my best efforts by hand, and is the easiest quality of all to obtain; and however erroneous the figure may be after any unsuccessful effort, the proper curve may be recovered without resorting to the grinder, or indeed materially impairing the polish; at least, I have not found it needful, even when the difference of foci of the central and exterior portions of a mirror has amounted to fifteen-hundredths of an inch. In three or three and a half hours, by the polisher alone, it is possible to annihilate an error even as egregious as this. I have a strong persuasion that this machine might prove eminently serviceable in working the curves of object-glasses of large dimensions, though of this I have no experience.

The 20-foot telescope has been mounted so exactly on the plan of my 9-foot equatoreal, that a reference to my description of that telescope, already alluded to, will suffice, with a few comments, to give a general and pretty accurate idea of the mounting of the larger telescope. The diameter of the dome is 30 feet, and is made of the same material and *scantling* as the smaller, therefore proportionally less stiff, yet sufficiently so to keep its form, and after two years to give no indication of warping or failure in any respect whatever. The opening for observation is 3 feet 8 inches wide, constructed exactly like that of the smaller dome, except that the shutter, from its weight, is necessarily divided into three. For opening and shutting, each shutter has a rope attached to each end; these ropes pass over a roller at the apex of the dome, but only three of the six are over the roller at any one time. In opening and shutting, one rope of each shutter is used for drawing up that shutter to a little beyond the zenith, when the other becomes employed to check the too rapid descent of the shutter down the opposite quadrant of the dome. The base of the dome is supported by *twelve* 13-inch wheels or rollers. The lateral motion of the dome by wind or other violence is prevented by six frames, containing rollers of 6 inches diameter, equally distributed round the circumference. I rarely use any mechanical power for the purpose of turning the dome; it moves so freely that by placing my foot against one of the six frames as a fulcrum I move it easily and quickly to any azimuth required. I have, indeed, hooks attached to each of the frames or wall-plates, and to the *following* side of the opening, between which I sometimes employ a small pair of blocks. When surveying one object for a long time these are useful, as by having the rope brought up to the observing gallery I can carry on the dome without the trouble of descending. The entire weight of the dome I have estimated at about 2800 lbs.

The gallery of observation is a framework attached to the *following* side of the opening, and nearly concentric with the centre of motion of the telescope; by ascending this the eye of a person of ordinary stature is nearly level with the eye-piece at all altitudes of the telescope.

The wall of the building is 9 inches thick and 12 feet high, and the height of the axis of the telescope is such that it is just clear of the base ring of the dome when directed horizontally. The upper floor is 2 feet 3 inches below the base ring, and from the large central opening required for the sweep of the lower end of the telescope, partakes more of the nature of a very wide circular gallery than of a continuous floor.

The external covering of the dome is painted canvas, which, I think, combines in the greatest degree cheapness, lightness, and durability. The covering of the smaller dome, after nearly ten years' exposure, exhibits no symptoms of decay. It has been twice painted during that interval.

The rotation of the tube on its axis, necessary in order to keep the axis of the eye-tube horizontal in all positions of the telescope, is effected by four cast-iron sockets, fastened to the outside of the tube near the lower extremity. By introducing an iron bar about two feet long into any one of these which may be most conveniently situated, the telescope is with moderate effort made to revolve within the cast-iron frame or box by which it is inclosed.

The circles of right ascension and north polar distance are the same size as those of the 9-foot, and read to the same quantities, but owing to the large size of the circular plate at the base of the *uprights* supporting the polar distance axis (4 feet 5 inches diameter) the right ascension circle could not be placed there; it is, therefore, placed much lower down on the cone—indeed within 2 feet 4 inches of its vertex. When there is no assistant observer this position is certainly too far off for convenience; but, as in the majority of observations I have had to make this circle has never been required, the inconvenience is more imaginary than real. The upper part of the large circle at the base of the *uprights* is roughly divided, and is read to a minute by instant inspection from the observing-floor, so that for the mere purpose of finding an object the finely divided circle is rarely needed. The outside edge of the large circle is racked, and the tangent-screw being attached to its most southern and highest part, but little lower than the floor, it is very accessible, and the apparatus for locking and unlocking, when observing anywhere near the meridian, are close at hand. The tangent-screw is prolonged both ways, east and west, under the floor, and by means of some wheel-work the motion is communicated to vertical shafts inclosed in two pillars standing on the floor.

By means of a pair of bevel-wheels the right ascension handle can be conveniently attached to one or other of these pillars in every possible position of the telescope.

To afford some notion of the degree of facility attained in the management of so large a dome and telescope, I may mention that, with an assistant, I can, without hurry, place an object, invisible to the naked eye, within the field of the telescope in nine or ten minutes from leaving my house. This includes opening the dome, uncovering the large speculum, attaching the eye-piece, setting from the catalogue for the object, and turning the dome to the required azimuth. Without an assistant, I should require three or four minutes longer, which would be principally occupied in opening the shutters of the dome.

The tube of the telescope is of sheet iron, barely a tenth of an inch thick, 20 feet long, and 25 inches inside diameter, united by rivets with the heads inside, so that the outside is smooth and apparently without seam. Its weight is 594 lbs. The square box or casting which incloses the tube is 5 feet $6\frac{1}{2}$ inches long, 2 feet $3\frac{1}{2}$ inches in the side, and weighs 992 lbs.

The *uprights* are 7 feet long and 3 feet wide in the base, each weighing 450 lbs. The cone and large circle to which the uprights are bolted, all in one casting, weighs about 2010 lbs. The speculum weighs about 370 lbs., and is mounted in a sort of skeleton-box, which, instead of a rim or edge to confine the speculum, has four brackets about 4 inches broad and 3 inches deep. These are equally distributed in the circumference, so that two of them are at the ends of the horizontal diameter of the speculum. The back of the box is of wrought iron, 0·28 inch thick, and when in its place fills exactly the end of the tube. On the inner surface of the back of this box is placed the system of levers on which the speculum reposes; and the box is held in its place in the tube by a wrought-iron triangular frame, fastened exteriorly to the tube, in which are three stout screws working in collars in the frame, and tapped into the back of the box. The object of this is to command the adjustment of the box, and, therefore, of the speculum, by means of the square heads of these screws, while the speculum is approximately in its place. One of the greatest difficulties I have encountered in supporting the speculum equably, in its various positions, is to avoid the effects of the friction of its edge under considerable changes of altitude of the telescope.

It is obvious that when the altitude is low the principal part of the weight of the speculum must be borne upon its edge, and the plates in this position being in a great measure relieved from the pressure of the speculum, must, by their elasticity, tend to distort the metal by pressure at its back; and when the telescope is moved towards the zenith, the plates yield again by the weight of the speculum, while the lower edge, still in hard contact at the points of support, is unduly borne up there, and the equilibrium is destroyed. To remedy this evil, I have slung the speculum in a hoop of thin iron, equal in length to half its circumference, the ends of the hoop being attached to swivels fixed in each of the two horizontal brackets, and the lower part of the hoop being thus quite at liberty to rise and fall with the plates.

This has nearly, if not entirely, removed all perceptible distortion, yet in some positions and under some circumstances vestiges of it are to be perceived. I have devised a plan of supporting the metal laterally by an equal tension on the several points of support, and think it may probably be useful, but I have not yet had leisure to carry it into effect.

Instead of a plain speculum I usually employ a prism, which transmits a pencil two inches in diameter, made for me by Messrs. Merz and Son, of Munich. I am persuaded from repeated experiments that the prism has an obvious advantage in light over a speculum, and the material is so fine and the surfaces so exquisitely wrought that no perceptible injury of the image exists. The only care necessary in the use of the prism is to preserve it from dew, which it is extremely liable to collect. This I effectually secure by having a chamber made in the mounting of the prism, which receives a cube of cast-iron enveloped in thick *felt*. This being moderately warmed and placed in the chamber, effectually prevents the deposition of dew for at least some hours, while the extremely slow radiation through the felt does not suffice to produce any sensible disturbance in the formation of the image. The prism is rather small, for, though it transmits the entire pencil, there is scarcely anything to spare, and had it been easy to obtain a sufficiently good one half an inch larger I should have procured it.

The finder of the telescope is a Newtonian Reflector of 4·2 inches aperture, and 42 inches focus, with a magnifying power of 27 times. This sort of finder is more convenient than an achromatic, for it shews objects in the same relative positions as in the great telescope, however it may be directed.

*Starfield, 30th November, 1848.*

Further experience in the use of the polishing machine applied to various foci and apertures induces me to add, by way of appendix, an account of some modifications I have advantageously introduced in the mode of working.

For the economy of time, I have placed the *sovereign* on the pitch during one minute only, and regulated its temperament so that it should never receive less than three nor more than four full and distinct impressions of the *milling;* taking especial care that the pitch and sovereign should be, by previous immersion in water, of the exact temperature of the apartment in which the process is conducted. The testing process, however, was not itself performed under water. I have also found a further shortening of the quick-moving crank efficacious in producing a *greater truth of curve;* and have advantageously carried the reduction as far as a radius of only seven or eight-tenths of an inch in a 2-foot speculum, and as far as thirty-five hundredths of an inch, in specula nine or ten inches diameter. The figures, moreover, of these last, have proved more exquisite by reducing (proportionately) the speed of the machine: the quick-moving crank making only thirty-four or thirty-five revolutions per minute—the same velocity with which I have usually driven the machine when polishing a 2-foot speculum. The control over the curve I have maintained principally by varying, alternately or conjointly, the radius of the slow-moving crank and the size of the polisher. There are limits, however, to these variations. I have always considered it necessary that during some part of every revolution of the quick-moving crank the edge of the polisher should come fairly over the edge of the speculum, and, securing this, they cannot both be indefinitely reduced. The more, however, that they are reduced within this limit, the greater is the *spherical tendency.* The more they are increased the greater is the *hyperbolic tendency.* The limit to this increase is the danger to the figure arising from an undue portion of the circumference of the polisher generally overhanging the speculum, and, as it would appear, vitiating the regularity or truth of the curve. The best defining power seems to be produced by the smallest radius of the slow-moving crank and size of polisher, which can be made to come up to the parabola.

The settings of the machine which produced a very fine figure, recently, on a 12-inch speculum of only $89\frac{1}{2}$ inches focus, were as follows: $S = 1{\cdot}10$ inches, $Q = 0{\cdot}50$ inch $= 34$ revolutions per minute. Pitch received four impressions of the milling of the sovereign in sixty seconds. The surface of the tool divided into three-quarter inch squares, with intermediate channels three-tenths of an inch wide; its diameter was 12·0 inches. Duration of the process two hours. The speculum, however, had been polished, and this process was for the purpose of correcting the figure.

I now usually add the water alternately through the hole in the polisher, and at its edge, and do not allow the speculum to approach so near dryness. I finish with it decidedly wet, to the improvement, as I think, of the regularity of the curve and consequent sharpness of definition. I have also frequently used again the same polisher, when the interval between the polishings has not been great, and, of course, when the change of temperature has not been material. Indeed I have, I think, done this sometimes with advantage, as the pitch surface, being already charged with powder, does not cut so keenly; and when a very slight alteration is required, it is apparently thus effected with more truth.

If, however, in the previous use of the polisher any of the grooves have become obliterated, they must be cut anew with a penknife, and made as symmetrical as possible.

An improvement I have made in the mode of support of the 2-foot speculum has been thus effected. Taking away the disks of *felt* from the eighteen points, I have drilled through the centres of the places they occupied holes two-tenths of an inch in diameter. Over these I have placed eighteen disks of brass 1·7 inches diameter, the upper surfaces plane and smooth, the under surfaces *small* segments of spheres, with a slightly taper pin in the centre, projecting downwards, and loosely fitting the holes drilled in the ends of the levers. The upper surfaces of the disks are well greased. The advantage gained is a greater uniformity of contact of the supporting disks, and a greater freedom of lateral motion of the speculum on their surfaces.

In the description of the polishing machine I omitted to mention, that in order to facilitate the removal of the 2-foot speculum when polished, I have had a carriage of four wheels of 15 inches diameter attached to the lower bracket, so that the speculum can be taken away for trial and returned to the machine, with only the trouble of withdrawing and replacing the upper two bolts which attach the bracket to the wall-plate.

*Starfield, August* 9, 1849.