THE THIRTY-SIX INCH EQUATORIAL TELESCOPE OF THE LICK OBSERVATORY.

BY JAMES E. KEELER.

The great telescope of the Lick Observatory was mounted in the south dome on Mt. Hamilton in the early part of the present year, and is now, so far as the work of the builder is concerned, practically completed. There still remains the adjustment of all its complicated details, which properly devolves upon the astronomers who are to use the instrument, and the gradual perfecting of which will doubtless extend over a period of many weeks or even months.

The history of this great undertaking, from the conception of the original idea in the restless brain of James Lick to the completion of the actual instrument in brass and steel on the summit of Mt. Hamilton, is so well known that I shall not further revert to it, but confine the present article to a description of the telescope and the machinery necessary for its operation, as they now stand in the dome of the observatory.

The pier of the telescope is a rectangular cast iron column weighing 20 tons, built up of four sections rigidly bolted together. The thickness of the iron is about 1¼ inches. The lower section, which at the floor level is 9 by 5 feet, expands into a broad base, 16 feet long and 10 feet wide, resting upon the solid masonry foundation which forms the tomb of James Lick. This casting weighs 5 tons, and is the heaviest single piece hauled to the summit in the construction of the observatory. On top of the pier is a balcony, surrounding the massive head piece which forms the support for the polar axis. The upper section of the pier, 4 by 8 feet at the top, contains the driving clock. A light iron spiral staircase, running from the base of the pier on the south to the balcony, gives access to the clock room and machinery above, and adds greatly to the appearance of the mounting.

The weight of the pier is distributed over a number of heavy steel screws in the base, which afford means for the exact adjustment of the polar axis, but it is possible that, after this adjustment is perfected, the base will be set in cement and the pier permanently fixed in position.

The telescope is intended to be moved by an assistant stationed on the balcony which surrounds the top of the pier. In the specifications for the construction of the mounting, most of the following mechanical movements or conveniences are called for.

An observer at the eye end can:

1. Clamp in declination.
2. Give slow motion in declination.
3. Read the declination circle (two verniers).
4. Clamp in right ascension.
5. Give slow motion in right ascension.
6. Stop or start the clock.
7. Read the right ascension circle (one microscope).

An assistant on the balcony can:

8. Clamp in declination.
9. Give quick motion in declination.
10. Give slow motion in declination.
11. Clamp in right ascension.
12. Give quick motion in right ascension.
13. Give slow motion in right ascension.
14. Stop or start the clock.
15. Read the right ascension circle (two microscopes).
16. Read a dial showing the approximate declination.

The arrangement of the various devices by which these movements are effected was left to the makers, Warner & Swasey, who designed the entire mounting, with the exception of the eye end, which was made essentially from plans prepared by Professor Langley and Professor Holden. The telescope can also be moved quickly in the ordinary way by the observer at the eye end, although, as the whole train of gearing extending to the balcony must then be set in motion, this cannot be done as easily as if the quick motions had not been provided. A pressure of 10 lb. on the spokes of the quick motion wheel on the balcony will move the telescope in right ascension; a pressure of 20 lb. is required for the motion in declination. The telescope can be reversed, or the same star brought into the field on opposite sides of the pier, in a little over two minutes.

The polar axis is a finely finished shaft of steel, 12 inches in diameter and 10 feet long, weighing 2,800 lb. It is pierced centrally by a 6 inch hole, through which passes a shaft for communicating the motions in declination to the telescope from the balcony. The polar axis turns in bearings of Babbitt metal, but the greater part of the weight on its upper end (some 14 tons) is supported by a collar containing hard steel rollers encircling the axis just outside of the upper bearing, and carried by a lever which leads down into the hollow head piece and can be adjusted for tension. The lower end of the axis is turned to a flat surface, and the thrust of about 8 tons is taken by two rows of hard steel balls rolling in concentric grooves. To the upper end of the axis is bolted the cast iron cylindrical case, 9 feet in length, which contains the bearings of the declination axis.

The declination axis is 10 feet long and 10 inches in diameter, and is also made of steel. To one end is bolted the cast iron central section of the telescope tube. The other end is just outside of the 6 foot declination coarse circle, and carries indexes which point out the approximate declination. The coarse circle is fixed to the declination axis case, and supports the rod which carries the weights for counterpoising the tube. This rod is made of a brass tube shrunk on to a steel core, and the weights, which are in the form of circular disks, travel on a thread cut in the brass. Each disk is 2 feet in diameter and weighs 240 lb. Eight of these disks are required to counterpoise the telescope.

As the indexes of the coarse circle cannot always be conveniently read from the balcony, a dial is fixed to the sleeve of the declination axis where it can always be seen by the assistant, and its pointer shows the declination of the telescope equally with the coarse circle.

The bearing of the declination axis toward the telescope is relieved of the weight of the tube and its attachments (about 4½ tons) by a double counterpoise lever, one end of which carries a collar with steel rollers, like that on the polar axis, the other an annular iron casting weighing 500 lb., which surrounds the sleeve of the declination axis just inside the coarse circle. The steel rollers embrace the axis close to the telescope tube, and as the counterpoise levers are always parallel to the axis, they relieve the same proportion of the pressure on the inner bearing in every position of the telescope.

The center of motion of the telescope, or intersection of the polar and declination axes, is 37 feet 10 inches above the masonry foundation. The sight line of the telescope is 5½ feet from the center of motion, and the end of the rod for counterpoising the tube 12 feet.

The tube is made of hard steel plates riveted together. It was shipped in four sections (besides the cast iron central section), which are connected by bolts through flanges at their extremities. The plates near the middle of the tube are $\frac{3}{16}$ inch thick, and the thickness of the sheets diminishes toward the ends, where it is ⅛ inch. The tube is 52 feet long, 4 feet in diameter in the middle, and tapers to a little over 3 feet at the ends. In the shops of the makers it was tested by placing a ton on each end when supported in the middle, and in other ways, the greatest deflection produced being about one-eighth of an inch. The inside of the tube is well blackened and provided with numerous diaphragms, which can be removed when it necessary to work in the interior. It was a curious sight during the erection of the instrument to see a number of painters and other workmen emerging from the end of the tube, like humble-bees swarming out of a hollow stalk.

The object glass, by Alvan Clark & Sons, is secured to a flange on the outer end of the tube in the usual manner. Its clear aperture is 36 inches, and the distance of the focal plane from the back surface of the flint lens is 56 feet. The lenses are 6½ inches apart, and the total thickness of glass traversed by a ray of light is about 2¼ inches. The weight of the objective in its cell is 530 lb. An ingenious machine was devised by Captain Floyd for mounting the objective and photographic lens.

The tail piece at the eye end of the telescope is surrounded by a revolving jacket, provided with position circle, clamp, and slow motion screws, for carrying the spectroscope and other accessory instruments. Clamps on opposite sides of the jacket receive two hollow brass rods 6 feet long and 3 inches in diameter, and any apparatus attached to these can be rotated easily and yet firmly about the axis of the telescope.

The draw tube at the eye end is 8 inches in diameter, and is focused by a wheel surrounding and concentric with the tube. This wheel acts upon three screws, parallel to the telescope axis, which move the draw tube in or out, and allow the heavy micrometer or other instrument to be adjusted to the proper focus with great ease and accuracy. The eye end is surrounded by a steel ring 39 inches in diameter, to which lead all the clamps, slow motions, and other contrivances operated by the observer. The spokes of the right ascension wheels are notched, so that they can be distinguished from the declination wheels in the dark.

There are three finders of 2¾, 4 and 6 inches aperture, and in addition to these, brackets to which the objective and eye end of the 12 inch equatorial can be attached when a finder of great power is desired. The makers are providing a double slide micrometer eyepiece for this or the 6 inch finder, which will enable the great telescope to be pointed at a faint object by means of any neighboring bright star—a contrivance especially valuable for photographic work.

The three microscopes for reading the finely divided circles from the eye end (two for declination and one for right ascension) also pass through this ring. By turning a switch close to the eyepiece of the corresponding microscope, the circle to be read is illuminated by an incandescent electric lamp. Attached to the ring are also a small sidereal clock, a telegraph key for recording the time of an observation, and an electric switch for starting or stopping the driving clock.

A cable containing nine wires for the electric lights, switches, and key leads from the pier to the eye end. It was not considered advisable to introduce the complicated contact apparatus which would be required to make the proper connections through wheels on the axes, and a simple cable is employed, but two safety plugs are inserted where it crosses between moving parts, and their parts can be easily reinserted in case they should draw when the telescope is inadvertently turned too far in one direction.

The driving clock in the top section of the pier is, on a large scale, essentially the same as the clocks employed by Warner & Swasey on their smaller equatorials and chronographs, except that it has an electric control, by which its rate is kept in agreement with that of a standard astronomical clock. One of the arbors which turns in one minute is converted into a chronograph, and connected with the system of electric circuits at the switch board in the long hall of the observatory. The electric control is operated by the relay points of this chronograph, so that any clock recording on the chronograph regulates the driving clock of the telescope. The clock can thus be controlled equally well on either sidereal or mean solar time.

The equipment for photographic work is very complete. The photographic corrector is a meniscus of crown glass, 33 inches in clear aperture, and weighing in its cell 150 lb. When in use it is placed in front of the visual objective, and the focus of the combination thus formed is about 10 feet above the eye end. At this point a large aperture is cut in the telescope tube, giving access to a plate holder capable of taking a dry plate 20 inches square or any smaller size, and provided with all the necessary adjustments. An image of the moon formed here is about 5½ inches in diameter. Instead of a dry plate, a board holding an enlarging lens can be inserted in the plate holder, and a magnified image of a planet projected into a small box camera screwed to the draw tube at the eye end.

The system of counterpoising differs considerably from that used for small instruments. On account of the size of all the parts, it would be very troublesome to readjust the balance by shifting the position of the counterpoises when any change of weight is made. The telescope therefore always carries its maximum load, and when an accessory instrument is added, its equivalent in weight is taken off at the same place.

The most important of the accessory instruments are a filar micrometer by Fauth & Co. and a large spectroscope by Brashear, both admirable specimens of the instrument maker's art.

A few words about the surroundings of the telescope may be in place here. The steel dome, 75 feet 4 inches in diameter, was made by the Union Iron Works of San Francisco. The weight of its moving parts is 100 tons. It is rotated on the plan devised by Captain Floyd and Mr. Fraser, by an endless wire rope which passes around the circumference of the dome, over guiding pulleys, and around a grooved wheel turned by a hydraulic motor in the basement. The dome can be turned completely around in nine minutes.

The slit for observing is 9½ feet wide. It is closed by two steel shutters weighing 15 tons, which are opened by an endless rope hanging inside the upper gallery. A pull of 5 lb. is sufficient to move the shutters.

The hydraulic elevating floor weighs 26 tons, is 61½ feet in diameter, and is movable between fixed galleries through a range of 16½ feet. It is operated by four telescoping hydraulic rams, which have replaced the motors formerly employed for the purpose, their motion having been found inconveniently slow. The motors are retained, however, and can be connected in place of the rams whenever desired. By means of the rams, the floor can be raised in a little less than ten minutes, and lowered in four, with an expenditure of 300 gallons of water. The floor is counterpoised by eight heavy blocks of iron, which slide in vertical columns and relieve the rams of all but two tons of the weight to be lifted. The waste water from the rams and motors runs into a reservoir forty feet below the level of the observatory, whence it is pumped by a windmill back into the high service reservoir which supplies the pressure.

Two small hand wheels on the elevating floor control the hydraulic machinery in the basement. The direction of the motion imparted to the machinery is determined by the direction in which the wheels are turned, the rapidity by the number of turns given to them, thus securing a perfect control. The dome continues to turn as long as its wheel is displaced from the normal position; but in order to avoid accidents to the telescope, the mechanism of the other wheel is so contrived that the floor rises or falls only when the wheel is turning, and stops when the wheel is stopped.

The interior of the dome is beautiful and impressive. The walls are of California redwood, handsomely finished with a dead surface to prevent annoying reflections. The elevating floor and galleries are laid in narrow concentric rings, with ornamental borders of walnut and cherry. The dome overhead is painted pale pea green, the edges of the girders and intercostals and the square tie plates salmon pink, giving an appearance of airiness and lightness to the structure which is in harmony with its movable character.

The somber black with which the great instrument in the center is painted, relieved from absolute deadness by the polished brass work of the fittings, increases the ponderous aspect of the telescope and asserts the dignity of its purpose. I have always been interested in observing the impression made by the interior of the dome on the many visitors who come to the observatory. Even the habitually frivolous become thoughtful when they enter the presence of the great telescope.

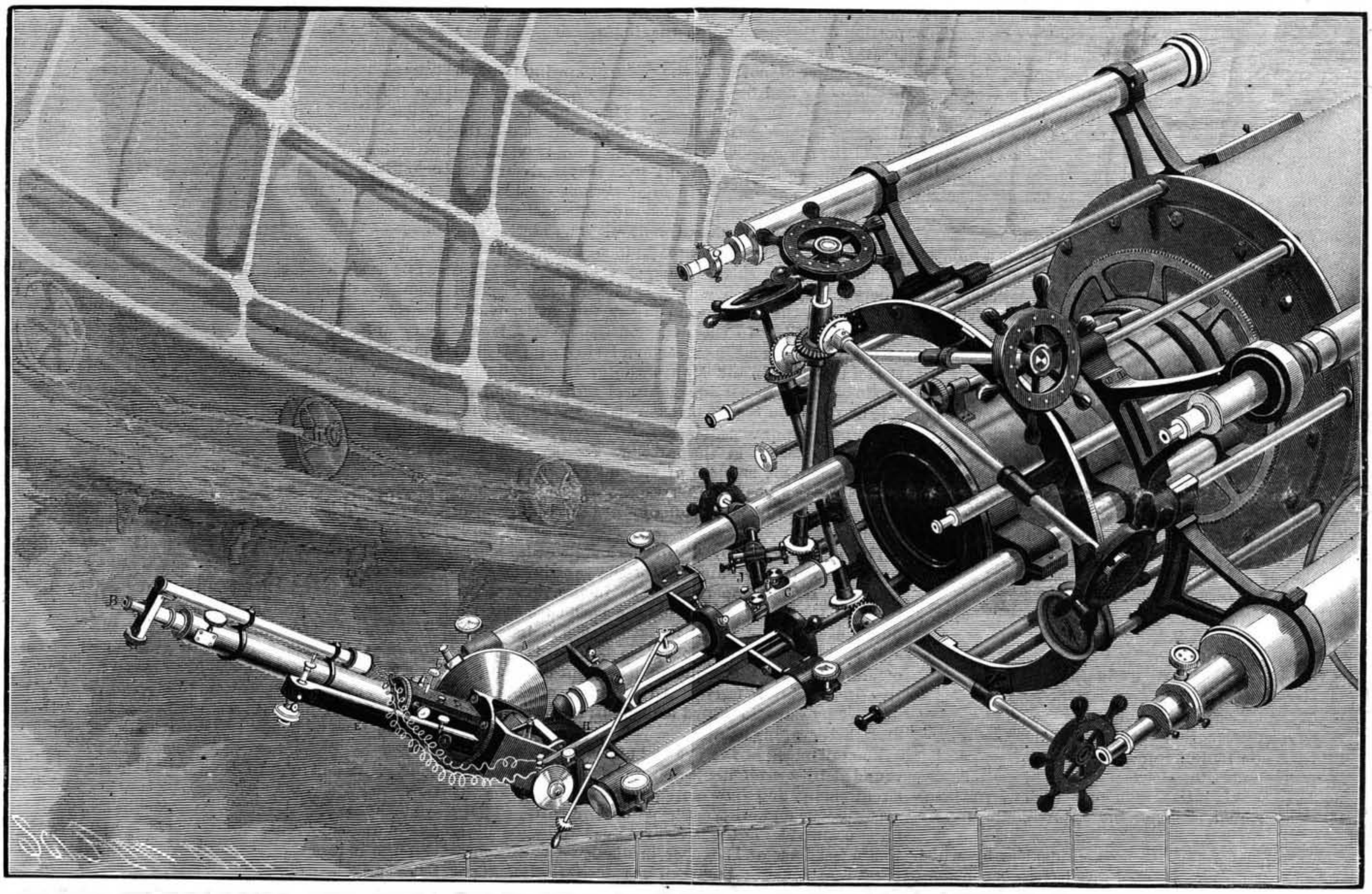
It is as yet much too soon to attempt any judgment as to the success with which this instrument will meet the different requirements which have been laid down for it. The great size which makes it most valuable for one class of work renders it unsuitable for another. But few observations have been made; no photographs have been taken, except for correcting the figure of the lens; but the glass has been tested officially by Prof. Newcomb, and pronounced by him and by the Clarks themselves to be as near to perfection as the art of the optician can attain, while the mounting has been inspected officially by Prof. Newcomb and Mr. Burnham, unofficially by Mr. Brashear, Mr. Saegmuller, and others, and has met with their entire approval.

The only actual work which has been attempted is a series of micrometric measurements of the satellites of Mars, made by myself during the past opposition whenever the work of construction would allow; but these observations, although made under the most unfavorable circumstances with an imperfectly adjusted instrument, promise success in this important field of work, while the brightness with which these ordinarily difficult objects appear in the great telescope attests the extraordinary light-gathering power of its objective. Enough has been shown, however, to demonstrate its undoubted fulfillment of the condition imposed in the trust deed of James Lick, that of being "superior to and more powerful than any telescope ever yet made."

ONE of our contemporaries rightly observes that radical changes in the science of steam engineering have not been numerous in the last quarter of a century, but improvements in the details of construction and operation have been many and of high utility. How important this progress has been in its economical results is indicated by a statement recently made that railway trains in England are now driven at an average speed 14 per cent higher than twenty years ago, with but little more than half the quantity of coal.

SPECTROSCOPE FOR THE LICK OBSERVATORY.

There has recently been constructed at, and shipped from, the astronomical instrument works of Mr. John A. Brashear, Allegheny City, Pa., a spectroscope of unusual power and completeness. It was forwarded to its ultimate destination, Lick Observatory, Mt. Hamilton, California, there to be employed in astronomical research in connection with the great telescope. The contract for the spectroscope, which was let in December, 1886, called for an instrument of the highest capabilities, and for adaptation to the pursuit of two special studies. These were: 1, the study of the physical constitution of the stars, and, 2, the important study of stellar motion in the line of sight. To conduct the latter study requires mechanical adjustment of the greatest delicacy. The spectroscope in question is of the compound order, *i. e.*, possessed of both prisms and gratings. Of prisms, the instrument includes in its equipment three varieties. Of gratings, it contains one of the largest and most dispersive ever made, showing 46,000 parallel lines, ruled by a diamond splinter upon speculum metal, and so closely placed as to number 14,438 to the linear inch. This number is regarded as the best for general work. The ruling was done by Professor Roland, of the Johns Hopkins University, Baltimore, the plates being made by Mr. Brashear. The power conferred by this grating upon the spectroscope is equivalent to that of at least fifty prisms—assuming it to be possible for that number to be used at once. The office of this vital portion of the instrument is the dispersion of light, thus enabling the observer to define the nature of its source. For the purpose of comparing the spectra of celestial objects with those of known elements (in combustion), a "comparison attachment" forms part of this spectroscope. By its use, and with the aid of the electric current, can be obtained spectra of all gases or metals, which spectra, by means of a totally reflecting prism, can be sent into the spectroscope and there displayed, superimposed on a spectrum of a star or other celestial body. By means of a device invented by Professor J. E. Keeler, of the Lick Observatory, the two spectra can be placed in such exact relations with each other, and these relations and their absolute coincidence or displacements measured so accurately, that the study of stellar spectra, it is confidently expected, will be greatly advanced. The action of this instrument upon light may here be briefly outlined. The ray, proceeding from some infinitely remote body under contemplation, through the 36 inch lens of the Lick telescope, falls upon the slit of the collimator of the spectroscope, thence spreading in a beam that falls upon the lens of the collimator, to emerge therefrom in parallel rays that fall upon the grating, or pass through prisms, as the observer desires. Through the use of a prism, a single spectrum is produced—if the prism is of glass. With the grating, a multiple spectrum is obtained—a result of the highest importance, in that the separation of the dark lines is so much greater that these lines—the indices of the nature of the remote body—can more readily be identified and their significance interpreted. An additional advantage in the use of the grating is the production of a normal spectrum. With the prism the spectra show a compression or "crowding up" at the red end. By means of the observing telescope that forms a part of the Brashear instrument, the first, second, third, or fourth spectrum can be taken up and studied. This powerful instrument will be rigidly attached to the Lick telescope by means of steel projections at the eye end of the larger instrument. Every arrangement has been made for the most delicate adjustment, and for the collimation of all optical parts. Micrometers are employed for reading with the greatest degree of accuracy, and to the 1" of arc, and by the use of delicate and accurate mechanism, the relative qualities of the two spectra—that produced artificially and that from a celestial body—can be studied most satisfactorily. This spectroscope has been tested in the solar spectrum with splendid results, the great B group coming out with remarkable clearness and sharpness.



A A. Steel support rods on end of telescope. B. Observing telescope, 22½ in. focus, 2⅛ in. aperture. C. Collimator. D. Reversion attachment, containing a Christie half prism and reversion prism. E. Reversion micrometer. F. Prism and refraction grating table. G. Graduated circle and vernier. H H. Counterpoises. J. Electrical comparison attachment.

SPECTROSCOPE OF THE LICK OBSERVATORY.—(From photograph by H. E. Matthews.)

How to Use Glue.

For glue to be properly effective it requires to penetrate the pores of the wood; and the more a body of glue penetrates the wood, the more substantial the joint will remain. Glues that take the longest to dry are to be perferred to those that dry quickly, the slow drying being always the strongest, other things being equal. For general use, no method gives such good results as the following: Break the glue up small, put it into an iron kettle, cover the glue with water, and allow it to soak twelve hours. After soaking, boil until done. Then pour it into an air tight box, leave the cover off until cold, then cover up tight. As glue is required, cut out a portion and melt in the usual way. Expose no more of the made glue to the atmosphere for any length of time than is necessary, as the atmosphere is very destructive to made glue. Never heat made glue in a pot that is subject to the direct heat of the fire or of a lamp. All such methods of heating glue cannot be condemned in terms too severe. Do not use thick glue for joints or veneering. In all cases work it well into the wood, in a similar manner to what painters do with paint. Glue both surfaces of your work, except in cases of veneering. Never glue hot wood, as the hot wood will absorb all the water in the glue too suddenly and leave only a very little residue.