W. TAYLOR.

METHOD OF GRINDING GLASS.

APPLICATION FILED OCT. 28, 1916. RENEWED JUNE 13, 1921.

1,401,832. **Patented Dec. 27, 1921.**

3 SHEETS—SHEET 1.

Fig.1.

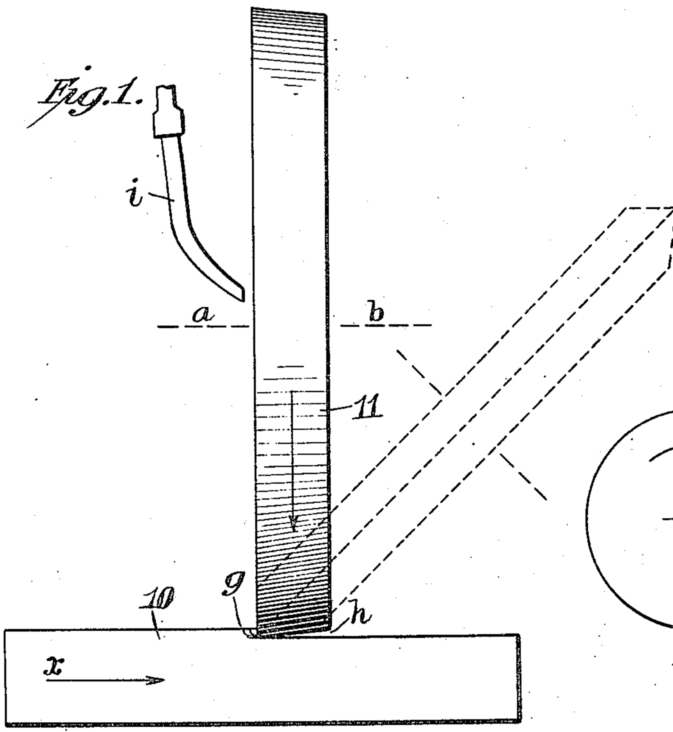


Fig.3.

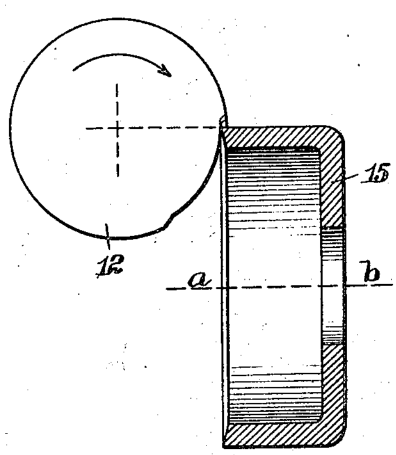


Fig.2.

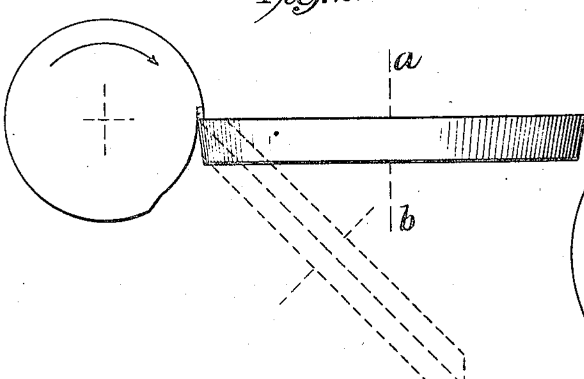
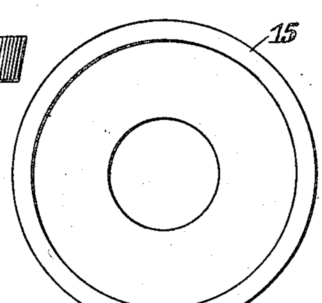


Fig.4.



WITNESSES:

Lillian R. Fox

Grace E. Bucher

INVENTOR.

William Taylor

BY Arthur L. Kent

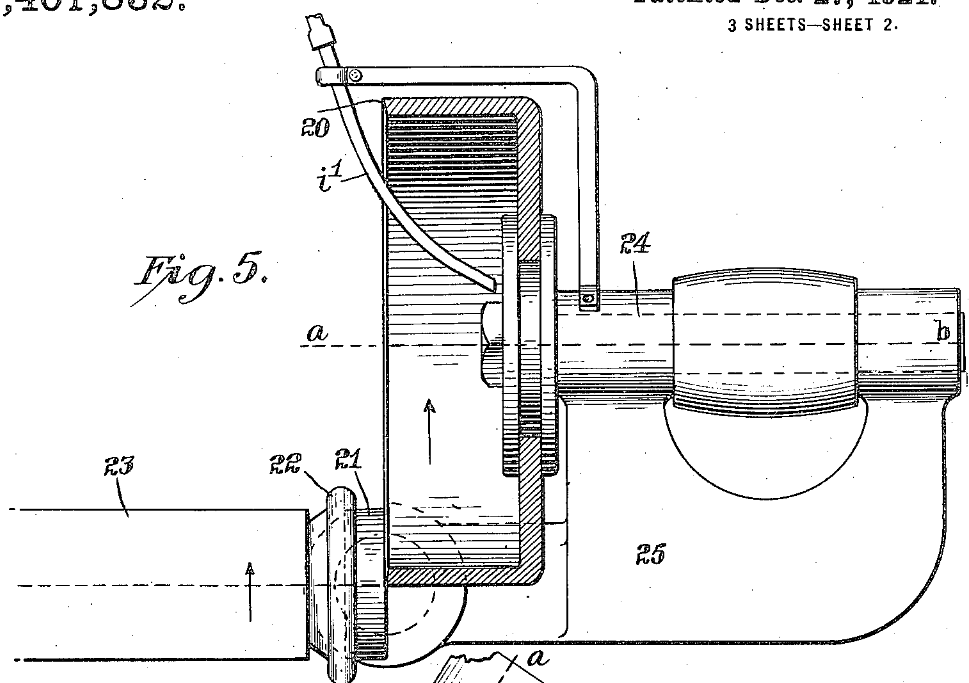
his ATTORNEY.

W. TAYLOR.
METHOD OF GRINDING GLASS.
APPLICATION FILED OCT. 28, 1916. RENEWED JUNE 13, 1921.

1,401,832. Patented Dec. 27, 1921.

3 SHEETS—SHEET 2.

Fig. 5.



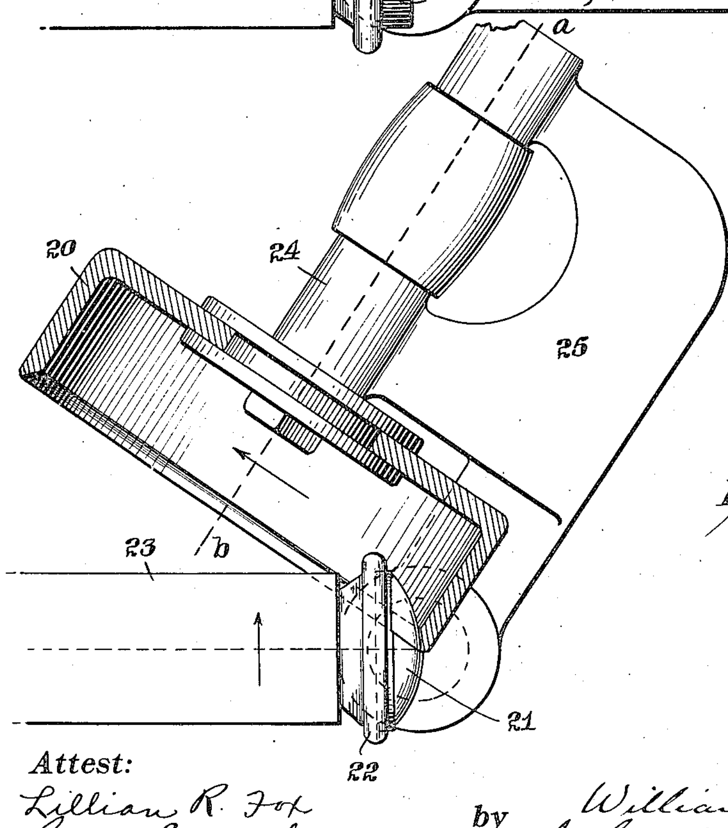


Fig. 6.

Attest:
Lillian R. Fox
Grace E. Bucher

Inventor:
by William Taylor
Arthur L. Kent, his Atty

W. TAYLOR.
METHOD OF GRINDING GLASS.
APPLICATION FILED OCT. 28, 1916. RENEWED JUNE 13, 1921.

1,401,832.

Patented Dec. 27, 1921.

3 SHEETS—SHEET 3.

Fig. 7.

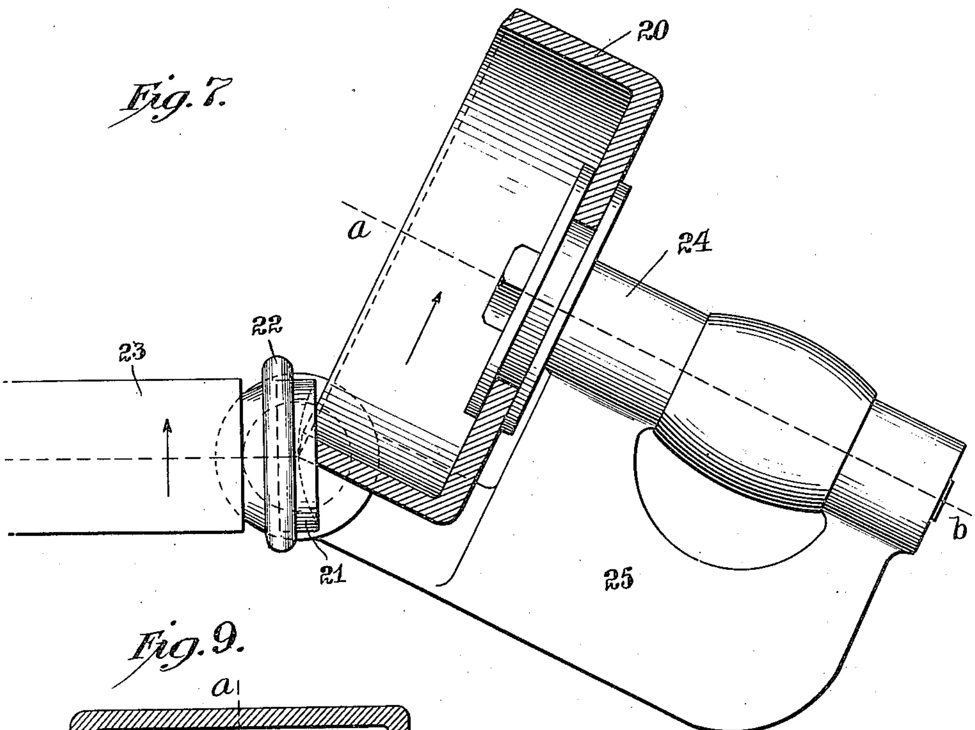


Fig. 9.

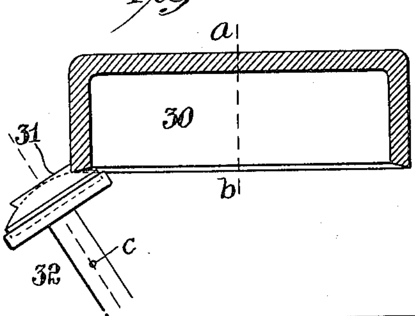
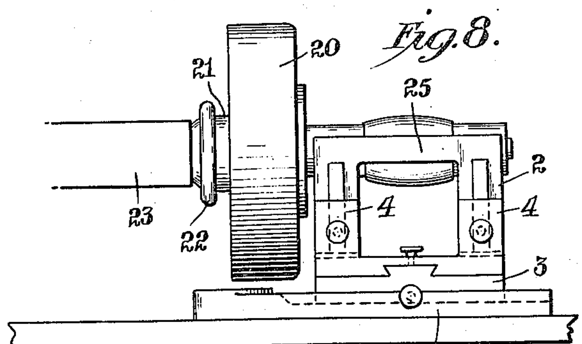


Fig. 8.



WITNESSES:
Lillian R. Fox
Grace E. Bucher

INVENTOR.
William Taylor
BY Arthur L. Kent
his ATTORNEY.

UNITED STATES PATENT OFFICE.

WILLIAM TAYLOR, OF LEICESTER, ENGLAND.

METHOD OF GRINDING GLASS.

1,401,832. Specification of Letters Patent. Patented Dec. 27, 1921.

Application filed October 28, 1916, Serial No. 128,235. Renewed June 13, 1921. Serial No. 477,348.

To all whom it may concern:

Be it known that I, WILLIAM TAYLOR, a citizen of Great Britain, residing at Leicester, in the county of Leicestershire, England, have invented certain new and useful Improvements in Methods of Grinding Glass, fully described and represented in the following specification and the accompanying drawings, forming a part of the same.

This invention relates to methods of grinding glass and similar hard, non-plastic materials by means of abrasive wheels.

Heretofore, although abrasive wheels, and particularly wheels made up of particles of abrasive materials such as carborundum and the like bonded with fusible earth or in other ways, have been used very largely in grinding metals, comparatively very little use has been made of such wheels in grinding glass. Before the advent of artificial abrasive wheels, certain natural stones were used for grinding the channels in what is known as cut glassware, and also for grinding the edges of spectacle lenses, and since their introduction artificial abrasive wheels have been used with some success for the above purposes as a substitute for the natural stones, but in such use they have not been run at the high velocities at which they are generally most efficient; nor have they been used with economy and success when much material has to be removed. Nor have they been used for grinding the surfaces of lenses.

The object of the present invention is to provide an improved method whereby glass and similar hard, non-plastic materials may be ground with artificial abrasive wheels which shall make it possible to grind plane and curved surfaces accurately with a degree of efficiency and rapidity beyond what has heretofore been obtained in the grinding of glass. Although the invention has been made with the idea of utilizing artificial abrasive wheels, and finds its greatest usefulness when wheels of such material are used, yet the invention may be carried out by the use of other kinds of grinding or abrasive materials and devices, as will be apparent.

I have found that the mode of applying an abrasive wheel to its work which is usual and proper in the case of grinding metal is unsuitable for grinding glass quickly for the reason, as I believe, that while metal is comparatively soft and plastic and a good conductor of heat, glass is very hard and non-plastic at ordinary temperatures, and is a bad conductor of heat. When the face of a piece of metal is applied to the face of a rapidly moving abrasive wheel, particles of abrasive protruding from the face of the wheel surface attack the metal, heating it somewhat by impact and friction, increasing its plasticity by such heating, and cutting away a portion of the metal in a more or less well defined way. Plastic action seems to be a necessary part of all real cutting action, and has an important function in the so-called grinding of metal surfaces by rapidly moving abrasive surfaces. On the other hand, glass at ordinary temperatures has no plasticity; and when the pressure between the glass and the wheel is such as in the case of grinding metal would generate sensible heat and add to the efficiency of the operation by increasing the plasticity of the metal which is being removed, the result in the case of glass is apparently to heat and expand the surface locally (it being a bad conductor of heat), and produce in the glass strains which tend to detach splinters or particles from the surface. Such strains, together with the shock, pressure and tearing action of the surface of the abrasive wheel, shatters and breaks away the surface of the glass. When the abrasive wheel is applied in the usual way for grinding glass, that is, according to the practice in surface grinding of metal, with the peripheral face of the wheel bearing against the glass with a relative movement between the glass and the wheel in the direction of the plane of the wheel, and with the pressure of the wheel on the glass chiefly normal to the surface to be formed on the glass, the pressure of the wheel tends to oppose such separation of the splinters or particles of glass, and even when, in spite of this, splintering and separation does occur, the splinters are unable to escape freely, being trapped between the wheel and the glass, and the surface being formed is damaged by such splintering. The tendency of the glass to splinter under the action of the grinding wheel, thus interferes seriously with the grinding operation when this is carried on according to the usual practice, which practice is proper and highly efficient for grinding metals and similar relatively plastic or yielding materials. It has, therefore, been customary heretofore, when artificial abrasive wheels have been used in cutting glass, to run the same at relatively low velocities, so as to avoid or to reduce to a minimum the splintering or shattering of the glass, and such low velocity has resulted in low efficiency and slow grinding.

In accordance with my present invention, I turn to advantage this splintering of the glass under the action of the grinding wheel, with the result that the grinding wheel not only may be, but desirably is, operated at a high rate of speed, such as that which is employed in the grinding of metal, and which I believe may be as high as conditions of safety permit.

Instead of applying the grinding wheel to the glass in the usual way, I apply the grinding wheel to the work in such a way that an abrupt step or terrace is formed between the unground or original surface and the ground surface of the work, which is best normal to, but which may be from say 80° to 110° to the original surface, and that this step is cut backward by the edge of the grinding wheel acting on the side of the step, a feeding movement being caused between the wheel and the work in a direction transverse to such step and transverse to the direction in which the successively active portions of the edge of the grinder move in the rotation of the grinder; and I shape that face of the wheel which is contiguous to, or faces, the surface of the glass to be formed so that it makes contact therewith only at the base of the step, the wheel acting only on the side of the step, and the pressure of the wheel being in a direction approximately parallel to the surface to be formed and chiefly normal to the face of the step. In such "terrace grinding" it is the edge of the step which is continuously splintered by the action of the grinding wheel, and the detached glass particles are thus free to escape immediately, their detachment and escape being assisted, instead of being hindered, by the pressure of the wheel.

In grinding glass in this manner it is possible, and for the highest efficiency desirable, to run the grinding wheels at high peripheral velocities such as are commonly employed in grinding metal with abrasive wheels. On the other hand, the rate of traverse between the wheel and the work is much slower than has been customary heretofore in grinding glass with abrasive wheels, but this is much more than offset by the increased depth of cut or rate of feed.

Certain features of the invention relating to the grinding of curved surfaces are not limited in their application to the use of my terracing method, although in most cases the highest efficiency is attained when the terracing method is practised.

The accompanying drawings illustrate more or less diagrammatically several ways of grinding glass or similar non-plastic material according to the present invention.

In said drawings—

Figure 1 is a diagrammatic view illustrating the grinding of a plane surface by means of a disk wheel;

Fig. 2 is a similar view illustrating the grinding of the face of a cylinder or the edge of a cylindrical disk by means of a disk grinding wheel;

Fig. 3 is a similar view illustrating the grinding of the face of a cylinder or the edge of a disk by means of a cup-shaped or other grinding wheel having a tubular grinding portion annular in cross section;

Fig. 4 is a face view of the cup-shaped grinding wheel shown in Fig. 3;

Fig. 5 is a plan view, partly in section, illustrating diagrammatically an apparatus for grinding flat or convexly or concavely curved surfaces;

Fig. 6 is a view similar to Fig. 5, but showing the grinding wheel adjusted for grinding a convex surface, and Fig. 7 is a similar view showing the grinding wheel adjusted for grinding a concave surface;

Fig. 8 is a side view of the apparatus shown in Fig. 5;

Fig. 9 illustrates another means for grinding a curved surface.

Referring first to Fig. 1, this figure illustrates a method of grinding a plane surface on a body or slab of glass or similar material 10, by means of a disk grinding wheel 11. The grinding wheel is shown in full lines as mounted with its axis of rotation *a—b* extending parallel to the surface to be ground, and, as indicated by the arrow *x*, the relative traversing movement between the grinding wheel and the work is in a direction transverse to, and most desirably at right angles to, the direction in which the edge of the wheel in its rotation moves against the work, or transversely to the edge of the wheel; that is, in this instance, the relative traversing movement is sidewise or flatwise of the wheel, the grinding being accomplished by the action of the side edge of the wheel against the side of the step or terrace formed between the unground and the ground portions of the surface of the glass, the step being progressively ground away by a process which consists largely of splintering the glass, as indicated at *g*, by reason of shock and pressure assisted probably by local heating and expansion of the glass. The particles or splinters of glass thus produced are free to escape and are thrown out by the rapidly moving edge of the wheel, so that the latter is free to come into contact with and successively and continuously cause the production and dislodgment of further particles as the traverse between the work and the wheel continues. The edge of the wheel between the grinding side and the peripheral face is left quite sharp and the depth of cut is sufficient so that an abrupt step is formed, and the periphery of the wheel is shaped to slant away from the ground surface of its glass, or given a so-called bottom rake, so as to have a clearance *h* to prevent dangerous heating of, and damage to, the finished surface, and enable the velocity and rate of traverse of the wheel to be a maximum. The grinding wheel is best driven at a high speed so that its operative edge will have a high surface velocity, a surface speed of about 5000 feet a minute being found to give excellent results. On the other hand, the speed of the traversing movement between the grinding wheel and the work is comparatively low, being far lower than is usual in grinding metal and less than that usually employed in grinding glass according to the old methods of grinding with abrasive wheels, with the wheel itself driven at a comparatively low speed.

It may be noted that in grinding in accordance with my method, either in the particular manner illustrated in Fig. 1, or otherwise, the particles or splinters of glass are detached without being wholly ground to powder, so that the time taken in removing material is reduced and the wear of the wheel lessened. It is found in practice that the side edge of the grinding wheel which does the principal work does not become quickly rounded, as might be expected.

Instead of being set with its axis parallel to the surface to be cut, the grinding wheel 10 may be inclined more or less, as indicated by dotted lines in Fig. 1, the edge of the wheel being then suitably shaped as indicated.

Fig. 2 illustrates the manner of grinding the edge or periphery of a disk or cylinder by means of a disk grinding wheel in accordance with my terracing method. As shown in this figure, the disk grinding wheel 11 is set with its axis *a—b* at right angles to that of the cylinder or disk 12 to be ground and with the plane of one side of the grinding wheel in the axis of the cylinder, as shown by full lines in Fig. 2, or inclined thereto more or less as indicated by dotted lines, so that the glass disk or cylinder, as it rotates slowly, is attacked by the side and sharp edge of the grinding wheel, with the resulting formation of the desired step or terrace and the removal of particles and continuous grinding backward of the step or terrace as before described, the rotation of the disk or cylinder in this case providing the relatively slow traversing movement between the work and the grinding wheel at right angles to the grinding edge of the wheel. By causing a relative movement between the grinding wheel and the cylinder or disk being ground in a direction parallel to the axis of the cylinder or disk, a true cylindrical surface will be ground; and by a bodily approaching or feeding movement between the grinding wheel and the cylinder or disk being ground, the latter may be ground to any desired size, either by grinding off a single step or terrace, or by grinding off a succession of steps or terraces.

If the cylinder to be ground is a comparatively short one, as in the case of most lenses, instead of using a disk-shaped grinding wheel and traversing it in a direction parallel to the axis of the cylinder, I find it most advantageous to use a grinding wheel having a cylindrical grinding portion annular in cross-section, such as the cup-shaped wheel 15 shown in Fig. 3, and I set such a wheel with the plane of the annular edge of the wheel parallel to the axis of the cylinder or disk 12 to be ground, and with the annular edge of the grinding wheel engaging the cylinder or disk at a point to which the plane of the annular face of the wheel is substantially tangential, so that the cylindrical edge of the wheel will form between the ground and unground peripheral surfaces of the disk an abrupt step whose side is approximately radial of the disk. In order that the surface formed on the disk shall be truly cylindrical, the axis of the grinding wheel should be located substantially in the middle plane of the cylinder or disk being ground. The annular edge of the grinding wheel is so formed that it makes contact with the ground surface only at the base of the step. The grinding wheel, as before, is driven at a high speed of rotation, and the cylinder or disk being ground is rotated slowly, the outer or peripheral edge of the wheel grinding the step backward. Since the annular edge of the cup-shaped grinding wheel lies in a plane which is parallel to the axis of the cylinder or disk being ground and tangential to its surface, a true cylindrical form is given to the surface of a short cylinder, such as an ordinary lens, without the need of any longitudinal movement between the grinding wheel and the lens. For grinding longer cylinders, however, with a cup-shaped grinding wheel, or other grinding wheel having a cylindrical grinding portion annular in cross-section, a relative movement between the grinding wheel and the cylinder in the direction parallel to the axis of the cylinder is resorted to. The annular edge of the grinding wheel will be worn back equally at all points, so that all points in such edge will at all times remain in, and describe a path lying in, a true plane, the only adjustment required for taking up such wear being an adjustment in the direction of the axis of the wheel.

Figs. 5 to 8 inclusive illustrate an application of my method to the grinding and generating of spherical surfaces on lenses, the apparatus shown being also adapted for the grinding of a plane surface on a lens or other piece of glass or similar material. As illustrated in these figures, the grinding wheel 20 is a cup-shaped wheel having a cylindrical grinding portion annular in cross-section, the annular edge of the wheel being applied to grind the surface of the lens. The lens or disk of glass 21 to be ground is mounted in a chuck 22 on a rotating spindle 23 which is usually mounted so that it may be given a longitudinal feeding movement to feed the lens toward the edge of the grinding wheel. The grinding wheel is mounted with its axis of rotation in, or approximately in, a plane in which the axis of the work spindle 23 lies, and the wheel is set so that as it rotates its annular grinding edge will sweep over the center of the glass disk 21 carried by the work spindle; and the grinding wheel spindle 24 is mounted in bearings in a swinging support 25 mounted to turn about an axis which is perpendicular to the axis of the work spindle and which, in order to permit the inclination of the axes of the wheel spindle and work spindle to be varied without displacing the edge of the wheel from the center of the work, passes through the line of the axis of the work spindle at the point of contact of the edge of the grinding wheel with the work. The axes of the grinding wheel spindle and of the work spindle may thus be variously inclined to each other while remaining in the same plane, or in closely adjacent parallel planes, by swinging the work spindle support about its swivel, such varying of the inclination of the axes causing no displacement of the edge of the grinding wheel from the center of the work. For taking up wear on the annular edge of the grinding wheel, provision is made for advancing the wheel longitudinally of its axis of rotation, as by forming its swinging support 25 of an upper part 2 adjustable in the direction of the axis of rotation of the wheel on a lower part 5, as shown in Fig. 8. The grinding wheel is driven at a high rate of speed, and the work spindle rotates at a low rate. The upper part 2 of the support should also be transversely adjustable on an intermediate part 3 as shown, and the support is also formed to provide for vertical adjustment of the wheel as indicated at 4, such vertical adjustment permitting a small adjustment of the wheel in the direction longitudinal of the axis of its swinging support, so that the wheel may be set with its axis slightly above or below the plane of the work spindle axis which is normal to the axis of its swinging support.

When the axis of the grinding wheel is set parallel to the axis of the work spindle, as shown in Fig. 5, a plane surface will obviously be ground on the glass 21 coinciding with the plane of the annular edge of the grinding wheel. If now the axis of the grinding wheel spindle be set at an angle to the work spindle as shown in Fig. 6, there will be ground on the face of the glass disk a portion of a sphere whose radius depends on the diameter of the annular edge of the wheel and on the angular relation between the axis of the work spindle and the axis of the grinding wheel spindle. If the spindles are set with their axes nearly at right angles as in Fig. 6, there will be ground on the face of the glass disk a convex surface whose radius approaches the radius of the grinding wheel, and at any intermediate angle at which the spindle axes may be set a curved surface will be ground whose radius is somewhere between infinity and this inner radius of the grinding wheel. By swinging the grinding wheel in the opposite direction so that the grinding is done by the outer edge of the wheel, as shown in Fig. 7, a concave surface may be ground on the glass disk and the radius of curvature of such surface will similarly depend upon the engular relation between the axes of the two spindles. By feeding the cup-shaped grinding wheel forward longitudinally of its axis of rotation as it wears away, and just enough to compensate for such wear, any change in curvature of the lens produced is prevented. By providing graduations (not shown) on the swivel of the grinding wheel support, I facilitate the setting of the machine so that it may be readily set to grind curves of any desired radius.

In grinding a spherical surface in accordance with my terracing method and by the method and means illustrated by Figs. 5, 6, 7 and 8, the grinding wheel should be set with its axis a little to one side or the other of that plane of the work axis which is parallel to the axis of the wheel, according to whether a concave or a convex surface is being ground, and according to the direction of rotation of the work, so that the depth of cut will be slightly greater on one side of the lens center than on the other. Terrace grinding will then take place on the side of the greater depth of cut, and grinding more in the nature of ordinary abrasive action will take place on the other side of the center of the lens.

The grinding wheel should be set so that its active edge just slightly overlaps the axis of the work spindle, and the wheel should rotate in the direction so that its active edge shall move from the periphery toward the center of the lens on the side of the deeper cut where the terrace grinding is taking place, thereby reducing the risk of splintering the peripheral edge of the lens.

With the work spindle and the grinding

wheel rotating in the directions indicated by the arrows in the drawings, the grinding wheel, when set for grinding a convex lens, as shown in the plan view Fig. 6, should be set with its axis slightly below the work axis, and the annular edge of the grinder should be beveled both outwardly and inwardly from a substantially sharp edge so that its outer bevel will be adapted to cut in the glass the desired abrupt step with its side substantially at right angles to the ground surface, and so that its inner bevel will make contact with the ground surface of the glass only at the base of the step. True terracing action will then take place from the periphery of the lens inward on that side of the center where the depth of cut is slightly greater, and on the other or lower side of the lens center where the depth of cut is less, abrasive action which is not true terracing will be accomplished by the inner portion of the end of the abrasive annulus which is beveled to give it clearance in the terracing action which takes place above the lens center. The difference in level of the two axes, that is, the distance between the parallel planes of the two axes, must be only very slight so that the abrasive action when the cut has any appreciable depth shall take place clear across the lens surface. It is best to make the greatest depth of cut in grinding curved surfaces in this manner less than the depth which is found most suitable and efficient for terrace grinding in other ways, as, for example, in grinding edges of lenses or in grinding plane surfaces. A depth of cut of about .005″ on the deeper side of the center of the lens where the terracing action takes place from the periphery of the glass to its center is ordinarily found about right; with a depth of say .002″ on the other side of the center where ordinary abrasive action may occur. In such case the rate of work rotation suitable for the terracing action may also suit the abrasive action, so that there is a substantial net gain in rate of grinding from employing terracing action in the major part of the work.

When the grinding wheel is set for grinding a concave lens, as shown in plan in Fig. 7, its axis should be displaced slightly in the other direction from the parallel plane of the axis of the work spindle, or slightly above the plane of the work spindle axis in the position of the parts shown, so that in this case terrace grinding will take place as before from the periphery of the lens inward on the upper side of the center and ordinary abrasive action will take place below the lens center. For such concave grinding, the edge of the grinding annulus may be formed about as shown in Fig. 7 so that on the portion of the surface ground by the outer face of the grinding wheel an abrupt step will be formed and the inwardly extending edge or face of the annulus will clear the ground surface of the lens on this side of the center, contacting therewith only at the base of the step. With regard to the angle of the step-forming face or side of the grinding wheel, it should be noted that such angle, and the corresponding angle of the step to the ground surface, will be less, that is steeper, toward the periphery of the lens than the angle shown at the center in Fig. 7; and as the rotary movement of the lens gives the highest velocity at and near the periphery where the step angle is best, and material has to be removed from a greater perimeter the somewhat excessive angle at the center is not ordinarily objectionable. By using wheels of suitable diameter any excessive angle may be readily guarded against.

It will be understood that the vertical adjustment of the swiveled or swinging support for the grinding wheel by the means indicated at 4 in Fig. 8 provides for setting the wheel axis slightly above or below the work spindle axis as and for the purpose above described.

It is to be understood that while terracing action increases the rapidity of the grinding operation, yet the grinding of curved surfaces by the means and in the manner illustrated may be accomplished without terracing, in which case the rate of rotation of the work may be faster and the depth of cut desirably less.

With the grinding wheel set as shown in Fig. 5 for grinding a truly plane surface, the axis of the grinding wheel must of course be parallel with the work spindle axis, and in such case the depth of cut can not be made greater on one side of the center of the glass disk than on the other. Plane surface grinding with such apparatus may, however, be accomplished by merely causing a relative traversing movement between the abrasive wheel and the work in a direction parallel with the plane of the annular edge of the wheel, and the whole action would then be terracing action.

Another way of grinding a convex lens and one which is specially suitable for grinding a deep convex curve is illustrated in Fig. 9. As shown in this figure, the grinding is done by means of a cylindrical or cup-shaped wheel 30 mounted with the wheel axis *a—b* and the axis of rotation of the work in a common plane, and the glass disk 31 to be ground is carried by a spindle 32 which is mounted to swing about an axis *c* at right angles to the plane in which the spindle axis and the grinding wheel axis lie, and intersecting the spindle axis at a point which is the center of the spherical surface to be ground.

A convex lens surface may be ground in

this manner in accordance with the terracing method, and for terrace grinding the annular edge of the cylindrical grinder should be shaped back from the active outer side so as to clear the ground surface, as hereinbefore explained. The side of the terrace formed on the glass is substantially square to the finished or ground surface of the lens, or to the shifting tangent throughout the operation, but is square to the original flat surface of the disk only at the end of the operation at the center of the lens where the depth of the step is relatively small. In the early stages of the operation, the original surface of the disk forms, as will be seen, an acute angle with the side of the step, and the consequent fragility of the side of the step here facilitates removal of the glass by splintering and enables the wheel to attack successfully a deeper step than it otherwise could.

The work spindle is swung slowly about to carry the work past the grinding edge of the wheel, preferably so that the grinder attacks first the periphery of the disk and grinds inward toward the center. In so grinding the work spindle may be rotated much faster than in grinding in the ways illustrated in Figs. 2 to 8 since the rotation of the work has merely the effect of increasing or decreasing, according to the direction of such rotation, the speed of the relative movement between the face of the step and the grinding face of the wheel. Usually the work spindle is rotated in the direction to cause the work at the place of contact with the grinding wheel to move in the opposite direction to the wheel, and at a comparatively slow speed, as, for example, about 100 revolutions per minute for grinding a glass disk one inch in diameter.

It is found, however, that in this way of shaping a curved surface, as shown in Fig. 9, the terracing method has not the same relative advantage over ordinary abrasive action as it has in other ways of operating; and especially where the radius of the spherical surface to be formed is relatively small, it is difficult to retain the sharp corner on the edge of and the clearance on the end of the abrasive wheel which are necessary for true terracing action, and it is found that almost as much glass may be removed in a given time in such case with ordinary abrasive action. This is probably due largely to the fact that the heat generated in grinding is distributed around the step by the rotary action of the work, this tending to lessen the splintering action desirable in terrace grinding.

It will be apparent that in all the means shown and ways illustrated for grinding glass, when operating in accordance with my terrace grinding method the abrasive or grinding wheel forms a step on the glass and, moving at high speed longitudinally of the step, attacks continuously the side or face of the step so that particles or splinters separated from the glass are free to escape. Particles of glass are thus detached and thrown off without being wholly ground to powder, and because of this the time taken in removing material is reduced and the rate of grinding increased and the wear on the grinding wheel lessened. The method permits, as has been pointed out also, and for best results calls for, a high surface speed of the grinding wheel. It should also be noted that the traversing movement between the glass and the grinding wheel transversely of the grinding edge of the wheel and of the step formed in the glass is a relatively slow movement.

As before stated, a surface speed of the grinding wheel of about 5000 feet per minute has usually been found most satisfactory, this being a safe working limit for the artificial abrasive wheels such as are usually most desirable, and being about the speed which is considered the best practice in the case of grinding metals with abrasive wheels. Such speed is much in excess of what has been heretofore commonly used for grinding glass with abrasive wheels. On the other hand, the surface speed of the work, or the relative speed of movement between the work and the grinding wheel in the direction transversely of the edge of the latter, is far lower than is usual in metal grinding and less than is usual in grinding glass by the ordinary methods. For example, in grinding the edges of certain lenses or glass disks, the depth of cut is usually best about two hundredths of an inch, and the surface speed of the work across the grinding edge of the wheel only about 5 or 6 inches per minute; and this is also a suitable speed in grinding plane surfaces of glass with a cup-shaped wheel and using a similar depth of cut. Where, however, the depth of cut is less, or the contact surface of the wheel with the work is less, as in the case of grinding a plane surface with the edge of a disk wheel and using repeated traverses of the wheel, the surface speed of the work relatively to the wheel may be correspondingly increased. And in grinding spherical surfaces by means of a cylinrical cup wheel, in accordance with my terracing method, where the wheel sweeps continuously over the center of the glass and at this point the terracing vanishes, it is impossible to have a deep cut, and it is necessary to compromise by running the work faster in order to obtain an efficient rate of grinding. In such a case a lens of 2 inches diameter may be rotated at about 60 revolutions per minute, and the feeding movement between the work and the grinding wheel may be at about .002 to .005 inch per revolution of the work. As will be gathered from the above, the thickness of the steps or terraces ground away, that is, the rate of feed, may vary quite largely.

Artificial abrasive wheels of a suitable degree of softness have been found most desirable for most grinding in accordance with my terracing method, but the method is of course not to be limited to the use of such wheels, and other suitable grinding wheels may be employed. For example, in grinding curved surfaces of very small radius with a cup-shaped grinding wheel, it has been found desirable to use a diamond charged tubular metal cutter, or grinder, since an ordinary abrasive wheel of suitable small diameter would not have sufficient durability. In using artificial abrasive wheels, it is most desirable that the bond holding the abrasive particles should be such as to hold the same with such a degree of tenacity that the wheel shall be what is ordinarily called "soft," so that when the particles of abrasive become somewhat blunt in use they may break out and expose fresh cutting particles. This is the common action of such abrasive wheels, but in grinding glass in accordance with the present method it is desirable to use wheels considerably softer than those which are best for grinding metal, and it is found desirable also to select wheels of degrees of softness to suit different kinds of glass, and generally the faster the work is crowded on the wheel the harder the wheel should be.

It is desirable that the grinding wheel and work be kept cool by means of water or other suitable cooling agent, as usual in grinding operations. For this purpose, I direct by suitable means such as the nozzle shown at *i* in Fig. 1 or at *i'* in Fig. 5 a jet of cooling liquid on to the active side or face of the wheel at a point near the wheel axis where its velocity is low, the jet being directed in the direction of rotation of the wheel. The liquid is thus supplied to the wheel without splashing and spreads by centrifugal action outwardly to the active edge of the wheel. Any suitable cooling liquid or lubricant may be used for this purpose.

The specific method which has been described in connection with Figs. 4, 5 and 6 and the apparatus shown in these figures is not claimed herein as this method and certain features of this apparatus constitutes the subject matter of my divisional application Serial No. 420,077, filed October 28, 1920. The method of grinding which has been described in connection with Fig. 9 is not specifically claimed herein as it forms the subject matter of my divisional application Serial No. 420,076, filed October 28, 1920.

What is claimed is:

1. The method of grinding glass and like hard, non-plastic materials, which comprises applying to the material the edge of a rapidly rotating abrasive wheel, and so setting and so traversing said wheel relative to the original surface of the material that a step in said surface with its side at an angle not exceeding 110° to such surface is formed and ground continuously backward, the depth of the step and the rate of traversing being such that a substantial proportion of the glass removed is removed by splintering the side of the step.

2. The method of grinding glass and like hard, non-plastic materials, which comprises applying to the material the edge of a rapidly rotating abrasive wheel, and so setting and so traversing said wheel relative to the original surface of said material that an abrupt step in such surface is formed and ground continuously backward while the abrasive wheel contacts with the surface formed only at the base of the step, the depth of the step and the rate of traversing being such that a substantial portion of the glass removed is removed by splintering the side of the step.

3. The method of grinding the peripheral face of a body of glass or like hard, non-plastic material, which comprises rotating the body of glass while applying to its peripheral face the circular edge of a rapidly rotating abrasive wheel, and so setting said wheel relative to the original peripheral face of said material that an abrupt step in such face is formed and ground continuously backward by the rotation of the body, the depth of the step and the rate of rotation of the body being such that a substantial portion of the glass removed is removed by splintering the side of the step.

4. The method of grinding the peripheral face of a body of glass or like hard, non-plastic material, which comprises rotating the body of glass while applying to its peripheral face the circular edge of a rapidly rotating abrasive wheel, and so setting said wheel relative to the original peripheral face of said material that an abrupt step in such face is formed and ground continuously backward by the rotation of the body and that the plane of the circular grinding edge is tangential to the surface formed upon the body, the depth of the step and the rate of rotation of the body being such that a substantial portion of the glass removed is removed by splintering the side of the step.

In testimony whereof I have hereunto set my hand in the presence of two subscribing witnesses.

WILLIAM TAYLOR.

Witnesses:

ARTHUR PIERCE,

DOROTHY FOSTER.