Photograph 1.

Photographing Sound*

A Fine Demonstration of Wave Motion

By Prof. Arthur L. Foley and Wilmer H. Souder

Photograph 2.

At the Chicago meeting of the American Physical Society in 1905, the senior author of this paper exhibited photographs of interference and diffraction fringes about electric discharges and fluid streams, taken by what might be called the point source shadow method.¹ The light from a point source is allowed to fall directly upon a photographic dry plate several meters distant from the source. About half way between the source and the plate is placed the fluid stream or whatever is to produce a shadow on the plate. Say the object is a stream of warm air issuing from a glass tube. The air stream maintains for a time a more or less definite lateral surface and produces diffraction fringes on the plate. The light is refracted on passing through the stream of air of density differing from the air about it, and so the stream casts a sort of shadow on the plate. The method is so sensitive that it gives a shadow of a stream of water in water. Inasmuch as a sound wave in air consists of a compression and rarefaction, the method should enable one to photograph the shadow of a wave, provided a sufficiently strong instantaneous point source of light is obtainable. Mr. Wilmer H. Souder, while teaching fellow at Indiana University, undertook the problem and succeeded in obtaining sound wave photographs, but discontinued the work to accept a position elsewhere. The writer con-

T_0 horizontally, or by moving K and K_0 vertically. Glass plates G and G_0 about 20 centimeters square are fastened to a wooden bar or rod R , arranged so that it can be rotated on a horizontal axis. In the position shown in the figure the plates are directly between the spark knobs T and K , and T_0 and K_0 , thus preventing a spark. A quarter turn of the handle of the rod R removes the plates and allows the spark to pass. In practice, however, it was found best to make the spark gaps $T-K$ and T_0-K_0 just long enough to prevent sparking when the glass plates are out of the field. Rotating the rod then causes a spark just as the edges of the plates pass through the gaps.

To get a strong sound wave at S and an intense light at I , the sparks to the knobs K , K_0 should be heavy, consequently from one to three Leyden jars L , L_0 are put in multiple with each of the jars on the machine itself. Most of the work was done with one additional jar connected to each of the machine jars.

The knobs K , K_0 are connected to the gaps S and I through a large commutator C . Thus the direction of the spark at the gaps is readily changed. It was found that the apparatus worked about equally well with the spark in either direction. The chief effect of reversing the

piece of No. 24 magnesium wire in the end of a metal cylinder M which is fastened in the end of a hard rubber rod R about 1.4 centimeters in diameter and 10 centimeters long. A wire W passing through a hole drilled in the rubber rod R connects the metal cylinder M , and therefore T_1 , with one terminal of the electric machine. G_1 is a glass tube 0.7 centimeters in diameter and 5 centimeters long, fitting tight in a glass tube G_2 , which is 1.4 centimeters in diameter and 18 centimeters long. G_2 passes through a cork C in the end E of a wooden box made of inch lumber. The rubber rod R slides back and forth (like a piston) in the tube G_2 , and thus moves M back and forth in the tube G_1 , and so changes the length of the spark gap T_1 , T_2 . Fig. 2 shows how R is connected to the lever arrangement L_1 , L_2 , which passes to the other end of the box and enables the observer there to change the light gap at will while the sparks are passing, and thus regulate the time interval, and consequently the size (diameter) of the sound wave.

T_2 is a piece of No. 24 magnesium wire passing through a cork to the wire W_2 connecting with the terminal of the sound gap. The other end of T_2 is bent at right angles as shown in the figure and adjusted so that the spark takes place along the axis of the tube G_1 . The wire T_2 is so small that its shadow is practically negligible. The source is thus an end on spark—itsself practically a point

Fig. 2.

Fig. 1.

Fig. 3.

tinued and extended the work, and succeeded in obtaining a light source many times as intense as the source previously used—so intense that, in photographing sound waves, no further increase is desirable.

The general arrangement of the apparatus in this experiment is shown in Fig. 2.

The sound wave is produced by an electric spark at the spark gap S , which will be called the sound gap. The light is produced by a second spark at the illuminator gap I , which will be called the light gap. If the sparks at I and S are simultaneous the light from I passes S before the sound wave emerges from behind the spark terminals. If the time interval between the sparks is any considerable fraction of a second the sound wave at S passes out of the field before the light from I reaches S . But when the interval between the two sparks is properly timed the sound wave at S casts its shadow on the photographic dry plate P .

The spark gaps S and I are connected in series to the spark knobs K , K_0 which receive sparks from T , T_0 , the terminals of a large electric induction machine having four rotating mica plates 30 inches in diameter, driven by a variable speed electric motor. The length of the spark gaps $T-K$ and T_0-K_0 is adjusted by sliding T and

spark direction appeared to be a slight change in the time intervals of the sound and light sparks.

The sound gap S is in series with the light gap I , nevertheless the spark at S occurs before the one at I , because of the capacity K_1 which is in multiple with the gap I , as shown in the figure. The capacity K_1 consists of from two to eight Leyden jars of the usual type, standing on a sheet of tinfoil F , with one coat connected to earth. The time interval between the sound and light sparks depends on the capacity K_1 , the greater the capacity the greater the interval. However, it is not at all necessary to have here a variable condenser or one made up of small units. One can vary the capacity K_1 between rather large limits and still keep the proper time interval by varying the circuit in other ways. The time interval is increased by decreasing the capacity L , L_0 , by decreasing the length of the spark gaps $T-K$ and T_0-K_0 , by decreasing the length of the sound gap S , and by increasing the length of the light gap I , the last having the greatest effect. One can vary the capacity K_1 by 100 per cent and readily maintain an approximately constant time interval between the sound and light sparks by merely changing the length of the light gap. The length of this gap is adjusted by means of the lever arrangement L_1 , L_2 , as will be understood by reference to both Figs. 1 and 2.

Fig. 1 is a cross section of the light gap, the spark taking place between the terminals T_1 and T_2 . T_1 is a short

source. Considerable light must be reflected from the end of the cylinder M and the walls of the glass tube G_1 , the tube acting as a sort of gun to direct the light toward the photographic plate. But inasmuch as the tube is only seven millimeters in diameter and the plate is several meters distant, the entire source is relatively a point source.

The light gap is at one end, the photographic plate at the other end, and the sound gap near the center, of a long light-tight wooden box or tube consisting of three sections, the two end sections telescoping into the central section, all painted black inside. This combination permits of a quick and independent variation of the distance between the light and sound gaps, and between the sound gap and the dry plate.

The central section of the tube is 4 feet long and 14 inches square inside. The end sections 3 feet long and 12 inches square inside, all made from planks 1 inch thick. Two additional sections, not shown in the figure, were sometimes used to get still greater distances between the gaps. Most of the pictures shown in this paper were obtained with the sound gap about 130 centimeters from the light gap, and about 1 meter from the dry plate.

The front side of the central section of the box is cut away in Fig. 2, to show the general arrangement of the sound gap.

Fig. 3 shows the details of the gap itself. P_1 and P_2 are the platinum terminals between which the sound

Photograph 3.

Photograph 4.

Photograph 5.

Photograph 6.

* Reproduced from the *Physical Review*.
¹ "Diffraction Fringes from Electric Discharges and from Fluid Streams," A. L. Foley and J. H. Haseman, *Physical Review*, Vol. 20, 1905, page 399.

Photograph 7.

Photograph 8.

Photograph 9.

Photograph 10.

Photograph 11.

Photograph 12.

Photograph 13.

Photograph 14.

Photograph 15.

Photograph 16.

Photograph 17.

Photograph 18.

Photograph 19.

Photograph 20.

Photograph 21.

Photograph 22.

Photograph 23.

Photograph 24.

Photograph 25.

Photograph 26.

Photograph 27.

Photograph 28.

Photograph 29.

Photograph 30.

spark occurs. These consist of short pieces (0.5 centimeters long) of No. 20 platinum wire soldered in the ends of brass rods bent as shown. The brass rods are held by wooden blocks arranged to slide snugly between two cleats or guides fastened on a wooden base, permitting an easy adjustment of the length of the sound gap. The two halves of the sound gap are adjusted so as to be in the same plane with the light gap so as to give but one shadow of the terminals on the photographic plate, and also, as will be explained later, to give the best shadow of the sound wave.

The sound gap must be made long enough and the intensity of the spark great enough to produce a strong sound wave, if a distinct wave shadow is to be obtained. Consequently more or less light is produced at the sound gap, where it is not wanted. Moreover, the sound gap is much nearer the dry plate than is the light gap.

The photographic plate P is carried in an ordinary 8 by 10-inch plate holder placed in the reversible back taken from an 8 × 10 camera. The end of the box was arranged to fit the camera back, light tight, in either position, of the plate. When the plate holder is removed the sound wave shadow falls directly on the ground glass of the camera back, and is distinctly seen by an observer looking through the glass along the axis of the tube; that is, with his eyes in line with the light and sound gaps and the center of the ground glass. If the experiment is carried on in a darkened room the wave shadow on the ground glass can be seen at a distance of several meters even when the glass is viewed obliquely, therefore, the waves can be seen by several observers at the same time. Indeed the camera end of the box may be removed entirely and the shadow be allowed to fall on a white screen, or better, on a large sheet of white paper, and the waves be seen by reflection. The author has used this method in exhibiting the waves simultaneously to a number of observers. The screen is placed so that the light strikes it obliquely. This gives a distorted image of the waves, but it enables one to seat all the observers in a single group in front of the apparatus.

In Fig. 2 the connecting wires are shown looped in the conventional way in order that the connections may be easily traced. In the experiment the wires were run through glass insulating tubes and as nearly straight as possible. Most of the connections were soldered. In fact many precautions must be taken if one is to obtain even an approach to regularity in the time interval between the sound and light sparks. One must be able to regulate the time interval and maintain it approximately constant, or he may expose photographic plates by the dozen and not once catch the sound wave in the position desired. By experience the writer finds that the following conditions give the best results:

The connecting wires should be of ample size. Small wires (No. 30) appear to slow down the spark and so decrease the intensity of the sound wave and the brightness of the light spark. And the tendency of the discharge to jump from the wires is much greater than when larger (No. 14) wires are used.

The Leyden jars, particularly those on the electric machine and in multiple with it, should not have the usual dangling chain for connection with the inner surface. The connection between the links of the chain and between the chain and the metal lining of the jar is entirely too haphazard to produce the regularity of charge and discharge required in this experiment. The dangling chain is a makeshift in any case.

In this experiment the jars were of the type frequently furnished with large oscillator sets. The short metal rod and dangling chain were replaced by a long rod—reaching almost to the bottom of the jar. On the end of the rod there was soldered a star-shaped disk of thin spring copper with the several radial arms bent so as to make spring contact with the inner tin foil coat of the jar. The results obtained with such jars are far more regular than those which are obtained when using chain connection jars.

Let us suppose the capacities L , L_0 , of Fig. 2 consist, respectively, of three Leyden jars, including the one on either terminal of the machine. Besides the Leyden jar capacity there is the added capacity of the machine itself, which is considerable in the case of a machine of the size and construction used in this experiment. Suppose further that six Leyden jars are used as the capacity K_1 and that the sound gap S is made about 3.5 centimeters long. The speed of the electric machine is then adjusted so that sparks will almost, but not quite, pass when the gaps TK and T_0K_0 are made, say, 6 and 7 centimeters long respectively. As explained elsewhere a spark will then occur when the rod R is rotated so as to bring the edge of the glass plates, G , G_0 , between the spark knobs. Sparks continue to pass if the glass plates are not immediately rotated out of the field. By a rapid to and fro rotation of the plates single sparks can be produced at will. This may be done by the observer himself, but preferably by an assistant. The observer stations himself so as to view the ground glass normally and by pulling the lever L_1 makes the light gap very short, say 1 centimeter long. The assistant then pro-

duces sparks at regular intervals, say 1.5 seconds. If these intervals are not approximately constant the time intervals between the sound and light sparks will vary greatly due to variation in the ionization of the air about the spark gaps, the potential of the Leyden jars, etc. At every spark the observer sees the shadow of the sound gap terminals and, if the interval between the sound and light sparks is within the proper limits, he sees also the shadow of the sound wave produced at the sound gap. If he sees no sound wave at all, but sees about the shadow of the terminals a cloud resembling a puff of smoke, it indicates that the time interval between the sound and light gaps is too long, that the sound wave has passed

Fig. 4.

beyond the limits of the field and that the hot air from the spark has had time to pass out from behind the sound gap terminals, as shown in photographs 9 and 10. The time interval must be made less. Since the length of the light gap is already a minimum the interval should be decreased by decreasing the capacity K_1 by removing one or more jars.

If the observer sees neither sound wave nor cloud about the sound gap terminals it indicates that the interval between the sound and light sparks is so short that the sound wave has not had time to emerge from behind the terminals—rather from behind the cylindrical buttons shown in Fig. 3. The observer readily increases the interval by pushing the lever L_1 and thus lengthening the light gap. If the latter is made much longer than the sound gap, sparks will not pass at the light gap. The best illumination is obtained when the light gap is about two thirds as long as the sound gap, say about 2.5 centimeters long. If at this length the interval between the two sparks is still too short to show the sound wave, the interval is increased by increasing the capacity K_1 . To get the best results it may be necessary to vary the lengths of the machine spark gaps and possibly the length of the sound gap. The latter is reached through a door or lid in the central section of the box. Several adjustments and trials may be necessary before the sound wave appears. When it does appear it repays all the time spent in trying to get it, for—if the conditions under which

Fig. 5.

the wave is formed are at all favorable—the wave shadow will stand out with surprising definition and brilliancy whether reflected, refracted, or diffracted.

At first thought it might appear that the sound waves are spherical and that their shadows should be disks, not circles, as shown in the accompanying photographs. In the case of a linear spark the waves are not spherical, but cylindrical—with curved ends. In Fig. 3 the dotted lines represent a longitudinal section of the cylindrical wave that one would expect from a spark between the points P_1 , P_2 . The cylindrical buttons B_1 , B_2 keep the wave cylindrical until it passes beyond them. The wave then takes on curved ends due to diffraction, but the intensity of the wave at the ends is far less than on the sides. In Fig. 3 the intensity of different parts of the wave is indicated by the breadth of the dotted lines. That this representation is valid is shown by photographs 1 and 2. To obtain these pictures the sound gap was turned at right angles to the position shown in Fig. 2, that is, the sound spark was at right angles to the axis of the tube and

therefore perpendicular to the path of the light from the light gap.

A moment's consideration will show why the wave shadows are always cross sections of the wave—why, in all the pictures except the first two, we do not see any shadow of the ends of the cylindrical wave. In the first place, the energy of the wave is relatively much smaller at the ends than at the sides. This means that the change in the density of the air is less at the ends than at the sides, and that light waves in passing through the ends of the sound wave suffer less change in their velocity than when passing through the sides of the wave.

In the second place, whatever deviation is produced in the light ray in passing through one end of the cylinder is largely counter-acted by the opposite deviation produced in passing through the other end.

The only rays of light that undergo uncompensated prismatic deviation are those that lie just inside the surface produced by drawing a system of tangents from the point light source to the sound wave. These light rays enter the sound wave with a large incident angle, pass along approximately parallel to the sound wave front without passing through the inner surface of the wave at all, and pass out near the other end of the lateral surface at a large angle of emergence. Such rays are deviated more or less and so change the otherwise uniform distribution of light on the plate, giving a shadow of that portion of the sound wave. In any case the only parts of a sound wave that give strong shadows are those to which tangents can be drawn that are parallel (approximately) to the light rays from the light gap. Thus the shadow closely represents a meridian section of the sound wave at right angles to the path of the light from the light gap.

Most of the work of these experiments was done with Cramer's Crown plates and a strong hydrochinon (contrast) developer. To save time the plates were developed and fixed in an Eastman tank, a dozen plates at a time. The time of development varied from 10 to 20 minutes.

DETAILS OF SOUND WAVE PHOTOGRAPHS.

Photograph 1. A longitudinal section of a sound wave from a linear spark at right angles to the axis of the tube, showing that the wave is cylindrical with approximately hemispherical ends. (Compare with Fig. 3.) In this position the light from the sound spark falls directly on the photographic plate and fogs it, and on this plate the light from the light gap superposes the shadow of the sound gap and the sound wave. Distinct sound wave shadows cannot be expected under such conditions. However the photograph shows that the wave form corresponds with the theoretical form shown in Fig. 3.

Photograph 1 shows also that the luminous discharge in air at normal pressure is striated. On the original negative the striations are quite distinct. Moreover, besides the principal sound wave the negative shows other systems of sound waves. This method of study promises to enlarge our knowledge of the conditions attendant upon the spark discharge in air.

Photograph 2. This photograph is the same as photograph 1, except that the direct light from the sound spark gap is prevented from falling on the photographic plate by placing between the gap and plate a small rectangular block of wood supported on a metal rod.

Photograph 3. A sound wave just emerging from behind the spark terminal. For this photograph and all the others except Nos. 1 and 2, the spark was axial with the tube, in the position shown in Fig. 2.

Photographs 4, 5, 6, 7, and 8 show the wave as it gradually travels outward from the source until it finally passes beyond the limits of the plate.

Photograph 9. Here the sound wave has passed beyond the limits of the plate and the hot air produced by the sound gap has had time to puff outward from behind the spark buttons. It will be noticed that in photograph 8 the puff has begun to emerge from behind the buttons.

Photograph 10. The puff at a still later time than shown in Photograph No. 9. The photograph shows how clearly changes of temperature and pressure are recorded by this method.

Photographs 11 and 12 show a wave reflected at the plane surface of a piece of glass plate about 10 centimeters wide and 20 centimeters long, held vertically a short distance from the spark gap, with the surface of the plate parallel with the gap.

Photograph 13. This shows a wave (cylindrical) reflected from a concave cylindrical reflector. The reflector was made from a piece of lead about 6 centimeters square bent around a gas pipe and held at the end of a vertical strip of sheet brass to which the reflector was soldered. Note the reflected wave front, and the reflected and diffracted waves about the edges of the reflector which are parallel to the spark gap.

Photograph 14. Wave reflected from a concave surface, here the surface of a cylindrical convex lens as described in the next paragraph.

Photograph 15. A plane wave produced by placing the spark gap at the principal focus of a convex lens of sulphur dioxide gas. The lens was constructed as follows:

A block of wood, *W*, Fig. 4, was shaped like a cylindrical lens about 10 centimeters long, 4 centimeters wide, and of the thickness desired,—almost 2 centimeters in the case of the lens used in photograph 15, more than 3 centimeters in photographs 16, 17 and 18. To form the lens space *L* a section 5 centimeters long was cut from the center of the block, except for a narrow strip *S* at the bottom, to hold the end sections in place. A rubber band *B* was stretched between the two extreme ends at the upper edge of the block and a portion of the thin edge of the block cut away just under the band so the band might be as free to move as possible. The sides of the block near the ends and the lower cross strip (the surface shaded in the figure) were coated with a light coat of thin shellac varnish. Before the shellac had time to dry the block was covered with a single collodion film with the lap on the wood strip *S*, and everywhere made gas tight by the shellac; thus forming between the collodion surfaces a cylindrical gas lens, *L*. The rubber band *B* was to keep the surfaces in position and still permit of considerable distortion of the walls of the lens without tearing the film. This was not possible when the films were pasted on lens forms having both an upper and lower rigid strip (*S*) and when the films were pasted to the form up to or close to the lens space *L*. A very few sound sparks invariably sufficed to rupture the films on such lenses, the rupture always being on the side away from the sound spark. There was no rupture when using a lens of the construction shown in Fig. 4. The points of attachment of the edges of the film are so far apart that the film has considerable freedom of motion, and is therefore not so easily ruptured. Obviously the freedom of motion is still further increased by the use of the rubber band *B*.

Collodion films are exceedingly strong considering their thickness, but they are rather stiff and they will not stretch without tearing. The writer found that a film made of so-called "liquid skin" is more flexible and extensible. The formula for the liquid skin is: 92 grammes collodion, 5 grammes Canada balsam, 3 grammes castor oil. When thoroughly mixed and free from air bubbles a small quantity of the fluid is mixed with three or four times its volume of ether. This is then poured into a glass dish with a flat bottom, or on a piece of glass plate, and the dish or plate drained at once by standing on edge. When the film is thoroughly dry it is floated off in the usual way—by allowing water to creep in between the film and the glass. The film should

dry thoroughly before one should attempt to mount it.

The gas is introduced into the lens *L* through a small glass tube *E*₁ connected with the gas generator. The gas escapes from the lens by means of the glass tube *E*₂, to which a long rubber tube is attached so that the gas can be passed into a hood or out at a window. The tube *E*₂ is larger than *E*₁, so that there may be no danger of the gas pressure increasing in *L*, and rupturing the film. A continuous flow of gas through the lens was maintained whenever the lens was in use. The sulphur dioxide gas was generated by the action of hot concentrated sulphuric acid on copper and the flow of gas controlled by regulating the heat. The pressure of the gas in the generator was maintained at about 5 centimeters of water, as indicated by a manometer attached to the generator.

All of the lens photographs show the original wave, the wave reflected from the convex surface of the lens, the refracted wave, and the wave diffracted about the upper and lower edges of the lens. The film of the lens in photograph 15 has a minute perforation in it through which the SO₂ gas escapes. The path of the escaping gas is clearly indicated.

Photograph 16. A sulphur dioxide lens—thicker than the lens of photograph 15. Here the divergent sound wave has been rendered convergent.

Photograph 17. A carbon dioxide lens. Here the refracted wave is still divergent; that is, the spark gap is nearer the lens than the principal focus.

Photograph 18. A hydrogen lens. Here, contrary to what one should expect from the velocity equation, the refracted wave has suffered practically no change in curvature. In fact the several pictures appear to indicate that the velocity of the sound wave of an explosive character is not given by the Newton equation. This fact has been observed by others.²

Photographs 19 and 20. Sound waves reflected from a parabolic reflector made from a sheet of lead 6 centimeters wide and 20 centimeters long and supported by an upright strip of brass as shown in the photographs. The spark gap was placed at the focus of the parabola. The reflected wave is plane except (photograph 20) for the disturbance produced by the hot air through which the central part of the wave must pass.

Photographs 21, 22, 23 and 24 show four different positions of the sound wave reflected by an elliptical reflector. The reflector was made from a strip of sheet

²P. Vielle, *Comptes Rendus*, 127, p. 41-43, 1898.

lead about 5 centimeters wide and 25 centimeters long bent into the form of an ellipse and the two ends of the lead sheet soldered together. It was supported on a block of wood cupped to fit it. The brass rods that support the spark terminals are so far apart (see Fig. 3) that the lead reflector is readily placed in position between them. The sound wave is produced at one focus and in photograph 24 it has almost reached the other focus. The expected symmetry of the direct and reflected waves at the center of the ellipse is shown nicely in photograph 22.

Photographs 25, 26, 27 and 28 show four positions of a sound wave reflected from and transmitted by a diffraction grating. The grating was made by cutting four equal and equally spaced rectangular slits (*O*, Fig. 5) in a strip of sheet tin 6 centimeters wide and 18 centimeters long. The slits were 7 millimeters wide and 3.5 centimeters long, with a strip of tin 7 millimeters wide between the openings. The tin was tacked to a wooden block which served as a supporting base. The grating is placed with its apertures parallel with the spark gap. In this position the shadow on the photographic plate is edge on and the location of the apertures is not shown on the plate. To correct this fault pieces of heavy wire (*W*, Fig. 5) were soldered to the upper, lower and intermediate strips of tin, so that an edge on shadow of an aperture is narrow, of a reflecting surface it is broad.

Both the reflected and transmitted system of waves are in complete accord with Huygens's principle. It seems to the writer that such photographs as these, or better, a chance to see the waves themselves, might be used by a teacher to give a concrete and definite idea of Huygens's principle and deductions from it, to students who have difficulty in forming mental images. Reality would be given to such terms as secondary waves, center of disturbance, pole of wave, wave front, common tangent, diffraction, etc.

Photographs 29 and 30. These pictures were made by substituting a curved grating for the plane grating of the last four photographs. The grating is similar to the plane grating already described except that it has eight slits instead of four, and is cylindrical—having been curved over a piece of gas pipe. It was intended that the spark gap should be on the axis of the cylinder but it was accidentally displaced slightly before the photographs were taken. This explains why the transmitted and reflected wave systems are not symmetrical with respect to the grating and the spark gap.

Lugs, Facings and Bosses*

By Francis W. Shaw

LUGS, facings and bosses are but details, yet lax consideration of their form or position may result in enhancement of cost and weaknesses in construction.

Fig. 1.

For instance, a projecting boss, as shown at *A*, Fig. 1 has several disadvantages. It is necessary that the would-be designer know these disadvantages. First, in many

Fig. 2.

cases the boss, or facing, would entail a loose piece in the pattern, apt to get out of place in the mold during ramming, and, when removed, apt to get lost in the sand. It not only entails extra work for the molder, but also extra work to the fitter in trimming it up. It hinders the painter, and particularly so if the modern style of finish by filling and rubbing down is adopted. If out of position, it has a very ugly appearance.

In modern design all such excrescences are gradually disappearing, the method adopted being that shown at *B*—a simple counter-bore in a bossless flange, to give a level seating for the nut or bolt-head.

If, however, the parts to be bolted together are as shown in Fig. 2, at *C*—made so in order to correspond in outline with other parts, or for the sake of homogeneity in appearance—a lug is better than a boss, being less conspicuous, and needing no trimming. Such a lug should never be concentric with the hole. If made as

Fig. 3.

shown in plan *C*, errors in positioning the hole will be less apparent.

In that rare case where a facing is necessary (such a case is shown at *d*), it should be carried back to the main part of the casting, as shown. This particular form of facing serves as a key to prevent the bolt turning while tightening the nut.

Fig. 4 shows a case where the bracket to be attached is made to correspond in outline with the facing. Many designers would have made both the bracket and the facing with four uniformly-rounded corners, as a consequence of which it would be necessary for the molder to joint down in the mold to allow the pattern to be withdrawn. With the form shown, the joint in the mold would be flat. Fig. 3 is a similar case, serving the same end.

It might be argued that appearances are somewhat spoiled by these changes in shape. But what is it that rules or determines fitness in this respect? Is it not merely custom—ocular training? In the old days, when

the Corinthian column, the flute, the bead, the ogee, had their vogue in machine construction, these were regarded as things of beauty. To-day, who would wish to go back to these types? In the eye of the present beholder, the new forms—simple in outline and unornamented—are vastly superior. He sees in them not only harmoniousness of form, but an incorporate fitness to

Fig. 4.

their end. He sees how this piece in form is governed by the exigencies of machining, the other by some attempt to rationalize the theoretical for some manufacturing reason. He sees not only the outward and visible forms, but the inward and invisible—the forethought of the designer expended not only to make each member a fitting part to a completed whole, but also to make it capable of filling every requirement of the pattern-maker, the

Fig. 5.

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