case of firing from a stationary ship at a target steaming at a speed of k knots per hour on a course at right angles to its bearing; we assume that there is no breeze, and that we have standard conditions in the atmosphere and ammunition.

In Fig. 5, $SS'T$ is the line of sight, MmT is the trajectory, R is the range; the sight has been set in azimuth with deflection-pointer touching the fifty-line, so the drift is compensated. T is the position of the target at the instant of firing, and t is the time of flight of the projectile for the range R. The shot will fall to the right of the target; for, during the time of flight, the target has moved to the position T; the lateral error is $TT'=kt$, and the

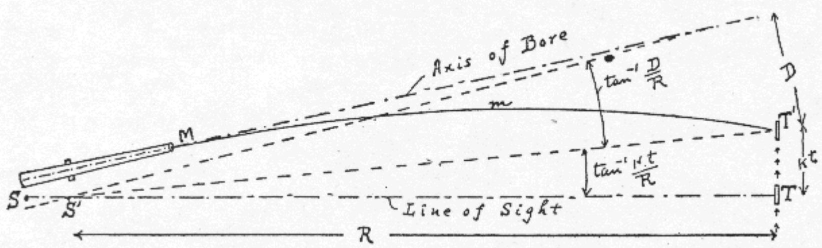

FIG. 7.

angular error is $\tan^{-1}\dfrac{kt}{R}$. To correct this error we move the pivot-bar to the left through an angle $\tan^{-1}\dfrac{kt}{R}$, which gives the condition shown in Fig. 7.

11. In the above example we will assume the range is 1000 yards, the time of flight is t_1 and the speed of the target is two knots per hour. Then, laying off on the azimuth-plate in Fig. 6 the arc $p_1n_1=\tan^{-1}\dfrac{2t_1}{1000}$, we locate the point n_1; when the pivot-bar is moved to the left so that the reference mark on the deflection-pointer is at the position n_1, the sight will be set for compensating the speed of two knots in the example given. Similarly, for ranges 2000, 3000, 4000, etc., and corresponding times of flight t_2, t_3, t_4, t_5, etc., we locate the points n_2, n_3, n_4, n_5, etc., and can lay down a fair curve through these points and n_1; then, when the sight-bar is raised to any range and the pivot-bar is

moved to the left until the reference mark touches this curve, the error due to two knots speed will be compensated when the target is moving in the direction shown in Fig. 7. The curve for compensating two knots speed when the course of the target is in the opposite direction, is plotted by laying off arcs equal to p_1n_1, p_2n_2, p_3n_3, p_4n_4, p_5n_5, etc., to the right, instead of to the left, of the fifty-line. The other speed-lines shown in Fig. 6 are computed in the same manner, using the proper values of speed, range, and corresponding times of flight. The method of numbering the lines shown in this figure obviates the use of the words "right" and "left" in designating the setting of the sight in azimuth. This avoids the errors that formerly were frequent on account of confusing right with left; it also simplifies the visual fire-control instrument, because the indication for the azimuth-setting requires only two numerals, instead of two numerals and the designation right or left.

12. Multiplying scales.—With high-power guns it is often impracticable to design the pivot-bar long enough for distinct spacing and numbering of the range-divisions at 100-yard intervals and the deflection-divisions at two-knot intervals. In such cases the range-scale is placed on a dial geared up from a rack on the sight-bar, and the deflection-scale is placed on a drum geared up from a rack on the rear end of the pivot-bar; this amounts to a mechanical magnification of the scales. As the details of the various methods of accomplishing it are readily understood upon examining the sight-mount, no illustrations are given. In sights of this type great care must be taken to keep lost motion out of the multiplying-gears; this would result in sight-setting errors in range or in deflection, or in both. Such errors are detected as follows: Lay the gun by the bore-sight on some fixed mark; then move the rear end of the sight-bar up and to the right until the line of sight is directed to some other point whose position with reference to the first mark is fixed; note the exact reading of range- and deflection-scales. Now run the sight-bar well up above, and move the pivot-bar well to the right of these readings; then by motion down and to the left come back to the noted readings. See that the axis of bore is directed to its mark; then, if the line of sight is not directed to its mark there is lost motion between the pivot-bar and the scales. The errors may be due to any of the following causes:

(a) Lost motion in the multiplying-gear.

(b) Bending of the sight-bar due to very tight fitting of sight-axes.

(c) Play in the front end of the sight-bar due to loose fitting of the sight-axes.

The above test, in the case of parallel-motion sight-mounts, should be made in dry dock or in still water with the ship moored to the dock unless both marks can be set up on the ship; the reason for this will appear later when that type of turret sight-mount is described.

13. Azimuth errors.—The speed curves on the deflection-scale shown in Fig. 6 are accurate only under the following circumstances: (a) when there is no breeze on the range, (b) when we have standard conditions in ammunition and atmosphere, and (c) when we fire from a stationary ship at a target steaming on a course at right angles to its bearing. The error that arises when the course of the target is at an angle a with its line of bearing is shown in Figs. 8 and 9. In these figures R is the range at the instant of firing; t is the time of flight for that range; T is the position of the target at the instant of firing; T' is its position at the instant of impact; I is the point of impact when the azimuth-setting is k knots to the left of the fifty-line.

It should be noted in both figures that an error in range as well as an azimuth error is introduced. In both cases the sight is over-compensated in azimuth; instead of the angle $d=\tan^{-1}\frac{kt}{R}$, the setting to bring the shot in line with the target should be, in Fig. 8, $d'=\tan^{-1}\left(\frac{x}{R+y}\right)=\tan^{-1}\left(\frac{kt\sin a}{R+kt\cos a}\right)$, and in Fig. 9 it should be $d'=\tan^{-1}\left(\frac{x}{R-y}\right)=\tan^{-1}\left(\frac{kt\sin a}{R-kt\cos a}\right)$. Since the value of $kt\cos a$ is small in comparison with R, we can neglect it and can say the approximately correct angle of compensation is $d'=\tan^{-1}\left(\frac{kt\sin a}{R}\right)=d\sin a$, and the reading of the deflection-

scale should be $(50\pm k\sin a)$. For instance, if the course of a target steaming at ten knots speed makes an angle of 45° with the line of its bearing, the approximately correct setting when the target is passing to the left will be 43 instead of 40; when it is passing to the right it will be 57 instead of 60.

14. The speed curves on this deflection-scale are not correct when we reverse the example shown in Fig. 7, and fire at a stationary target from a ship steaming at a speed of k knots per hour, even when there is no breeze and we have standard conditions in ammunition and atmosphere. This is because the mo-

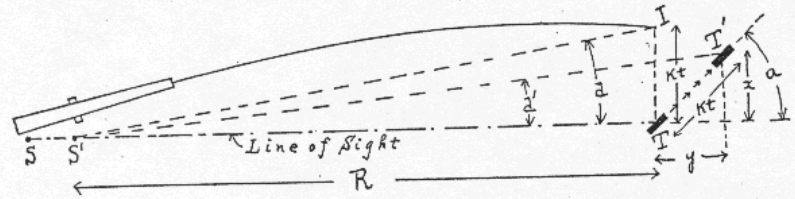

FIG. 8.

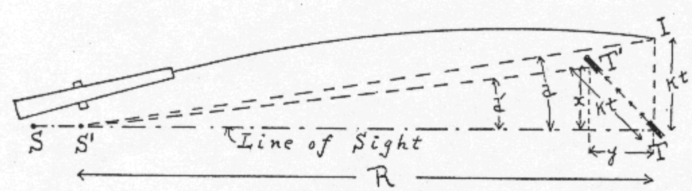

FIG. 9.

tion of the ship creates an apparent wind of k knots per hour; this gives us a wind component across the plane of fire which pushes the shot to the right when firing is to starboard, and pushes it to the left when firing is to port. If we assume that the wind component has no effect, our scale will be very nearly correct if, when we make the setting, we consider the ship is stationary and consider the target is moving at k knots (the speed of the ship) on a course opposite to the heading of the ship. The angle that the apparent course of the target makes with the line of its bearing is a, the angle that the line of bearing makes with the actual course of the ship. Then, if the target bears to starboard, our deflection-scale reading should be $(50+k\sin a)$ knots; if the target bears to port, it should be $(50-k\sin a)$.

15. When both ship and target are moving, the compensation-setting is the algebraical sum of the compensation for speed and course of the target and the speed and course of the ship. If there is no breeze, that part of the setting involving speed and course of the ship will be in error by reason of the effect of the apparent wind component. If there is a breeze, both parts of the compensation may be in error; the part involving speed and course of the ship will be affected by an apparent wind component; the part involving actual speed and course of the target will be affected by the actual wind component. It may appear from this that we should have two scales on the sight for correcting the effect of wind: one to apply on the setting for course and speed of the ship, in accordance with the apparent wind component; the other to apply on the course and speed of the target, in accordance with the actual wind component. But it is not worth while, for the following reasons, to add such a complication to the sight-mount:

(1) The actual course and speed of the target are never known accurately.

(2) The force and direction of the apparent wind at the ship may be observed with fair accuracy, and from these, knowing the speed and course of the ship, we could quickly determine the actual force and direction of the wind; but at long-range firing, these observations are not reliable for the locality of the target, and for altitudes much above the level at which they were taken; the maximum ordinate of the trajectory at modern battle ranges is more than twice the height of the ship's mast (the maximum ordinate for the 45-caliber 12-inch at 9000 yards range is 718 feet; see column 8, Range Table, 1906). Furthermore, the amount of azimuth errors in firing can be judged with sufficient accuracy by observation of the splashes, and as the length of the target is usually considerably greater than its virtual height, the correction of azimuth errors presents comparatively little difficulty to the spotter.

16. Range errors under standard conditions.—Even when we have standard conditions in ammunition and the atmosphere, it will be evident, from the preceding article, that when either the

ship or the target is steaming there will be a range error in the fall of the shot. Under the usual conditions of battle, where the differences in course and speed of ship and target are not large, this error will probably be less than the danger space. A wind component in the plane of fire will decrease or increase the range according as it is towards or away from the ship. This error is comparatively small; for instance, with the 45-caliber 12-inch gun, when the target is distant 9000 yards, a wind component of 12 knots in the plane of fire will cause a change of 39 yards in the range. (See column 13, Range Table, 1906.)

17. Range errors due to variations from standard conditions are as follows:

(a) *Change of range caused by variation of the density of the atmosphere.*—A density above unity, the density for which the range-strip is calculated (barometer 29.53 inches, thermometer 59° F.), will make the shot go short; density below unity will make the shot go over; other conditions being normal. For instance, a variation of 5 per-cent will make a change in range of 137 yards at 9000 yards range with the 45-caliber 12-inch gun. (See column 12, Range Table, 1906.) This is an error that can be foretold by observation of the barometer and thermometer (outside) immediately before firing; if the change of distance of the target is not to be considerable, it can be satisfactorily compensated by applying a correction to the initial sight-bar range equal to the error picked out for the mean distance of the target. But as the error for a given density of the atmosphere varies with the range, it is evident that this method of compensation fails when there is a wide change in the distance of the target during the firing.

(b) *Variation in the range caused by variation in the temperature of the powder.*—Temperature of the charge above 90° F., the standard for which the range-strip is calculated, will make the shot go over; and temperature below 90° will make it short. This is an error that can be avoided by keeping the magazines at the standard temperature by means of refrigeration or heating. On ships where these appliances are not installed, the worst feature of the temperature error is that magazines in different parts of the ship, for guns of the same caliber, will have different temperatures, and so the guns they supply will have different range errors. For instance, if the forward 45-caliber 12-inch magazine has a temperature of 93° and the after 45-caliber 12-inch magazine has a temperature of 87°, when the target is distant 9000 yards, the forward 12-inch guns will shoot 49 yards over while the after 12-inch guns shoot 49 yards short. (See column 10 and explanatory note in Range Table, 1906.) Here is a difference amounting to more than the danger space of 30-foot target-screen (77 yards at that range); consequently one turret may be hitting at the base of the target while the other is firing over the top edge. We must therefore apply corrections to the initial range to each gun in accordance with the temperature of the magazine that supplies it; and, since the temperature error varies with the distance of the target, we must select the correction for the mean range expected. If there is not much variation in the distance from this mean, this method of compensation will be satisfactory.

(c) *Change of range caused by variation in weight and coefficient of form of the projectile.*—A projectile of different weight from that for which the range-strip is calculated will fall short if over weight, or will fall over if under weight. For instance, a 45-caliber 12-inch projectile 5 pounds under weight will fall 20 yards over when the target is distant 9000 yards. (See column 11, Range Table, 1906.) Where the projectile is of standard weight, but is of a coefficient of form different from that for which the range-strip is calculated, the trajectory will differ in range and drift; the new long-pointed projectile has a flatter trajectory than a blunt-pointed projectile of equal weight. Of late the inspection of projectiles before issue to the ship has become so reliable that errors in the weight need not be expected. When projectiles of different coefficients of form are supplied, range- and deflection-strips for each kind are furnished.

18. The calibration of a gun is determined by firing a string of accurately aimed shots at a target bearing nearly abeam, whose distance, at a mean battle range, is accurately measured. The point of fall of each shot is plotted as accurately as possible; the

setting of the sight is the same for each shot, making the sight-bar range the same as the actual range; and care is taken that there are no errors in the adjustment or in the mechanism of the sight-mount or in the adjustment of the telescope. Prior to this the graduations of sight-strips should be checked up. The ship is moored in still water and normally trimmed; the powder is all of one index and is kept at the same temperature for each shot of the string—preferably as near as possible to 90°; the projectiles are brought to standard weight if any variation is found; and the density of the atmosphere is carefully recorded throughout the string. The mean force and direction of the wind on the range is determined as well as possible, but on account of the difficulty in getting reliable data of this kind, the firing should be done in nearly calm weather. After applying to the mean point of impact the corrections for height of bull's-eye from the water, variation from standard density of atmosphere, variation from standard temperature of powder, and the effect of a wind component in the plane of fire, and across the plane of fire, there will still be found a discrepancy between the setting of the sight in range and azimuth and the mean point of impact. A small part of the discrepancy may be due to unlevel installation of the gun-mount or improper adjustment of the frictionless trunnions, either of which will produce "tilting" of the line of sight and consequent vertical and lateral errors. The greater part of the discrepancy is due to the appearance of jump, partly vertical and partly lateral, which does not appear at the proof-firing, where the gun-mount is set up on shore on a structure which is practically unyielding. These two errors can now be compensated by shifting the range- and azimuth-strips; for example we find the mean point of impact for a string of four shots at a target distant 7500 yards is 250 yards over and 25 yards right, the sight being set to range 7500, deflection 50. Correcting the observed mean error for the height of bull's-eye and the variations from standard conditions, we find the standard error is 100 yards over and 12 yards right. To calibrate this gun in range we would raise the sight-bar to reading 7500, then shift the range strip to make it read 7600; to calibrate the gun in azimuth we would set to the fifty-line (when range reads 7500), then shift the azimuth-scale to the left the number of knots corresponding to 12 yards lateral error at 7500 yards range. (For instance with 45-caliber 12-inch, column 18 of Range Table, 1906, gives 71 yards deviation for 12 knots; then 1 knot corresponds to 5.9 yards and 2 knots corresponds approximately to 12 yards.) Calibration errors of different guns of one caliber will usually be found different; when each has had its correction applied, all guns of this caliber will bunch their shots well, when the target is at a distance that does not differ greatly from the distance of the calibration target and when its bearing is about the same, relative to the ship, as the bearing of the calibration target. A change of index of powder from that with which the calibration tests were made will make but little difference in the results, provided the powder is in good condition.

19. The line of sight was defined in Art. 1, paragraph (4), as the straight line prolonged through the front and rear sight-points; there are three principal arrangements for establishing these sight-points, any one of which may be applied to the sight-mounts described in this chapter; these arrangements are named: (a) *the open sight,* (b) *the peep-sight,* and (c) *the telescope-sight.*

(a) *The open sight* is the earliest and least efficient arrangement of the sight-points; as shown in Fig. 1, the front sight-point is the apex of a cone and the rear sight-point is the bottom point of a V-shaped notch. The chief defect in the open sight lies in the fact that the eye can not simultaneously see the target and the two sight-points distinctly; it must accommodate (focus) successively for three different distances. This sight is not only fatiguing to the eye but is inaccurate even under the most favorable conditions (namely, when both gun and target are still, and there is no difficulty in keeping the optical axis coincident with the line joining the sight-points); this is because changes in the direction and intensity of the illumination of the front sight-point will make an apparent change in its position and a consequent apparent change in the direction of the line of sight. In addition to the above, there is no magnification of the target, and

a considerable portion of its area is obscured by the sight-points. This type of sight is rapidly disappearing from the service, and its use probably will soon be restricted to revolvers and automatic pistols. At the present time it is still used on the 3-inch field gun, but the mounting for the sight-points differs from the type sight-mount that has been described above. In Fig. 10 it will be seen that there is no pivot-bar; the sight-bar is straight instead of being machined to an arc of a circle. The compensation for drift is accomplished (approximately) by fitting the

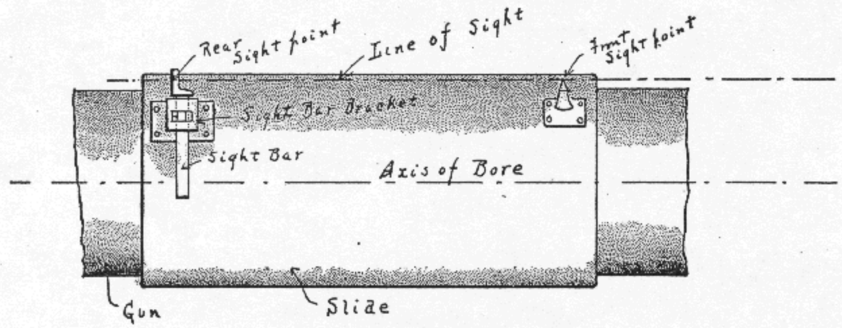

FIG. 10.

sight-bar bracket so that the sight-bar is inclined slightly to the left at a permanent angle. This is illustrated in Figs. 11 and 12. In Fig. 11, with the sight-bar at zero, the front sight, rear sight and bull's-eye are in line; in Fig. 12, with the sight-bar raised and the gun elevated until the two sight-points and bull's-eye are in one plane, it will be seen that the line of sight is pointing to the right of the bull's-eye. Now, to bring it on, we must train the gun a little to the left, which in a measure will compensate the right-hand curvature of the trajectory.

(b) *The peep-sight* is an improvement of the open sight for the reason that it requires the eye to focus successively for two distances instead of for three; Fig. 13 shows the essential parts of this type of sight.

The front sight-point in a peep-sight is about the same as in an open sight; but instead of a notch for the rear sight-point there is a circular hole in a diaphragm *d* (Fig. 13). The line of sight is defined by the tip of the front sight-point and the center of the peep-hole. It is evident that the accuracy of this type of sight depends primarily on the accuracy with which the eye is centered at the peep-hole; if r be the radius of the hole and R is the distance between it and the front sight-point, by moving the axis of the eye from the center of the hole over to the edge we shall make an angular error, called *parallax*, in the line of sight

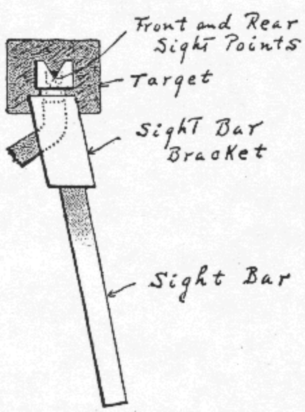

FIG. 11.

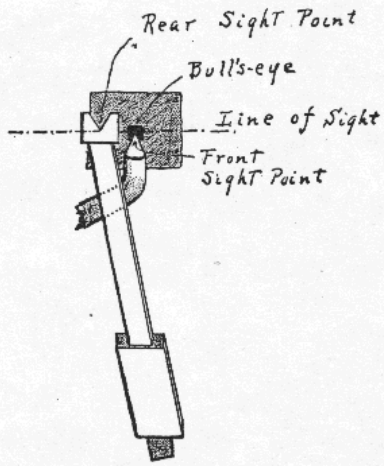

FIG. 12.

that is equal to $\tan^{-1} \frac{r}{R}$. Now the value of r determines the sectional area of the pencils of light from the target that reach the eye. Since the apparent brightness of an object of a given intensity of illumination per unit of area is dependent on the sectional area of the pencils of light from it that enter the eye, it is evident that if r_1, the radius of the eye pupil, be larger than the radius of the peep-hole, the apparent brightness of the target as seen through the peep-hole is to its apparent brightness when viewed by the unobstructed eye as the ratio $\frac{r^2}{r_1^2}$. Since the radius of the normal eye pupil when dilated at night is one-tenth inch, if our peep-sight is to be effective at night the radius of the peep-hole should be at least one-tenth inch; but with this value of r, it

is impracticable to make R, the distance to the front sight, great enough to ensure sufficient accuracy. For this reason, even if there were no others, the peep-sight could not be made an efficient night sight. However, in the daytime the apparent brightness of the target is of no consequence, and we can make the peep-hole small enough to reduce the parallax error to a negligible quantity. The peep-sight is installed on many of our sight-mounts and was designed to be the night sight, being arranged so that the front sight-point can be illuminated; but in August, 1905, after some experiments in the subject of night sights at the Naval Gun Factory, the telescope was developed to such an ex-

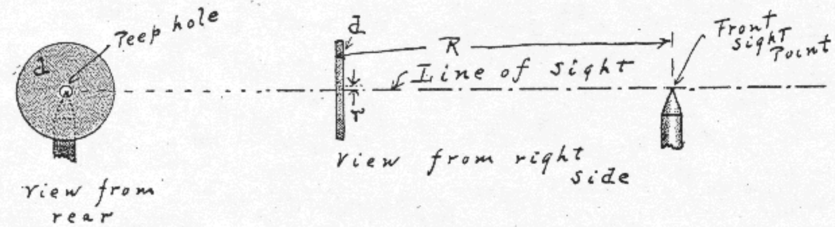

FIG. 13.

tent that its gain in efficiency over the peep-sight for night work is something over three thousand per-cent. The peep-sight is therefore retained merely as a stand-by in event of injury to the telescope.

(c) *The telescope-sight* is the most convenient and most efficient means of establishing the sight-points; it may be defined as the combination of two systems of lenses on a common axis spaced so that the second focal plane of the first system (the objective equivalent) is coincident with the first focal plane of the second system (the eye-piece equivalent), which plane contains a pair of intersecting cross-wires or etched cross-lines. There are three points in the telescope that determine the line of sight, namely: the intersection of the cross-line, and the first and second unit points of the objective equivalent. The stability of the line of sight with reference to the sight-mount therefore depends on the rigidity of the point of intersection of the cross-lines and all optical parts in front of it.