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G-5.

SAUMER ARTILLERY SCHOOL.

MANUAL OF ARTILLERY.

VOL. II.

NOTES ON ARTILLERY.

BALLISTICS AND DISPERSION.
EFFECTS OF PROJECTILES AND FUSES.
ARTILLERY MATERIELS.
AMMUNITION.

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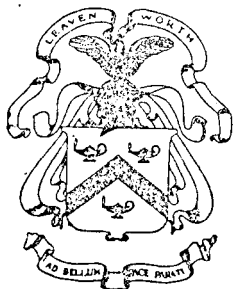
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PART I.

BALLISTICS.

FOREWORD.

USEFULNESS OF BALLISTICS.

Ballistics is that branch of the science of gunnery which treats of the motion of a projectile. Interior Ballistics treats of the motion within the bore of a gun and Exterior Ballistics of the motion outside the gun. Ballistics is concerned with all that happens from the moment the primer is struck, until the moment when the projectile reaches the end of its trajectory.

Ballistics affords, as far as its present state of development allows, an explanation for the existence of the technical regulations of the service, for the minute precautions they prescribe, for the incidents or accidents which may occur

if they are neglected; in short, ballistics gives the **import** of all matters pertaining to artillery. For example: why are there guns and howitzers? — why various kinds of powder? — why do some charges give flashes? — why does the range vary from one moment to another? — why dispersion? — why abnormal bursts? — why do various noises occur at the moment of the shot? — why do guns wear out? — what is the cause of swellings, of premature bursts, etc.?

These are all questions, the answers to which are provided by ballistics.

CHAPTER I.

PRESSURES AND VELOCITIES.

THEIR DEVELOPMENT.

THEIR EFFECTS ON THE PROJECTILES AND THE GUN.

ART. I.

GENERAL CONSIDERATIONS.

After the gun has been loaded, the projectile lies in the bore, with its rotating band fitting closely a tronconic part called the forcing slope, at which the rifling begins (fig. 1).

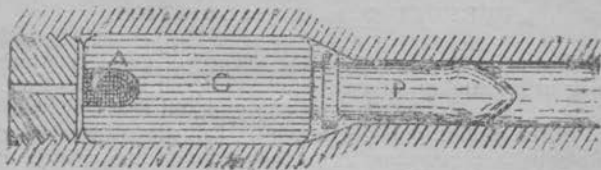


Fig. 1.

Behind the projectile P lies the propelling charge, made of smokeless powder (B, US₃, Ballistite, etc...) contained in a bag of cloth or a metal cartridge-case.

A certain quantity of black powder, called the igniter is placed at the base of this charge. Finally, a primer, of some kind is used to fire it.

The flame from this primer ignites the black powder almost instantaneously and the explosion of the latter creates a temperature (about 200° c.) and a pressure (200 kg. per cm^2), both necessary for the ignition of the smokeless powder under favorable conditions.

This ignition is **propagated** along the surface of the powder elements with a speed such that their **inflammation** may be considered as instantaneous (1).

This period of inflammation is followed by that of **combustion**, during which the flame proceeds with regularity from the outside to the inside of the powder sticks or grains which make up the charge.

The duration of this combustion — usually less than that of the travel of the projectile through the bore — may vary between one thousandth and thirty thousandths of a second.

The motion of the projectile, due to the pressure exerted on its base by the charge gases, does not begin until this pressure has reached an amount sufficient to overcome the resistance due to the forcing (2) the amount of which varies from 200 to 400 kg. per sq. cm., according to the materiel used (10 tons for a 75 projectile).

At this moment the projectile starts, and the development of the pressure depends upon two causes, which have opposite effects :

- a) The production of the gases, which tends to increase it;
- b) The enlargement of the space afforded them, which tends to decrease it.

At the beginning of the motion, the first cause is predominant and the pressure increases. Later, the second cause prevails and the pressure decreases.

Meanwhile, it has passed a **maximum** which, according to the various loading conditions, is reached when the projectile has travelled through a length of the bore equal to two to eight times its caliber.

This phenomenon is illustrated by fig. 2 in which the abscissæ indicate in calibers the distances travelled by the base of the projectile, and the ordinates the pressures, in

(1) By instantaneous it must be understood that the duration of inflammation is very short when compared with that of combustion. But there is no absolute instantaneousness and it appears that the mode of inflammation has a great influence upon the accuracy of fire.

(2) i. e., the difference between the diameters of the rotating band and the bore, measured between the groove bottoms.

kilograms per square centimeter, exerted by the gases on its base.

It will be noticed that the pressure is still considerable at the moment when the projectile leaves the muzzle.

The velocity of the projectile increases continuously during its travel through the bore; it also continues to increase for a short distance beyond the muzzle, under the action of the gases issuing from the muzzle at high velocity and impinging against the base of the projectile. The diagram of

DIAGRAM OF PRESSURES.

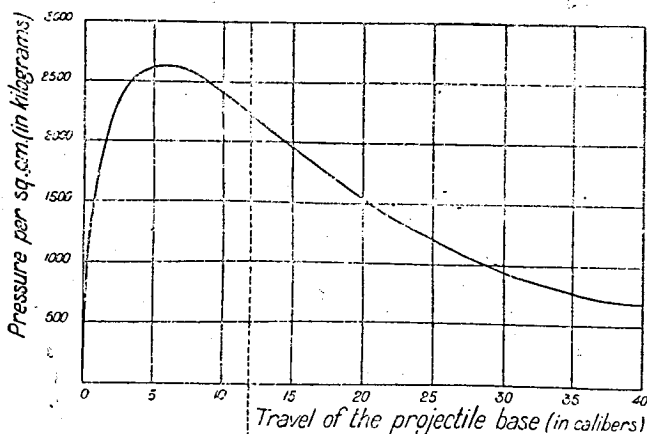


DIAGRAM OF VELOCITIES

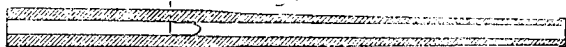
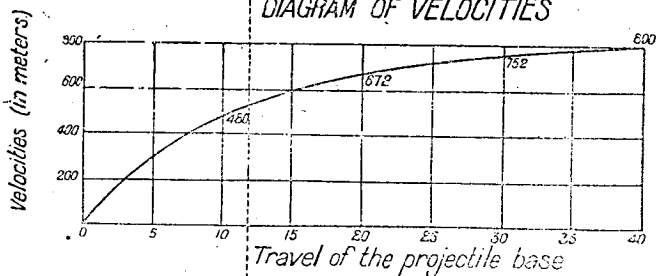


Fig. 2.

velocities (fig. 2) in which the abscissæ indicate the distances travelled by the base of the projectile, and the ordinates

the velocities at the corresponding points, illustrates this phenomenon.

The methods for the calculation and measurement of pressures and velocities, which pertain to ballistic experiments, will not be considered here, but their effect upon materiel will be studied.

ART. II.

EFFECTS OF PRESSURE ON PROJECTILE AND GUN.

The pressure, exerted in all directions, tends to blow out the breechblock and burst the tube, at the same time that it propels the projectile, but modern guns have a sufficient resistance to withstand this pressure with a reasonable factor of safety.

Projectiles also must be designed so as to have sufficient strength and in this connection it is necessary to study the action of pressure upon a projectile.

A pressure equal to several thousand times the weight of the projectile is exerted against the base of the projectile (1). This pressure is transmitted through the projectile in diminishing amount to its point, its amount at any section of the projectile being that necessary to accelerate that portion of the projectile in front of the section.

For example, in the case of a 75 shell, weighing 5.315 kg., acted upon by a pressure of 1800 kg. per sq. cm., the total pressure to which it is submitted is :

$$1800 \times \pi \times \frac{7.5^2}{4},$$

i. e. approximately 15000 times its own weight (2). In particular, all the interior load will have a tendency to settle in the projectile body as if acted upon by a powerful press. If the walls are not sufficiently strong they will swell out, sink into the grooves of the bore and then cause so much friction that the motion of the projectile may be retarded or even it may be completely stopped. The powder gases, thus suddenly checked in their expansion, act on the walls of the tube in a manner similar to the water-hammering in a pipe

(1) See Ammunition.

(2) This ratio of the total pressure on the base to the weight of the projectile — owing to the principle of forces being proportional to accelerations — is equal to the ratio of the acceleration imparted to the projectile by the pressure, to that which would be imparted to it by its own weight. For this reason this ratio has been named **coefficient of acceleration**.

when the tap is suddenly turned off. This may cause the tube to swell (fig. 3), and sometimes the breechblock to be

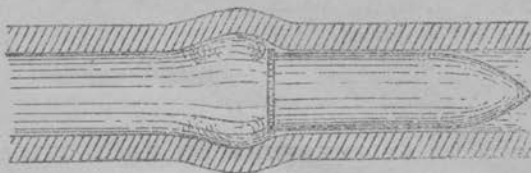


Fig. 3.

blown out. Worse may happen, for by settling against the base of the projectile, the whole charge of the latter may be **exploded** (as happens sometimes under much smaller pressures, when projectiles are being loaded) and cause a more or less complete **rupture** of the tube (fig. 4).



Fig. 4.

Finally, the fuse may act under this shock, in which case there will be an **instantaneous detonation** of the whole charge, the gun will be destroyed and its fragments flung broadcast (fig. 5).

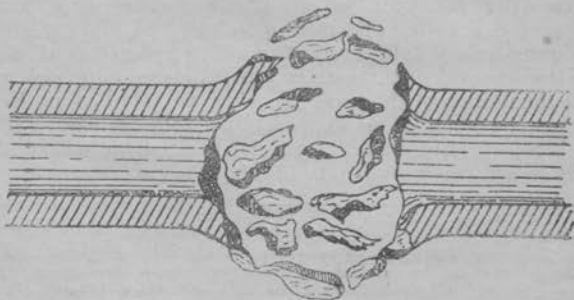


Fig. 5.

These accidents — due to the projectile having undergone too great a pressure (1) — show the necessity :

a) For the officer in charge of Ammunition Inspection to insist upon an exact compliance with the regulation tests, which are intended to insure the strength of the projectile and the compactness of its load, and not to countenance approximation under the pretext that "a shell is always good enough to be fired at the Boches", as was sometimes heard in the early days of the war;

b) For the battery commander **never** to fire any projectile mentioned as suspicious in the instructions emanating from higher authority, and **never** to use with a given type of projectile a charge heavier than the regulation charges, *e. g.* never to fire semi-steel shells with charges intended for steel shells.

In particular, in the case of trench mortars, the range of which is small, there may be a temptation to increase the charge in order to obtain a longer range : the danger of a premature burst is all the greater in this case as the chlorated explosive which constitutes the bursting charge of the bombs is apt to settle suddenly through an excess of pressure, because it was not very strongly compressed when loaded, and also because it is naturally **very sensitive to friction**.

As soon as the least play — be it even a few tenths of a millimeter — exists between any two parts of the projectile or of the fuse, these may be thrown together by the shock of discharge, and bring about, by the violence of the shock, a more or less complete detonation of the projectile.

A few examples follow :

1. The first H. E. shells, put in service some thirty years ago, caused premature bursts because the melted explosive with which they were loaded shrunk on cooling (fig. 6). This produced pockets, the roof of which, collapsing on the departure of the projectile, produced fragments of explosive, the impact of which on the bottom of the pocket exploded the bursting charge.

2. Some H. E. shells used to contain, underneath the booster, a tube A full

of phosphorus, intended to increase the visibility of the

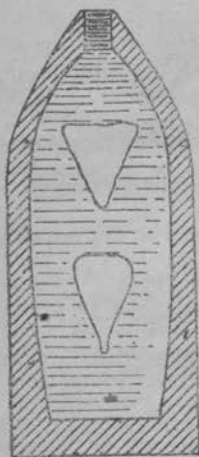


Fig. 6.

(1) This explanation does not, of course, cover all cases.

burst. As the result of insufficient compression of the explosive on loading, it happened that the tube A was brought violently into contact with the explosive at B and exploded it (fig. 7).

Booster casing.

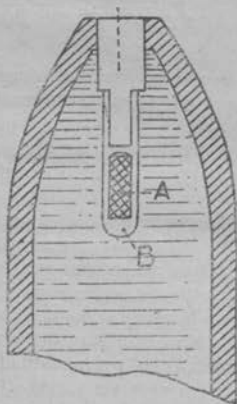


Fig. 7.

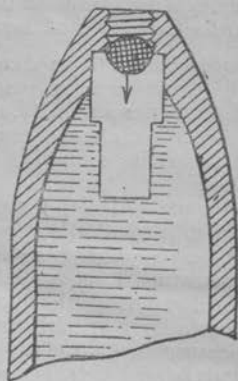


Fig. 8.

3. A commission, having to execute test fire with loaded but unfused projectiles, conceived the idea of closing the threaded eye of the booster casing with a lead plug. When the projectile was fired, this plug came violently into contact with the bottom of the booster casing like a bullet and exploded the charge.

4. Some 58 trench mortar bombs fitted with IT fuses (free striker fuses in which the striker is made fast by a safety pin) produced bursts on departure without any apparent causes. Close examination of these bombs revealed that in the course of transportation, their tails had become slightly unscrewed, thus creating a small clearance, sufficiently great to cause the breakage of the pin by the shock of discharge and consequently the explosion of the projectile (fig. 9.).

5. When the section of a fuse is considered, or the rules concerning fuses are studied, at each joint will be found felt washers, which serve to wedge all the parts which on departure might strike against one another or be displaced, *e. g.* felt washer under the shoulder of the primer tube in 24-31 fuses; felt washers at the base of the 1895-1904 Model detonator. This is a precaution against the effects of inertia on departure.

The examination of shells selected from lots which had given premature bursts has shown that these bursts might often be attributed to the inobservance of these regulations.

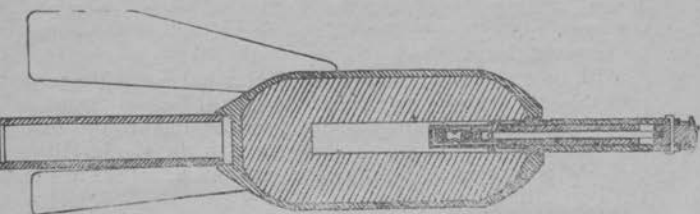


Fig. 9.

The preceding considerations make it easy also to understand the operation of the **arming of fuses** through inertia.

This is developed in the discussion of ammunition, but special stress is here laid on the following particularly important point :

The ease with which a fuse is armed depends only upon the ratio of the total pressure upon the base to the weight of the projectile (coefficient of acceleration), and not upon the muzzle velocity of the projectile.

EXAMPLE :

Assume that it is desired to compare — from the point of view of the ease with which the arming takes place — the same fuses fitted on a 75 m/m shell and a 300 m/m shell, fired with the same pressure (1800 kg. per sq. cm.).

In the first case (75), the ratio of the pressure to the weight (coefficient of acceleration) will be :

$$\frac{1800 \times \pi \times \frac{7.5^2}{4}}{5.315}$$

or about 15000.

In the second case the caliber of the shell is four times as great, the surface of the base is 16 times as great, and the same is true of the total pressure. But the weight of the shell, being proportional to the cube of the caliber, becomes 64 times as great. The ratio of the pressure to the weight is therefore one fourth as great, *i. e.* 3750.

It is therefore evident that the pressure exerted by the plunger upon its spring is, when the pressure is the same,

much smaller with large caliber than with small caliber projectiles.

The above considerations explain the difficulties involved in the fusing of very large caliber shells, which are to be fired with a low pressure, and for which fuses have to be devised that possess at the same time great sensitiveness and sufficient safety in handling.

With guns of the same caliber, but of different lengths, the same muzzle velocity will be accompanied with a greater pressure in the howitzer than in the gun. Therefore certain fuses will be armed in the 155 howitzer with a given muzzle velocity, and will not be armed in the 155 gun with the same velocity.

In the same piece — for reasons which will be given further on — the various reduced charges are not always made up of the same powder; a case in point is the 75 :

No. 1 reduced charge, giving a muzzle velocity of 344 m/s consists of 250 gm. of B C powder.

No. 2 reduced charge, giving a muzzle velocity of 290 m/s consists of 160 gm. of B G₀ powder.

And the latter, much quicker, gives a maximum pressure slightly greater (750 kg. per sq. cm.) than the first (700 kg.): hence the case with which fuses are armed will be greater with charge No. 2 than with No. 1, contrary to the conclusion that might be reached by a superficial examination of the question.

The following table gives, as examples, the values of the coefficient of acceleration corresponding to various charges for the 220 mortar and the No. 2-58 trench mortar.

MATERIEL.	PROJECTILE.	CHARGES.			MUZZLE velo- city.	MAXIMUM pressure.	COEFFI- CIENT of accele- ration.
		No.	Weights.	Nature.			
220 Mortar. 1880 Model.	Long shell. 1909 Model 100 kg....	0	2.300 kg.	B C	256 m.	1700 kg.	6450
		8	1.200 —	B C	173 m.	700 —	2650
		14	0.900 —	B C	146 m.	400 —	1500
No. 2..... 58 Trench.. Mortar..	 16 kg. Bomb.	....	0.110 kg.	B C	80 m.	1050 —	1730
		....	0.085 —	B C	70 m.	550 —	910
		....	0.060 —	B C	57 m.	250 —	410

The following table gives the minimum value of the coeffi-

cient of acceleration necessary to insure the arming of the principal fuses in use :

FUSES.	VALUE of COEFFICIENT.
24/31 I fuse 1914 Model.....	3600
22/31 combination fuse 1897 Model or 24/31 combination detonating-fuses 1916 and 1917 L. D. Models.	2500
24/31 percussion detonating-fuses 1899 and 1899-1908 Models.	2500
24/31 percussion detonating-fuses 1899-1915 Model S. R., C. R. or L. R.	1800
Schneider base fuse.....	2000
S. M. or 30/45 fuse 1878-81 M., 1915 Model.....	1250
P R percussion detonating-fuse 1916 Model.....	400
R Y percussion detonating-fuse 1917 Model.....	400

The firing tables give (in the Introduction) the fuses which are to be employed with the various charges.

Should new models of fuses be put into service, they must not be used before it is known with what charges they are to be employed.

On account of lack of this information, quantities of shells were wasted when the I fuses were put into service because the pressures developed by the reduced charges with which they were used were insufficient to arm them.

When the projectile moves, the gun moves to the rear, under the influence of the pressure which causes the recoil and which is slightly greater than that which causes the movement of the projectile (1).

In the same manner, as each element of the projectile is impelled by the pressure towards the front with a force equal to the product of its own weight multiplied by the ratio of the total pressure of the gases to the weight of the projectile (coefficient of acceleration of the projectile), so each element of the gun is impelled by the pressure toward the rear with a force equal to the product of its own weight multiplied by the ratio of the total pressure of the gas to the weight of the gun (coefficient of recoil acceleration of the gun).

NUMERICAL EXAMPLE:

In the case already examined of a 75 m/m projectile, the pressure on the gun is about 85000 kg.; hence as the recoil-

(1) There exists between the two the following ratio: Pressure upon gun = Pressure upon base $\times (1 + \frac{1}{2} \frac{\omega}{p})$, in which ω represents the weight of the charge and p that of the shell.

ing mass weighs about 500 kg., the ratio of the pressure to the weight (coefficient of recoil acceleration) will be about 170, and each element of the recoiling part of the gun will be, at the moment the shot is fired, impelled toward the rear with a force equivalent to 170 times its own weight.

Just as the shock of discharge on the projectile is made to arm the fuses, the same effects on the gun are made use of to arm the safety devices (plunger in the 75 m/m gun, for instance).

Just as the shock of discharge on the projectile may have harmful consequences in causing swellings or explosions, the same effects on the gun may bring about the breaking or bending of the insufficiently secured parts of the recoiling mass.

ART. III.

MUZZLE VELOCITY AND RECOIL VELOCITY.

Knowledge of the muzzle velocity permits :

1. The computation of the firing tables, as will be explained further.
2. The determination of the recoil velocity of the gun : for, there exists between the recoil velocity of the gun and the muzzle velocity of the projectile a very simple relation :

Let w be the weight of the projectile,
 — W be the weight of the recoiling mass,
 — V_0 be the muzzle velocity of the projectile,
 — v be the velocity of the recoiling mass,
 — ϖ be the weight of the charge

$$Wv = wV_0 \left(1 + 2.5 \frac{\varpi}{w}\right).$$

NUMERICAL EXAMPLE :

Assume that $W = 500$ kg.

— $w = 5$ kg.

— $V_0 = 500$ m. per second.

— $\varpi = 500$ kg.

this will give :

$$v = \frac{1.25 \times 2500}{500} = 6.25 \text{ m. per second.}$$

Just as the projectile is checked by the resistance of the air, so is the gun checked and finally stopped in its recoiling motion by the resistance of the recoil apparatus. It stops when its kinetic energy has been completely absorbed by the resisting work of the latter.

EXAMPLE :

In the preceding case the recoil kinetic energy of the gun would be :

$$\frac{1}{2} \frac{w}{g} v^2 \text{ or about } 1000 \text{ kilogrammeters.}$$

Assume that the recoil apparatus offers — as has been frequently realized in practice — a constant resistance $R = 800 \text{ kg}$. The gun will stop after travelling a length x such that

$$Rx = 1000 \text{ kilogrammeters.}$$

$$x = \frac{1000}{R} = \frac{1000}{800} = 1.25 \text{ m.}$$

As will be shown later, it is extremely difficult to obtain powders imparting to projectiles **identical** velocities, even with charges of the same lot of powder, and one of the greatest difficulties met with in adjustment is due to the greater differences between various lots of powder.

It will now be seen how the very simple principles just developed enable this difficulty to be obviated in some cases.

Assume that the muzzle velocity imparted to a projectile by powder from a certain lot is not the same as that from another lot previously employed. In the field there are no means of measuring directly this difference in velocity.

But to this new and unknown muzzle velocity corresponds a recoil velocity different from the first, and hence a different **length of recoil** : *e. g.*, for a 155 Gun 1877-1914 Model, a variation of two millimeters in the length of recoil corresponds to a variation of one meter in muzzle velocity.

This materiel is provided with a **recoil index**, with the help of which the length of recoil may be determined, and the new and unknown velocity deduced. This will render possible the computation from the firing tables of the corrections to be made in order to bring the point of fall to its former place (1).

(1) On account of the liquid in the recoil apparatus becoming heated in the course of quick and prolonged fire, the resistance of the recoil apparatus increases progressively, and causes a slight diminution in the length of the recoil. Hence, if the above method is to be applied correctly and to

Tables VI in the Firing Tables indicate the variations in range corresponding to this variation in muzzle velocity and thus the modification to be made to the elevation.

This method has been applied with great success in certain batteries of H.F.A.

ART. IV.

DISPLACEMENT OF THE GUN DURING THE MOVEMENT OF THE PROJECTILE IN THE BORE. INFLUENCE OF THE PLATFORM ON THE ACCURACY OF FIRE.

Under the considerable pressure exerted on the breech-block, the gun begins its recoiling motion while the projectile is moving in the bore, but — for L.F.A. and H.F.A. materials in which the weight of the recoiling mass is considerable as compared to that of the projectile — the displacement of the gun is of small magnitude.

It can be demonstrated indeed that the displacement e of

give accurate results, it is advisable to measure the lengths of recoil obtained by firing **two consecutive rounds**, so that the conditions of resistance have varied but little.

As, besides, a single measurement would not afford an accurate determination, it is advisable to repeat it several times, alternating the two charges to be compared.

NUMERICAL EXAMPLE :

Fire for effect is being executed with charges from a certain lot of powder; this lot is about to be exhausted and fire will have to be continued with a new lot. Five charges will be set apart from the old and five from the new one. These will be fired alternately, and their several lengths of recoil measured as in the following table :

No. of ROUNDS.	POWDER LOT.	LENGTH of RECOIL.	DIFFE- RENCE of RECOIL.	MEAN.	CORRES- PONDING dV_0 .
1	Old.....	1.224 m.	12	12	+ 6 meters.
2	New.....	1.236 m.	13		
3	Old.....	1.224 m.			
4	New.....	1.237 m.	12		
5	Old.....	1.225 m.			
6	New.....	1.237 m.	13		
7	Old.....	1.225 m.			
8	New.....	1.238 m.	11		
9	Old.....	1.226 m.			
10	New.....	1.237 m.			

the recoiling weight W (the latter being assumed to be free to move along the axis of the bore), is connected with the displacement E of the projectile by a relation of the same kind as that mentioned with regard to pressures.

$$We = wE \left(1 + \frac{1}{2} \frac{\omega}{w} \right)$$

This, when applied to the preceding example of a 75 gun firing under the above conditions, and in which the projectile would travel 2 meters, will give:

$$e = 0.022 \text{ m. (1)}$$

This longitudinal displacement is accompanied by a slight rotating movement around a horizontal axis; hence a slight difference between the quadrant angle of departure and the elevation that the axis of the bore had before the round was fired. This difference is called the *jump*. This jump is fairly small with the 75 materiel (1' to 7' according to the kind of projectile) - greater with howitzers (17' with the 65 mountain Howitzer; 33' with certain charges in the 120 Howitzer). It is negative with some guns (- 10' with the 100 m/m gun 1897 Model).

Finally there is a slight shift in direction which causes the plane of departure to make a small angle with the plane of fire. This angle is always very small ($< 4'$) and is called angle of lateral deviation.

It must be remembered that, in practice, no account has to be taken of these angles, as they have already been accounted for in the computation of the firing tables. **No correction must therefore be made on account of them.**

With trench mortars in which the ratio of the weight of the projectile to the weight of the gun is not so small, but in some cases reaches $\frac{1}{4}$, the ratio of the velocity of recoil to the initial velocity is about the same as the ratio of the weights, as well as the ratio of the length of recoil of the piece to the length of movement of the projectile in the bore.

This point must be insisted upon, if one of the main difficulties which have to be contended with, when firing such

(1) Let it be noted, by the way, that the presence of the recoil apparatus does not alter sensibly the value of this displacement, for the resisting force of the recoil apparatus (*e. g.*, 1000 kg.) is negligible when compared with the pressure exerted on the breechblock and which in the above example reaches 85 tons.

It is during this displacement that the pawl is armed. It is only after this displacement that the recoil apparatus begins to operate, in order to absorb the kinetic energy imparted to the gun by the charge gases

matériel, is to be well understood. Assume that fire is executed at the same time with two mortars, weighing 200 kg. each and throwing 50 kg. projectiles with a 60 m/s. muzzle velocity. The first recoils freely, the second is so placed that it cannot recoil: under these conditions, the first will have, when the projectile leaves the bore, a recoil velocity of 15 m/s., so that the actual velocity of the projectile on departure will only be $60 - 15 = 45$ m/s. which (with a quadrant angle of departure of 45°) corresponds to a range of about 300 m.; while, with the other mortar, the actual velocity being 60 ms., the range will be about 360 m.

In practice, mortars will not be placed under conditions corresponding to these extreme cases, but to intermediate cases; they will, during the departure of the projectile, undergo displacements more or less great according to the nature of the ground on which they rest.

This explains why the stability of the platform has a capital influence on the accuracy of these mortars.

On the other hand, it would be inadvisable to check entirely the recoil of these matériels when, as in the case of some of them, they are not provided with a recoil apparatus, for the considerable force which tends to cause this recoil would rapidly loosen the assembled metal parts and put all the matériel out of service.

This is the reason why the platform, which must be stable, *i.e.* not get out of true, must also not be entirely lacking in elasticity. Really remarkable results have been obtained by the use of wooden platforms mounted on thick shoes of compressed cork.

CHAPTER II.

ELEMENTS CONTROLLING VELOCITIES AND PRESSURES.

ART. I.

GENERAL CONSIDERATIONS.

The development of pressure and velocity depends on the following elements :

1. The charge: Its composition (kind of powder
Its condition ;

Its arrangement in the chamber :

The way in which it is fired ;

Its weight.

2. The projectile : Its weight ;

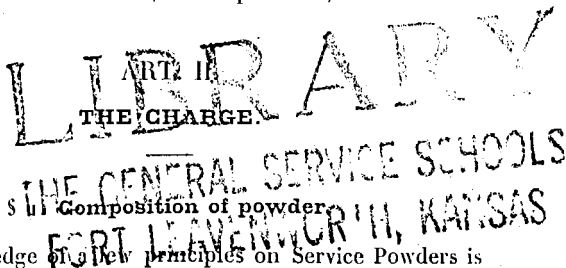
The form and position of the rotating band or bands

Its condition as to lubrication,

3. The tube : The volume of the chamber ,

The volume of the tube ;

The wear of the tube, its temperature, etc.



The knowledge of a few principles on Service Powders is necessary if this chapter is to be understood.

Until the end of the 19th century, guns were loaded with black powder, consisting of a mixture of charcoal, potassium nitrate and sulphur, the first being the combustible element, the second the oxidizing element, and the third serving mainly to facilitate the ignition. These powders, dangerous to manufacture (1), had the following great disadvantages from the ballistic point of view :

1. Thick, solid residues which foul the bore, and make it necessary to clean it after each shot, thus rendering impossible the execution of rapid fire, **however perfect the material may be.**

2. Thick smoke revealing the position of the gun.

3. Too great a quickness, i. e., too great a speed of burning, owing to which they cannot be used — as will be explained further on — in guns firing with a great muzzle velocity.

In consequence, since the invention of chemical powders, the black powders are no longer used as gun powders, but :

a) As an aid to ignition, for B powders in charge bags;

(1) Black powder will explode by ignition, percussion and friction, even when not in a closed space.

b) For loading shrapnel or case shot — or cast iron shells for range practice;

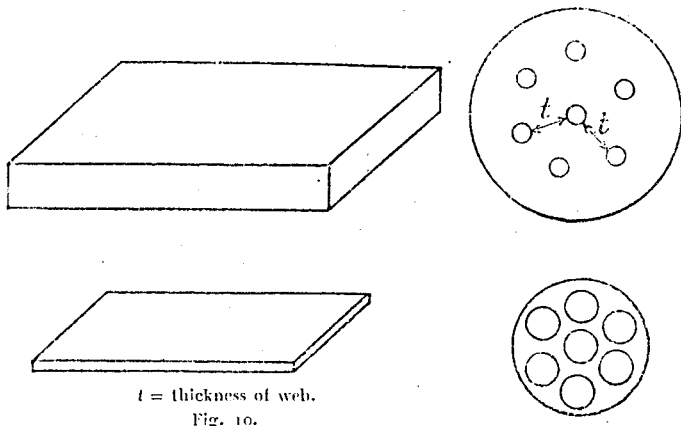
c) For ignition or transmission of fire devices.

In colloidal powders, on the contrary, the combustible and oxidizing elements are in a state of chemical combination.

These elements are, in nitrocellulose powders such as the French B and American US₃ powders **cotton** and **nitric acid**. These two bodies, when combined, form **gun-cotton** which, after being kneaded with ether, alcohol, drawn out and dried, makes up the colloidal nitrocellulose powders⁽¹⁾.

These have the following advantages over black powders :

1. No solid residue, and, therefore no fouling;
2. No smoke;
3. Quickness adjustable at will, according to the size and shape of the grains or strips of powder, as colloidal powders burn in parallel layers, *i. e.*, the combustion is propagated inwardly in a fairly even manner from the surface (see fig. 10),



(1) Nitrocellulose may also be brought to a colloidal state by incorporation in a very powerful explosive, **nitroglycerine**. Powders so constituted have for an equal weight a greater ballistic power than the powders mentioned above, but their drawback is that they cause a speedier wear of the tube, owing to their high temperature of combustion (British Cordite, Italian ballistite, German navy and High Power Artillery powders). These effects of erosion may be lessened by the admixture of other chemicals as in the case of **weakened ballistites**, composed of nitrocellulose, nitroglycerine and dinitrotoluene and cut into flat squares the thickness of which is $\frac{1}{10}$ of the side, which are used in France for howitzers and mortars.

and the rate at which gas is emitted is a direct function of the area.

The speed of this combustion, *i.e.* the quickness with which the thickness or thickness of web of the powder decreases, depends, for a given type of powder only, on **the pressure developed by the combustion gases**, and increases rapidly with this pressure (1).

It is plain therefore that, if equal weights of colloidal powder of the same nature — but of different thicknesses — are ignited within chambers of the same capacity, the thicker powders, having a total surface smaller than the thinner ones, will give forth a smaller quantity of gas during the first moments after ignition. The pressure will consequently increase more slowly.

Powders are characterized by an index of quickness which is greater for a smaller thickness.

French service powders for the use of artillery are indicated below in order of increasing quickness.

Powder (2).....	B G ₀	B M ₁	B C	B M ₂	B S P	B M ₃	B G ₄
Thickness.....	<0.5	0.5	—	—	0.9	—	—
(approximate)							
Index of quickness....	—	10.2	8	—	5	4.5	—
Powder.....	B G ₅	B M ₅	B M ₇	B G C ₁	B M ₉	B M ₁₀	B M ₁₁
Thickness.....	1.3	—	—	1.9	—	—	—
(approximate)							
Index of quickness....	3.2	—	2.2	2.1	1.7	1.5	1.3
Powder	B M ₁₃	B M ₁₅	B M ₁₆	B M ₁₇			
Thickness.....	3	—	—	5			
(approximate)							
Index of quickness....	1	0.7	—	—			

§ 2. Condition of the powder.

Great care must be taken not to look upon the index of quickness of the powder as a rigidly constant characteristic.

(1) With a constant pressure of 1000 kg. per sq. cm. the speed of combustion of B powder would be 7 cm. per second; with a pressure of 3000 kg. it would be 15 cm. per second.

(2) The characteristic letters of the powder designations mean:

B smokeless powder.

G (guerre) intended for War Dept. guns.

M (marine) — Navy — guns.

SP (siège et place) — Siege and Fortress guns.

C (campagne) — Field Artillery guns.

But, in reality, these names no longer correspond to the use now made of these powders.

AM 12 — Weakened (atténuée) Ballistite in squares 12 m/m square and 1.2 m/m thick.

The powders are in fact made up of organic matter which decomposes slowly and is sensitive to all atmospheric variations : **temperature, humidity, and changes of season.**

In order that two equal charges of powder of the same nature — for instance of B S P powder — should impart in the same gun the same initial velocity to two identical projectiles, it is necessary, **not only that these charges have been manufactured at the same time and under the same conditions, but also that they have passed simultaneously through the same states throughout their existence.**

Some information on the various circumstances in which powders are handled will help to make precise this point which its consequences render especially important.

Powder manufacturers, after tests which will not be described here, make up stocks of powder as nearly identical as possible. Each of these constitutes what is called a **powder lot**, and is designated by the initials of the factory, a number, and the year of the manufacture.

For instance B P S. 74. 17. means :
Pont-de-Buis. 74th lot of 1917.

Specimens from this lot are used in test fire, so as to make sure that the lot is homogeneous, and to determine the weight of powder that is necessary to impart to the projectile the muzzle velocity given by the firing tables.

When these tests have yielded satisfactory results, the charges are made up by the competent service in a special workshop. For this purpose, the powder cases are opened and now the powder begins to undergo atmospheric influences. In particular, if the manufacture of charges takes place in a more or less damp room, the powder absorbs a more or less great quantity of water vapor, which will alter its quickness. If a case has been opened too soon and the contents not used for several days, the powder will undergo some further modification.

Two charges from the same powder lot will be comparable only if the loading into bags or cartridge cases has taken place at the same time. But this is not all : after the charges have been made up, they will lie in various stores, and be carried in freight cars or trucks, or in boats, or ammunition wagons, and finally remain for a time sometimes long in battery dumps. During transportation and these various halts, the powder again undergoes **variations in temperature** very injurious to its state and capable of modifying greatly its quickness(1).

(1) Metal cases containing powder and left to lie in the sun have been found bulging under the pressure exerted by gases from decomposing powder.

Thus errors as high as 25 m. in muzzle velocity have been noted when firing charges which had been left to lie in the sun. Furthermore, if as is the case for all materiels greater in caliber than 75 m/m, the powder is not made up in complete cartridges, and if, as unfortunately happens too often, the cartridge cases or charge bags are not packed in **absolutely air-tight** metal cases, the charges may absorb such a quantity of water vapor that their very ignition may become impossible (1).

It has been noted in particular that charges of the same lot, but carried in uncovered wagons from the railway station to the batteries, some in dry and the others in rainy weather, gave differences in range of **several hundred meters**.

It is therefore evident that a correct use of powder absolutely requires minute care and supervision, not only from the manufacturers and artillerymen, but also from **all who, at any time, are in charge of the transportation or preservation of ammunition**.

Great improvement in accuracy of fire will certainly be obtained when all charges are always carried and kept in soldered metal **cases**.

NOTE. — The firing tables give for the calculation of the influence of the temperature of the powder upon the muzzle velocity the following formula:

$$dV_0 = K V_0 (t - 15)$$

in which t is the temperature of the powder (in degrees centigrade) and K a coefficient approximating $\frac{1}{1000}$.

It is necessary to specify the conditions of use for this formula, so that no information which it cannot give will be expected from it.

a) It is very difficult to know the exact temperature of the powder, which is rarely the same as that of the air, especially in the case of fixed ammunition and in the case of great variation in the temperature of the air.

b) As the quickness of a powder depends upon all previous states through which it has passed, there is, about the muzzle velocity V_0 , an uncertainty, the amount of which may be as great as or greater than the correction for temperature, and the sense of which is unknown.

(1) 155 cartridge cases have been found standing on their bases in the rain and transformed into veritable rain gauges.

EXAMPLE :

Let $V_0 = 400$, and $t = 25$;

the formula $dV_0 = \frac{V_{01}}{1000} (t - 15)$ will give :

$$dV_0 = \frac{400 \times 10}{1000} = 4 \text{ m.}$$

This means that the charge of powder used under the present conditions ($t = 25^\circ$) will give a muzzle velocity exceeding by about 4 m. the velocity it would have produced at 15° ; but, if no proof exists that the velocity at 15° is exactly 400 m., it is impossible to deduce that it will be 404 m. at 25° .

In short, this formula gives, at most, a means of computing **approximately** (1) the difference between the velocities which will be given by two charges **otherwise identical**, but the temperatures of which are different at the moment of firing.

For instance, it shows what will happen if, after quick and prolonged firing, during which the tube has become greatly heated, the gun is kept loaded for some minutes before fire is resumed : the increase in the temperature of the powder may easily reach 50° , which causes an error in range of as much as 500 m. at a range of 10 km., accompanied with an excessive pressure, very injurious both to the projectile and the gun.

§ 3. Arrangement of the charge.

The arrangement of the powder charge in the chamber is very important from the point of view of the regularity of pressures and velocities. Any unsymmetrical arrangement results in an increase in dispersion.

Example: When test fire was executed with a certain type of 155 Howitzer using a powder called Ballistite, the charge was made up in flat bags placed on top of one another and held secure inside the cartridge case by a disc *w*.

To fire with reduced charges, the disc was removed and the necessary number of bags taken away until the required charge was obtained.

Considerable errors (dispersion of 1000 m. at 6 km.) occurred. Fragments of unburnt powder were blown out of the tube.

This result was mostly due to the fact that the cannoneers did not put back the disc over the charge after removing the

(1) Within 20 to 30 g/b.

extra bags. The remaining bags then fell over each other in the cartridge case (see fig. 11). By putting the disc back

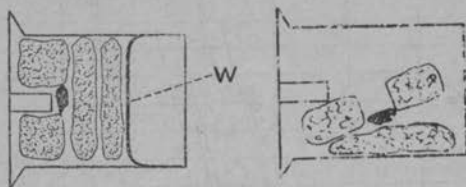


Fig. 11.

in its place, the regularity of fire was much improved. The arrangement of powder is fixed, after a study of the question, in the powder factories and test commissions. **It must not be altered in any way**, except when such alteration is prescribed for firing in different zones, as is the case with the 8" Howitzer and certain other heavy guns.

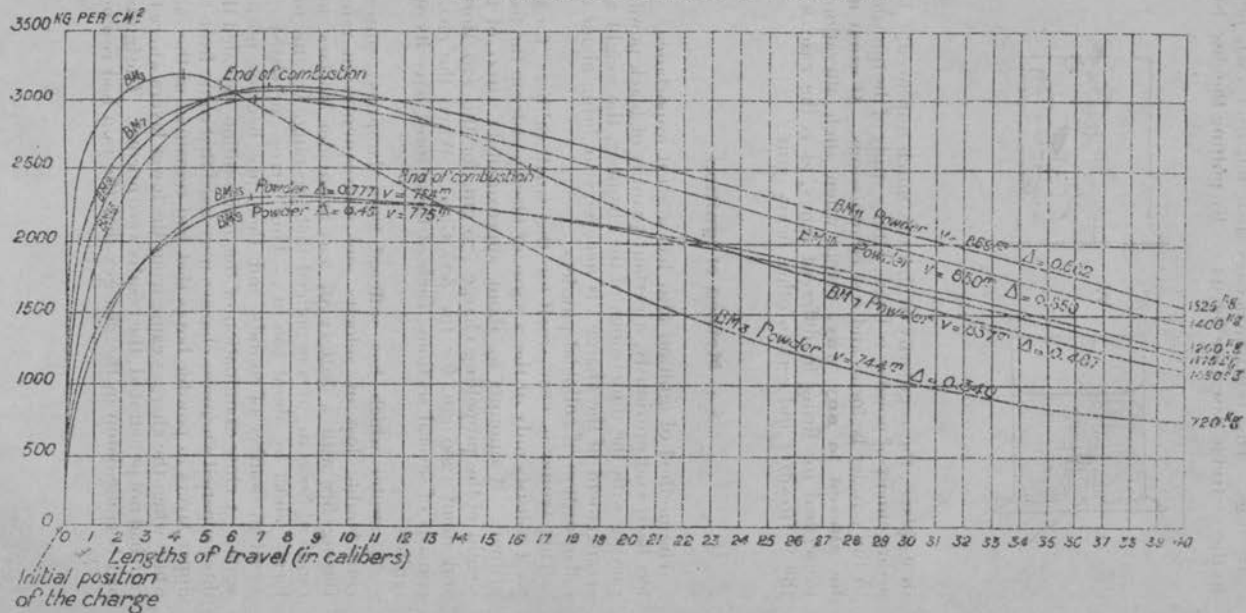
§ 4. Method of ignition.

The method of ignition also has a great importance. As has been said previously, a certain quantity of black powder, varying with the dimensions of the chamber, the weight and arrangement of the charge, is necessary to bring about the inflammation of colloidal powders.

This igniter is very small for the small calibers (for the 75 it consists only of the 2.7 gm. of black powder in the fixed primer). It amounts to about approximately 1/100 of the weight of the propelling charge (75 gm. for the 220 Mortar and about 1200 gm. for the 305 Gun). When the charge consists of several sections, each of these must have its own igniter:

An igniter which has suffered from dampness causes a considerable loss in velocity and consequently in range. During fire with a battery of 220 Schneider Mortars, at a range of 8000 m., it was noticed that the range became uniformly short by about 400 m. This error persisted for a certain number of rounds and then fire became normal again. A close examination of the ammunition revealed that this happened whenever charges were used that came from the upper layers in powder boxes that had remained in the rain, while when the charges came from the lower layers where the rain had not penetrated, the results were normal. The igniters had become damp in the charges that the rain had reached.

DIAGRAM OF THE DEVELOPMENT OF PRESSURES IN THE 10% GUN 1902 MODEL
WITH VARIOUS CHARGES OF POWDER.



§ 5. Weight of the charge.

With powders of equal quickness, an increase in the weight of the charge increases the muzzle velocity of the projectile, which is an advantage, but increases the pressure also, which may be dangerous.

§ 6. Combined influence of weight and quickness.

As with equal weights of powder a decrease in quickness decreases the pressure, it is easily seen that it is possible, by combining the two influences, to increase the muzzle velocity without altering the pressure.

Thus, by increasing at the same time both the charge and the slowness (*i. e.*, in practice, the thickness of web of the powder), the muzzle velocity and consequently the range are increased without the maximum pressure increasing.

There is always a limit to this increase, and for a given type of gun and projectile, there exists a type of powder called "maximum velocity powder", which gives the highest velocity for a given pressure.

Numerical example :

Fire with 10 c/m Gun, 1902 Model.

WEIGHT OF CHARGES.	3.400 kg.	4.200 kg.	5.300 kg.	6.000 kg.	7.400 kg.	9.700 kg.	10.500 kg.
Nature.....	BM ₁	BM ₂	BM ₃	BM ₇	BM ₉	BM ₁₃	BM ₁₈
Density of charges...	0.275	0.340	0.429	0.487	0.599	0.786	0.850
Muzzle velocity.....	680	744	810	837	887	885	850

There is little advantage in using "maximum velocity powder"; its effects may be illustrated by a diagram of the following form (see fig. 13) :

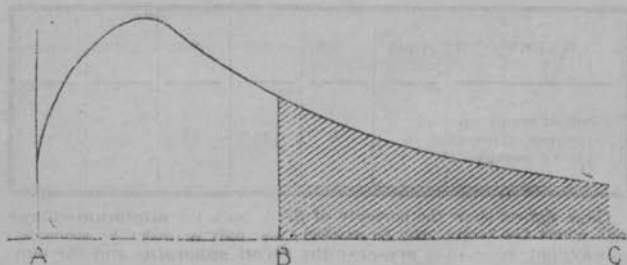


Fig. 13.

1. A large quantity of the energy contained in the powder is wasted.

2. The pressure at the muzzle is great, which is undesirable from the point of view of the resistance of the materiel and the accuracy of fire, as will be explained further on.

In consequence the charge that would give the maximum velocity compatible with the resistance of the projectile and tube is not employed, but a slightly smaller charge of a somewhat quicker powder (1).

3. From fig. 13, it can be seen that, by lengthening the tube to C, a greater part of the force of the powder is used and therefore a greater muzzle velocity is obtained: this is the reason why **guns**:

a) Make it possible to obtain greater muzzle velocities than howitzers.

b) Fire slower powders than howitzers (2).

ART. III.

INFLUENCE OF THE PROJECTILE.

§ 1. Weight.

An increase in the weight of the projectile causes an increase in the pressure and a decrease in the velocity.

(1) It should here be noted that even if the use of heavy charges were not objectionable with reference to the resistance of the projectile and tube, the same does not apply to the resistance of the recoil apparatus and gun-carriage. The resistance of the recoil apparatus increases in proportion to the square of the recoil velocity, and the latter increases much more rapidly than the muzzle velocity.

The table given below, which relates to the above example of a 10 c/m gun firing with various charges, gives in ton-meters the work that the recoil apparatus must do in order to absorb the kinetic energy of the gun recoil.

CHARGES.	3.400	4.200	5.300	6.000	7.400	9.700
Work of recoil apparatus = Recoil kinetic energy...	6	8	12	14	20	29

These figures show the necessity of firing with the **minimum charge** with which the target may be reached, not only in order to economize powder, but above all to **preserve the recoil apparatus and the gun-carriage**.

(2) For equal calibers,

This is the reason why some materials, which fire projectiles of greatly varying weights (370, 400, etc... mortars) use powders, the quickness of which varies with these various types of projectiles, the slower powder being used with the heavier projectile.

§ 2. Forcing.

The effect of forcing (*i. e.* the engraving of the rotating band by the lands) is to increase the speed of combustion of the powder by delaying the departure of the projectile — which tends to increase the velocity — and on the other hand the friction of the rotating band against the lands tends to retard the projectile and decrease the velocity. With a heavy charge the first cause is generally the stronger one, so that an increase in forcing brings about, as a rule, an increase in velocity. But, with a **very small charge**, the second cause, on the contrary, is the stronger one, so that an increase in forcing brings about a decrease in velocity.

§ 3. Greasing.

The greasing of the projectile and tube, which is necessary to avoid the premature wearing of the latter, works in a contrary way to forcing : it decreases the resistance on departure — hence a decrease in the quickness of action of the powder — as well as passive resistances — hence an increase in velocity. It will therefore bring about either an increase or a decrease (very slight at most) in the velocity, according to the other ballistic conditions (amount of forcing, length of tube, pitch and shape of grooves, charge, etc.).

ART. IV.

INFLUENCE OF THE FORM AND CONDITION OF THE TUBE.

§ 1. Volume of the chamber.

If equal charges of the same powder are fired in guns of the same caliber, the chambers of which have different volumes, the greater pressure will occur in the smaller chamber.

The larger chamber will therefore allow a heavier charge to be used for a given maximum pressure.

The name “density of loading” (represented by the letter Δ) is given to the ratio of the weight $\bar{w}$ of the charge

(expressed in kilograms) to the volume c' of the chamber, (expressed in liters), $\frac{w}{c'}$.

This ratio rarely exceeds 0.7 with the maximum velocity powder, and is usually much less than this number.

§ 2. Total volume of the bore.

The greater the volume of the bore, the better the efficiency of the powder gases. In consequence, slower powders will be used with a bore of large volume than with a bore of small volume.

On the other hand, the volume of a bore varies in proportion to its length and the square of its caliber.

It will be seen from the above considerations, without the question being fully developed :

a) That a howitzer of a very large caliber (370, 400) will fire very slow powders (BM_9 , BM_{11} , BM_{13}) although it is very short, on account of its large capacity;

b) That a gun of very small caliber (37, 47,) will fire very quick powders (BC , BM_1) although it is very long, on account of its small capacity.

§ 3. Wear of tubes.

Experience shows that prolonged fire wears out a tube in the following manner :

1) In the region lying near the forcing slope, where longitudinal and irregular streaks are created;

2) At the muzzle, where a truncated cone tends to appear, eating away the lands entirely;

3) Along the tube, where the lands wear away regularly.

Various explanations have been proposed for the wearing out of the forcing slope and muzzle :

a) Leakage of gas occurring between the rotating band and the walls of the forcing slope on the one hand (fig. 14), and

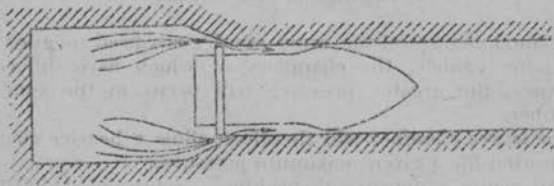


Fig. 14.

through the ring left free by the projectile when it leaves the muzzle on the other (fig. 15).

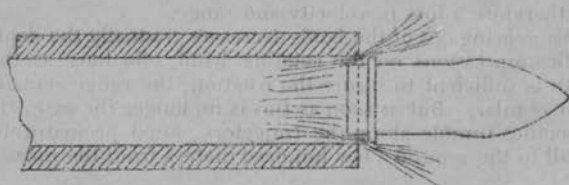


Fig. 15.

b) Eddies occurring in the same regions (forcing slope and muzzle), due to the fact that the gas jet does not exactly follow the profile of the tube, in the same way as eddies are

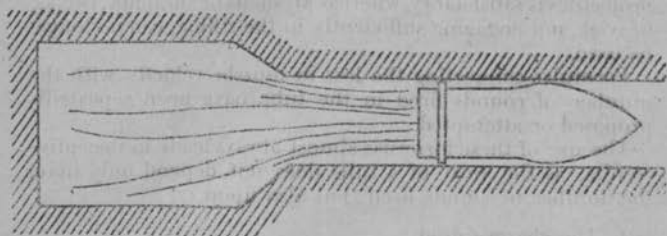


Fig. 16.

formed in the liquid flowing from a reservoir at points in the pipe where sudden changes in diameter or direction occur.

Nearly all of the gas is generated in the powder chamber and

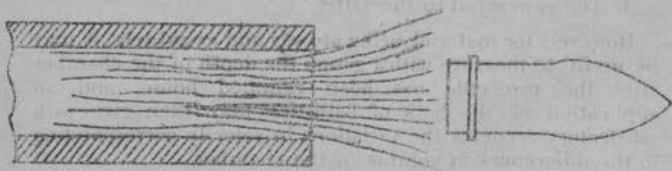


Fig. 17.

passes out with high velocity. At points where this stream of incandescent gas is constricted, it washes away a film of steel from the surface, as is the case with the oxy-acetylene flame. The effect of one shot is small, because the hot gas remains in contact with the bore for only a small fraction of a second.

The wearing out of the lands is due simply to the friction of the projectile against them. No erosions are ever found in the rifled part extending from a few centimeters in front of the forcing slope to a few centimeters in rear of the muzzle.

The wearing out of the forcing slope causes an enlargement of the chamber,¹ as the projectile must be rammed in farther; the result is a slower burning of the powder, and therefore a loss in velocity and range.

The wearing out of the lands decreases gradually the depth of the impressions on the rotating band. So long as this depth is sufficient to insure the rotation, the range remains fairly regular. But as soon as this is no longer the case, the projectiles tumble along the trajectory, burst prematurely, or fall to the ground a few hundred meters from the muzzle.

It is interesting to note that for the same caliber the depth of impression necessary to insure the rotation of a projectile is greater for a heavier projectile, provided the rotating bands are of the same shape: in consequence, when a 75 tube wears out progressively, there comes a time when H. E. shells still sufficiently engage in the rifling and the accuracy of fire with these projectiles is satisfactory, whereas AL shells or shrapnel, two kg. heavier, not engaging sufficiently in the rifling, can no longer be used.

Formulas connecting the loss in muzzle velocity with the number of rounds fired in the tube have been repeatedly proposed or attempted.

The use of these formulas almost always leads to deceptive results, as the wear of a tube does not depend only upon the number of rounds fired, but also upon:

1. The charges used;
2. The rapidity of fire;
3. The condition as to cleanliness and lubrication of both the projectiles and bore;
4. The care given to the latter.

However, for materiel firing **slowly** and **regularly**, it may be useful to measure with a gauge the depth of the chamber after the projectile has been rammed home, and an application of the laws of Ballistics may then give with satisfactory accuracy the variations in velocity corresponding to the differences in volume of the chamber.

It would be a fallacy to believe that it is economical to fire with a much worn-out tube; as a matter of fact, quite the contrary happens:

- 1) With every round fired, there is a risk of having a burst short and hitting the friendly infantry;
- 2) There is a considerable waste of ammunition, the value of which soon exceeds that of the tube. (1)

(1) Two hundred rounds represent more than the value of a tube.

3) There are greater risks of the tube swelling and bursting, which causes not only the tube but also the rest of the materiel (gun-carriage, recoil apparatus, etc...) to be put out of service, not mentioning the casualties which might occur.

How is the wear of a tube noticed and when must it be considered as unfit for further service? Numerous recent experiments have shown that the **occurrence of abnormal bursts** (1) is the surest indication of the state of wear of a tube.

The wearing out of a tube is made apparent as a rule by a few abnormally short bursts (*i. e.* short by some hundreds of meters), which at first occur very rarely, and the proportion of which increases to as much as 50 o/o, together with their becoming more and more abnormal. Finally some of the projectiles will tumble on departure, as pointed out above.

The first abnormal bursts can be noticed only by observing the points of impact, but as soon as the shearing off of the rotating band — chief cause of abnormal bursts — increases in importance, the projectile assumes an ever increasing movement of nutation, giving rise to a characteristically rhythmic noise, as will be explained in the next chapter.

When standing near the gun, and without any measurement or observation, it is therefore possible to observe when firing with a certain piece is becoming dangerous.

If this piece can be fired with various propelling charges, it is as a rule possible to use it for a longer period provided **that only fire with charges of a reduced muzzle velocity be executed with it.**

Drying shot. — Experience shows that the range obtained with the first round differs, as a rule, — especially with large caliber pieces — very much from the range given by the following ones; the corresponding point of fall is often outside of the zone of dispersion of the following ones. The explanation of this phenomenon, which was known as early as the 16th century, is not yet clearly ascertained. For this reason, too great account must not be taken, when adjusting, of the first shot, called the **drying shot.**

(1) *i. e.*, bursts occurring clearly outside of the zones of dispersion of the Firing Tables.

CHAPTER III.

PHENOMENA ACCOMPANYING THE DEPARTURE OF THE PROJECTILE.

ART. I.

PRESSURE OF THE GASES.

OSCILLATION OF THE AXIS

OF THE PROJECTILE (NUTATION).

POSSIBLE PREMATURE BURSTS AT THIS MOMENT. — FLASH AND BACK FLASH.

§ 1. Action of gas pressure at the time the projectile leaves the muzzle.

When the projectile leaves the muzzle, the pressure of gases in the bore is still great (see fig. 18). They then

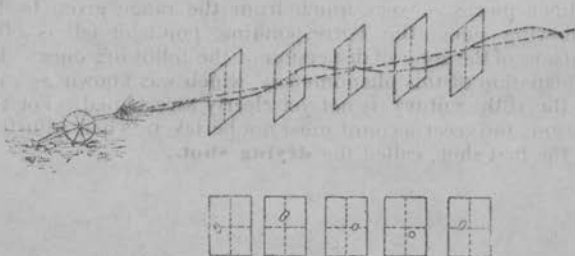


Fig. 18.

expand in the atmosphere with extreme rapidity, producing an eddy to the action of which the projectile is subjected during the first few meters of its flight through the air.

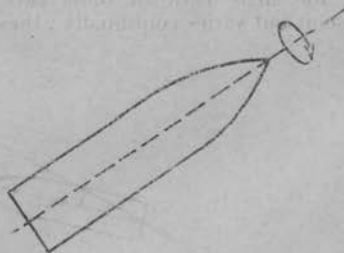
This results in a very slight increase of its velocity (a few

meters), at the expense of accuracy; for, at this moment, the projectile, still driven forward by the gas, is no longer guided by the tube, and the resistance of the air in front of it tends to tilt it.

In consequence, the motion of the projectile during these first few meters is rather irregular; if cardboard screens are placed in front of the muzzle at regular intervals (3 meters for instance), it is found that the holes bored by the projectile through the screens are not on the straight line which is the prolongation of the axis of the bore but slightly right or left, below or above. Besides, these holes, instead of being circular, as would happen if the projectile lay flat on its trajectory, are oval and of various lengths, and the directions of their axes of symmetry vary from one screen to another.

These experiments make it possible to trace the motion of the projectile, which can be approximately explained as follows (1):

a) On account of the rifling of the bore, the projectile acquires a motion of rotation about its axis: this is called **rotation proper**, which is necessary to prevent the projectile



Rotation proper

Fig. 19.

from tumbling because of the resistance of the air, as will be explained further on.

b) The axis of the projectile does not maintain a fixed direction but turns round an axis which is close to the

(1) The explanations which follow do not pretend to the accuracy of a mathematical demonstration; their only object is to give some idea of a very complex motion.

tangent to the trajectory : this is called the **motion of precession**.

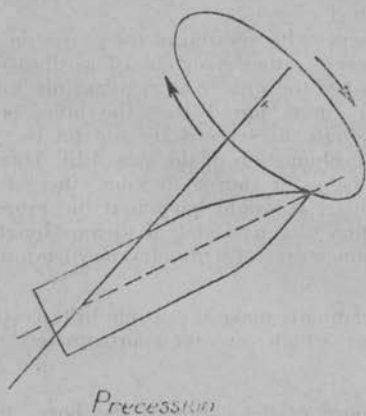


Fig. 20.

c) Lastly, the angle between these two axes does not remain constant but varies continually : these oscillations of

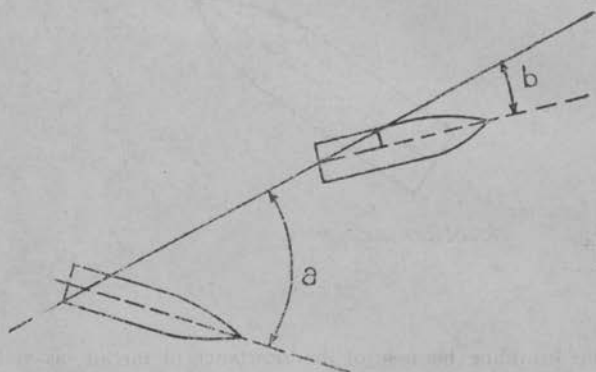


Fig. 21.

the projectile axis constitute what is called the **motion of nutation**.

The consequence of this motion is to make the projectile more or less oblique with reference to the tangent to the trajectory, and to vary the shape of the holes in the screens.

Furthermore, as the projectile presents to the air a resisting surface more or less great, according to the value of the

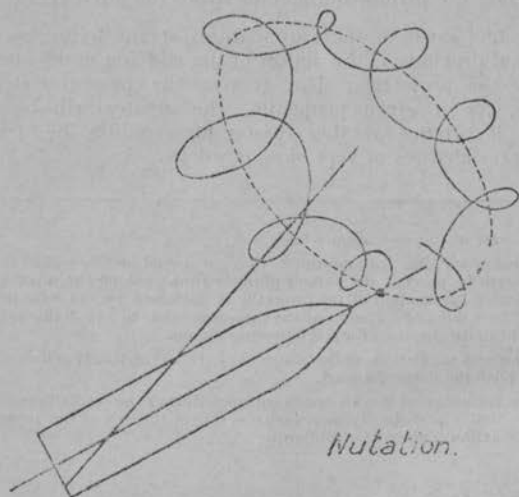


Fig. 22.

nutation, the hissing sound it produces will be successively reinforced and, if it is sufficiently strong, will give the impression of the noise of steam periodically escaping.

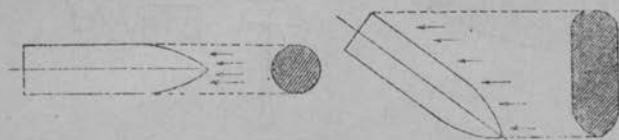


Fig. 23.

This characteristic noise is thus the correlative of the strong oscillations of the projectile when it leaves the bore (1).

(1) Therefore, this noise must not be always attributed to the **tearing off of the rotating band**, which is much more serious but fortunately much less frequent. Numerous observations made on proving grounds have established this beyond doubt; the projectiles that have produced the noise above described are nearly always found at their point of fall with their rotating bands uninjured.

These oscillations hinder the regularity of fire because of the differences in the action of the resistance of the air from one round to another. Besides they may make fuses unsafe (1) by causing the primer-plunger to strike the anvil (2).

The chief cause of these oscillations seems to be, as has been said previously, the action of the eddying gases on the base of the projectile. The greater the pressure at the muzzle, for a given projectile, the greater will be this action (3). Hence another reason for avoiding the use of very heavy charges of very slow powders.

(1) At least in the case of nose fuses.

(2) It is known (See Ammunition) that a special device called safety spring serves to prevent the primer-plunger from striking the anvil at the moment when the motion of the projectile is slackened by the resistance of the air. The motion of nutation of the projectile tends to cause the primer-plunger to strike the anvil for the following reasons :

a) The rapid oscillations of the projectile have a centrifugal action which tends to push the sleeve forward.

b) The resistance of the air is not constant during the oscillations of the projectile, but is periodically increased every time the axis of the projectile takes its maximum amount of obliquity.

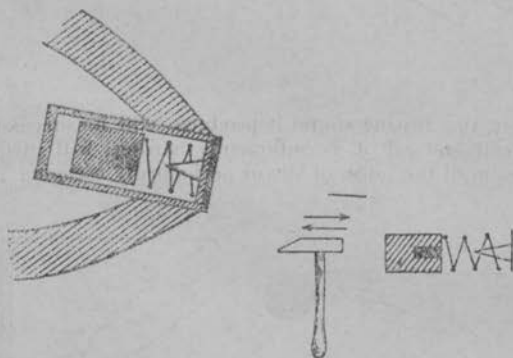


Fig. 14.

To the periodical increases in the resistance of the air correspond naturally, as a result of inertia, periodical impulsions of the primer-plunger against the safety spring. Under the action of these successive impulsions, the effects of which are apt to be cumulative, the primer-plunger may bring about a flattening of the spring sufficient to allow the primer to strike against the anvil.

(3) In 1914 reasons of a tactical nature led to the use of a very heavy charge of very slow powder, with the 155 Gun, in order to hit very distant objectives with long shells. Although this charge had been determined so as not to give the maximum pressure, which might be too strong for the resistance of the shell and the gun, numerous premature bursts occurred in front of the muzzle of the piece; and the same thing has occurred with several large caliber materials every time an attempt has been made thus to modify the established charges in order to increase the range.

With a given pressure at the muzzle, the resistance of the projectile to this disturbing action is increased :

a) In proportion as it has been better centered in the bore. Centering by means of rotating bands, almost universally adopted, does not seem to be the best from this point of view, for the Withworth polygonal shells (fig. 25) which have been tried several times, and the shells with prepared grooves and without rotating bands, have always had a more regular departure than the others (circular holes, no periodical hissing).



Fig. 25.

b) In proportion as it is shorter. For a given caliber, the maximum length that may be given to a projectile depends upon the speed of rotation and also the interior distribution of the weight of the projectile, as will be shown further on. It practically never exceeds five calibers and is generally less.

The oscillating motion of the projectile is generally deadened by the air resistance and, after a very short time, its axis is generally very close to the tangent to the trajectory for the rest of its flight.

However, it may happen in exceptional cases that nutation increases in the course of flight and the shell tumbles, or bursts at several thousand meters from the gun, especially in the case of fire with high angles of elevation, in that part of the trajectory where the curvature is greatest.

The charge gases sometimes form torus shaped eddies, especially visible when the charges include a large black



Fig. 26.

powder igniter. These eddies, which are formed at the muzzle of the piece and tend to rise along the direction of the axis of the bore, if the air is calm, are deviated laterally by the wind, if there is any. The continuous hissing sound, which usually accompanies this phenomenon, seems to originate from a point moving to the right or left of the plane of fire, according to the direction of the wind; this may lead one to believe that a fragment of the shell or of its rotating band has broken away and been hurled in this direction.

§ 2. Flash and back flash.

Among the charge gases, there is a certain quantity of combustible gases, especially carbon monoxide, which is greater as the charge is heavier and slower. These gases, which have a high temperature (600° C. at least), tend to ignite when leaving the muzzle, thus producing :

a) A flash very visible at night.

b) A very loud report.

The same thing may also happen at the breech when it is opened : it is then called the back flash.

If a substance capable of stirring the gases (sawdust for instance) or an alkaline salt (1) [potassium nitrate for instance, which acts in the same way on account of the potassium carbonate it produces when burning] is mixed with the charge, flashes and back flashes are eliminated to a greater or lesser extent, and the loudness of the report on departure is reduced in the ratio of about 5 to 1.

On the other hand, anti-flash substances have the effect of increasing the smoke; for this reason, they must be used at night only.

CHAPTER IV.

EXTERIOR BALLISTICS. — THE TRAJECTORY.

After the first few meters of its flight through the air, the projectile is no longer pushed forward by the gases of the charge and is acted upon only by the following forces :

1. Its weight, a force passing through its center of gravity and directed along a vertical.

(1) A heavy igniter of black powder eliminates flashes.

2. The resistance of the air, acting upon the whole of its surface.

The mode of action of these forces will now be briefly examined.

ART. I.

GRAVITY AND THE MOTION OF THE PROJECTILE IN VACUO.

If gravity alone acted upon a projectile left with no initial velocity (the case of a body falling from a motionless balloon), its effect would be to make it fall vertically, in accordance with the following laws :

The acquired velocities after :

0 1 2 3 4 5.... t seconds

would be :

0 9.81 9.81×2 9.81×3 9.81×4 9.81×5 $9.81 \times$

and the distances travelled would be :

0 $\frac{1}{2} 9.81$ $\frac{1}{2} 9.81 \times 4$ $\frac{1}{2} 9.81 \times 9$
 $\frac{1}{2} 9.81 \times 16$ $\frac{1}{2} 9.81 \times 25$ $\frac{1}{2} 9.81 \times t^2$.

Each second the velocity is accelerated by the same amount 9.81 ; this is expressed by saying that the motion is uniformly accelerated.

The distance travelled is proportional to the square of the time.

Example :

How long will it take a projectile to fall down from a balloon 2000 m. high ?

$$2000 = \frac{1}{2} 9.81 \times t^2.$$

Therefore $t = 20$ seconds, approximately.

As will be seen further on, the resistance of the air changes this result but little for projectiles of medium or large caliber ; it is very close to the actual duration of fall.

Assume that a projectile is thrown with a certain velocity, for instance 60 meters per second, at a certain angle with the horizontal, 30° for instance : it tends to travel with a uniform motion along its initial direction and, if gravity did not exist, it would after :

0 1 2 3 4 5 6 seconds

be at a distance of :

0 60 120 180 240 300 360 meters

and, the angle of projection being 30° , it would reach the heights :

0 30 60 90 120 150 180 meters.

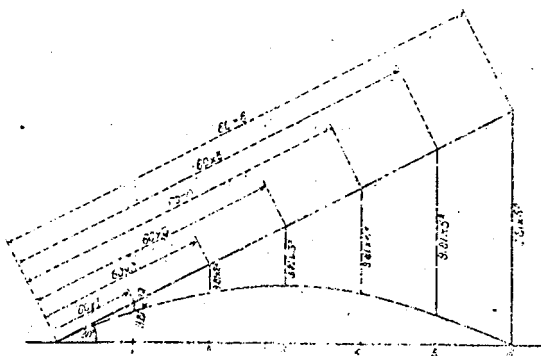


Fig. 27.

On the other hand, gravity lowers it, during the same time, by amounts equal to :

$$0 \quad \frac{1}{2} 9.81 \quad \frac{1}{2} 9.81 \times 4 \quad \dots \quad \frac{1}{2} 9.81 \times 36 \text{ meters.}$$

It is therefore possible to plot the points through which the projectile passes at the different moments of its flight.

The velocity at each point may be obtained, from place to place, in the following way :

Let V be the velocity of the projectile at the origin of the

curve; after one second, the velocity with which it travels is the resultant of this velocity V , and g the vertical velocity due to gravity acting upon it during one second.

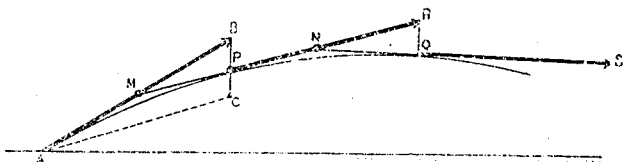


Fig. 28.

The resulting velocity will therefore be obtained by drawing the diagonal of the parallelogram having V and g for sides, *i.e.*, AC , or, to get it more quickly, by joining point P to M , the middle of AB , and prolonging MP by a length $PR = 2MP = AC$.

The relation of the range to the quadrant angle of departure and to the velocity under standard conditions is expressed by the following equation:

$$P = \frac{V_0^2 \sin 2\phi}{g}.$$

ϕ being the angle of departure.

It reaches its maximum amount when $\phi = 45^\circ$; in that case,

$$P = \frac{V_0^2}{g} \quad \text{or approximately} \quad \frac{V_0^2}{10}.$$

Consequently, in order to obtain in vacuo ranges equal to:

1 2 3 4 5 10 20 30 40 50 100 150 200 km.

the corresponding velocities with $\phi = 45^\circ$ must be equal to:

100- 140- 170- 200- 220- 330- 450- 550- 630- 710-
1000- 1250- 1400 meters per second.

As will be seen further on, for velocities less than 100 meters, the results are about the same in the air as in vacuo; this is the case with trench mortars.

It is possible to reach an objective with the same muzzle velocity and either one of the two angles of elevation which are complementary, for instance 25° and 65° , for $\sin 2\phi$ has the same value in both cases.

The maximum ordinate F is given by the formula :

$$F = \frac{P}{4} \tan \phi.$$

The time of flight T is given by :

$$T = \frac{P}{V_0 \cos \phi}.$$

In short, in vacuo, the trajectory depends only on the angle of elevation and the muzzle velocity ; it is wholly included in the vertical plane of the line of departure.

It is entirely symmetrical with reference to the maximum

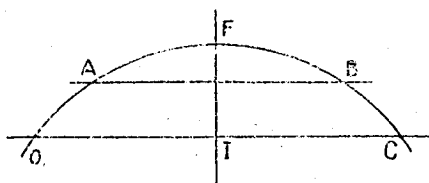


Fig. 29.

ordinate F , and, for two points A and B having the same ordinate, the velocities are the same and make the same angle with the horizontal.

ART. II.

MOTION OF THE PROJECTILE IN THE AIR.

The motion is altogether different in the air, the resistance of which acts differently according to the kinds of projectiles. In this case the range does not depend solely on the angle of elevation and muzzle velocity, but also on another factor which characterizes the way in which the projectile opposes the resistance of the air and is called the **ballistic coefficient**, designated by the letter c .

The resistance of the air, acting upon a projectile — the ballistic coefficient of which is c — propelled with a certain velocity v , tends to decrease this velocity v by a certain number of meters per second ; this is expressed by saying that the resistance of the air imparts to the projectile a **negative acceleration** — called **retardation** — and is expressed in algebraic terms as follows :

$$r = c f(v) \delta,$$

$f(v)$ being a quantity, varying with the velocity, the value of

which is given by the diagram (fig. 30) and δ being the ballistic density of the air, i. e., the ratio between the weight of a cubic

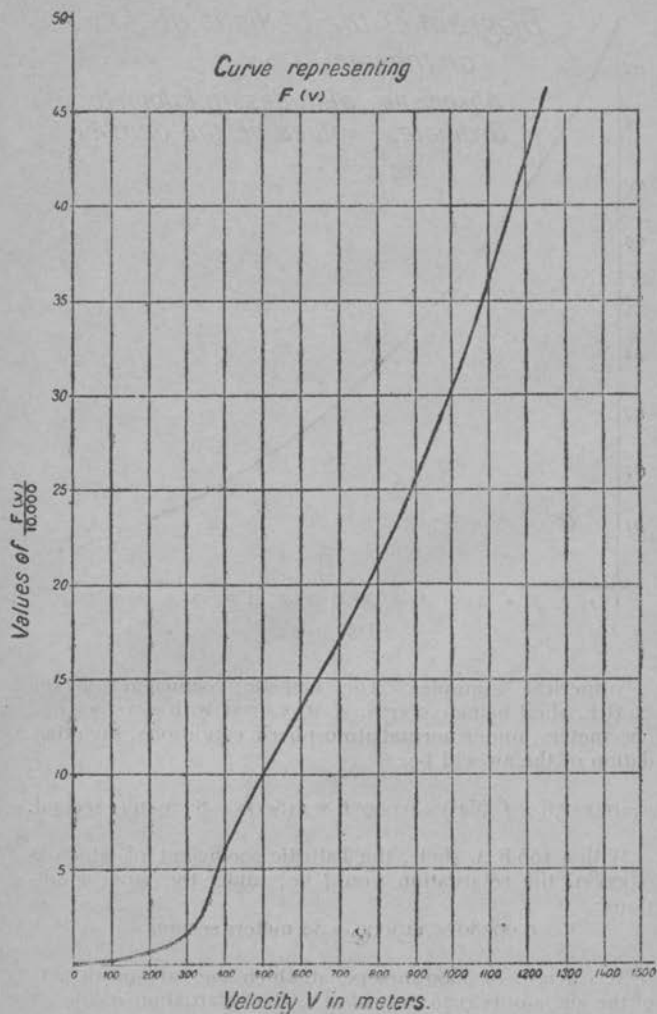


Fig. 30.

meter of air under the conditions of fire, and the weight of a cubic meter of air under normal atmospheric conditions (i. e., temperature 15° C., air pressure 750 m/m. or 1.208 kg.).

This ratio, which rapidly decreases with the altitude, is

given by the following diagram, in which the abscissae represent altitudes and the ordinates the values of δ (fig. 31).

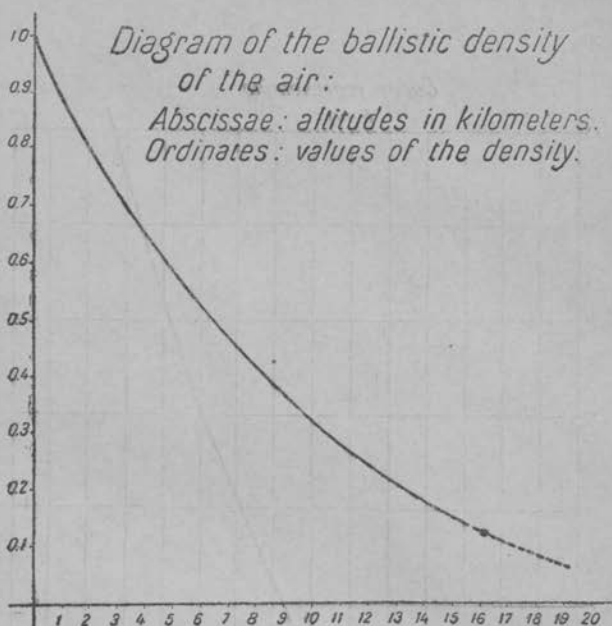


Fig. 31.

Numerical examples. The ballistic coefficient of the 75 H.E. shell being 0.00076, if it is fired with a velocity of 550 meters, under normal atmospheric conditions, the retardation of the air will be :

$$r = 0.00076 \times f(550) = 0.00076 \times 115000 = 87 \text{ meters second.}$$

With a 155 F.A. shell, the ballistic coefficient of which is 0.00030, the retardation would be, under the same conditions :

$$0.00030 \times 115000 = 34 \text{ meters second.}$$

At a height of 3000 meters, at which the ballistic density of the air is only 0.75 instead of 1, the retardation of the air would be respectively for the two above mentioned projectiles :

64 meters second instead of 87 for the 75,

25 meters second instead of 34 for the 155.

It is therefore understood that, the smaller the ballistic coefficient, the greater the range will be — the angles of departure and muzzle velocities being the same — and this is so for two reasons :

The loss of velocity brought about by the resistance of the

QUADRANT ELEVATION 10°

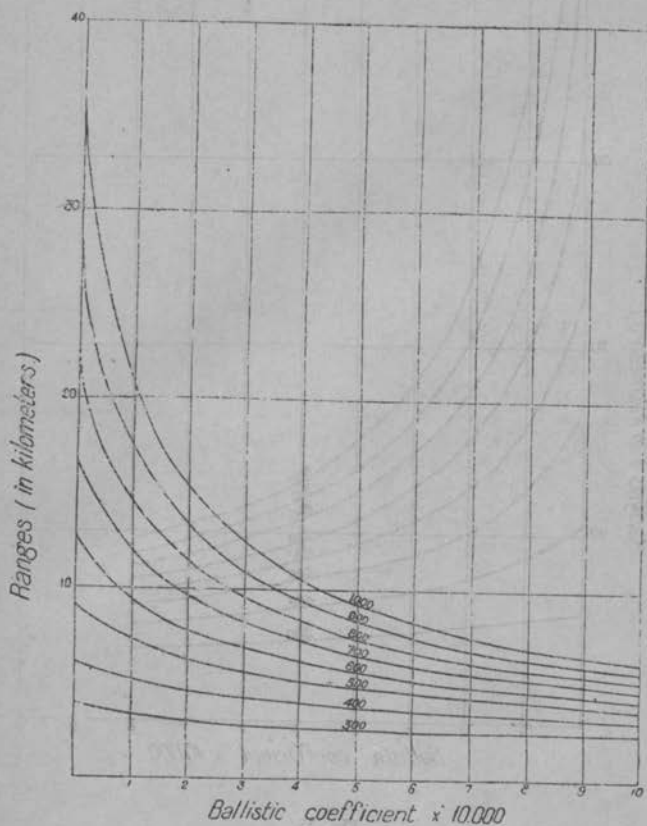


Fig. 32.

air being smaller, the projectile would travel a greater distance, even if the density of the atmosphere was constant.

Furthermore, as, for the same reason, it reaches greater heights, it travels through layers of air which are more and more rarefied and consequently offer less and less resistance.

QUADRANT ELEVATION 20°

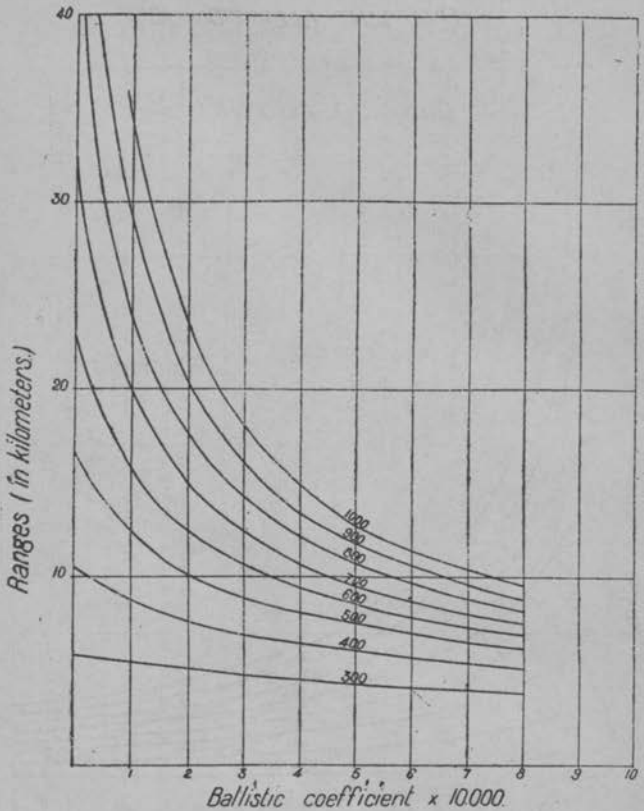


Fig. 33.

The importance of the ballistic coefficient is emphasized by the diagrams (fig. 32, 33, 34 and 35), indicating the ranges that may be reached by projectiles of ballistic coeffi-

cients varying from 0 (vacuo) to 0.001 fired with velocities of :

300 400 500 600 700 800 900 1000 meters

with elevations of:

10° (fig. 32), 20° (fig. 33), 30° (fig. 34) and 40° (fig. 35).

QUADRANT ELEVATION 30°

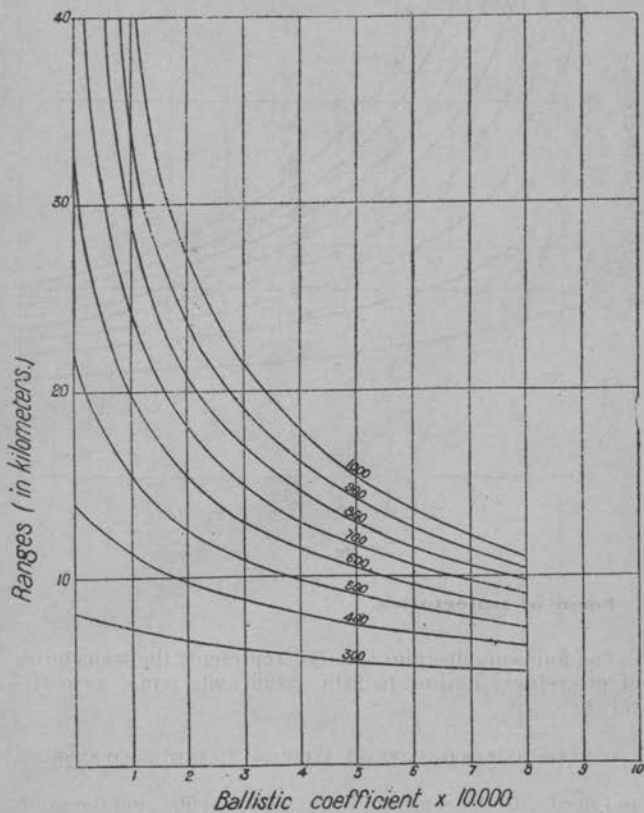


Fig. 34.

QUADRANT ELEVATION 40°

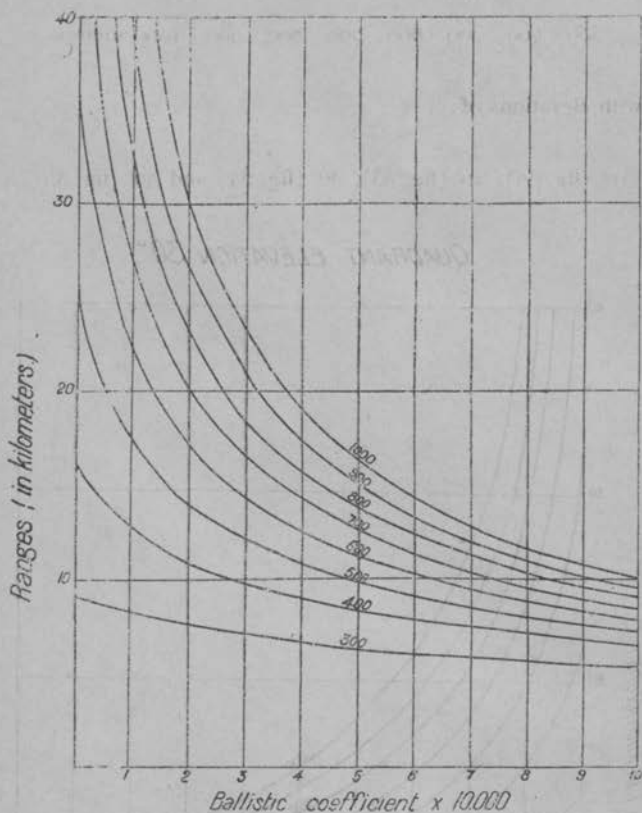


Fig. 35.

Form of trajectories.

The following diagram (fig. 36) represents the trajectories of projectiles, having ballistic coefficients equal respectively to :

0.00096 0.00060 0.00038 0.00024 0.00015 0.000096,

and fired with the same angle of elevation (36°) and the same muzzle velocity (900 m.).

This diagram emphasizes the following points ;

Trajectories of various projectiles fired with a muzzle velocity of 990 meters and an elevation of 38°.

Abscissae — Ranges in kilometers.

Ordinates — Heights in kilometers.

$S_1, S_2, \dots, S_6$ Summits of trajectories.

Figures on trajectories — Ballistic coefficients multiplied by 10000.

Figures to the left of points of fall — Angles of fall in degrees —

Dotted lines — Remaining velocities at points of fall.

Figures above dotted lines — Amounts of remaining velocities in meters.

Figures below dotted lines — Times of flight in seconds.

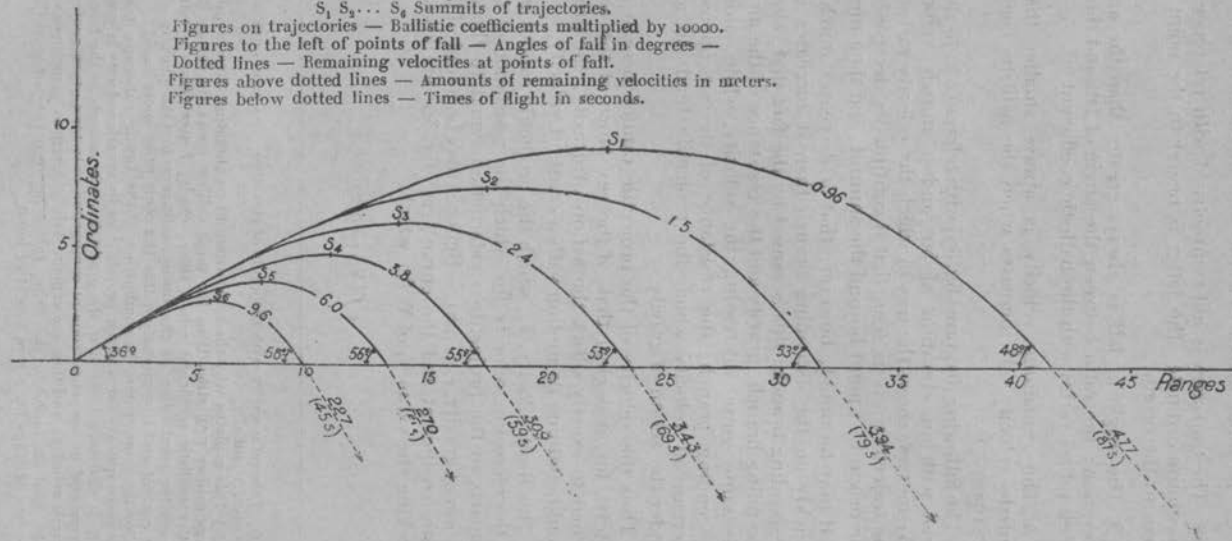


Fig. 36.

1. The range increases as the ballistic coefficient decreases.
2. The trajectory is not symmetrical with reference to the maximum ordinate: the latter is nearer to the point of fall than to the origin.
3. The angle of fall is always greater than the angle of elevation: the ratio between the angle of fall and the angle of elevation varies with the ballistic coefficient (1).
4. The remaining velocity is always smaller than the muzzle velocity. It increases when the ballistic coefficient decreases (2).

The following diagram (fig. 37) with reference to 75 shrapnel fired with an elevation of 50° and a muzzle velocity of 551 meters, shows the way in which the velocity varies along the trajectory: it is seen that it continually decreases from the origin to a point beyond the summit, and then increases.

It may be noted, however, that it decreases much more quickly on the ascending branch than it increases on the descending branch: this is caused by the fact that, along the ascending branch, gravity and the resistance of the air act in the same sense, decreasing the velocity, while, along the descending branch, the resistance of the air opposes the increase in velocity which the projectile tends to acquire under the action of gravity.

Thus the velocity of the projectile cannot increase indefinitely: for, it is clear that, if the resistance of the air happened to exactly offset the action of gravity, the projectile would continue its motion with a constant velocity.

This limit velocity, V_l , which the projectile cannot exceed, is therefore the velocity for which the resistance of the air imparts to the projectile a retardation equal to the acceleration of gravity, *i. e.*, 9.81. Hence it may be found, if the ballistic coefficient and the curve $f(v)$ [fig. 30] are known, by seeking the value V_l of V , for which

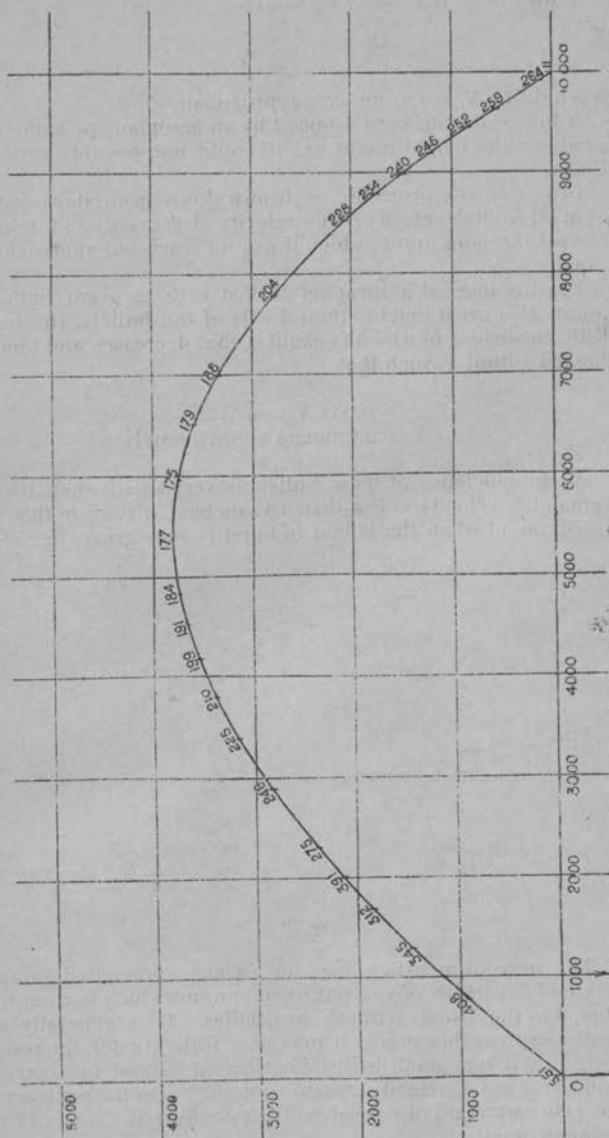
$$cf(V_l) = 9.81.$$

(1) This ratio varies with the angle of elevation. Its values are comprised between 3 and 1.

(2) This explains why the combustion of combination fuses is quicker for large caliber projectiles than for small caliber ones: the former having a better ballistic coefficient retain their velocity better than the latter; this causes the combustion of the fusing substance to take place in a quicker air current and consequently makes the combustion more rapid.

For the same reason the combustion of the fusing substance takes place the more quickly for a given projectile as its muzzle velocity is greater.

It is therefore clear that the graduations in seconds of the fuse-settings correspond to the actual time of combustion only for a given projectile and muzzle velocity; and thus are explained the differences, sometimes considerable, that are found in the firing tables between the times of flight and the fuse-settings for a zero height of burst.



Trajectory of 75 m/m shrapnel fired with a muzzle velocity of 551 meters , and an elevation of 50° — with indication of velocities at various points.

Fig. 37.

With the 75 H.E. shell for which

$$c = 0.00076,$$

it would be $V_l = 270$ meters, approximately.

If this projectile were dropped by an aeroplane or balloon, whatever the height might be, it could not possibly exceed that velocity.

Inversely, if a projectile is thrown down from above with a great initial velocity, the velocity decreases, and tends toward the same limit, which it cannot reach but approaches rapidly.

For instance, if a shrapnel loaded with 10 gram bullets bursts at a great height, the velocity of the bullets, the ballistic coefficient of which is about 0.032, decreases and tends toward a limit V_l such that :

$$0.032 V_l = 9.81$$

i.e., $V_l = 50$ meters approximately.

As the efficiency of these bullets is very small when their remaining velocity is less than 180 meters, it is clear that it will be nil when the height of burst is very great (fig. 38).

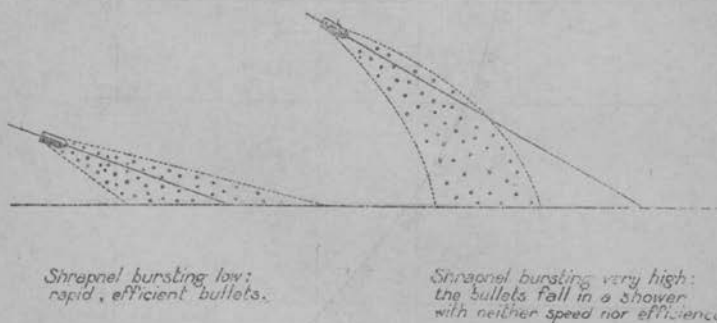


Fig. 38.

The maximum range does not exactly correspond to an angle of departure of 45° , but to an amount which is close to this, for the usual artillery projectiles. It is generally a little less than this angle; it may be a little greater, for projectiles of a very small ballistic coefficient (0.0001 to 0.0002) and great initial velocity (700 to 1000 m.). On the contrary, for rifle cartridges of a great ballistic coefficient (> 0.001) it is much smaller.

It is possible to hit a target with two different trajectories but, in the present case, the two angles of departure are no longer exactly complementary, as in vacuo.

The following diagram represents the trajectory of the 75 shrapnel, fitted with the 30/55 fuse (D.C.A. cartridge),

TRAJECTORIES FROM 5 TO 8
OF THE 75% SHRAPNEL WITH
MODIFIED OGIVAL HEAD.

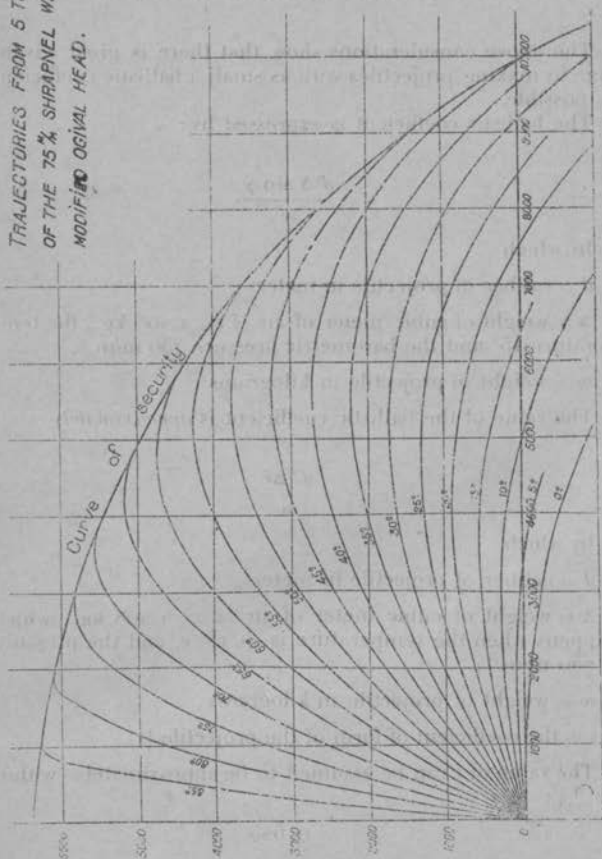


Fig. 39.

fired with a muzzle velocity of 525 meters at different elevations (fig. 39).

ART. III.

THE BALLISTIC COEFFICIENT.

The above considerations show that there is great advantage in making projectiles with as small a ballistic coefficient as possible.

The ballistic coefficient is expressed by :

$$c = \frac{d^2 \Delta \sin \gamma}{w}$$

In which :

d = caliber of projectile in meters ;

Δ = weight of cubic meter of air (*i.e.*, 1.208 kg., the temperature 15° and the barometric pressure 750 m/m.);

w = weight of projectile in kilograms.

The value of the ballistic coefficient is *approximately* :

$$c = \frac{d^2 \Delta i}{w}$$

In which :

d = caliber of projectile in meters ;

Δ = weight of cubic meter of air (*i.e.*, 1.208 kg., which happens when the temperature is + 15° c. and the pressure is 750 m/m.);

w = weight of projectile in kilograms ;

i = the coefficient of form of the projectile (1).

The value of i can be assumed to be approximately (within 10 %) :

$$i = \frac{0.625}{\sqrt{h}}$$

in which h stands for the sum of the heights of the ogival

(1) This coefficient is often designated by $\sin \gamma$. This designation is due to the fact that, for projectiles in use a few years ago, the value of the coefficient was equal to about the sine of half of the ogival angle of the projectile.

head and the truncated part of the base, using the caliber as a unit of measure :

For instance if $o = 1.7$ calibers.

and $b = 0.5$ calibers.

$h = 2.2$ calibers.

and $i = \frac{0.625}{1.48} = 0.42$.

For pointed projectiles and for the D shells now used, this is no longer true. However, this designation of the

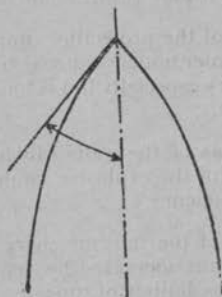


Fig. 40.

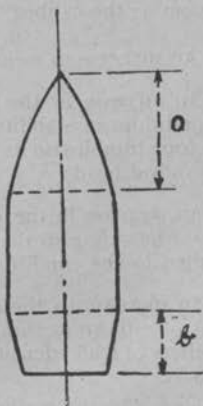


Fig. 41.

coefficient of form has been preserved, because it makes it possible easily to classify projectiles, which are the better as their γ is smaller. But when it is said that the γ of a projectile is equal to 25° , it does not mean that the ogival angle is actually 25° , but that the coefficient of form is equal to $\sin 25^\circ$, i. e., 0.42.

Numerical example.

For the 75 H.E. shell :

$$w = 5.315 \text{ kg.}$$

$$d = 0.075 \text{ m.}$$

$$\Delta = 1.208 \text{ kg.}$$

$$i = 0.59.$$

and :

$$c = \frac{0.075^3 \times 1.208 \times 0.59}{5.315} = 0.00076.$$

It is therefore possible to decrease the amount of C :

1. By increasing $\frac{w}{d^3}$.
2. By decreasing i .

I. An increase of $\frac{w}{d^3}$ may be brought about by :

a) An increase in caliber, the projectile remaining the same otherwise, for, in this case, the weight of the projectile increasing as the cube of the caliber, i.e., d^3 , the ratio $\frac{w}{d^3}$ increases as the caliber.

b) An increase in weight, which may result from :

1. An increase in the **length** of the projectile, limited by the conditions of stability above-mentioned (a projectile that is too long tumbles on its trajectory especially if it is too heavy at the ogival head).

2. An increase in the **thickness** of the walls which, as it causes a lessening in the weight of the explosive contained, is limited by the conditions of efficiency.

3. An increase in the **density** of the interior charge : the weight of a 65 m/m shrapnel is thus increased by replacing the bullets of lead (density 11.5) by bullets of tungsten (density 15.5).

Whatever be the method used to increase the weight, this increase results, as above stated, in raising the pressure of the powder charge, which calls for a lessening in the weight of the charge, or the use of a slower powder.

II. A decrease of the coefficient i may be brought about by :

a) An increase in the length of the ogival head, or

b) A tapering of the base of the projectile. The increase of the length of the ogival head is always advisable, but it is limited by the following conditions :

1. The projectile cannot be lengthened to more than 5 calibers without its stability being endangered.

2. The base plane of the ogival head cannot be placed too near the rotating band, for, if the rotating band and the bourrelet are too close, the projectile is insufficiently maintained in the bore.

When the projectile is very long (between 4 and 5 calibers), it is advisable to make the front part as light as pos-

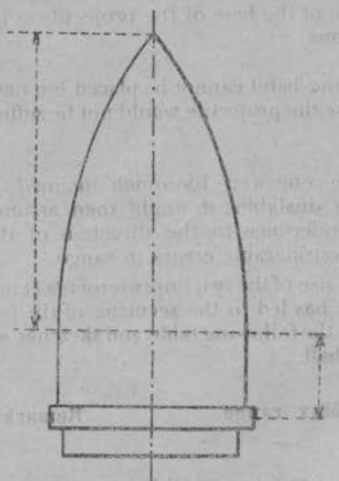


Fig. 42.

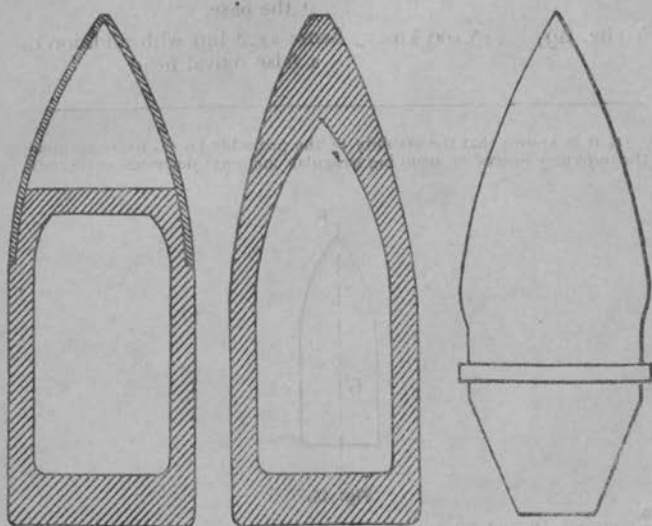


Fig. 43.

sible (1); this result is obtained by fitting it with an ogival head of sheet-steel, which lengthens it without greatly increasing its weight.

§ The tapering of the base of the projectile is limited for the following reasons:

1. The rotating band cannot be placed too near the bourrelet, as otherwise the projectile would not be sufficiently guided in the bore.

2. If the base cone were too much inclined, the projectile would become unstable; it might then assume an oblique position with reference to the direction of the trajectory, thus causing considerable errors in range.

The rational use of the two improvements (tapering of front and rear parts) has led to the securing of the ballistic advantages shown by the following table and sketches with reference to the 19 c/m shell.

Shape.	Max. range.	Remarks.
—	—	—
1 (fig. 46).	12.800 km.	Old shape.
2 (fig. 47).	15.700 km.	False ogival head.
3 (fig. 48).	16.900 km.	Longer nose and truncated cone at the base.
4 (fig. 49).	18.100 km.	Same as 3 but with addition of a false ogival head.

(1) It is known that the stability of the projectile (*i. e.*, its lying along the trajectory instead of assuming irregular motions) decreases as the ratio



Fig. 44.

$\frac{B}{C}$ increases (B and C being the principal moments of inertia MK^2 , of the projectile with reference to the axes G B and G C passing through its center of gravity).

The coefficient of form, i — and consequently the ballistic coefficient — depends also on the kind of fuse and boost-

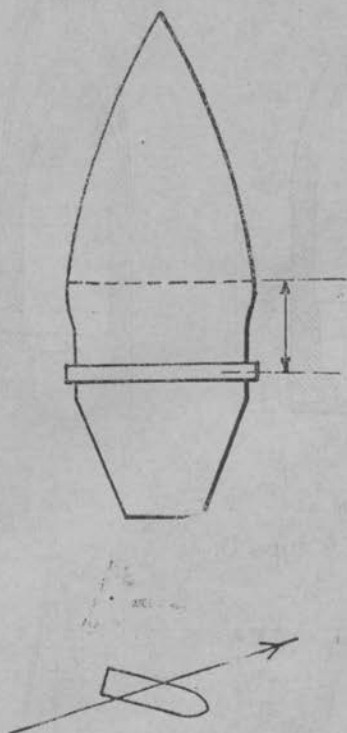


Fig. 45.

er casing adopted, the position and shape of the rotating band, and, in short, all that is apt to modify the outside form of the projectile.

For this reason, there are distinct firing tables for short and long fuses.

Lastly, it should be noted that the above mentioned laws about the resistance of the air must not be considered as mathematically strict; they are only approximate laws, the accuracy of which is sufficient to enable the manufacturer to know beforehand, within 2 or 3 o/o, what may be expected from a given materiel, but not to compute firing tables *a priori*, without having recourse to experiments. This is shown by the example given further on.

19 cm. ogive.

19 cm. M

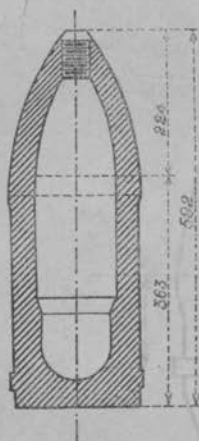


Fig. 46.

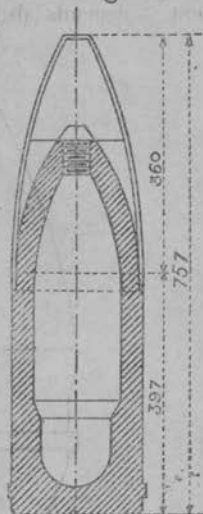


Fig. 47.

19 cm. F.A. type D.

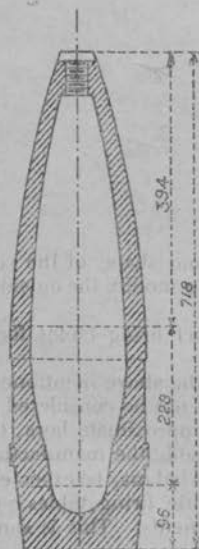


Fig. 48.

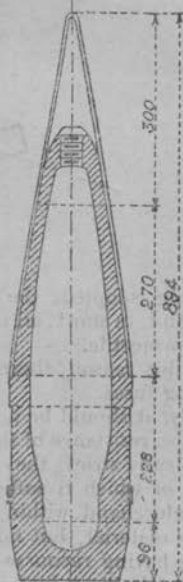


Fig. 49.

It has been said above that the formula $\frac{d^2\Delta i}{w}$ must be considered only as an **approximate** value of the ballistic coefficient c .

This is due to the fact that the latter is not an absolute constant of the projectile; it varies slightly with the **velocity of rotation**, the muzzle velocity, the elevation — and perhaps other conditions still not exactly known. These variations may reach in certain cases 10 o/o of the value of the coefficient.

For instance there are two kinds of 100 m/m guns; the pitch of their rifling is respectively equal to 7° and 5° , and they fire with the same velocity (760 meters) the same projectiles to ranges differing by

400 meters at 9 kilometers

and 650 meters at 12 kilometers.

This corresponds to a difference of 10 o/o between the amounts of the ballistic coefficients of the same projectiles fired by the two guns.

Consequently, the indication of the ballistic coefficient of a projectile should be given, in all strictness, together with that of the muzzle velocity and pitch of the rifling (1).

The following table merely gives the approximate values of this coefficient for different kinds of projectiles now in use, for no attempt is here made at teaching the methods of computing firing tables, but only at furnishing an approximate idea of the ranges that may be reached with a given kind of projectile.

(1) In order to be complete, it may be added that the ballistic coefficient does not remain **exactly** constant all along the trajectory; this fact may be

explained as follows: when the projectile leaves the muzzle, as has been said (Chapter III), the projectile undergoes great oscillations (nutation). Generally these oscillations diminish rapidly during the first few meters of the flight of the projectile through the air. However, the axis of the projectile does not exactly coincide with the tangent to the trajectory, and the angle S between these two directions varies **slowly** all along the

Fig. 50.

trajectory, so that the surface which the projectile offers to the resistance of the air does not remain the same from one end of the trajectory to the other.

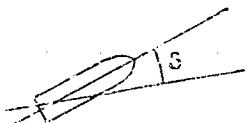


Table giving the approximate values of the ballistic coefficient C of some kinds of projectiles.

CALIBER (milli- meters).	KIND OF PROJECTILE.	MUZZLE VELOCITY.	WEIGHT in KILO- GRAMS.	10000 C (1)	FICTI- TIOUS ogival angle γ (in degrees).
75	Shrapnel.....	535	7.240	5.6	37°
	H. E. shell (short fuse).	550	5.315	7.6	37°
	A. L. (short fuse).	525	7.445	4.0	26°
155	Case shot.....	440	40.800	3.9	33°
	H. E. shell.....	433	43.000	4.3	40°
	F. A. shell.....	450	43.550	2.9	26°
240	P. (1898-1915) [H. E. shell].	526	160	1.74	24°
	F. A. 1915 D (H. E. shell).	575	164	1.66	23°
	Steel 1916 D (H. E. shell).	614	140	2.09	25°
320	F. A. D. (with false ogival head) H. E. shell.	606	392	1.10	23°

(1) The coefficient multiplied by 10 000 is given here instead of the coefficient itself, in order to avoid the use of numbers beginning with three or four zeros, which makes their reading difficult and is a cause of errors.

Conversely, on the diagram giving the amounts of $f(v)$, these amounts are obtained by dividing the actual ones by 10 000, so that, if it is desired to make use of the above table and the diagram $f(v)$ in order to determine, for instance, the resisting acceleration of the air upon a projectile, it is sufficient to multiply the number in the above table corresponding to this projectile by the ordinate of the curve corresponding to its velocity.

EXAMPLE : The retardation of the air upon the 320 m/m shell, the velocity of which is 606 m, will be :

$$1.10 \times 13.5 = 14.85 \text{ m.}$$

CHAPTER V.

DRIFT OF PROJECTILES.

The resistance of the air, acting upon an oblong projectile rotating round its axis, causes it to deviate from the vertical plane of fire. The distance between the point of fall and the plane of fire is called drift.

The causes of this phenomenon are imperfectly known because the resistance of the air acts in an uncertain way.

However, the following general laws may be given:

1) The sense of the drift is the same as that of the rotation of the projectile; if, for an observer looking at the projectile base, the rotation of the projectile is clockwise, it is said to rotate to the right; in this case, the drift carries the projectile to the right of the plane of fire. In the contrary case, it carries it to the left (case of the 95 m/m gun and some Marine Guns).

2) For a given projectile, the drift varies nearly proportionally to the maximum ordinate or (which amounts to the same) to the square of the time of flight (1). Therefore it rapidly increases with the range in the case of fire with flat trajectories.

EXAMPLE:

75 m/m gun H. E. shell. $V_0 = 550$ m.

Range (kilometers).....	1.	2.	3.	4.	5.	6.	7.	8.
Drift (meters).....	0.	3.	9.	20.	45.	90.	160.	330.

In the case of vertical fire, it reaches values which are much more considerable than in fire with flat trajectories.

EXAMPLE:

The 220 m/m mortar firing the long shell, 1909 Model, with a muzzle velocity of 260 meters, can reach a range of 4000 meters:

a) Either with an elevation of $20^{\circ}41'$ giving a drift of 34 meters,

(1) However, for small caliber projectiles, the drift increases more rapidly than this law indicates.

b) Or with an elevation of $65^{\circ}29'$ giving a drift of 383 meters.

3) The drift increases rapidly with the velocity of rotation *i. e.*, with the final pitch of the rifling.

EXAMPLE:

There are two kinds of 270 m/m coast artillery mortars, the rifling of one having a pitch of 7° and the other 12° .

The corresponding drifts are the following:

Ranges.....	2000	4000	6000	8000	8900
Drift of mortar (pitch 7°)	5.2	26	76	195	348
Drift of mortar (pitch 12°)	9.1	45	132	337	602

4) The drift decreases as the length of the projectile increases.

This explains why the drift of some semi-steel shells is greater than that of long shells of the same caliber, same weight and same coefficient of form, and therefore same ballistic coefficient, but a greater length.

5) The drift increases with the ratio $\frac{B}{w}$ between the moment of inertia of the projectile with respect to its longitudinal axis and its weight.

CHAPTER VI.

CIRCUMSTANCES MODIFYING THE FORM OF THE TRAJECTORY.

The form of the trajectory depends, as has been said, on the angle of departure, the muzzle velocity, and the forces which act on the projectile during its flight, *i. e.*, gravity and the resistance of the air.

All circumstances modifying any one of these elements will therefore modify the form of the trajectory, and particularly the range, which, in certain cases, may differ by 10 o/o more or less from the range of the firing tables.

It is therefore all important to understand the nature of these circumstances in order either to avoid them or compute their effects, if possible.

ART. I.

VARIATION OF THE MUZZLE VELOCITY AND ANGLE OF DEPARTURE.

The circumstances which are apt to modify the muzzle velocity and angle of departure have already been indicated (condition of powder — weight of projectile — condition of gun — nature and condition of the platform, the sinking or sudden tilting of which at the moment of fire may bring about an error either in range or direction).

To avoid these disturbing causes, ammunition should be carefully separated into lots and sheltered, and materiel and platforms taken good care of.

When the muzzle velocities of certain charges are different from those of the tables, and this difference is known, the correction tables (VII for the 75 and V for the 155) of the firing tables make it possible to calculate the necessary corrections to take into account the difference in muzzle velocity.

ART. II.

VARIATION OF THE BALLISTIC COEFFICIENT AND THE BALLISTIC DENSITY OF THE AIR.

The effect of the resistance of the air is to decrease the velocity of the projectile; the amount of retardation is expressed, as has been said, by :

$$c \delta f(v)$$

It therefore varies with the ballistic coefficient of the projectile, $\frac{d^2 \Delta}{w} i$, and the ballistic density of the air.

a) Variation of the ballistic coefficient.

For the same kind of projectile, for instance 75 m/m H. E. shell, fitted with the same fuses, the exterior form being the same, i and d do not change; w alone varies and it is clear that an increase of w decreases the ballistic coefficient; this increases the range for the same muzzle velocity.

But, in practice, the latter condition, *i. e.*, the equality of muzzle velocities, is not to be secured with projectiles of different weights fired with the same charge: the heavier ones

have a smaller muzzle velocity than the lighter ones, which tends to decrease their range.

For short ranges, the influence of the increase of velocity is the strongest, and, of two projectiles of the same kind fired at the same time with equal charges in identical guns, the lighter one keeps ahead at first. Then, at a certain range, which may be called the range of equivalence, the two projectiles travel abreast, and afterwards the heavier one gets ahead.

The firing tables (tables VII for the 75, V for the 155) give the variations in range brought about by differences in the weights of projectiles (1).

b) Variation in the weight of a liter of air.

It has been said previously that the ballistic density of the air decreases with the altitude, and a diagram has been given which indicates the value of this density under normal conditions, *i. e.*, when the temperature and pressure at the origin of the trajectory are respectively 15° and 750 m/m; the weight of one cubic meter of air is then 1.208 kg.

Now, the weight of one cubic meter of air at a given place depends on the temperature and barometric pressure at this place; if it amounts to 1.095 kg. for instance, at the origin, the ballistic density amounts to $\frac{1.095}{1.208} = \frac{9}{10}$, and the resistance of the air at the departure is reduced in accordance with the same ratio: $\frac{9}{10}$.

If it is assumed that this ratio remains nearly constant for the various layers of the atmosphere, the ballistic coefficient of the projectile may be considered as being reduced according to the same ratio. This hypothesis, though it is not strictly correct, especially with reference to the upper layers of the atmosphere, gives results which are sufficiently approximate in practice. It is adopted for lack of more accurate determination.

It is therefore apparent that it is possible to deduce the difference between the range of the moment and that of the

(1) In reality the weight w of the projectile decreases slightly with the altitude; the result is therefore a progressive diminution of the ballistic coefficient as the maximum ordinate of the trajectory becomes greater. But no correction should be made on this account, as this change is taken into account in the data given in the firing tables.

Besides, it is only for very long ranges that the decrease in gravity has any importance: for a range of 120 km., it is approximately 1000 m., or barely $\frac{1}{100}$ of the range.

firing tables, from the knowledge of the weight of a cubic meter (or liter) of air at the battery.

The firing tables (Charts I and II and Tables VII and V) give the necessary indications for this correction (1).

ART. III.

INFLUENCE OF THE ATMOSPHERIC WIND.

It has been thus far assumed that the air was calm. It is evident that, if it is stirred by the wind, the range will be modified and the projectile displaced in the same direction as that toward which the wind blows.

§ 1. Influence of the wind upon the range.

In order to form an idea of the mode of action of the wind, first assume that it blows horizontally, with a constant velocity, in the direction piece-target.

If an observer placed near the muzzle of the piece is assumed to be carried by the wind and looks at the projectile, it will seem to be propelled, not with its actual velocity with reference to the ground, but with a velocity which is the resultant of the latter and of another velocity equal to that with which the observer himself moves and of contrary sense (2).

To the observer, the projectile will seem to follow a trajectory corresponding to an angle of departure and muzzle velocity different from those of the tables, the amounts of which

(1) The examination of numerous meteorological soundings has shown that the density of the air decreases with the altitude in summer according to the rule assumed as correct above, but that this decrease is somewhat greater in winter.

Hence, for the same value of the air density computed at the battery level, the range will be longer in winter than in summer.

It is only for ranges exceeding 10 km. that this difference becomes noticeable. For instance, with the 155 G. P. F. gun, firing B shell with a muzzle velocity of 735 ms., the difference may be about 30 m. at 10 km. and 300 m. at 16 km.

No correction should be made to offset this variation, as the meteorological bulletins do not at present give the data necessary for this purpose.

The above is given only for the sake of information and to explain certain differences that may occur between the firing table ranges and the ranges found by actual experiment, even when corrections have been made to offset all known perturbing causes.

(2) This is what happens when two trains leave a station simultaneously: it seems to the passengers of the slower train that the speed of the quicker one is decreased by an amount equal to that with which they themselves are carried on; and it seems to the passengers of the quicker train that the other moves backward with a speed equal to the difference of the two speeds.

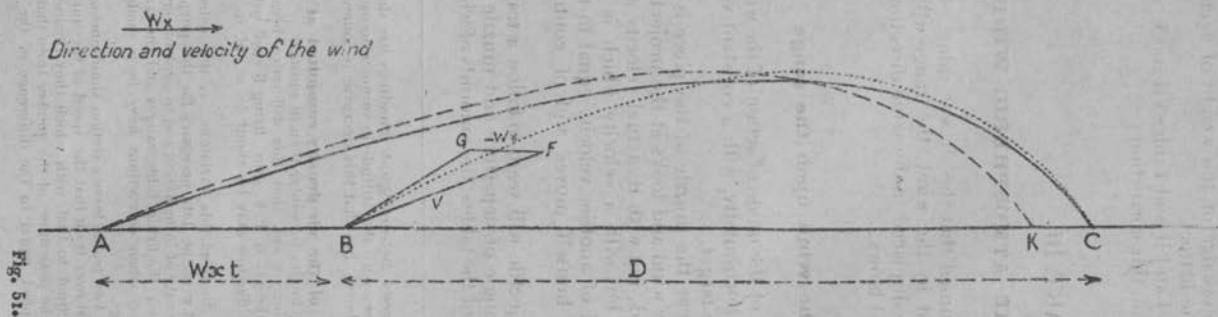


Fig. 51.

- A ——— K (dashes) trajectory in calm air
- B C (dots) apparent trajectory for the observer carried by the wind.
- A ——— C (continuous line) actual trajectory in the wind.

may be determined by means of the construction given in fig. 52; the projectile will therefore have its point of fall at a

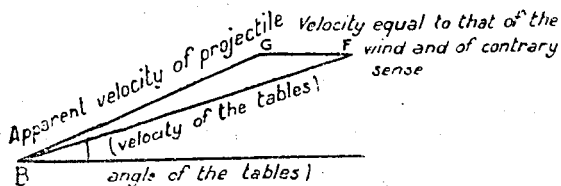


Fig. 52.

distance D , from the observer carried by the wind, equal to the range corresponding to the trajectory with the observer as an origin.

But, during the time of flight t , the observer carried along with the velocity W_x of the wind, has himself travelled a distance equal to:

$$W_x t$$

and consequently, the range R (distance between the point of fall and the muzzle of the piece that is motionless) will be:

$$R = W_x t + D.$$

NOTE. — It is sometimes thought that the displacement caused by the wind is merely equal to the product $W_x t$ of the velocity of the wind by the time of flight; this practically amounts to supposing the projectile to be carried by the wind like a balloon.

A numerical example of the above reasoning will show the error which is thus made:

Assume that the long 155 m/m shell — charge 3 — $V_0 = 249$ — short fuse — is fired at a range of 4000 m., the wind blowing in the direction piece-target with a velocity of 10 meters per second.

The angle of elevation given by the tables for 4000 m. is $23^\circ 20'$, corresponding (with a jump of $20'$) to an angle of departure of $23^\circ 40'$.

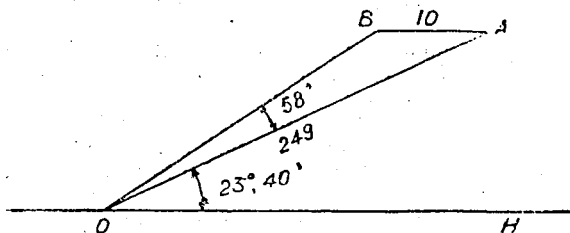


Fig. 53.

Draw line $OA = V_0$ making with the horizontal the angle of $23^\circ 40'$, then AB , equal and of contrary sense to the velocity of the wind, *i. e.*, 10 m., OB represents in size and direction the muzzle velocity of the projectile in the apparent trajectory, *i. e.*, 239.90 and

$$HOB = 24^\circ 38'.$$

From this quadrant angle of departure, deduct the jump $20'$; hence an angle of elevation of $24^\circ 18'$.

The apparent velocity of the projectile is therefore reduced by:

$$249 - 239.90 = 9.10 \text{ m.},$$

corresponding to a decrease in range of 208 m.

The apparent elevation is increased by:

$$24^\circ 18' - 23^\circ 20' = 0^\circ 58'$$

corresponding to an increase in range of 102 m.

Therefore, the apparent range is decreased by:

$$208 - 102 = 106 \text{ m.}$$

On the other hand, the time of flight being:

$$t = 19.5 \text{ sec.},$$

the moving observer has travelled, during this time t , a distance of:

$$10 \times 19.5 = 195 \text{ m.}$$

in the direction of the target.

The actual increase in range is therefore:

$$195 - 106 = 89 \text{ m.}$$

(this result is practically equal to that given by the firing tables *i. e.*, 88 m.).

It is hereby seen that, if the amount of correction made had been:

$$W_z t = 195 \text{ m.}$$

the error thus made would have been:

$$195 - 89 = 106 \text{ m.}$$

§ 2. Influence of the wind upon the direction.

A similar method and reasoning make it possible to determine the influence of a lateral wind, *i. e.*, wind blowing in a direction perpendicular to the plane of fire. To the observer carried laterally by the wind, the projectile seems to be propelled with a velocity which is the resultant of its own velocity and another velocity equal to that of the wind and of contrary sense.

The muzzle velocity and the angle of departure will undergo but little modification, so that the difference in range will be

It may be noted that this displacement is much smaller than the longitudinal displacement caused by a wind of the same velocity.

When the wind blows obliquely to the line of fire, it may be resolved into two components : one parallel to the line of fire, leading to the displacement in range, the other perpendicular to this line, leading to the displacement in direction.

The firing tables (Chart III and Tables VII and V) show how to work out these corrections.

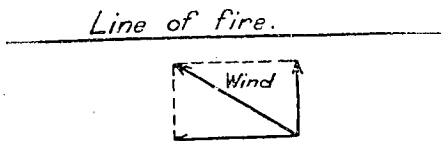


Fig. 56.

NOTE. — It has been said already that wrong conceptions about the influence of the wind are frequent; this is explained by the following example :

Assume two projectiles having different calibers, weights or exterior forms, but having the **same ballistic coefficient** and fired at the same time with the same elevation and velocity.

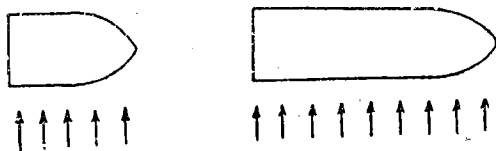


Fig. 57.

According to what has been said previously, the lateral displacement caused by a lateral wind will be the same for both projectiles.

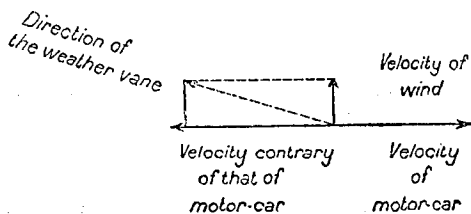


Fig. 58.

Yet it is sometimes thought that the projectile having the larger lateral surface will be displaced by a greater amount than the other. This assumption is wrong, for both projectiles are propelled in a direction which is the resultant of that of the wind and another direction equal and contrary to the one they would assume if there were no wind. The movement thus considered may be compared to that of weather vanes placed on motor cars : if the automobile is motionless and the wind blows perpendicularly to the road, the vanes, whatever their shapes may be, will be turned in the same direction.

As soon as the car moves on, the direction of the vanes changes and, after some oscillations, they become steadily directed along two parallel planes which are closer to the direction of the road as the motion of the car is quicker; they assume the direction of a fictitious wind which is the resultant of the actual atmospheric wind and another force of a velocity equal to that of the car and of contrary sense.

The same thing will happen with projectiles, the axes of which will be oriented in the same manner, whatever their lateral surfaces may be; the resistance of the air will act in a direction parallel to their common axis in the case of move-

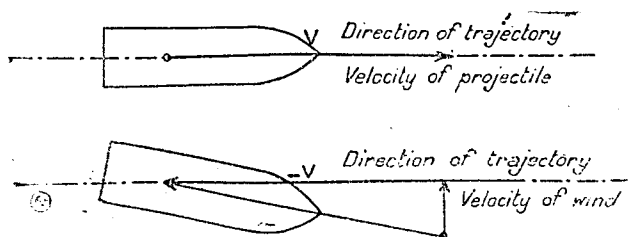


Fig. 59.

ment in calm air; the only difference is that the axis will be oblique with reference to that of the trajectory, just as, in

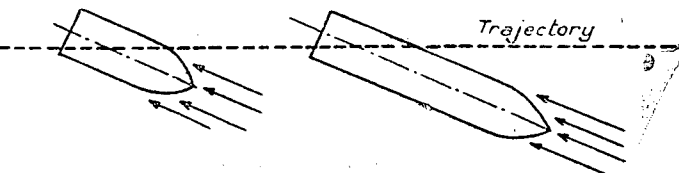


Fig. 60.

the example given, the plane of the vanes is oblique with reference to the direction of the car (fig. 59 and 60).

§ 3. The ballistic wind.

Thus far, the wind has been assumed to be constant in velocity and direction throughout the trajectory. But this condition is not fulfilled as a rule. The velocity of the wind at various altitudes is found by means of an aerological sounding, the principle of which consists of sighting with a theodolite a balloon rising with a constant speed of ascension *e.g.* 100 meters per minute. It is thus known that, so many minutes after its departure, it has reached a height of 100, 200, 300 $n \times 100$ meters. Consequently, if its azimuth and angular height above the horizon are taken from minute to minute, its position may be plotted on a map.

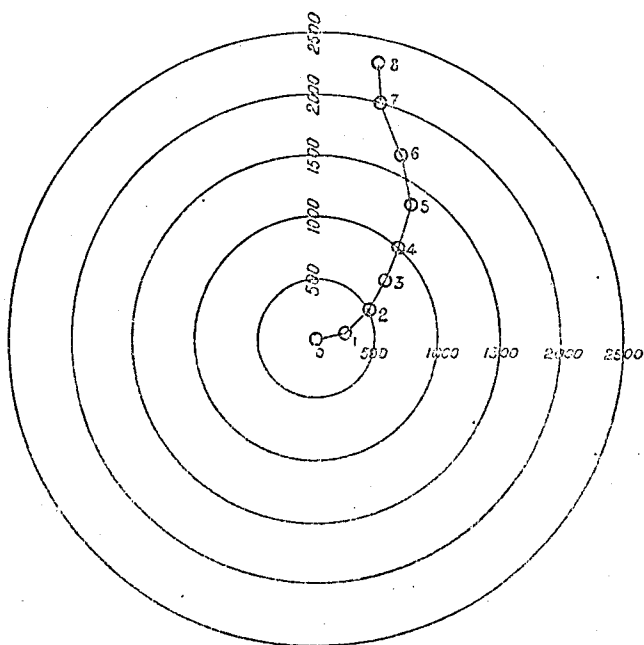


Fig. 61.

The horizontal projection of the trajectory of the balloon being thus drawn and its positions marked for successive minutes, it is possible to know its speed at each moment.

But how is this result to be made use of? It is certain that, if time were available, it would be possible to determine

separately the action of the wind upon each section of the trajectory. As this method would be far too long, the meteorological station staff compute and send to the batteries an intermediate velocity between the amounts thus determined. This is called the ballistic wind.

The determination of the ballistic wind is based on the following considerations:

If all the trajectories having the same maximum ordinate (for instance 1500 m.) are considered, and they are divided into a certain number of sections (3 for instance) having the same height (500 m.):

1) The times of travel of the projectiles through the same section.

2) The times of travel of the projectiles in sections :

3 2 1

are proportional to the numbers

$$\begin{array}{ccc} 1 & \sqrt{2}-1 & \sqrt{3}-\sqrt{2} \\ 1 & 0.41 & 0.32 \end{array}$$

More generally, if the trajectory had been divided into four sections, the times of travel in the successive sections would have been

$$\begin{array}{ccc} n & n-1.. & \sqrt{n-1}-\sqrt{n-2} \\ 1 & \sqrt{2}-1 & 2 \\ & & \dots 1 \dots\dots \\ & & \sqrt{n}-\sqrt{n-1} \end{array}$$

It is assumed (1) that the action of the wind upon each element of the trajectory is proportional to the corresponding time of travel, and an intermediate value is computed between the components of the wind in the various sections, first along the line North-South, then along the line East-West.

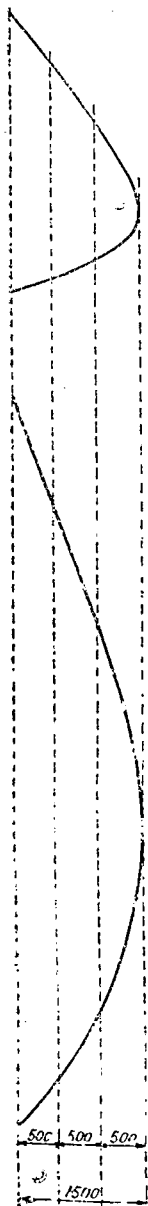


Fig. 2.

(1) This assumption is but roughly approximate, but the results it leads to are satisfactory in practice, with reference to the range at least.

This value is obtained by adding their respective values multiplied by the above coefficients, and dividing the result by the total of these coefficients.

NUMERICAL EXAMPLE :

Assume that the components of the wind in the various sections :	1	2	3
are respectively			
toward the North :	5	7	12
toward the East :	4	2	- 1

The North component of the ballistic wind will be :

$$\frac{(5 \times 0.32) + (7 \times 0.41) + (12 \times 1)}{1.73} = 9.50$$

The East component will be :

$$\frac{(4 \times 0.32) + (2 \times 0.41) - 1}{1.73} = 0.60$$

The ballistic wind resulting from the above components will have a direction : North 3 grades East, and a velocity of 9.5 m. The latter value is the one that will be taken from the correction formulas with reference to trajectories having maximum ordinates of about 1500 meters.

ART. IV.

INFLUENCE OF THE SHAPE AND MOTION OF THE EARTH.

1) Shape of the earth.

The earth being spherical and not plane, as it has] been thus far assumed, the result is that a trajectory A B, the point of fall of which would be point B on horizontal ground, cuts

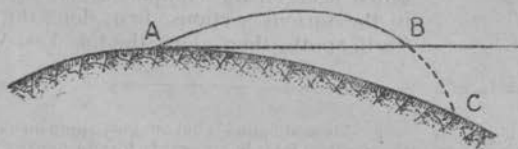


Fig. 63.

the earth, in reality, at point C: hence a small increase in range (1).

This increase does not exceed 10 meters for ranges less than 10 kilometers, in the case of the 75 or 155. Besides, it is not to be taken into account, for, as it is independent of the direction of fire and position of the pieces, it is included in the ranges given by the firing tables.

2) Rotation of the earth.

The rotation of the earth brings about :

1) A lateral deviation to the right of the plane of fire. This deviation is almost independent of the orientation of the plane of fire, at least in the case of fire with flat trajectories and for ranges less than twenty kilometers.

Therefore, though it is not negligible, it is not generally to be taken into account, for — except in the case of certain high-power guns — this deviation is included in the drift given by the tables.

Note here that this deviation may reach from 15 to 25 meters at the extreme ranges (from 10 to 11 km.) of the 75 (AL shell) and 155 H. It may reach from 1300 to 1400 meters for a gun firing at a range of 120 km. in a southwesterly direction.

2) A variation of range, the sense and amount of which vary with the direction of fire. The error is nil in the North and South directions; it reaches its maximum amount in East and West directions; it is positive towards the East and negative towards the West (2). It generally amounts to less than half a probable error in range, except for very precise guns having very long ranges. It is therefore to be taken into account only in very special cases.

(1) The amount of this increase is $\frac{d^2}{2R \tan \omega}$

d = range in meters.

R = radius of the earth = 6,366,000 m.

ω = angle of incidence

It would be about 600 meters for a gun firing at a range of 120 km.

2) At least for elevations less than 45°.

ART. V.

SUMMARY AND CONCLUSION.

In short, the corrections to be made when preparing the initial data of fire, refer to:

- 1) The muzzle velocity (calibration of the pieces — condition of the powder).
- 2) The atmospheric conditions (weight of the air, wind).
- 3) The weight of the projectile.

The Firing Tables sufficiently indicate how these corrections must be worked out in practice.

However, on account of the uncertainty of certain elements (quickness of powder — daily decrease of air density — actual force of wind), the use of these corrections does not allow one to dispense with adjustment fire. But, in most cases, these corrections will make adjustment shorter and allow efficient surprise fire so harmful to the enemy.

CHAPTER VII.

RAPID METHODS FOR THE APPROXIMATE DRAWING OF TRAJECTORIES FROM THE DATA GIVEN BY THE FIRING TABLES — VARIOUS APPLICATIONS.

The firing tables give, as a rule, besides the maximum ordinate, only the data corresponding to the origin and point of fall of the trajectory.

In certain cases, it may be very useful to draw the whole trajectory (or at least parts of it, near its origin and point of fall). This is the case, in particular, for the problem of the angle of site, that of defilade, the determination of zones that cannot be covered by a piece firing from a given position, and lastly for adjustment by high air bursts.

It is impossible to develop here the methods by which a trajectory may be constructed with theoretically unlimited

accuracy. It will be shown only how a trajectory may be drawn, by means of the data given by the tables, with an accuracy sufficient in practice.

The various methods that follow, being based upon different principles, will not give strictly the same results, but this has but little importance, since their accuracy is satisfactory.

I. Method of the "French Artillery Memorandum"; its application to the problem of the angle of site.

Let Φ be the quadrant angle of departure of the trajectory T, to be constructed, for a range R — for instance 10,000 meters — and let ϕ be the angle of departure of the trajectory for a range X less than the previous one, for instance 3000 meters.

From a demonstration, it is found that the drop (1), with reference to the line of departure, of the point of the trajectory, the abscissa of which is x , is expressed by :

$$a = \frac{x \sin^2 \phi}{2 \cos^3 \Phi}$$

As ϕ and Φ are given in the tables opposite the amounts of x and R, it is possible to plot as many points of the trajectory as required, after having drawn the line of departure of the trajectory T.

(1) Remember that the drop for a given point of the trajectory has been thus defined :

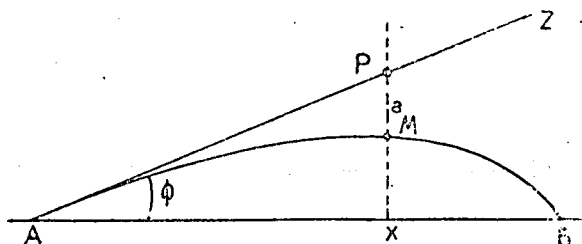


Fig. 64.

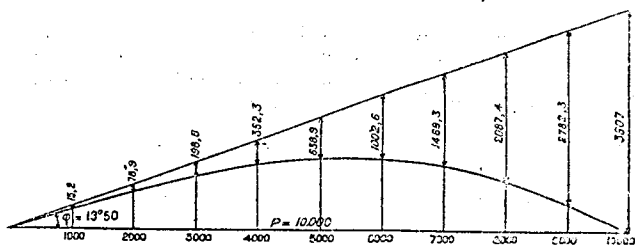
Let AZ be the line of departure (making with the horizontal plane a angle of departure Φ equal to the sum of the angle of elevation and the jump). Let M be a point of the trajectory, MX the vertical line drawn through this point. The drop for M is the vertical line PM.

NUMERICAL EXAMPLE :

Assume that it is desired to construct, by plotting successive points for each thousand meters, the trajectory of the 155 Gun, D. shell, fired with the charge 000 and an elevation of $19^{\circ} 50'$ corresponding to the range 10000 meters.

$x.$	$\phi x.$	$\sin^2 \phi x.$	$\cos^2 \phi.$	$\frac{x \sin^2 \phi x}{2 \cos^2 \phi}$
1000.....	$46'$	0.0266	0.8849	15.2
2000.....	$2^{\circ} 0'$	0.070	0.8849	78.9
3000.....	$3^{\circ} 22'$	0.1175	0.8849	198.8
4000.....	$4^{\circ} 52'$	0.1695	0.8849	382.3
5000.....	$6^{\circ} 32'$	0.226	0.8849	638.9
6000.....	$8^{\circ} 36'$	0.295	0.8849	1002.6
7000.....	$11^{\circ} 3'$	0.3766	0.8849	1488.3
8000.....	$13^{\circ} 43'$	0.462	0.8849	2087.4
9000.....	$16^{\circ} 35'$	0.547	0.8849	2782.3
10000.....	$19^{\circ} 50'$	0.629	0.8849	3607

The results of the calculation are plotted on the following diagram.



[Fig. 65.

This method will be sufficiently accurate for angles of elevation less than 30° — and even 40° — especially in the vicinity of the point of fall. It cannot be applied to vertical fire.

In the case of small angles of elevation, a more simple method is frequently used, which is based on the principle of the rigidity of the trajectory. It may be explained as follows :

Let T and t be the trajectories corresponding to angles of departure Φ and ϕ of small amounts (5° or 10° at most) : if the trajectory t is made to rotate round point O by an angle $\beta = \Phi - \phi$, it will coincide with the trajectory T . During this motion, point X describes an arc of radius x , which arc may

be considered as a part of a vertical line on account of the smallness of the angle $\Phi - \phi$.

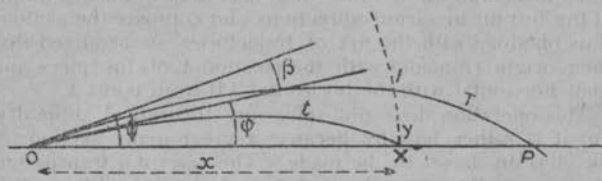


Fig. 66.

The ordinate y of point M , the abscissa of which is x , on the trajectory T , may be expressed by :

$$y = x (\Phi - \phi) [1].$$

NUMERICAL EXAMPLE :

Assume that it is desired to plot the point, the abscissa of which is 1200, of the trajectory for 2,500 m. of the 75 m/m shell with reduced charge.

$$\Phi = 7^\circ 44' = 138 \text{ mils.}$$

$$\phi = 3^\circ 20' = 59 \text{ mils.}$$

$$\Phi - \phi = 4^\circ 24' = 79 \text{ mils.}$$

$$y = 1.2 \times 79 = 95 \text{ meters.}$$

The application of this formula to angles of elevation of more than 10° may lead to gross errors, and the trajectory



Fig. 67.

thus constructed may sometimes pass several hundred meters above the actual trajectory.

The drawing of trajectories is particularly useful for the

(1) When applying this formula, be careful to express : x in meters and Φ and ϕ in fractions of the radius; or (which amounts almost to the same thing) x in kilometers and Φ and ϕ in mils, as is done in the above example.

determination of the zones that cannot be covered by a piece occupying a given position.

To determine these zones, it is necessary to make sections of the terrain in various directions and compare the sections thus obtained with the net of trajectories so arranged that their origin coincides with the position A of the piece and their horizontal with the horizontal AH from point A.

This operation does not offer any theoretical difficulty, but it is rather lengthy because a great many sections of the terrain have to be made. The use of a transparent diagram, called "surface of trajectories", facilitates this method.

Problem of the angle of site.

The same method gives a solution for the following problem (problem of the angle of site): Given the distance battery-target and the difference of altitude between these two points (or, which amounts to the same thing the site of the target), find the quadrant elevation to be given to the piece.

Let ϕ be the elevation corresponding to the horizontal distance of the target OA.

S the site.

Φ the desired quadrant elevation.

It is demonstrated that the following relation exists :

$$\sin (2 \Phi - S) = \sin S + \sin 2 \phi \cos S.$$

This makes it possible to calculate Φ , since S and ϕ are known (1).

In practice, the above equation will not need to be solved and Φ will be determined by using tables II, III and III bis of the firing tables.

Table II gives, in minutes and *hundredths* of minutes and for ranges distant by 100 meters, the value of the site corresponding to a difference of altitude of 1 meter. Therefore

(1) In fact this formula gives for the angle $2 \Phi - S$ two supplementary values A and $180^\circ - A$ (as these two angles have the same sine) and, hence, for the desired angle Φ two values

$$\Phi_1 = \frac{A + S}{2}, \quad \Phi_2 = \frac{180^\circ - A + S}{2}$$

Both these values can be accepted in the case of a vacuum. But in the air, the one smaller than 45° alone is admissible, for the hypothesis used as a basis for the calculations does not apply to greater quadrant elevations.

it is possible to compute from it the site S corresponding to a difference of altitude y for a distance x .

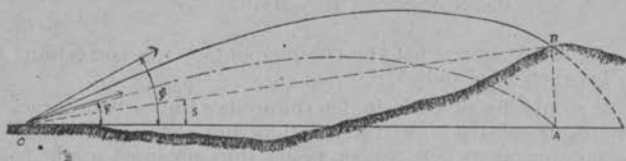


Fig. 68.

Table III, which is a double entry table, gives, for the site S of the target, supposed to be higher than the piece, and for the elevation corresponding to the horizontal distance of the target, the *complementary site correction*, i. e., the amount (positive or negative) to be added to the sum of the angles φ and S in order to obtain the elevation Φ to be given to the piece. Hence

$$\Phi = \varphi + S + c.$$

This table is drafted as follows.

Target higher than the piece.

SITES.	QUADRANT ELEVATIONS OF THE TABLES.			
	26°	27°		
5°	1°49'	2°06'		
5°30'	2°1'	2°21'		

Table III *bis* is similar to the preceding one but it refers to a target **lower than the piece**; the complementary correction is, in this case, negative.

Tables II, III and III *bis* are the same for all materiels.

NUMERICAL EXAMPLES :

What is the elevation to be given to a 155 Howitzer firing with charge 3 on a target situated at a distance of 3000 m. and at an altitude 280 m. higher than that of the battery?

Table VI gives for the elevation for 3000 m. the value

$$\varphi = 26^{\circ}51'$$

Table II gives for the value of the site corresponding to a height of 1 m. the value 1'15.

Hence

$$S = 280 \times 1'15 = 321' = 5^{\circ}21'$$

Table III shows that the complementary site correction c is between 1'49' and 2'21'.

It would be possible to determine its value with accuracy by means of a double interpolation, but such a calculation is not necessary, for the precision thus obtained would be useless on account of the size of the fork corresponding to this kind of fire and the probable uncertainty of the initial data.

The notice at the beginning of the Firing Tables recommends the use as first element of the data in table III, the site to the nearest $1/2$ degree and the elevation of the tables to the nearest degree.

In the present case $5^{\circ}30'$ and 27° will be taken [as the respective values of these angles, which will give for the site correction :

$$\begin{aligned} c &= 2^{\circ}21' \\ \text{Finally } \phi &= 26^{\circ}51' \\ S &= 5^{\circ}21' \\ c &= 2^{\circ}21' \end{aligned}$$

$$\text{Hence } \Phi = 34^{\circ}33'$$

The interpolation made between the data of table III to obtain an accurate solution of the problem would have furnished, for the value of c , the angle $2^{\circ}13'$, instead of $2^{\circ}21'$; the value of Φ would have been $34^{\circ}25'$. The corresponding difference in range would be less than 10 m., whereas the proving ground probable error for this range is 12.40 m. It would therefore be useless to strive for greater accuracy.

$$\text{If } \phi < 10^{\circ} \text{ and } S < 30'$$

the complementary site correction is less than one minute, *i. e.* completely negligible; the elevation to be commanded to the piece is then equal to the sum of the elevation of the tables and the site.

II. Another method for drawing trajectories.

When a great number of trajectories must be drawn, but only for a part of their descending branch, — which is the case, in particular, for preparing long range adjustments by

high air bursts (1) — sufficient accuracy is obtained (2) if the trajectory is replaced by an arc tangent to it at the point of fall, the radius R of which is

$$R = \frac{v^2}{g \cos \omega} \quad (\text{in meters})$$

in which :

v = remaining velocity at point of fall in meters,
 ω = angle of incidence,
 $g = 9.81 \text{ m.}$

} given by the tables.

EXAMPLE :

For the 155 G.P.F. gun firing D shell with a muzzle velo-

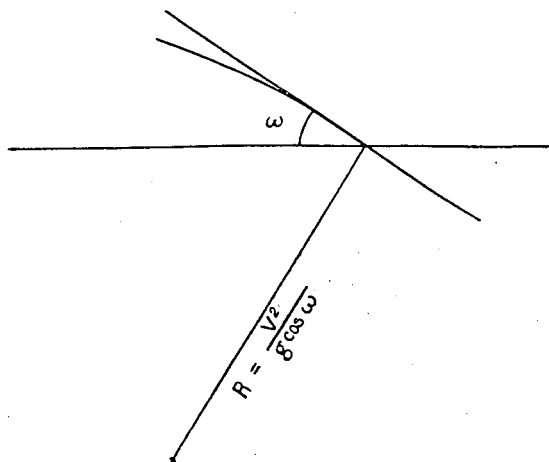


Fig. 71.

(1) This occurs in the following case: fire is executed on a zone where it is impossible to observe the points of fall. The fuse is then set so as to



Fig. 69.

have bursts at a certain height (200 or 400 meters for instance) above the ground. Let M be the point of burst which may be located with the desired

city of 650 m. and an elevation of 25° , the angle of fall of the tables $\omega = 38^\circ 10'$, the remaining velocity $v = 273$

$$\text{and } R = \frac{273^2}{9.81 \times 0.786} = 9666 \text{ m.}$$

Draw then, with a radius of 9666 meters, at the scale of the drawing, an arc tangent to the trajectory at the point of fall; this gives the approximate drawing of the trajectory.

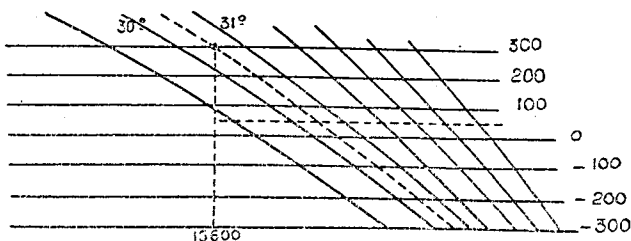


Fig. 72.

The adjoining figure represents part of a diagram thus drawn for the 155 G.P.F.

Assume that the observation of an air burst makes it possible to locate it at a horizontal distance of 15,600 m. from the piece and at a height of 300 m. above the latter.

Plot the point thus determined on the diagram. By graphical interpolation, the trajectory to which it belongs may be drawn and thus the point of impact on a given plane determined. For instance, if the level of the objective is the same as that of the piece, the distance of the point of impact will be 15900 m. in the case considered. If the map range of the target is 16100 meters, the elevation will be

accuracy by means of a telescope. The problem is to deduce from the knowledge of this point that of the trajectory on which it is placed and consequently that of point B, — which is possible if a sufficient number of trajectories have been drawn.

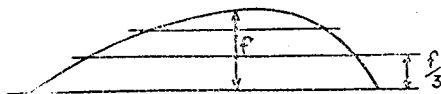


Fig. 70.

(2) Provided, however, that this method be applied to a zone, the height of which does not exceed a third of the whole height of the trajectory above the ground — which is generally sufficient.

increased by an amount corresponding to the increase of range: $16100 - 15900 = 200$ m., i.e., in the present case, 34" (1).

III. About some empiric formulas.

The following points should always be borne in mind. There is no simple formula giving with accuracy the value of the range and other ballistic data (maximum ordinate, angle of fall, time of flight) with reference to the elevation.

These data are given by the firing tables and nothing can supersede their use for the preparation of fire.

If it is merely sought to have an idea of the amount of the maximum ordinate or time of flight, the following formulas may be used :

1. The maximum ordinate (in meters) is approximately given by

$$F = \frac{P \times \tan \phi}{4}$$

(P being the range in meters, and ϕ the elevation).

(1) The following objection may be made with reference to this reasoning :

If the atmospheric and ballistic conditions were the normal conditions of the firing tables, the point of burst would be on the trajectory corresponding to the elevation with which the round has been fired, for instance $29^{\circ} 30'$. Observation would then be useless, or rather would only prove the correctness of the statement. The fact that it is not so and the point of burst is not on the trajectory of $29^{\circ} 30'$ but on that of $30^{\circ} 20'$, is due to the atmospheric and ballistic conditions being different from the normal ones; this results, as is known, in an alteration of the trajectory which causes the projectile fired with an elevation of $29^{\circ} 20'$ to burst on the trajectory of $30^{\circ} 20'$.

It is clear that the trajectory thus altered does not coincide either with the normal trajectory of $29^{\circ} 30'$ (OA) — to which it is tangent at the time of

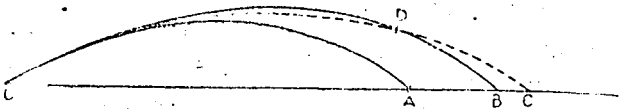


Fig. 73.

departure, since $29^{\circ} 30'$ is assumed to be the angle of departure — or with the trajectory of $30^{\circ} 20'$ (OB) which it cuts at the observed point of burst D.

An error is therefore made when B is said to be the point of impact; the latter point is C which slightly differs from B. The distance between B and C may be computed by means of the ballistic methods. But if the height D does not exceed 300 meters, if the elevation is greater than 25° , this distance does not exceed twenty meters.

It is therefore not necessary to take it into account, especially if the object of the operations in question is the preparation of zone fire (See Appendix XIV of the Artillery Firing Instruction, Nov. 19, 1917).

2. The time of flight T (in seconds) is approximately given by

$$T = \frac{2 V_0 \sin \phi}{g}$$

(V_0 being the muzzle velocity in meters, and $g = 9.81$ m., i.e., about 10 m.)

or
$$T = \sqrt{\frac{2P \tan \phi}{g}}^{(1)}$$

CHAPTER VIII.

SONOROUS PHENOMENA ACCOMPANYING THE MOTION OF THE PROJECTILE.

When a projectile is fired with a velocity smaller than that of sound a (i. e., about 340 m.), an observer perceives the following noises, whatever his position may be:

1. Report of shot,
2. Continuous hissing noise,
3. Report of burst.

(1) The following is an interesting application of this formula to time fire.

Assume that, on account of their difference of calibration, two pieces must be laid respectively with the angles

$$\phi \text{ and } \phi + d\phi$$

so as to hit the same target, the range of which is X .

What must be the difference between the fuse settings of the projectiles fired by the two pieces in order to get bursts at the same height?

It may be deduced from the above formula:

$$\frac{dT}{T} = \frac{d\phi}{\sin 2\phi}$$

in which $d\phi$ is expressed in portions of the radius or in mils.

Let $T = 47.7$ seconds,

$$\phi = 30^\circ,$$

$$d\phi = 0.36',$$

$$\frac{dT}{47.7} = \frac{0.009}{0.866}$$

$$\text{and } dT = 0.5 \text{ sec.}$$

The difference between the times of flight will therefore be 0.5 sec; the same difference will be adopted for the fuse settings. If this correction were omitted, there would be an error of 400 m. in the point of burst.

If the projectile is fired with a velocity greater than that of sound, the phenomenon is more complex because the

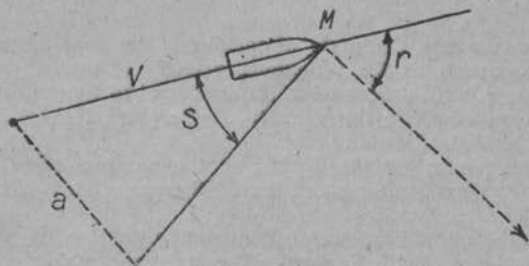


Fig. 74.

projectile produces in the atmosphere a kind of ripple like the wake of a ship, but with the shape of a conical wave, the apex of which follows the projectile while the wave sweeps the atmosphere, giving rise as it passes to a loud snap succeeded by complete silence.

A moment later, the observer may perceive, in an order of succession varying according to his position, a continuous hissing sound, the report of the shot, and the report of the burst.

Fig. 75 is a sketch showing how the wake called **shock wave** changes its form in travelling.

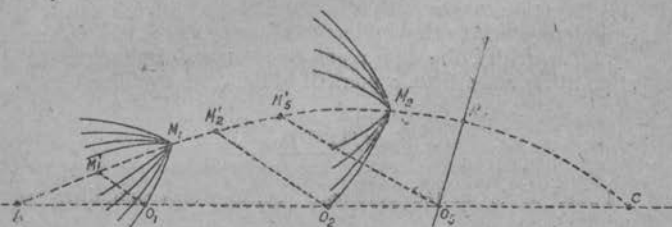


Fig. 75.

M_1, M_2 , etc., successive positions of the projectile at the times when the observers O_1, O_2 , etc. hear the shock wave.

M_1', M_2' etc., sonorous centers corresponding to the positions M_1, M_2 , etc.

M_3 point at which the decreasing velocity of the projectile reaches that of sound.

M_3C part of the trajectory along which a shock wave is no longer created.

This conical wave, which is called **shock wave** or ballistic

wave makes with the trajectory an angle s , the sine of which is expressed by :

$$\sin s = \frac{a}{v}.$$

Consequently, the angle of opening of the cone increases in proportion as the remaining velocity of the projectile decreases, until it becomes a plane normal to the trajectory at the point where the velocity of the projectile becomes equal to that of sound.

As is shown by the figure, at the moment when the observer perceives the shock wave, the projectile is already very far from him.

But the sound he perceives does not come from the point where the projectile is **now**. The wave moves along in a

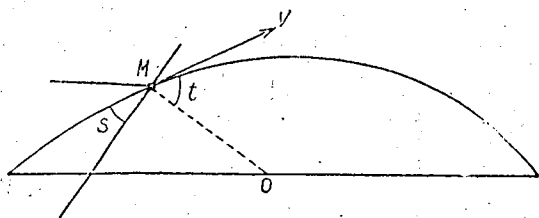


Fig. 76.

direction perpendicular to that of its generatrices ; therefore this direction makes with the trajectory an angle t which is complementary to the angle s of the cone.

Consequently, the noise perceived by an observer placed at point O comes from a point M of the trajectory, such that .

$$\cos \angle OMV = \frac{a}{v}.$$

Point M is called sonorous center corresponding to point O.

The shock wave cannot be heard everywhere in the space ; the zone within which it is heard is limited by a cone having

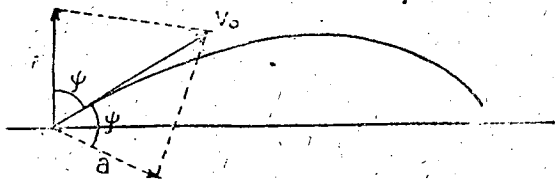


Fig. 77.

its apex at the muzzle of the piece, the line of departure for its axis, and for half its angle of opening an angle ψ such that $\cos \psi = \frac{a}{V_0}$, V_0 being the muzzle velocity.

For instance, with the 75 H. E. shell, the muzzle velocity of which is 550 m., this gives :

$$\frac{a}{V_0} = \frac{340}{550} = 0.62, \text{ hence } = 51^\circ 40'.$$

The interval between the moments when the observer perceives the shock wave and the report of the shot depends on his position. It is greater, **at a given distance from the muzzle**, when the observer stands nearer to the plane of fire, and smaller as he is nearer the cone limiting the zone of the space in which the shock wave can be heard. Along the surface of the cone the shock wave and the report of the shot are confused.

This interval is fairly small for the 75 (it hardly exceeds 1 second), which explains why many observers, whose ear is deeply impressed by the first sound, do not perceive the second.

But for the guns with a great muzzle velocity (*e. g.*, the 155 G. P. F.) this interval reaches **several seconds**.

As a rule an observer perceives the shock wave only once. However, with large caliber guns with great muzzle velocities (greater than 800 meters) and very long ranges (over 30 km.) it is possible to hear three successive shock waves, when at certain positions.

This happens when the velocity of the projectile on the descending branch is increasing and exceeds that of sound.

For instance, in the case of a projectile with a ballistic coefficient of 0.0001, fired with a muzzle velocity of 1000 m., and an angle of 55° , an observer located at M, 42700 m. from the muzzle, would perceive successively at the following times, reckoned from the firing of the round, the following sounds :

TIME SINCE THE FIRING of the round.	SOUND PERCEIVED and ITS CAUSE.	POSITION OF PROJECTILE AT THE MOMENT the sound is perceived.
122.2 sec.	Shock wave of point A..	A.
125 sec.	Report of shot at O	O.
137.7 sec.	Shock wave of point B..	The projectile has reached its point of fall before these sounds are heard.
142 sec.	Shock wave of point C..	
148.7 sec.	Burst at E.	

The zone of the plane of fire in which three shock waves can be heard is shaded in the figure (fig. 78).

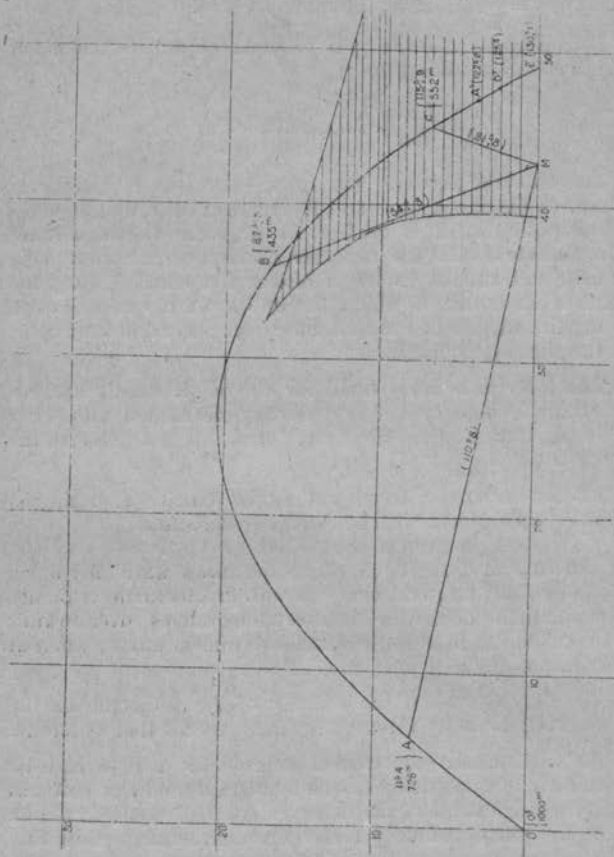


Fig. 78.

In all the remainder of the plane, only one shock wave can be heard.

The figures written near the points O, A, B and C indicate : the first, duration of the flight between the origin and the corresponding point, the second, the velocity at this point.

The figures written near the points A', O' and E indicate the durations of flight corresponding to these points.

The figures written along AM, BM and CM indicate the times taken by sound in covering the corresponding distances.

PART II.

DISPERSION.

CHAPTER I.

GENERAL CHARACTERISTICS OF DISPERSION.

ART I.

GENERAL CONSIDERATIONS.

The study of ballistics has shown that the range covered by a projectile fired with a certain elevation was different, as a rule, from that of the Firing Tables. Between these two ranges there exists a difference — often a considerable one — called **error of the moment**, the causes of which were dealt with in Ballistics, Chapter VI. The Firing Tables give the data for a computation, at least approximate, when the topographical conditions (site), atmospheric conditions (temperature, pressure and wind) and ballistic conditions (weight of the projectile and state of the powder) are known.

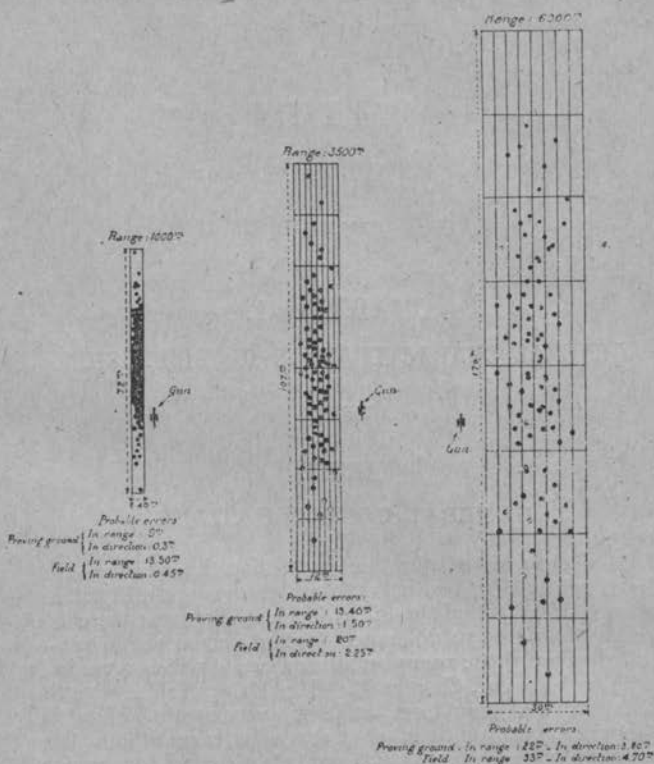
If the corresponding corrections are not made in due time, there is a risk of a burst occurring as much as several hundred meters short.

Experience shows, besides, that a series of projectiles of the same model, fired in succession with the same elevation, the same piece and the same charge, under conditions as nearly identical as possible of temperature pressure, and wind, do not fall at the same spot, but are distributed in a somewhat irregular manner over a certain zone, as is shown in fig. 1.

This phenomenon is called **dispersion** and the area over which the bursts are distributed is called **zone of dispersion**.

There can be no expectation as to the order in which the bursts occur. A burst occurring at one end of the zone of

dispersion may be followed by two others at the other end; four or five bunched bursts may be followed by another over by more than 100 m. with respect to the preceding ones, etc.



Angles of elevation.

1°8'

6°41'

17°1'

Angles of fall.

1°23'

10°22'

27°17'

N. B. — The guns represented in the figure are drawn at the same scale as the zone of dispersion and the shell craters and are intended to give an idea of their natural proportions.

Fig. 1.

DISPERSION OF 100 BURSTS
from a 75 m/m field gun. H. E. shell, short fuse
Muzzle velocity: 550 m. Angle of site: 0.

In consequence, the onlooker when observing this phenomenon for the first time, may be unfavorably impressed by it — especially if he stands in the vicinity and to one side of

the target — and may attribute this fact solely to the carelessness and inefficiency of the gun squads or to the poor quality of the ammunition. This is not the case, however, and experience from fire conducted with the minutest care, shows clearly that dispersion cannot be suppressed entirely.

Dispersion is a necessary evil, in spite of which the target must be hit. Therefore it is indispensable that the B. C. should know its causes and general characteristics thoroughly, so as to reduce its effects as much as possible.

ART II.

CAUSES OF DISPERSION.

§ 1. — Systematic errors and accidental errors.

It is evident that if all the ballistic and atmospheric conditions always remained **strictly identical**, there would be no dispersion. This phenomenon is therefore due to certain irregularities in these conditions. But these irregularities differ from the variations studied in Ballistics in that:

1. They are very small;
2. Their sense and amount change continually, and make any determination impossible.

EXAMPLE:

Fire is executed with a 75 gun, H. E. shell, normal charge, range 5000 m. Assume that previous information has shown that the muzzle velocity obtained in this fire is 538 m. instead of 550.

Table VII^b indicates that the ranges will be systematically short by more than 80 m. of those which would be obtained with a muzzle velocity of 550 m.

But this muzzle velocity does not remain strictly constant and equal to 538 m. with every round fired. It may vary accidentally, for instance, between 536 and 540 m. which will cause errors of about 30 m. between the corresponding bursts.

Besides, in the present state of our knowledge, it is impossible to know in advance which rounds will give a 540 m. muzzle velocity and which a 536 m. one; there exists, at the moment of the shot, no means to foretell in which part of the zone of dispersion the burst will occur.

Thus, there exist together, on one side, **systematic causes**, the amount and sense of which can be measured, and which bring about a difference sometimes considerable, called **error of the moment**, between the range of the moment and that of the Firing Tables, and on the other side,

accidental causes, the sense and amount of which constantly vary and cannot be measured, and which bring about differences between the successive ranges obtained with the same elevation. These differences are generally smaller than that of the moment, and may be called **errors of dispersion**.

§ 2. — Review of the principal causes of dispersion.

The principal causes of dispersion are enumerated below, their relative importance is mentioned, as are the measures which can alleviate their effects.

I. Causes due to the projectile.

a) Differences in weight. The influence of the weight on the range has been explained in Ballistics (Chapter VI); it is, here repeated that of two projectiles of the same model but different weights, fired with the same charge in the same piece, the lighter one has a longer range at small distances, on account of its greater muzzle velocity, and the heavier one at great distances, on account of its better ballistic coefficient.

This cause of dispersion will be lessened by allotting the projectiles in such a manner as to use during the same fire only those which have **practically** the same weight.

For the 75, the allotting is made in advance as the II. E. shells are distributed into the five classes L, +, + +, + + +, + + + +.

If care is taken to use in one fire only shells from one class, the **maximum** errors which may result from inequalities in weight are

11	9	2	8	17	29	43	56	meters
at	1	2	3	4	5	6	7	8 kilometers.

b) Irregularities in the exterior shape of the projectile, or its booster, or its fuse (1), for instance, a slight variation in the diameter of the bourrelet, a booster casing which has not been screwed tight, **dirt adhering to the ogival head**, etc.

All these causes are of very little importance if the projectile has been carefully tested during its manufacture, and **thoroughly cleaned** before it is fired. But, in the contrary case, they may bring about considerable errors.

In particular any decrease (even of a few tenths of a millimeter) in the diameter of the bourrelet results in a faulty

(1) It must remain understood that the fuses are of the same type. Mixing fuses of different types, for instance 1899-1915 model fuses with 1899 or 1914 model fuses is the cause of fair sized errors, especially with the small calibers.

guiding of the projectile in the bore and a considerable increase of dispersion.

c) Irregularities in the interior forms or the loading; such irregularities may cause the projectile to be out of center, and result in wobbling in the bore and faulty flight on departure.

As with the above causes, these irregularities are usually eliminated by the manufacturer's tests.

d) Lack in ballistic stability of the projectile. In some types of projectiles (too long, or too heavy projectiles or those with a base tapering too much, etc.) the oscillations of the axis mentioned in Ballistics, Part I, Chapter III, instead of dying away almost immediately at the beginning of the trajectory, recur on the way, especially about the summit of the trajectory, and cause great errors in range.

For instance, the I A fuse gives to the mountain 65 shell such a dispersion that it cannot be used with it.

This cause is an important one, but progress in ballistics make it possible to do without such types of shells.

2. Causes due to the propelling charge.

Irregularities of the propelling charge cause differences of muzzle velocity. These errors are of great importance. In some cases, especially with projectiles, the stability of which is good, it seems that they are the **principal cause of dispersion** (1).

The irregularities themselves may be due to:

a) Wrong distribution of the elements of the charge, or faulty priming (see Ballistics, Chapter II, Art. II);

b) The impossibility to make up in practice charges giving the same **identical** muzzle velocity.

The errors due to this last cause are small, if care is taken to use **the same lot in the same fire**. They may be **great if lots are mixed**.

3. Causes due to the piece.

The wearing out of the tube **at the muzzle** (2) seems to

(1) Fire carried out recently with 23 cm. shells of a certain type, in which the muzzle velocity was measured at each shot, showed that the differences in range, measured on the terrain, practically correspond to the differences shown in the Firing Tables for the variations of muzzle velocity measured.

(2) The wear at the muzzle may cause a partial or total shaving off of the rotating band. On account of the wear of the lands, the tenons cut into the rotating band at the beginning of the movement of the projectile only press against the lands along a height insufficient to resist the rotation inertia of the projectile at the very moment it reaches its maximum velocity; hence the production of **burrs** along the tenons of the rotating band, and then, gradually, the shaving off of the latter.

have a great influence on dispersion. When this wear reaches a certain point, it may cause abnormally short bursts, as has been seen in Ballistics, Chap. VI.

The wear of the **forcing slope** may cause accidental irregularities in the ramming home of the projectile, and consequently differences in muzzle velocity.

In any case this will be a **systematic** cause of loss of muzzle velocity, which will have to be taken into account.

4. Causes due to the gun carriage and platform.

See Ballistics, Part I, Chapter I, for an account of the bad effects caused by the installation of a gun carriage on soft ground.

5. Causes due to laying instruments.

The accuracy of the laying instruments is always satisfactory, but clearances may appear in time between their supports and the piece, and, consequently, the axis of the latter may assume a direction different from that shown by the instrument, and varying from one shot to another.

Such clearances may be caused, for instance, during transportation, by the piece not being **fastened** in its travelling position.

The verification of the sights allows the importance of the clearances to be computed.

It is often possible to offset their influence, for instance by **always ending the laying operations in the same sense**.

If this is done, the difference between the direction of the piece and that shown on the apparatus remains practically constant for every shot; therefore the resulting systematic error in range or direction may be computed and corrected.

6. Causes due to atmospheric variations.

The influence of atmospheric variations on fire rapidly carried out (*e. g.*, within half an hour) is small, because such variations are, as a rule, slow.

Wind only increases the zone of dispersion when it is irregular, which is not the general case!

7. Causes due to the personnel.

Insufficient training, hurry, nervousness, or simply **fatigue**, may cause negligence in the service of the pieces

(e. g., faulty ramming), which may increase dispersion considerably and even produce abnormal shots.

ART. III.

LAWS OF DISPERSION.

Dispersion, being due to multiple causes, the sense of which varies continually, cannot obey **strict** laws. However a glance at fig. 2 makes clear the following points.

1. Although the distribution of the bursts is very irregular, it is evident that their density, great about the center of the zone, rapidly decreases toward the ends.

2. The area of the zone of dispersion increases with the range.

3. This zone is greater in range than in direction.

A more attentive examination of the distribution shows that :

1. If the average of the ranges of a large number of rounds is taken, there are practically as many shorts as overs with regard to the point of impact of the average range so obtained.

2. If the same is done for errors in direction, computed perpendicularly to the direction of fire, it is found that practically as many bursts occur on the right as on the left of the average direction thus obtained.

The name of **center of**

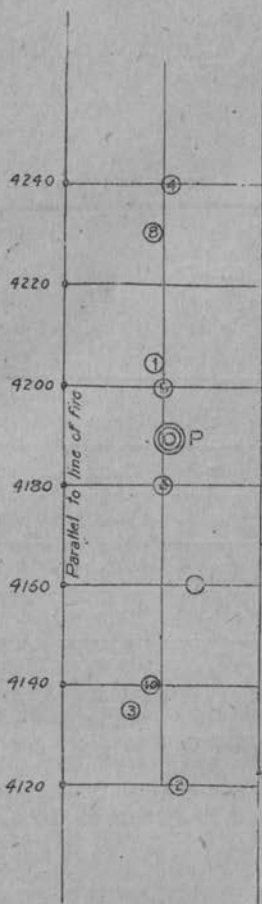


Fig. 2.

impact has been given to the intersection of the mean direction and mean range (1).

3. There are then in **relation to the center of impact**, about 50 % overs and 50 % shorts
50 % right bursts and 50 % left bursts.

4. The half of the overs nearest to the center of impact and the half of the shorts nearest to the center of impact are included in a zone limited by two perpendiculars to the line of fire, **practically equidistant from the center of impact**. This zone is sometimes called the **fifty per cent zone**.

5. Since half the bursts occur in the zone SO, consequently

(1) NUMERICAL EXAMPLE.

Assume that 10 rounds fired have given the following results :

NO. OF ROUND.	RANGE.	DIREC- TION.	ERROR WITH RELATION TO CENTER OF IMPACT.	
			Range.	Direction.
1	4205	20	+ 25	Left 1
2	4120	25	- 60	Right 4
3	4135	15	- 45	Left 6
4	4240	22	+ 60	Right 1
5	4180	21	0	0
6	4190	23	+ 10	Right 2
7	4160	27	- 20	Right 6
8	4230	19	+ 50	Left 2
9	4200	20	+ 20	Left 1
10	4140	18	- 40	Left 3

The center of impact will have for range 4180 m., for error in direction in relation to the witness line, 21 m.

the other half occur outside of this zone, and since no means exist of foretelling at the moment the shot is fired,

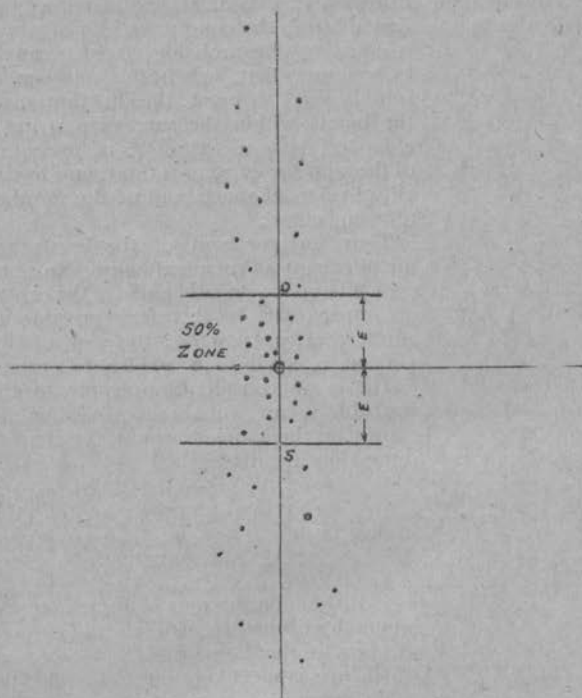


Fig. 3.

to which of these two classes the burst will belong, it is allowable to say that there is one chance out of two for it falling between S and O, or, which amounts to the same, for its error in relation to the center of impact C not exceeding the common amount E of CS and CO.

It may then be said, when the round is fired, that it is equally probable that its error in relation to the center of impact will exceed, or not exceed this amount E. For this reason, this error E has been given the name of **probable error in range**.

The same considerations apply to the errors in direction.

Therefore, when it is said that the probable errors of a piece firing at a certain range with a certain type of projectile are 30 meters in range and 2.50 meters in direction, it means that 50 % of the bursts will occur less than 30 meters

this side or beyond, less than 2.5 meters right or left of the center of impact.

6. If the zone covered by fire is divided into strips, perpendicular to the line of fire, the common width of which is equal to the probable error in range, it is found that, when the number of rounds fired is great, the distribution of the bursts within the successive strips is close to (1) 25, 16, 7, 1.5 % of overs out of the number of rounds fired, and to 25, 16, 7, 1.5 % of shorts, out of the number of rounds fired.

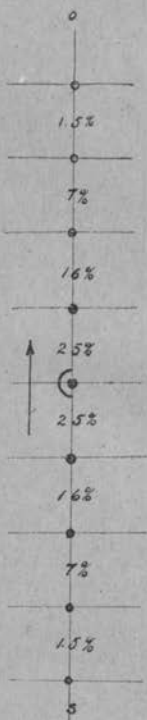


Fig. 4.

Thus 99 per cent of the bursts are included in a zone extending to four probable errors on either side of the center of impact. It is therefore possible to admit that, in practice, the zone of dispersion is equal to **8 probable errors**.

The same considerations apply to the probable error in direction. For instance, in the above example, the zone of dispersion in range is,

$$8 \times 30 = 240 \text{ meters, in direction,}$$

$$8 \times 2.5 = 20 \text{ meters.}$$

7. Divide now the zone of dispersion into rectangles limited by parallels and perpendiculars to the line of fire, the sides of which are respectively equal to the probable errors in range and in direction. The zone AB in depth receives about 16 % of the projectiles, and the distribution of the bursts in the strips parallel to the line of fire is proportional to the figures 25, 16, 7 and 1.5. Therefore, the rectangle

limited by the lines FF' and GG', distant respectively by 2 and 3 probable errors in direction from the axis of the zone of dispersion, will receive 7 % of the projectiles falling within the zone AB, *i. e.*, $0.07 \times 0.16 = 0.0112$, or a little

(1) **Close to** and not **equal to**, for, as has been said above, dispersion does not follow any **strict** laws, and in practice, the distribution will never be the same for two series of 100 rounds. For instance, no surprise should be felt at finding in the successive strips from S towards O the figures 0, 3, 12, 30, 28, 19, 6, 2 instead of 1.5, 7, 16, 25, 25, 16, 7, 1.5. Also, no surprise should be felt if, when fire is prolonged indefinitely, the theoretical distribution is not attained, for it would be impossible to actually fire 1000 rounds, for instance, without some **systematic** cause, known or unknown, making itself felt and disturbing the whole of the fire.

more than 1 % of the projectiles fired. Hence, if the target to be hit lies precisely over the zone FGF'G', it can

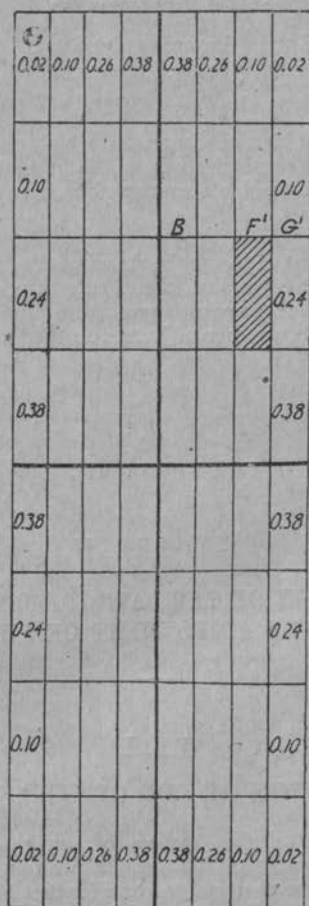


Fig. 5.

be expected (1) that out of 100 projectiles fired, this target is hit by one.

If on the contrary, the target occupied the zone CAM', of

(1) **It can be expected**, and not **it is certain**. It can be demonstrated that there are about two chances out of three for this zone to be hit in practice **once** in a fire of 100 rounds.

same area, but situated closer to the center of impact, it would receive,

$$0.25 \times 0.25 = 0.0625,$$

i.e. a little over 6 % of the projectiles fired.

From the preceding, it may be deduced that it is important to know :

1. The general laws of dispersion, which permit the determination in each particular case of the best-situation for the center of impact, to obtain as many bursts as possible on the target.

2. The **amount** of the probable errors in range and direction, by which it is possible to compute in advance, at least approximately, the **expenditure** of ammunition necessary to place a certain number of bursts on the target.

CHAPTER II.

APPLICATION OF THE LAWS OF DISPERSION TO THE ADJUSTMENT OF FIRE.

ART. I.

DETERMINATION OF THE CENTER OF IMPACT.

As adjustment of fire consists of causing the center of impact to occupy the most favorable position in relation to the target, it seems material to consider first how the **center of impact** of projectiles fired with a certain elevation can be determined.

Two cases may occur.

1ST CASE. — The **amount** of the errors of the various bursts may be computed in relation to a known point. The solution is then very simple, it is the one dealt with above- (See preceding note).

However an objection arises, for what is determined is the center of impact of a fairly small number of bursts (**observed point of impact**); but hazard might cause these bursts

to occur at one of the ends of the zone of dispersion; in this case the **observed center of impact** might be at a certain distance from the **true center of impact**, *i. e.*, from the one resulting from a great number of bursts.

What may be the amount of the distance between these two points?

From theoretical considerations which cannot be developed here, it results that the maximum amount of this error is given by the following table :

Number of observed bursts :

1 4 9 16 25 n^2 .

Maximum distance, expressed in **probable errors** :

$\frac{4e}{2}$ $\frac{4e}{3}$ $\frac{4e}{4}$ $\frac{4e}{5}$ $\frac{4e}{n}$

and there is one chance out of two that the desired distance will not exceed one fourth of the amounts thus found, *i. e.*, in the preceding cases :

e $0.5e$ $0.33e$ $0.25e$ $0.2e$ $\frac{e}{n}$

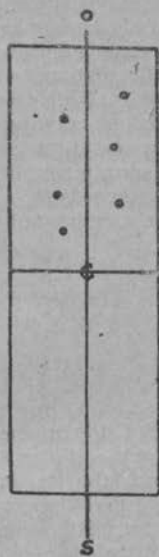


Fig. 6.

For instance, if the probable error in range is 30 m. and four bursts have been observed, it is practically certain (1) that the distance between the observed center of impact and the true center of impact does not exceed 60 meters, and there is one chance out of two for it not exceeding 15 meters.

2ND CASE. — Only the **sense** of the errors in relation to this fixed point may be observed, but not their amount.

Assume first that **all** observed bursts of a certain elevation are of the **same sense**, *e.g.*, shorts in relation to the target. The one conclusion which may be drawn with certainty is that the target is not situated short of the zone of dispersion, but it may be situated,

either beyond this zone,
or inside this zone,

and in this latter case, it is impossible to assert that it is situated beyond the true center of impact.

It is therefore not **certain** that by increasing the elevat-

(1) This means that there are 99 chances out of 100 for it being so.

ion, as is suggested by common sense, the center of impact will be brought nearer to the target — especially if the number of bursts observed is very small.

Besides, during fire for adjustment, in which the target should be bracketed as soon as possible, it is impossible to dwell indefinitely on bursts of the same sense.

Regulations prescribe to consider as a short one any elevation giving **two bursts short in succession**. In reality, it is not **certain** that the center of impact corresponding to this elevation is short, but it is demonstrated that there are 99 chances out of a hundred for it to be

either short,
or over by not more than two probable errors (fig. 7).

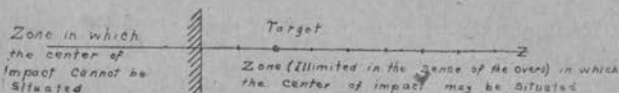


Fig. 7.

But it is impossible to measure the amount of the distance target — center of impact. In consequence the amount by which the elevation should be modified to bring the center of impact closer to the target is not known, and there would be no justification for the selection of a new elevation, if the first had been chosen **arbitrarily**.

But this is not the case, for the elevation should have been chosen only after the topographical and ballistic conditions have been estimated, at least roughly. It may therefore be assumed that the burst is not **very far from the target**, and that, consequently, the change in elevation to be made is not considerable.

But too small a change might make the adjustment too slow..

Regulations state that the change in elevation should be **four probable errors**. This amount, equal to half the zone of dispersion, has been given the name of **fork**.

The preceding considerations show that, when the target has been bracketed between two elevations differing by one fork, and having given respectively two shorts and two overs, it is practically certain:

a) That the target is situated not more than two probable errors short of the true center of impact S of the first elevation.

b) That the target is situated not more than two probable errors beyond the true center of impact O of the second elevation.

As the interval SO is four probable errors in length, if the

mean of the two bracketing elevations is selected as the next elevation, the new center of impact M will certainly be

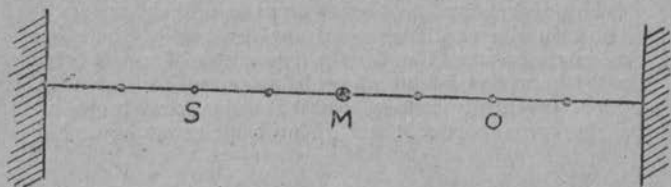


Fig. 8.

situated **less than four probable errors from the target.**

As the latter is now within the zone of dispersion, a sufficiently long fire will produce bursts of different senses.

Assume for instance, that this elevation gives five bursts short and one over.

What is the position of the center of impact in relation to the target?

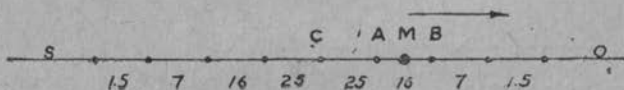


Fig. 9.

The principles explained above show that no **precise** solution can be found and that the one **reliable** piece of information available from observation is that the target is situated within the zone of dispersion, for otherwise, all bursts would be short, or all long.

Besides, whatever be the position of the target on the scale of dispersion, hazard may have caused the overs and shorts to be distributed as observed.

Common sense, however, suggests that it is very unlikely that a center of impact, fairly over in relation to the target, would give such a proportion of shorts.

It may be demonstrated that the **most likely portion** of the center of impact is the one which, **if it was realized in practice**, would give the theoretical proportion of shorts and overs in relation to the target which has been observed.

For instance, on the particular case selected, if the target was at M, middle of the interval AB, *i.e.*, over by 1.5 probable errors in relation to C, the proportion of shorts would be 0.83, or $\frac{1}{6}$ and that of overs 0.17, or $\frac{5}{6}$, which is precisely the one observed.

It will be admitted that this is so.

This solution will be sufficiently accurate in practice, for

it can be demonstrated that there are 3 chances out of 4 for the errors thus made on the determination of the center of impact not exceeding **one** probable error, and 98 chances out of a hundred for it not exceeding two probable errors.

Thus, in the particular case now dealt with, there are three chances out of four for the true center of impact being situated between 0.5 and 2.5 probable errors from point M, and it is practically certain that it is situated between 0.5 probable error short of M and 3.5 probable errors beyond M.

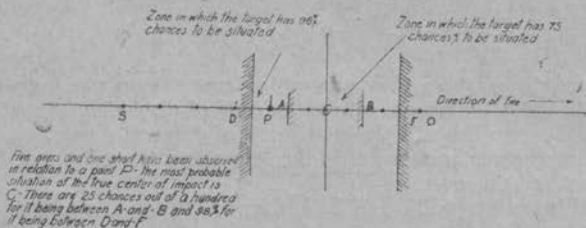


Fig. 10.

The amount of the next correction to be made in order to bring the center of impact on the target would then be 1.5 probable errors.

In practice, the following rule is adopted; it is somewhat simpler to apply, and practically equivalent.

If, out of n bursts observed from rounds fired with the same elevation, there are S bursts short and O

bursts over, the elevation is changed by $\frac{S-O}{2n}$ forks.

In the preceding example the corrections to be made would be $\frac{5-1}{12} = \frac{4}{3} = 1.33$ forks (instead of 1.5 forks, the theoretical amount).

ART. II.

APPLICATION OF THE ABOVE PRINCIPLES TO QUESTIONS OF EFFICIENCY OF FIRE.

The problems of efficiency amount practically to the following, already alluded to above.

Given the target, its situation in relation to the center of impact and the probable errors, calculate the percentage of projectiles that will hit the target.

The solution is most simple. If the target has but little relief, consider what parts of the zone of dispersion are covered by it and what is the percentage of bursts occurring in each of these parts.

If the target has a certain relief, it will be necessary to consider, not only its base, but the whole of the space covered by this base and the shadow cast by the target, supposing the latter to be lighted by rays parallel to the tangent to the trajectory at the point of impact. It will be assumed that the distribution is uniform within any of the rectangles of the zone of dispersion; the surfaces will be estimated

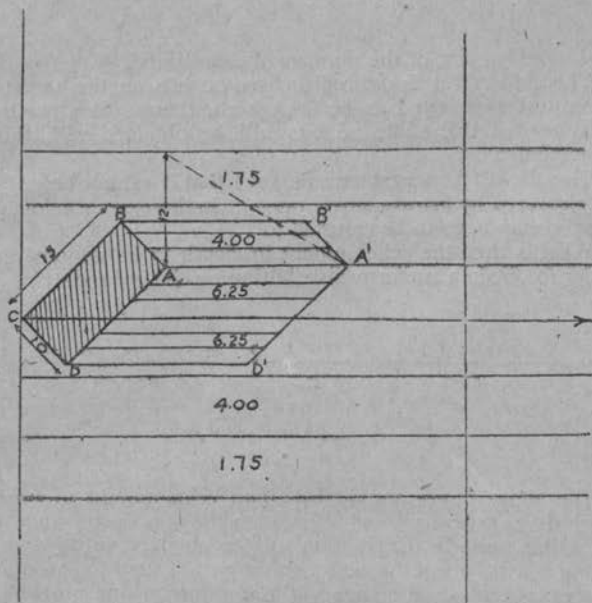


Fig. 11.

roughly, and precise computations will be avoided, as they are useless for calculation purposes.

EXAMPLE :

The target is a house 15 meters by 10 meters, and 12 meters high, situated as shown in fig. 10. The probable errors in direction and in range are respectively 6 m. and 40 m. The angle of impact is 30° . What is the expenditure in ammunition necessary to register 20 hits on the house?

Let AH be equal to the height of the house, and draw (roughly) HA' making the angle of impact 30° with the horizontal plane.

This line intersects the parallel (to the line of fire) passing through A, at A' which is the point where a projectile just clearing the top corner of the house would strike the

ground. Draw $A'B'$ and $A'D'$ respectively equal and parallel to AB and AD . The area $A'B'BCDD'$ represents the zone within which all trajectories hitting the house would strike the ground. It can be roughly estimated that this area is about $\frac{2}{3}$ of the two rectangles of 6.25 % and 4 %. Therefore, the number of hits comprised in it will be :

$$\frac{2}{3} (6.25 + 6.25 + 4)$$

i. e. roughly 10 % of the number of rounds fired ⁽¹⁾.

Therefore, if it is desired to have 20 hits on the target, the number of rounds to be fired is about 200. It is practically certain that 15 to 25 hits will be obtained with this expenditure.

The size of the target may be such that it cannot be entirely covered by fire at a single range. In this case, echeloned ranges may have to be resorted to.

What is then the echelonment in depth to be adopted in order to obtain a uniform distribution on the ground?

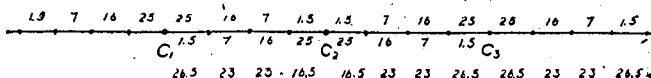


Fig. 12.

The above figure shows that, if an echelonment of **four probable errors** is adopted between the successive ranges, a sensibly uniform distribution will be obtained in the zone comprised between the centers of impact of the two extreme ranges, as each strip, whose width amounts to one probable error, includes about 25 % of the number of rounds fired with each range.

The uniformity of the distribution would not be sensibly improved if a smaller echelonment was taken.

ART. III.

MODIFICATION TO THE ZONE OF DISPERSION WHEN THE GROUND IS NOT HORIZONTAL.

Instead of being horizontal, as has been assumed, thus far, the ground may have a certain slope. In this case, the probable error on this ground is either smaller or larger than the

⁽¹⁾ The results are purposely given roughly. It is useless to strive for greater accuracy.

probable error on horizontal ground, according to whether it is a reverse or a forward slope.

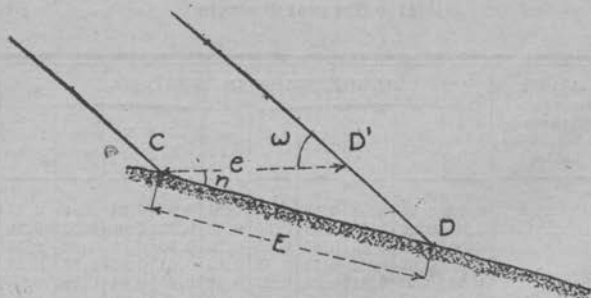


Fig. 13.

Two trajectories that would strike the horizontal ground at two points C and D' distant from each other by one probable error e , would strike the sloping ground at C and D, the interval of which would be either smaller or larger according to the case considered.

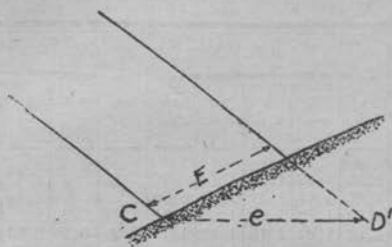


Fig. 14.

The probable error E on sloping ground is obtained by multiplying the probable error on horizontal ground by a coefficient λ , called **slope coefficient**, which may be shown to be equal to :

$$\lambda = \frac{\sin \omega}{\sin (\omega + n)}$$

In which ω is the angle of impact and n the slope. The value of λ is given by the following table

If a forward slope:

ANGLE OF FALL. (Given in the Firing Tables.)	PERCENTAGE OF GRADIENT.									
	1 o/o.	3 o/o.	5 o/o.	10 o/o.	15 o/o.	20 o/o.	25 o/o.	30 o/o.	40 o/o.	50 o/o.
5°.....	0.90	0.75	0.64	0.46	0.39	0.31	0.27	0.24	0.19	0.17
10°.....	0.95	0.86	0.75	0.64	0.55	0.48	0.43	0.39	0.33	0.29
15°.....	0.96	0.90	0.85	0.73	0.65	0.59	0.53	0.49	0.43	0.39
20°.....	0.97	0.92	0.88	0.78	0.72	0.66	0.61	0.57	0.51	0.47
25°.....	0.98	0.94	0.91	0.83	0.77	0.72	0.64	0.64	0.58	0.54
30°.....	0.98	0.95	0.93	0.85	0.80	0.76	0.72	0.69	0.64	0.60
35°.....	0.99	0.96	0.94	0.88	0.83	0.79	0.76	0.73	0.69	0.65
40°.....	0.99	0.97	0.95	0.90	0.86	0.82	0.79	0.77	0.73	0.70
45°.....	0.99	0.97	0.95	0.91	0.88	0.85	0.82	0.80	0.77	0.75
50°.....	0.99	0.98	0.96	0.93	0.90	0.88	0.85	0.84	0.81	0.79

If a reverse slope.

ANGLE OF FALL.	PERCENTAGE OF GRADIENT.									
	1 o/o.	3 o/o.	5 o/o.	10 o/o.	15 o/o.	20 o/o.	25 o/o.	30 o/o.	40 o/o.	50 o/o.
5°.....	1.13	1.52	1.78							
10°.....	1.06	1.21	1.39	2.38	6.70					
15°.....	1.04	1.13	1.23	1.63	2.31	4.04	15.20			
20°.....	1.03	1.09	1.16	1.39	1.73	2.26	3.26	5.90		
25°.....	1.02	1.07	1.14	1.29	1.49	1.79	2.22	2.92	7.57	
30°.....	1.02	1.06	1.09	1.22	1.36	1.56	1.81	2.16	3.51	8.35
35°.....	1.01	1.05	1.08	1.18	1.28	1.49	1.60	1.82	2.51	3.91
40°.....	1.01	1.04	1.07	1.14	1.23	1.34	1.47	1.63	2.06	2.77
45°.....	1.01	1.03	1.05	1.12	1.19	1.28	1.37	1.49	1.79	2.24
50°.....	1.01	1.03	1.05	1.10	1.16	1.23	1.30	1.40	1.62	1.93

Particularly, when the target is a **vertical surface**,

$$n = 90^\circ$$

$$\text{and } \lambda = \tan \omega$$

The corresponding value of the probable error, called **probable error in height**, is therefore expressed, with reference to the probable error in range e , by the equation :

$$h = e \tan \omega$$

EXAMPLE :

For $e = 60$ m., $\omega = 30^\circ$, $\tan \omega = 0.58$ $h = 34$ m.

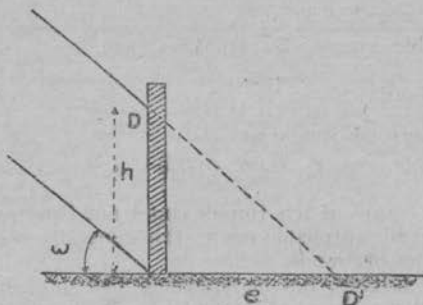


Fig. 15.

CHAPTER III.

VARIOUS SUPPLEMENTARY CONSIDERATIONS.

ART. I.

VALUES TO BE ADOPTED FOR THE PROBABLE ERROR.

The probable errors given in the firing tables might be computed by the method explained above, by delineating on the terrain the 50 % zone. In practice, however, the following method, simpler and more expeditious, is adopted. The ranges of a large number of bursts are measured, as was explained above, and the average taken.

Then the difference between the average range thus computed and the successive ranges of each projectile is computed. This gives the amount of the corresponding errors in relation to the center of impact (see the table in the note Ch. I, Art. III). If the average of the **absolute** values of these errors is taken, a certain figure is obtained which is called the **mean error E**.

From the theoretical principles used in the study of dispersion, the probable error is assumed to be equal to the product of the mean error by the number 0.845.

The same considerations apply to the errors in direction. For instance, in the above particular case there would be, in range :

Mean error $E = 32$ m.

Probable error $e = 32 \times 0.845 = 29$ m.

In direction :

Mean error $E' = 2.60$ m.

Probable error $e' = 2.60 \times 0.845 = 2.20$ m.

A single series of ten rounds could not be enough to fix the amount of a probable error ; this generally results from several series of rounds.

Besides, it must not be imagined that probable errors are computed with extreme accuracy. In this matter a precision 10 to 20 % is rarely of exceeded.

Consequently calculations based on dispersion must be made quickly and without useless details.

Frequent discussions have occurred on the following point :

The probable error thus determined on the proving grounds is based on fires executed with special care. Is not the probable error practically obtained in war firing much larger, and if so, by what amount should the proving ground probable error be increased.

This question does not admit of a rigorous solution. Yet, it is known that dispersion is caused either by the materiel, or the ammunition, or the personnel.

If the materiel is properly taken care of and the ammunition allotted as prescribed, their influence on dispersion remains the same in the field as on the proving ground.

The personnel alone is placed under different conditions. In order to realize the importance of its influence, a special case will be considered. Assume that, with a 75 m/m in good condition, H. E. shells, short fuses and a normal charge, a gunner has a probable error in height of 5', i. e. that he makes an error smaller than 5' once out of two, and an error larger than 5' once out of two (which would indeed be a sign of very bad training). What happens?

The table VI^b of the firing tables shows that, to a variation of 5' in the quadrant elevation, correspond the following errors in range :

59	40	30	24	19	15	10	6 meters
at 1	2	3	4	5	6	7	8 kilometers.

The probable errors of the tables are for the corresponding ranges :

9 10 12 15 18 22 28 39 meters.

On the other hand, it can be demonstrated that, if two independent causes of errors, which would give respectively probable errors amounting to e_1 and e_2 , act simultaneously, the resulting probable error is :

$$e = \sqrt{e_1^2 + e_2^2}$$

Therefore, if it is assumed that the probable errors given in the tables correspond to a perfect personnel, the probable errors obtained in practice with the "badly trained gunner" will be :

60 45 32 28 26 27 30 39

instead of :

9 10 12 15 18 22 28 39.

The ratio between the two errors will therefore vary between 6 and 1 according to the range.

With a gunner whose personal probable error would be 1' 1/4 only, which may be easily realized, the resulting errors would be :

17 14 14 16 19 22 28 39

whose ratio to the theoretical (*i. e.*, proving ground) error remains smaller than 1.5 except for very short ranges.

It is generally admitted that in practice, for fire under war conditions, the probable error may be equal to 1.5 that of the firing tables. This has been given the name of Field Probable Error.

The fork given by the firing table is generally determined in accordance with the above rule. It is taken as equal to 6 proving ground probable errors, *i. e.*, 4 field probable errors.

ART. II.

DOES THE TOTAL DISPERSION INCREASE WHEN SEVERAL PIECES FIRE TOGETHER, AND BY WHAT AMOUNT ?

To deal with this question, it is important to determine the data with precision.

a) If the pieces firing at the same target show **differences in calibration**, *i. e.*, if when laid with the same elevation they give different mean ranges, and the elevations are not corrected for these differences, it is evident that their res-

pective zones of dispersion will be shifted systematically as in fig. 16 b.

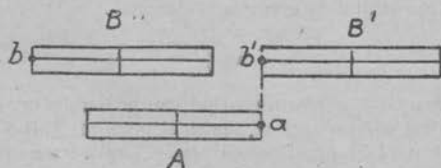


Fig. 16 a.

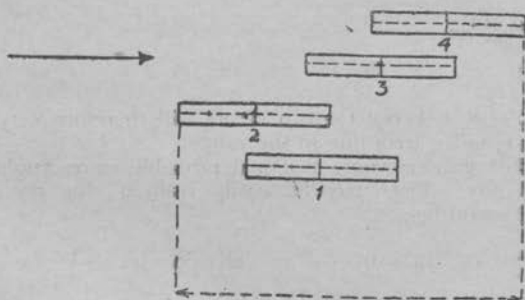


Fig. 16 b.

If the calibration of the pieces is the **same**, or, which amounts to the same, if their elevations have been corrected to offset the errors of calibration, the aggregate dispersion of the battery will not be increased.

It is therefore important to know with accuracy the calibration of the pieces. Such a computation can only be made by comparing the mean ranges of the various pieces fired with the same elevation.

As was said in Chapter II, Art. I, the center of impact observed from a limited number of bursts is generally different from the true center of impact, and the error between these two points decreases as the number of observed bursts increases.

It follows that the calibration of the pieces will be known with an accuracy smaller for a smaller number of rounds in calibration fire.

Consider for instance, the extreme case when only **one round** per piece would be fired. Let A and B (fig. 17) be the true center of impact. Let the corresponding zones of dispersion be represented by rectangles. It may happen that the projectiles fired from these pieces fall respectively

at a and b , i. e., at the opposite extremities of the two zone of dispersion.

If the range setting of the second piece is now corrected for the total error in range ab the effect of the correction

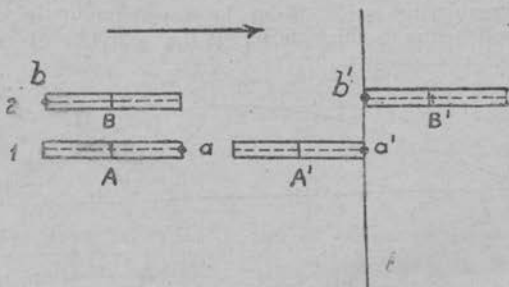


Fig. 17.

will be to displace the centers of impact of the two pieces by 8 probable errors, i. e., to double the depth of the zone of dispersion.

b) Assume that the calibration errors of the pieces of a battery are known, and the corresponding corrections have been made. If fire is executed by salvos it will frequently happen that the grouping of the bursts of **the same salvos** will be better than the grouping of bursts from an equal number of rounds fired **in succession** with one piece.

This result, verified by recent experiments, is due no doubt to the fact that the projectiles of a salvo are fired in **identical** atmospheric conditions; particularly wind, even when blowing in short and rough gusts, acts on all the projectiles of the salvo in the same manner and does not increase their dispersion.

ART. III.

DISPERSION IN TIME FIRE.

Projectiles fitted with time fuses set with the same fuse setting and fired under conditions as similar as possible, burst at different heights: this is called time fire dispersion.

The dispersion of time fire is characterized by its probable error which amounts to half the height of the zone including the best grouped half of the bursts.

The dispersion of time fire is due to two independent causes:

1. Irregularities in the time of combustion of the fuse owing to which the bursts would be distributed along an arc

of the trajectory if the latter remained the same from one round to another. In consequence of this irregularity, two successive rounds would give bursts, for instance, at A and B.

2. Irregularities arising from the dispersion of the trajectory itself, owing to which the bursts that would have occurred

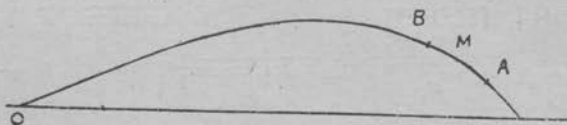


Fig. 18

respectively at A and B on the first trajectory, would occur on the second at points A' and B' corresponding on the latter

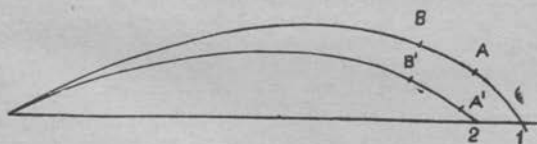


Fig. 19.

to times of flight respectively equal to those of points A and B on the first.

Of these two causes, the first one (irregularities of combustion) is generally the stronger; in order to reduce it as much as possible, it is necessary :

- 1) To use fuses of the same lot in the same fire.
- 2) To keep the fuses dry (*i. e.*, remove the cap at the time of fire only).
- 3) To take care of the fuse setters so as to avoid play in their mechanism, which would be prejudicial to the regularity of the fuse setting.

Note on the allotment by weight.

It has been previously said that the projectiles used in the same fire should have approximately the same weight. How is this to be understood ?

Failing regulations, the following considerations will make it possible to make this allotment: Assume that the condition to be realized is not to increase the zone of dispersion of the tables by more than **one probable error**.

To this effect, it is necessary that the weights of the projectiles be comprised between such limits that the corresponding errors do not exceed one probable error.

EXAMPLE :

155 G. P. F. gun. F. A. shell 1917. 99.15 fuse, charge
 $O - V_0 = 717$.

To the ranges :

8 9 10 11 12 13 14 15 16 km.

correspond probable errors of :

27 33 40 47 55 64 73 84 97 meters.

To a variation of 100 gr. in the weight of the projectile correspond the following amounts of probable errors :

1.5 0.8 0 0.9 1.8 2.8 3.8 4.8 5.8 meters.

Therefore, if the error between the weight of the projectile and the standard weight does not exceed :

0.8 2 — 2.5 1.5 1.2 0.8 0.8 0.8 kg.

the result sought will be obtained.

Consider now the 155 m/m S. How., long shells, short fuses, charge 5, $V_0 = 203$.

To the ranges :

1 2 3 km.

correspond probable errors of :

5 8 14 meters.

To a variation of 100 gr. in the weight of the projectile correspond the following amounts of probable errors :

1.7 2.9 3.9 m.

Therefore, to obtain the result sought, the error between the weight of the projectile and the standard weight must not exceed :

0.150 0.140 0.190 kg.

Consequently, a margin of 1500 gr. may be allowed in the first case and a maximum margin of 300 gr. in the second.

PART III.

EFFECTS OF PROJECTILES AND FUSES.

Artillery officers must have a perfect knowledge of the effects produced by all projectiles and fuses used by the artillery, because :

1. Any projectile, fired under bad conditions, is wasted : it means a useless expense in money, and a decrease of the stock of ammunition, without any results.

2. When in liaison with infantry, it is the duty of artillery officers to inform the infantry as to what effects are to be expected from their fire upon the enemy positions. They must also define the limits within which our shells may be dangerous for our own infantry.

3. In order to be able to build efficient shelters against hostile shells, it is necessary to know what degree of resistance must be secured to afford protection against the kind of projectile most likely to be used against the position by the enemy.

Artillery projectiles may be grouped into the three following classes :

1. **Shrapnel and case-shot** containing balls of hardened lead or cast-iron plates which break up into fragments when the projectile is fired, and a bursting charge of black powder.

2. **High-explosive shells**, containing a bursting charge of high-explosive, varying with the type of shell.

3. **Special shells**, containing a special composition suitable for the purpose of the shell : poison gas shells, tear shells, tracer shells, star shells, smoke shells, incendiary shells, etc.

These projectiles may be fitted with various types of fuses, as follows :

1. **Time fuses**, which cause the projectile to burst at some point on its trajectory, before reaching the point of impact.

2. **Percussion fuses**, which act at the moment the projectile strikes the ground or some obstacle.

3. **Combination fuses**, which can act either as time fuses or as percussion fuses.

In this chapter, the effects of single projectiles only will be considered. In prolonged fire, it is necessary to take into consideration dispersion in direction and range, and also in height in the case of time fire.

Experience has demonstrated the number of projectiles it is necessary to expend to obtain a desired result upon any given objective, and these figures are all given in the Regulations.

ART. I.

SHRAPNEL AND CASE SHOT (1).

Shrapnel is fired by the 75 m/m Gun and the 155 m/m How. Case shot is fired by the 155 m/m How. only.

Both are in general use in fire against unprotected personnel, against whom they act by means of the balls, or fragments of cast-iron plates which they contain. The direction taken by these balls or fragments, when thrown forward in a narrow spray, makes it impossible for them to strike sheltered personnel, such as personnel protected by a wall, or in the bottom of a trench (2). For targets of this type, high-explosive shells are customarily used, as their spray is wider, and splinters may be thrown backward from the point of burst.

Shrapnel and case shot are incendiary in effect, and may be used to set fire to combustible materiel.

The following tables show the different types of shrapnel and case shot fired by the 75 m/m Gun and the 155 m/m Howitzer, and also the fuses used with them:

Shrapnel and case shot.

CALIBER.	TYPE OF PROJECTILE.	WEIGHT of the PROJECTILE.	WEIGHT of the BURSTING charge.	NUMBER OF BALLS and splinters.
75 m/m G.	Base charged shrapnel.	7.240 kg.	0.110 kg.	261 balls of 12 gm. each.
155 m/m. How.	Shrapnel 1879- 1915 Model.	40.590 kg.	0.450 kg.	270 balls of 25 gm. each.
	Special case shot 1887 Model.	40.800 kg.	0.550 kg.	416 balls of 25 gm. each. 288 fragments

1) Sometimes called Canister shell.

(2) Except with enfilade fire.

Fuses.

CALIBER.	TYPE OF FUSE.
75 m/m G.....	Combination fuse 22/31 1897 Model. — Duration of burning 24 sec.
155 m/m H.....	Combination fuse 30/55 1889 Model. — Duration of burning 49 sec.

NOTE. — For the description and operation of these projectiles and fuses, see further, "Ammunition".

§ 1. Effects of time shrapnel (1).

When a shrapnel, fired with a time fuse, bursts at some point B, on its trajectory, the balls are thrown forward in a narrow spray called the **cone of dispersion**. The axis of this cone coincides with the tangent to the trajectory at the point B (fig. 1).

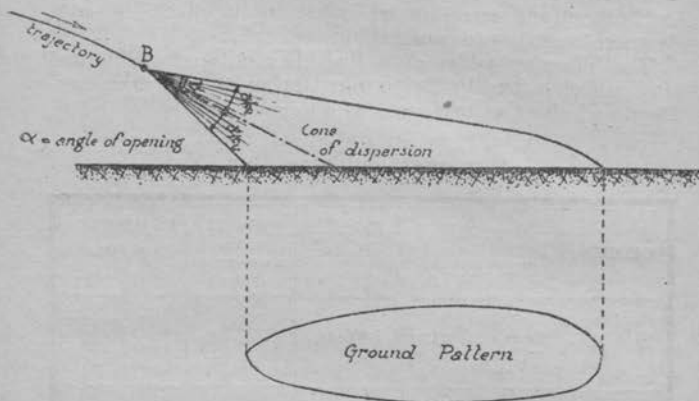


Fig. 1.

The balls may be considered to be uniformly distributed in the cone of dispersion. The cone is defined by the angle at its apex. This angle, called the **angle of opening** of the spray, is always small, being never greater than 30 degrees,

(1) Everything which applies to shrapnel, also applies to case shot.

and varies with the position of the bursting charge in the projectile, and the remaining velocity at the point of burst. The Firing Tables give one-half of the angle of opening for the different ranges.

The zone struck by the balls, or **ground pattern**, is the trace of the spray on the ground. Its shape varies with the range; and the size of the pattern, for the same range, varies with the linear height of burst.

It is evident that the trajectories of the balls do not remain rectilinear, and the pattern is a closed curve, as shown in figure 1. However, in the zone where the balls are effective, their trajectories may be considered as rectilinear.

Effect. — The effect of a shrapnel will be in direct proportion to the portion of the objective covered by its pattern, provided the balls have a sufficient remaining velocity to be effective.

In order to be effective, a shrapnel ball must be able to put a man in campaign equipment and in winter clothing entirely out of action. To do this, it must have a sufficient velocity at the moment it strikes its objective. For example, the ball of a 75 m/m shrapnel, which weighs 12 gr., is not effective unless it has a velocity of at least 180 meters per second.

The total effect of one shrapnel may be computed by determining the zone effectively covered by each ball, or the *danger zone*; i. e., the zone within which a man (whose height is AB or A_1B_1) would surely be hit (fig. 2).

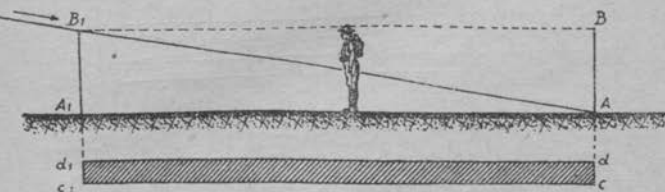


Fig. 2.

The zone of effect of one ball, the trajectory of which is B_1A , may be represented on the ground by a rectangular area having as its width cd , which represents the breadth of a man, and as its length the distance A_1A between which points a man would surely be hit. It is evident that the length of this zone will vary with the trajectory and the angle of impact.

The total effect of a shrapnel is computed by measuring the combined surfaces of all these danger zones (fig. 3). It is expressed in square meters.

Influence of the trajectory. — When a projectile bursts

at a given height above the ground, the flatter the trajectory, the longer the danger zone covered by each ball.

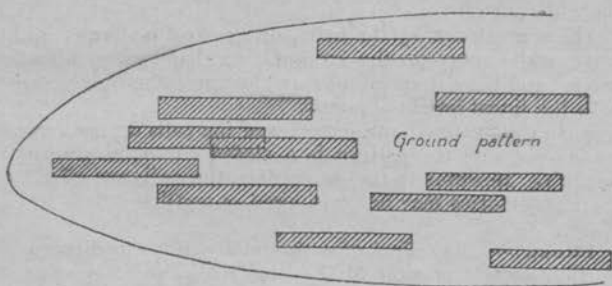
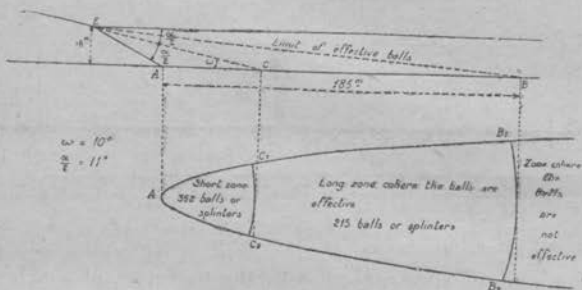


Fig. 3.

However, owing to air resistance, the balls rapidly lose their velocity, and at the same time their power of penetration, *i. e.*, they rather quickly lose their power to kill. A certain number of balls, on account of their initial direction, will have to travel a long distance through the air, and hence will have an insufficient velocity on reaching the ground. If the height of burst is properly adjusted, the balls contained in the lower part of the cone, *i. e.*, half of the balls contained in the projectile, will be effective. They are distributed on the ground densely in the short zone (see fig. 4) included



Spray from burst of special case shot 155 m/m How. 1917 S. Mod.

Fig. 4.

between the point A, where the steepest element of the cone meets the ground, and the point C, at which the axis of the cone meets the ground.

The balls contained in the upper part of the cone fall beyond the point C, in the long zone. All the balls falling between C and a certain point B are effective; but those which fall beyond B have not a sufficient velocity left to be effective.

It may easily be seen from figures 4 and 5 that as the curvature of the trajectory increases, the number of effective balls increases, while the size of the pattern decreases.

The density of the distribution of the balls also increases, but since it is useless to strike a man with more than one ball, the surface struck should be increased as much as possible, to accomplish which, the height of burst is increased as the curvature of the trajectory increases.

(Cf. time fire with the 155 m/m Howitzer)

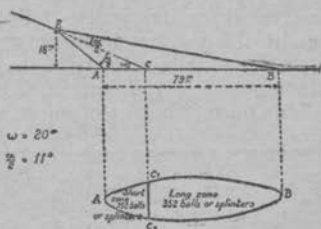


Fig. 5.

Influence of the height of burst. — In

order to have the balls strike the ground with a sufficiently great velocity it is necessary that the point of burst be not too high on the trajectory. Neither should the burst occur too close to the point of fall, because the pattern, and also the effect of the balls would be greatly reduced. The adjustment of the height of burst is therefore of great importance.

The following table, which relates to 75 shrapnel, shows the variation in effect as the height of burst varies.

RANGE.	HEIGHT of BURST (in mils).	VERTI- CAL HEIGHT at which projectiles burst above the ground (in meters).	NUM- BER of effect- ive balls.	LENGTH of the effect- ively covered area.	WIDTH of the pattern at C1 C2 (see figures 4 and 5).	TOTAL AREA EFFECTIVELY covered (in square meters).
2000	2 mils	4 meters	183	171 m.	20 m.	978 sq.m.
	3 mils	6 meters	171	162 m.	29.3 m.	900 sq.m.
	4 mils	8 meters	159	153 m.	39 m.	748 sq.m.
6000	3 mils	18 meters	261	88 m.	20 m.	387 sq.m.
	4 mils	24 meters	261	108 m.	27.5 m.	476 sq.m.
	[limit](1) 8 mils	48 meters	175	66 m.	52 m.	207 sq.m.

(1) If the height of burst exceeds 4 mils, a large number of the balls strike the ground with an insufficient velocity.

From an examination of this table, it is seen that:

1. For shrapnel, the height of burst above the ground

should be increased as the range increases. For this reason, we use an angular unit to measure the height of burst (in practice, the mil).

2. For a single round, it would be better to decrease the height of burst (expressed in mils) for short ranges, and to increase it for long ranges. But, owing to dispersion, a fixed height of burst has been determined upon, which depends upon the muzzle velocity of the projectile, and this is called the *normal height of burst*.

This normal height of burst is given in the Regulations.

MUZZLE VELOCITY V_0 (IN METERS).	NORMAL HEIGHT OF BURST (IN MILS).
$V_0 > 500$	2 mils
$400 < V_0 < 500$	3 mils
$300 < V_0 < 400$	from 4 to 8 mils
$200 < V_0 < 300$	from 8 to 12 mils

3. The fact that the number of effective balls increases with the range should not lead to the conclusion that the total effect is greater at longer ranges, for, owing to the steeper trajectories of the balls, the total effect is smaller (see par. 50: "Influence of the trajectory"). Besides, dispersion in height, and the possible difficulties of observation further reduce this effect.

Conclusion. — The kind of fire to be used depends upon the nature of the objective (unsheltered personnel, standing or prone, personnel sheltered in the bottom of a trench).

To secure the necessary angle of fall, either flat fire (Guns with flat trajectories), or curved fire (Howitzers) will be used. For the particular kind of fire employed, there will be a certain *normal height of burst* giving the maximum effect, *i. e.*, that which *effectively covers* as large an area as possible.

It is recognized that any variation from the normal height of burst reduces the total effect of a burst; but, there are limits between which, for all practical purposes, a burst is still sufficiently effective. The degree of the permissible variation from the normal height of burst becomes smaller as the weight of the shrapnel balls decreases. Shrapnel filled with large balls, weighing from 18 to 25 gm. each (155 How. shrapnel and case shot) are better suited for night firing than shrapnel filled with balls weighing but 12 gm. each (75 shrapnel) because it is generally impossible to adjust the height of burst accurately.

If the height of burst has been well adjusted, the effect of 155 m/m shrapnel or case shot may be considerable, owing to the number and weight of the balls and of the fragments of cast-iron plates which they contain.

The following illustrations, relating to 75 shrapnel and 155 case shot give a good idea of the zones effectively covered

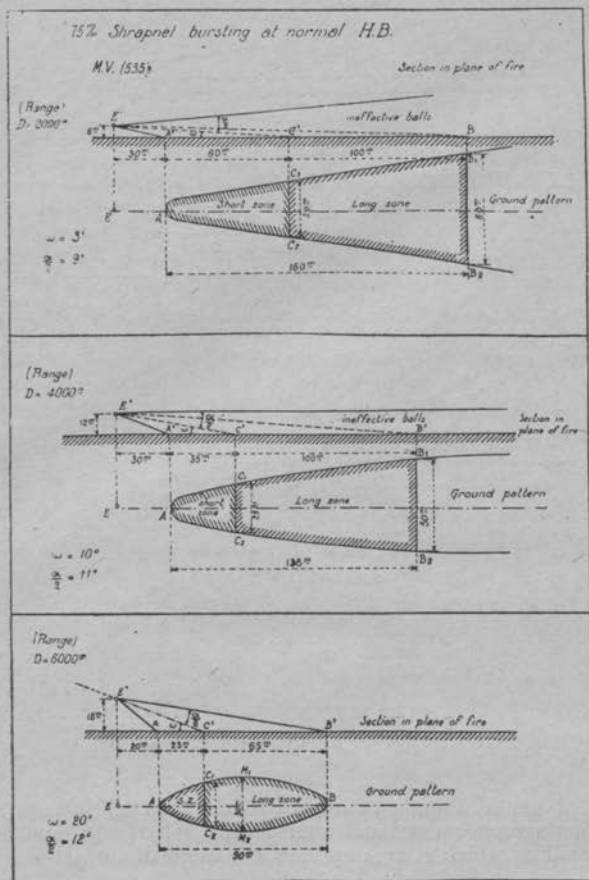


Fig. 6.

by these projectiles, with various trajectories and heights of burst (see fig. 6 and 7).

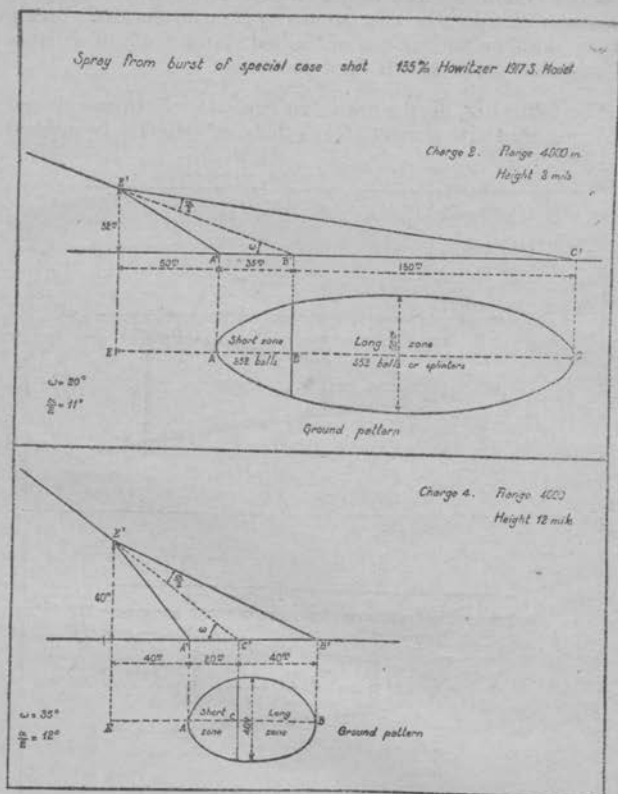


Fig. 7.

§ 2. Effects of percussion shrapnel.

1) When the angle of impact is less than 15° , the projectiles ricochet and burst after having left the ground at an angle β which is greater than the angle of impact ω .

The burst does not take place exactly at the point of impact, but a little above the ground after the ricochet, on account of the time it takes the fuse to act (1 or 2 hundredths of a second) [fig. 8].

The resulting spray sweeps the ground as long as the

angle of ricochet β remains small. This angle β increases with the range and if it is greater than half the angle of

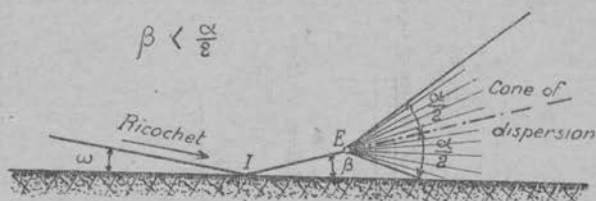


Fig. 8.

opening, the spray may pass entirely above the objective without striking it (fig. 9).

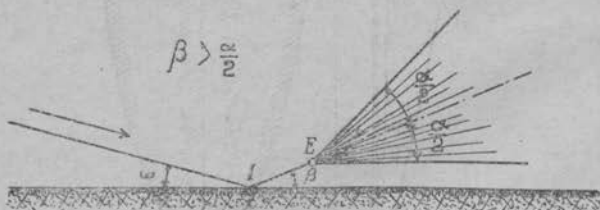


Fig. 9.

The projectile will not be effective unless the angle of impact is small, therefore ricochet should not be used beyond a certain range (1500 m. for the 75: angle of fall = $2^{\circ} 18'$). Figure 10 gives, as an example, the spray of the 75 shrapnel, fired for ricochet at a distance of 1000 meters.

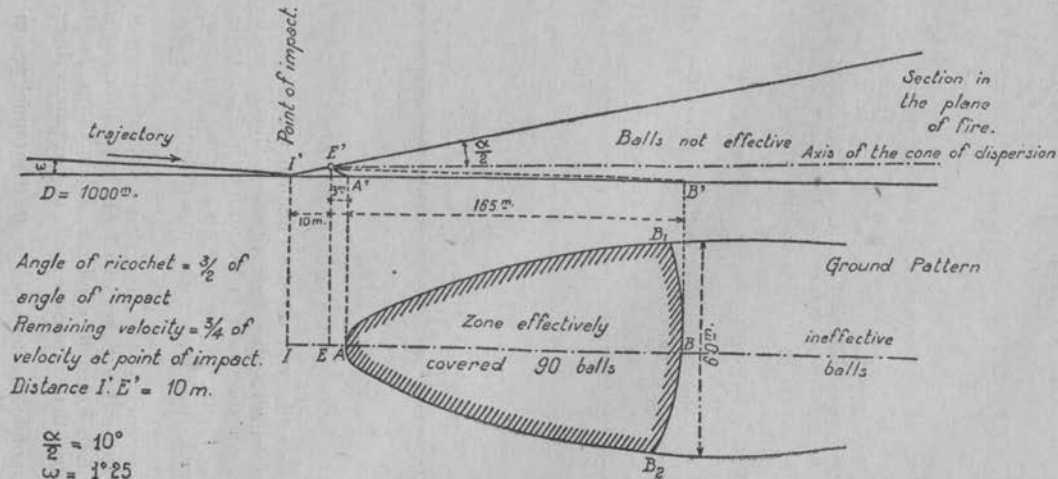
2) If shrapnel or case shot strike an obstacle (materiel, a wall, etc.), they burst on impact and have sufficient cohesion and strength to produce effects of demolition; but they are less effective than explosive shells of the same caliber.

For example, to destroy a wall, 3 shrapnel per meter, or 1 explosive shell are required.

3) If a shrapnel strikes the ground with an angle of impact greater than 15° , it will penetrate and burst in the ground, making a *fougasse* (no effect).

75 Shrapnel ricochet.

Fig. 10.



ART. II.

HIGH EXPLOSIVE SHELLS (H. E. SHELLS).

§ 1. General considerations.

Shells filled with high explosives are made of **steel** or of **semi-steel** (cast iron shells are no longer manufactured).

Steel shells normally have thin walls and a large explosive content, but their manufacture is a long and delicate operation, and consequently very expensive.

Semi-steel shells have thicker walls, contain only about one half the explosive filling of the steel shells, are not so strong but are easy to manufacture and are less expensive.

The following table gives, for the 155 m/m Howitzer, the approximate weights of shells and of their explosive fillings:

SHELL.	WEIGHT OF THE SHELL.	WEIGHT OF EXPLOSIVE FILLING.
Steel	43 kg.	10.2 kg.
Semi-steel	43.75 kg.	4.5 kg.

Fuses. — H. E. shells are fitted with detonating fuses which, from their manner of operation, may be :

- Time* detonating fuses,
- Percussion* detonating fuses, or
- Combination* detonating fuses.

Using as a basis the length of time which elapses between the moment the head of the projectile strikes the ground, or an obstacle, and the moment of the burst, percussion fuses are classified under the following heads :

Instantaneous, when the delay is less than 0.01 sec.

(I., I. A., I. A. L., R. Y. fuses.)

Without delay, when it varies between 0.01 and 0.02 sec.

(S. R. fuses.)

With delay when it is equal to or greater than 0.05 sec.

(A. R. fuses.)

The following tables show the different types of H. E. shells fired by the 75 m/m Gun and the 155 m/m How., as well as the detonating fuses used with the shells.

H. E. shells.

CALIBER.	TYPE OF SHELL.	NORMAL WEIGHT of shell with short fuse.	WEIGHT OF EXPLOSIVE filling.
75 G.....	H. E. shell, 1900 N Model.	5.315 kg.	0.80 kg.
	H. E. shell, 1915 F. N. or G. N. Model.....	5.515 —	0.75 —
	H. E. shell, type A. L. of semi-steel.....	7.445 —	0.40 —
	H. E. shell, steel. 1917 Model.....	6.200 —	0.60 —
	H. E. shell, semi-steel 1918 Model.....	6.510 —	0.45 —
	AL R/2 steel H. E. shell (anti-tanks).....	7.980 —	
155 H.....	Long steel shell, 1914 Model.....	43.00 kg:	10.20 kg.
	Semi-steel shell, 1915 Model.....	43.70 —	4.50 —

Fuses.

75 G. and 155 H.	Percussion detonating S. R. fuse 24/31 1899 Model. Without delay (<i>white head</i>). Percussion detonating A. R. fuse 24/31 1899-1908 Model. With 0.05 sec. delay (<i>black head</i>). Percussion detonating I. fuse 24/31 1914 Model. Instanta- neous (<i>red head</i>). Percussion detonating R. Y. fuse 24/31 1917 Model. Instan- taneous. Percussion detonating I. A. fuse 24/31 1915 Model. Instan- taneous (<i>long fuse</i>). Percussion detonating I. A. L. fuse 24/31 1916 Model. In- stantaneous (<i>long fuse</i>). Time detonating fuse 24/31 1915 Model. Duration of bur- ning 24 sec. Combination detonating fuse 24/31 1916 Model. Duration of burning 24 sec.
75 G. shell type A. L.	Percussion detonating I. fuse 24/31 1914 Model. Instanta- neous (<i>green head</i>). Percussion detonating A. L. fuse 24/31 Truncated 1917 Model Instantaneous.
155 H.	Percussion detonating S. R. fuse 24/31 1899-1915 Model. Without delay (<i>white head</i>). Percussion detonating C. R. fuse 24/31 1889-1915 Model. With short delay of 0.05 sec. (<i>black head</i>). Percussion detonating L. R. fuse 24/31 1899-1915 Model With long delay of 0.15 sec. (<i>black head and violet shank</i>). Combination detonating L. D. fuse 24/31 1917 Model. Du- ration of burning 51 sec.

For every caliber, it is necessary to adhere strictly to the directions contained in the firing tables, regarding :

I. Use of propelling charges. — As a rule, the heavier charges should not be used with semi-steel shells and they should not be used with steel shells below a specified range.

II. Use of fuses. — a) A detonating fuse does not infallibly act with every charge.

b) Instantaneous fuses act under the following conditions :

If the angle of impact is smaller than 10° , the I. fuse 1914 Model, acts only by inertia (forward movements of the primer plunger) giving effects similar to those of the SR fuse (fuse without delay).

c) Long fuses (IA or IAL) should not be used for the 75 gun with reduced charges, as abnormal shots may result.

If the angle of impact is smaller than 10° , the IA, IAL and RY fuses may not act at all, their action depending entirely upon the driving back of the anvil by the shock (1).

§ 2. Burst of H. E. shells.

The efficiency of high explosive shells depends upon :

1) **The effect of splinters** resulting from the shattering of the envelope by the burst. This effect is utilized only with the shells of small and medium calibers.

2) **The effect of the gases** freed by the explosion. This effect is utilized with shells of all calibers.

H. E. shells have no incendiary effects.

A. SPRAY OF SPLINTERS.

If an H. E. shell is made to burst when stationary, the splinters of the envelope are propelled nearly perpendicularly to the part of the surface of the envelope which they previously formed.

Consequently, the splinters form 3 sprays (see fig. 11) :

a) The ogival spray, projected in front, of little density, and composed only of a few large splinters.

b) The base spray, projected toward the rear, composed of medium size splinters, the number of which depends upon

(1) For the use of propelling charges and fuses, see further : Ammunition.

the metal forming the envelope and upon the caliber, and which may still prove effective at a distance of 150 meters.

c) **The lateral spray**, the most important, consisting of at least a thousand splinters, the weight of which varies

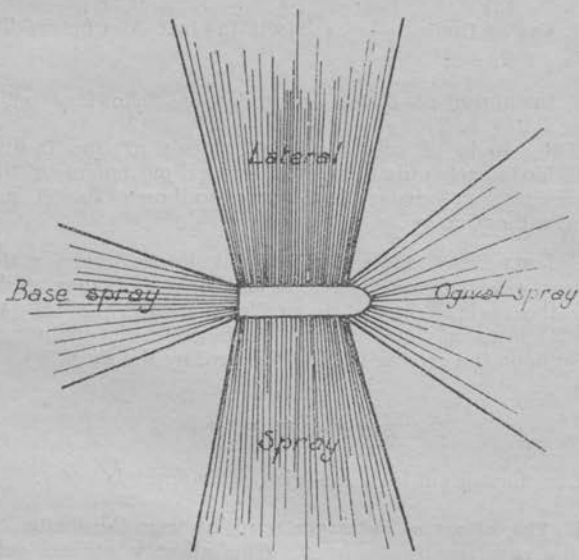


Fig. 11.

from 2 to 20 gr. each. This spray is included between 2 wide cones, the apex angles of which are very large and vary with the caliber and the quantity of explosive filling.

The distance at which most of the splinters of the lateral spray are still effective is not greater than 20 meters for the 75 H. E. shell and 50 meters for the 155 H. E. shell. A small number of splinters of larger size are effective at greater distances (100 to 500 m.).

If an H. E. shell is made to burst in flight, the burst produces similar results, but the trajectory of the splinters depends upon both their initial velocity, due to the burst, and the remaining velocity of the projectile itself.

Nevertheless, the velocity due to the burst being 3 or 4 times greater than the remaining velocity of the projectile, the influence of the former predominates, and the general form of the sprays differs little from the form produced by the explosion of a stationary projectile.

The axis of the projectile practically coinciding with the

tangent to the trajectory, the lateral spray forms a narrow sheaf perpendicular to this trajectory. If the angle of incidence is not too great and if the burst does not occur at too great a height, the central part of the trace of this spray on the ground is clearly visible: it is called the **axe stroke** [0.70 m. wide for the 75 m/m gun].

In high angle fire, with an instantaneous fuse, the ground is swept all around the point of impact.

With **steel shells**, particularly with long shells, the splinters assume the form either of long, narrow and jagged pieces of the envelope, or of fragments with beveled edges. Some of these may be extremely large. The initial velocity of these splinters is between 1,000 and 1,500 meters per second.

The 3 sprays are quite distinct.

Owing to their irregular shapes as well as to their usually light weight, the splinters rapidly lose their velocity. Small splinters do not generally travel farther than 30 meters. The large splinters may travel several hundred meters.

With **semi-steel shells**, the 3 sprays are less distinct than with steel shells. The splinters are smaller and more numerous; few of them weigh over 5 grams. The result is that in the immediate vicinity of the point of burst, the semi-steel shell is more effective than the long steel shell against unsheltered personnel, in spite of its small explosive charge.

But on account of the small size of the splinters and their lower initial velocity, the total radius of effect of a semi-steel shell is much smaller than that of a steel shell.

B. GAS GENERATED BY THE BURST.

The burst of a projectile generates a volume of gas which is proportional to the amount of explosive contained.

If the shell bursts above the ground, this volume of gas produces a concussion effect which tends to displace everything near the point of burst.

The concussion is particularly violent if the shell explodes inside a confined space. There is a resulting pressure on the walls of the enclosure which usually causes them to collapse, or, if they resist, an escape of gas under great pressure through all openings or connecting ways, with a destruction of all hindering objects.

If the shell explodes at a shallow depth in the ground or inside an obstacle, it causes an upheaval of a large mass of earth or debris. An explosion at a greater depth produces a subterranean cavity around which the compression of the ground is violent.

This compression is felt at some distance from the point of burst and can destroy dugouts situated nearby.

The gases generated by the burst of a shell are very poisonous. Through fissures caused in the ground by the explosion, these gases penetrate even undamaged dugouts and cause loss of life, especially if the dugouts are not ventilated.

§ 3. Effects of time shell.

H. E. shells of small and medium calibers can be fitted with time or combination detonating fuses, which may cause them to burst before impact. Nearly all their effect then depends upon their splinters.

In such a case (see fig. 12):

a) The base spray is directed upward and its fragments fall far from the point of burst and with very low velocity.

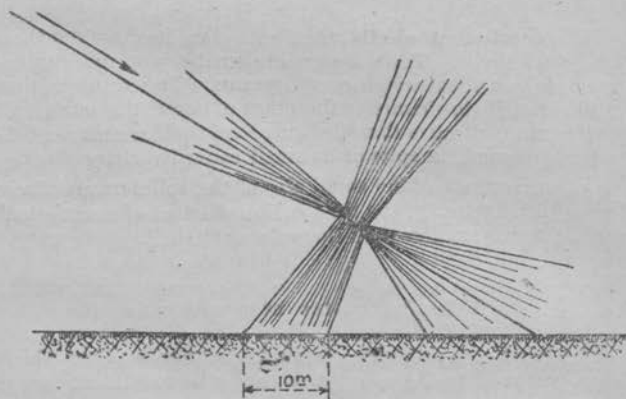


Fig. 12.

b) The ogival spray, of small density, produces practically negligible effects.

c) The lateral spray only is effective. Its depth does not generally exceed 10 meters near the plane of fire; outside of this narrow band, all objects are safe. Hence, for a burst to be very effective, it must burst exactly at the range of the objective.

A. INFLUENCE OF THE TRAJECTORY.

For a given kind of shell and a given height of burst, the effects are almost independent of the range. In contrast with

time shrapnel, the remaining velocity of the projectile may be neglected, and only the velocity due to the burst considered.

B. INFLUENCE OF THE HEIGHT OF BURST.

For a given shell, on the other hand, the effect is closely dependent upon the height of burst. If the shell bursts very close to the ground, the greater part of the splinters are effective, but only over a very limited area, owing to the small size of the pattern; the total effect will be slight, because too localized.

If, on the contrary, the shell bursts too high, the splinters will strike the ground with an insufficient force; only a few of the large splinters of a steel shell will prove effective.

With H. E. shells, either steel or semi-steel, fired by the 75 Gun and the 155 How., the effective height of burst is from 10 to 20 meters above the ground. In practice the latter height of burst is taken as the normal height of burst.

The following table shows the depth (along the line of fire) and the width (at right angles with the line of fire) of the area *effectively covered* (2 splinters per sq. m.) by dangerous splinters. It also shows the approximate radius within which the largest splinters may still prove fatal.

TYPE OF SHELL.	ZONE EFFECTIVELY COVERED.		EFFECTIVE RADIUS of LARGEST SPLINTERS.
	Depth.	Width.	
75 m/m 1900 Model, steel.	5 meters.	15 meters.	150 meters.
155 m/m 1914 Model, steel.	8 —	70 —	500 —
155 m/m 1915 Model, semi-steel.....	13 —	70 —	200 —

Effect, however, varies little when the height of burst ranges between 5 meters and 30 meters. It decreases rapidly after the 30 meter height is passed. At 80 meters it becomes practically nil, a very few of the largest splinters only being fatal.

When the height of burst is in the neighborhood of 20 meters, the semi-steel shell has more effect than a steel shell of the same caliber: it gives a greater number of dangerous splinters over the area effectively covered: therefore it is preferable.

The figure below (fig. 13) shows half of the zones effectively covered by the burst of a 155 m/m semi-steel time

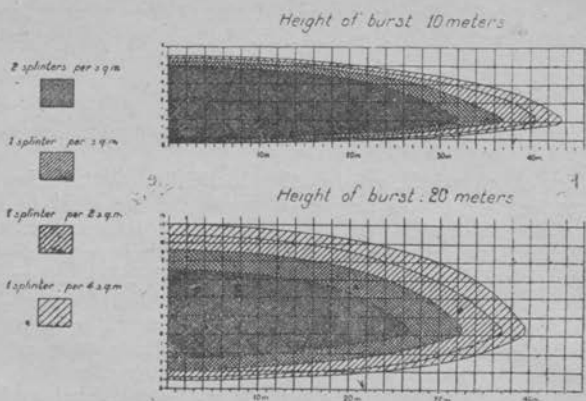


Fig. 13.

shell, 1915 Model, at heights of 10 meters and 20 meters with the density of splinters per sq. meter.

C. EFFECT OF FIRE.

Since the importance of the height of burst is recognized, it follows that its adjustment is vital for the maximum effect of time fire. The *range adjustment* must, at the same time, be very accurate, for the effective zone being perpendicular to the line of fire and very narrow, the objective will not be hit if the burst does not take place directly over it.

If the adjustment is correct, time fire with H. E. shells has great moral and material effect on *personnel in the open*, or sheltered in an open trench. It has very slight effect on materiel, as the bursts occur generally too high above it.

At very long ranges, taking into consideration the fuse dispersion, fire adjusted with a 20 meter height of burst may give graze and very high bursts; its effect is therefore much inferior to that of fire at mid-ranges; under these conditions fire with I. A. fuses generally gives better results.

As a general rule, owing to the narrow zone covered by each shell, and to the dispersion of bursts, a great expenditure of ammunition is required to cover the whole area and surely include the target.

On the other hand the projectile is effective only through its splinters. Accordingly:

1) For calibers permitting it, semi-steel shells will be used, as they are less expensive, and for a small charge of explosive, give the greatest possible number of effective splinters.

2) Effect on unprotected personnel only can be obtained.

It has been seen that the projectile to be used in this case is *shrapnel*. Therefore, it is only when *shrapnel* are lacking or when the objective is so defiladed that it is impossible to reach it with *shrapnel*, that H.E. shell is resorted to. Even under these conditions, it will often be of advantage to fire H.E. shell with a delayed action fuse, so as to take advantage of the ricochet; or else with instantaneous fuses (I. or I. A. fuses), as there is no height of burst to be adjusted in the latter two cases.

To sum up, time fire with H.E. shell should only be resorted to when time fire with *shrapnel*, ricochet fire with H.E. shell or percussion fire with H.E. shell fitted with instantaneous fuses cannot be used, i. e.:

1) When the objective is greatly defiladed.

2) When the ground at the point of impact is marshy or torn up.

§ 4. Effects of percussion shells.

The effects produced by an H.E. shell in percussion fire, at its point of impact, depend essentially upon the course that it follows after its contact with the ground, and upon the position of the point of burst upon this course.

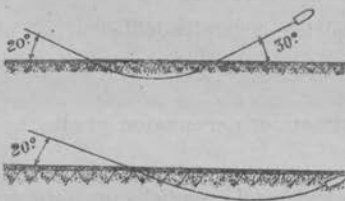
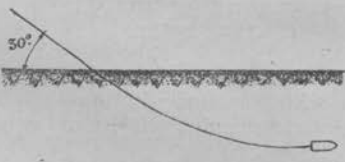
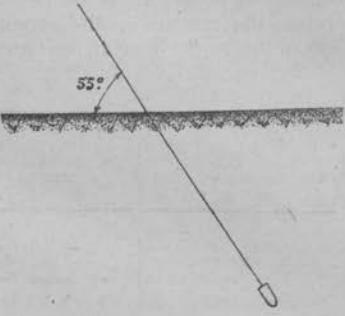
A. COURSE FOLLOWED BY THE PROJECTILE AFTER ITS CONTACT WITH THE GROUND.

The course which the projectile takes after it encounters the ground varies with the angle of impact, profile and weight of the projectile, remaining velocity and nature of the ground.

a) Influence of the angle of impact. — The most probable courses, in relation to the value of this angle, of an inert projectile are shown in the plate on the next page.

The table below gives the courses in the ground, which are followed by a 370 m/m projectile, with varying angles of impact:

ANGLE OF IMPACT.	PENETRATION IN DEPTH.	HORIZONTAL PENETRATION.
35°.....	3.00 meters.	6.50 meters.
50°.....	5.00 —	5.00 —
65°.....	6.00 —	2.50 —

ANGLE of IMPACT.	PENETRATION.	REMARKS.
Fire with flat trajectory $0 < \omega < 15^\circ$	 Furrow	The projectile ricochets after making only a shallow furrow in the ground.
Fire with flat trajectory $15^\circ < \omega < 25^\circ$		The projectile following the influence of its remaining velocity and its shape, which is more or less pointed, ricochets after having followed a certain course under the ground or else remains at a small depth.
Curved fire $25^\circ < \omega < 40^\circ$		The projectile follows an irregular course under the ground, with a tendency to return to the surface.
High angle fire $\omega > 40^\circ$		The projectile follows a course, which is straight in general, and penetrates to a depth which varies with the remaining velocity, the shape of the projectile and the nature of the ground.

b) Influence of the weight of the projectile, the remaining velocity and the resistance of the ground. — The elements which enter into the determination of the maximum depth of penetration of a projectile are too numerous for an exact figure to be given of the value of this penetration. They vary widely with the resistance of the ground, of the obstacles the projectile must penetrate, etc. However, penetration is above all governed by the weight of the projectile and its remaining velocity.

The following table gives a certain number of courses observed for inert (uncharged) projectiles, through ground of medium resistance.

CALIBER.	REMAINING VELOCITY.	WEIGHT OF PROJECTILE.	ANGLE of IMPACT.	VERTICAL PENETRATION.
75.....	220 m. per s.	5.30 kg.	25°	1.00 m.
155.....	260 —	43 —	30°	1.60 m.
220.....	225 —	100 —	42°	2.00 m.
280.....	350 —	275 —	38°	3.40 m.
370.....	250 —	400 —	50°	5.00 m.

Penetrations to great depths can only be obtained by the use of projectiles of the larger calibers, fired for a great angle of impact. To penetrate to a depth of 2 meters in ground of average resistance, a 155 m/m projectile at least must be used, with an angle of impact of at least 45°.

With medium calibers, up to and including the 155 m/m, projectiles fired for an angle of impact of less than 20° very rarely penetrate more than 1 m. or at most 1.50 m. below the surface of the ground.

The depth of penetration is evidently greater in soft ground than in hard. For example, when a projectile ricochets, the furrow is deeper in soft clay or marshy ground than in ground of average resistance; therefore the projectile will remain in the ground longer, and its effect may thus be modified.

The projectile and its fuse should not break during their penetration into the ground: semi-steel shells of 155 m/m and smaller calibers are too fragile to be used for purposes of penetration, and should be employed with instantaneous fuses (I. A., I. A. L. or R. Y. fuses) for surface effects only; no ricochet effect should be attempted with this type of projectile.

Penetration into **concrete** or **reinforced concrete** varies with the quality of the concrete, but is always much less than penetration into the ground. It depends essentially on the kinetic energy (mv^2) at impact, and therefore requires a

great remaining velocity and a projectile of considerable weight, i. e., of a large caliber. It is also necessary that the projectile should complete its penetration without breaking; in consequence, it is recommended in attacking concrete, to employ some armour-piercing type of shell, base-fused, with delay, and constructed with a thick pointed ogival head of hard steel.

B. INFLUENCE OF THE POSITION OF THE POINT OF BURST ON THE EFFECTS OF H. E. SHELLS. INFLUENCE OF FUSES AND OF THE BURSTING CHARGE.

The different kinds of fuses in use allow variations to be obtained in the position of the points of burst of H. E. shells, so that advantage may be taken either of the effects of the splinters (surface effects), or of the effects of the shock and of the gases generated by the burst (effects of demolition.)

The burst of a projectile may be regulated as follows :

a) **Above the ground.** — The shell bursts in the air at a certain height, either on its trajectory, before reaching the point of fall, or after ricochet on the ground.

The first case is that of *time fire* (fig. 14) obtained by the

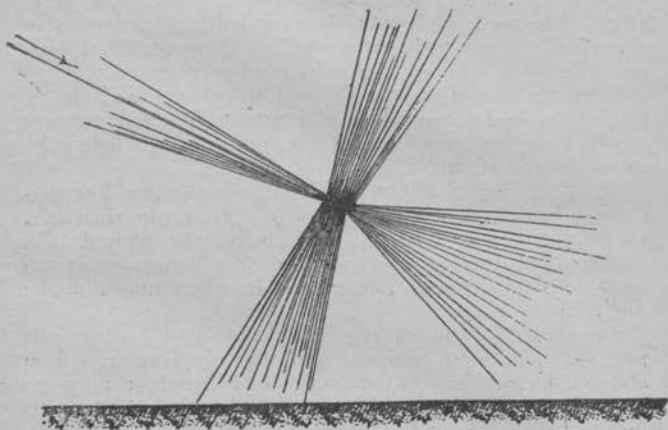


Fig. 14.

use of either time detonating fuses, or of combination detonating fuses.

The effects of this kind of fire have been studied previously (§ 3).

The second case is that of *ricochet fire* (fig. 15), which is used only with the 75 m/m gun. The purpose of this kind

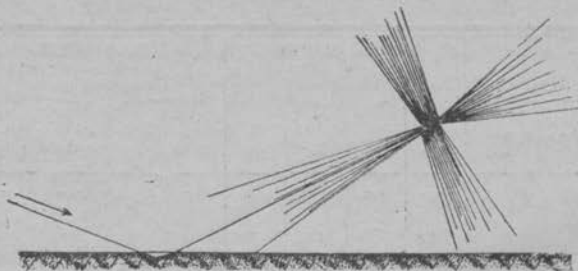


Fig. 15.

of fire is to obtain bursts at a height of from 2 to 10 meters above the ground, thereby utilizing to the maximum the effects of the fragments of the lateral spray. To accomplish this, it is necessary to fire so that the angle of impact will be less than 15° , and to fit the shell with a delayed action fuse [delay 0.05 sec, percussion detonating fuse, 1899-1908 Model, black head] (1).

The burst will occur about 10 m. beyond the point of impact.

The burst of H. E. shell after ricochet acts in the same way as a low time burst, except that the burst occurs on an ascending trajectory, and its direction is frequently changed by the contact of the projectile with the ground.

Under such conditions :

1. The base spray gives good effects, and
2. The varying angles which the "axe stroke" makes with the line of fire are an advantage, which compensates for the slight depth of the zone covered by each burst.

The proportion of ricochet bursts increases when the ground slopes in the same direction as the descending branch of the trajectory.

This proportion diminishes when the ground is inclined in the opposite sense.

(1) In order to obtain the burst at a sufficient height, the shell must not burst until a relatively long period has elapsed after it has struck the ground. With shrapnel, on the contrary, it is better to have a low burst, after ricochet, and therefore a delay is not used.

The following table shows the zones in which ricochet fire with the 75 m/m H. E. shell, 1900 Model, normal charge, may be used; these zones depend upon the value and the sense of the slope of the ground at the objective.

GRADIENT.	GROUND SLOPING IN THE SAME WAY as the trajectory.				GROUND SLOPING IN THE OPPOSITE WAY to the trajectory.			
	20 o/o.	15 o/o.	10 o/o.	5 o/o.	5 o/o.	10 o/o.	15 o/o.	20 o/o.
	from	from	from	from	from	from	from	from
Range, ...	3800	3500	2600	1700	500	500	500	500
	to 5900	to 5600	to 5300	to 4700	to 4000	to 3000	to 2600	to 1600

Very near the point of burst (less than 1 meter) ricochet fire has very serious effects upon **materiel**.

Against **personnel**, either unsheltered, sheltered behind a wall, or at the bottom of a trench, it has the effect of a time shell bursting at the same height, but this effect is slightly increased by the action of the base spray.

b) **Close to the ground.** — Bursts close to the ground may be obtained at all ranges, provided the angle of impact is sufficiently great, by the use of instantaneous fuses [I. A., I. A. L. or R. Y. fuses] (1).

The **I. fuse** causes the projectile to burst at the moment when the ogival head penetrates the ground (fig. 16). A

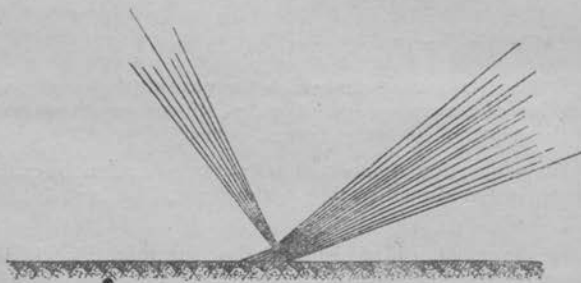


Fig. 16.

(1) On level ground the shortest range at which it can be obtained with the 75 m/m H. E. shell fired with normal charge and long fuse is 4000 m.

shallow crater is formed, the sides of which form a sharp angle with the surface of the ground (fig. 17).



Fig. 17.

The **I. A.** and **I. A. L.** fuses cause the projectile to burst just before the ogival head comes into contact with the ground. Only a slight depression is formed on the surface of the ground, as shown in fig. 18.



Fig. 18.

The **R. Y.** fuse gives effects midway between those of the **I.** and **I. A.** fuses, but more nearly approaching those of the latter. The effects of the splinters are less important than in the case of either time or ricochet fire, because of the low height at which the bursts occur. An axe stroke nearly perpendicular to the plane of fire is made at the point of impact, and, especially with long fuses, only a few fragments of the ogival head and of the fuse are found in the crater. By experiment, it has been found that the respective effects of shells bursting 1 meter above the ground, on the surface of the ground, and after the ogival head has penetrated 10 cm. into the ground, are in the ratio of 6, 4 and 3. It is therefore a mistake to use **I.** fuses to obtain surface effects, unless no others are available. *Long fuses* (**I. A.**, **I. A. L.**, **R. Y.**) should be used, for this purpose, whenever possible.

If the angle of impact is very great (in the case of high angle fire), the lateral spray takes the form of a thin circular sheaf of splinters, which rakes all the ground around the point of impact. The use of instantaneous fuses gives surface effects which make them particularly advantageous when firing on *unsheltered personnel*. In this case, similarly to that of time fire, semi-steel shells may be employed very successfully. The effect of the concussion supplements that of the splinters in *clearing away* the ground within a certain radius. Therefore, fire **H. E.** shells, fitted with instantaneous fuses, for destroying *barbed wire entanglements*, whenever the range is sufficiently great.

With materials with which various propelling charges may be used, it is generally advisable, when firing with instantaneous fuses, to employ the smallest charge that can reach the necessary range.

c) **At a small depth in the ground.** — Bursts at a small depth in the ground are obtained as follows :

1. With the *S.R. fuse* (without delay), at all angles of impact that give no ricochet (1).

2. With *delayed action fuses*, with angles of impact smaller than 25 degrees, if there is no ricochet.

The surface effects are slight. The shell bursts after penetrating to a depth equal to once or twice its length, forms a bowl-shaped crater and throws debris and fragments to a great distance (fig. 19). A considerable portion of the splin-

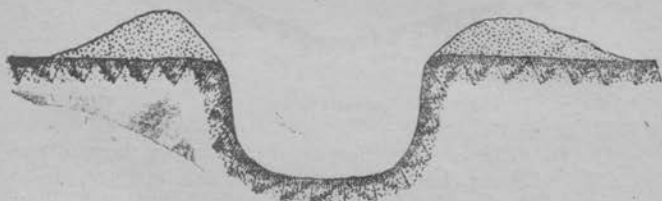


Fig. 19.

ters, however, remain in the crater. The effect with any given explosive increases as the bursting charge is increased.

The following table gives the dimensions of some craters formed in resistant natural ground (chalk, limestone or sand).

SHELL.	CRATER.	
	DIAMETER.	DEPTH.
Long steel shell 120.....	2.50 meters.	0.90 meters.
— 153.....	3.50 —	1.10 —
— 220.....	4.50 —	1.40 —
— 370.....	6.00 —	2.20 —

d) **At a depth 3 or 4 times the length of the projec-**

(1) If a projectile fitted with a S. R. fuse ricochets, the effects are similar to those produced by the ricochet of a projectile fitted with a delayed action fuse, though considerably less; owing to the fact that the burst occurs almost at the surface of the ground.

tile. — If the projectile is fitted with a *delayed action fuse*, and if the angle of impact exceeds 25° , the burst occurs at a greater depth. The volume of earth thrown up is greater, and, for equal depths, varies in proportion to the explosive charge. As in the preceding case, a bowl shaped crater is formed, but of greater depth. Moreover, a portion of the earth and debris thrown up fall back at the spot, and the ultimate inner face of the crater consists of pulverized earth which has practically refilled the hole, thus giving it a conical shape (fig. 20).

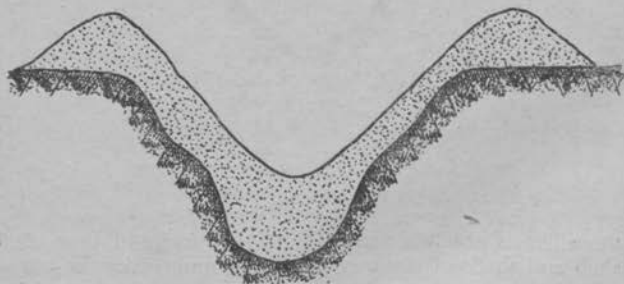


Fig. 20.

Such results are observed especially with angles of impact of 25° to 40° , and with short delay fuses (0.05 sec.). The following table gives the mean dimensions of craters formed in ground of average resistance by various long steel shells.

SHELL.	EXTERIOR DIAMETER.	MAXIMUM DEPTH.
Long steel shell 155.....	3.50 meters.	1.50 meters.
— 220.....	5.50 —	2.30 —
— 270.....	6.00 —	3.00 —
— 370.....	10.00 —	6.00 —

e) **At a great depth.** — If the depth at which the burst occurs is still further increased, the explosive charge may be too weak to throw up all the earth lying over the point of burst.

A subterranean *globe of compression* is formed. The only visible effect of the burst on the surface of the ground is the presence of a low mound which in some cases may be encircled by a narrow fissure (see fig. 21). The effect of such a burst is called a “camouflet”. The degree of compression of the ground around the point of burst is proportional to the bursting charge. For calibers smaller than 155 m/m.,

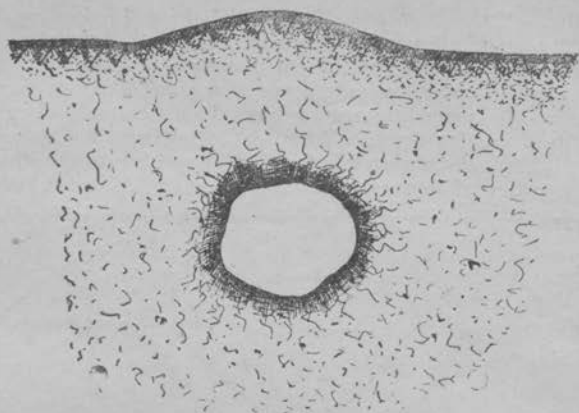


Fig. 21.

the effect is practically nil. With the 155 m/m long steel shell and shells of larger caliber, the compression is transmitted through the surrounding ground to depths greater than 1.5 m. from the point of final penetration. Thus the entire effect is subterranean; it may be considerable and cause the collapse of *deep dugouts*, particularly if shells of sufficiently large caliber are used. The effect is proportionally greater as the ground is more compact and forms a better tamping.

Camouflets are caused most frequently by high angle fire and occasionally by fire with an angle of impact of about 40 degrees, with long delay fuses (0.15, 0.25 and 0.35 sec. depending upon the caliber).

No splinters leave the ground, and the smoke, by the time it reaches the surface, is almost invisible. Observation of such a burst is impossible, and fire of this character can only be adjusted by the occasional use of the same type of shell fitted with S. R. or I. fuses.

The following table shows the depth of the lowest point of the subterranean cavity. It should be borne in mind that a dugout situated at a limited depth vertically beneath the point of burst, may still be destroyed by the compression of the ground.

SHELL.		DEPTH REACHED.
Long steel shell	120.....	3.00 meters.
—	220.....	4.50 —
—	270.....	6.00 —
—	370.....	10.00 —

The resistance of the ground and the remaining velocity of the projectile may greatly modify the depth at which the camoulet is formed.

The following table gives the percentage of fuses used with projectiles fired by the 155 Gun and by the 155 How. It shows how shells of the same caliber are fused differently according to the nature of the shell and the angle of impact that is required.

SHELL.	A. R. FUSES 1899-1908 delay 0.05 sec.	S. R. FUSES 1899.	I. FUSES 1914.	I. A. OR I. A. L. or R. Y. fuses.	FUSES 1899-1915.		
					S. R.	C. R. delay 0.05 sec.	L. R. delay 0.15 sec.
155 How. { semi-steel shell... steel shell.	0/0.	0/0.	0/0.	0/0.	0/0.	0/0.	0/0.
	.....	.....	.....	100			
	.....	.....	.....	.....	10	60	30
155 Gun. { semi-steel shell... steel shell.	.....	30	20	50			
	.....	50					
	50	50					

PART IV.

GENERAL FEATURES OF ARTILLERY MATERIELS.

CHAPTER I.

NECESSITY OF THE DIVERSITY OF ARTILLERY MATERIELS.

ART. I.

GUNS, HOWITZERS.

There are three requisites in the use of artillery. The projectile has to reach the target (Range), to fall on it under the best conditions (Angle of fall), and to produce the desired effect (Caliber, kind of projectile, etc.).

A single gun could not fulfil all these requirements.

If a projectile is to be shot a long distance, the muzzle velocity must be great (*e. g.*, 75 gun, $V_0 = 550$ m; 155 GPF, $V_0 > 700$ m). Therefore the propelling charge has to be considerable, and the projectile must have a long travel through the bore under the action of the powder gases, so as to utilize fully the force of these gases.

Length of rifled part of tube of the 75 = 2.20 m. approxim.

Length of rifled part of tube of the 155 GPF = 4.60 m. approxim.

Therefore, to fire at long ranges, guns, with a great muzzle velocity and flat trajectory are used.

To demolish a dugout by striking it on the roof, or to reach an objective which is greatly defiladed, the angle of fall must be large. Guns with flat trajectories only give a great angle of fall at long ranges; so it is necessary to use another kind of gun.

To obtain a great angle of fall, the quadrant elevation must be correspondingly great, and as a long range is not

wanted, a small charge of powder and a short travel of the projectile through the bore will be sufficient. These conditions are met by short guns (howitzers and mortars), firing with a small muzzle velocity and with a curved trajectory.

EXAMPLE :

155 H 1917 S: Long shell: Charge oo: $V_0 = 433$.

Range = 9000 m.; Angle of fall = 43° ; Maximum ordinate = 1700 m.

ART. II.

DIVERSITY OF CALIBERS.

Thus it is clear that we must have more than one caliber. If, for example, we have to fire at a fugitive target, infantry attacking for instance, it will be necessary to fire rapidly a large number of projectiles in order to thoroughly sweep the ground. Shells easy to handle, *i. e.*, light and of small caliber, must then be used, 75 for instance.

But, to destroy a gun casemate, the 75 projectile is not effective; more explosive is needed; so a shell of larger caliber, such as the 155, must be used.

This diversity of calibers is also necessary from the point of view of the mobility of the materiel. For some given purposes the materiel must be such that it can be drawn rapidly by horses even at a trot, on bad ground, and also be moved by the men when in the battery position.

It must therefore be light, and hence of small caliber.

A very powerful materiel must be of larger caliber and for this reason has not the same mobility.

The diversity of materials is the consequence of the above considerations.

Materials may be classified as follows :

a) Light Field Artillery, consisting of the 75 m/m, M. 1917, the French 75 m/m M. 1897, and the British 75 m/m, horse or tractor drawn.

b) Heavy Field Artillery, consisting of the 155 m/m and 6" Howitzers and the 4.7" Gun, horse and tractor drawn.

c) Heavy Artillery, consisting of the 155 m/m G. P. F., the 6" gun, the 8" and 9.2" Howitzers and the 240 m/m gun, tractor drawn, and of the 8", 10", 12", 14" Guns and the 12" and 16" mortars on R. R. mounts.

d) The Trench Artillery consisting of the 6" Newton and 58 m/m. Trench mortars.

e) The Anti-Aircraft Artillery consisting of the 3" and 4.7" A. A. Guns on Trench mounts.

CHAPTER II.

STRUCTURE OF THE TUBE.

The bore is composed of four parts (fig. 1):

The breech recess, the powder chamber, the forcing slope and the rifled part.

The rear part of the tube is closed by a breechblock.

The *powder chamber* is the space where the propelling charge is placed and burns.

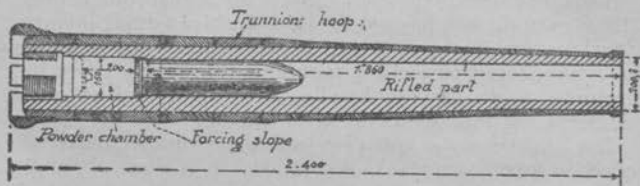


Fig. 1.

The *forcing slope* connects the powder chamber to the rifled part, the diameter of which is smaller than that of the powder chamber. It serves as a seat for the rotating band of the projectile. When, at each loading, the projectile is well seated, the capacity of the powder chamber remains constant.

The *rifled part* is the part of the gun where the projectile, shot forward by the force of the charge gases, acquires its initial velocity.

The rifling includes *grooves* and *lands*.

The *grooves* give the projectile the movement of rotation necessary to insure a stable flight. They are separated by the *lands*. Each groove has a *bottom* and two *flanks*.

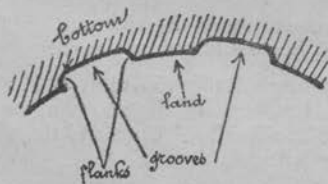


Fig. 2.

The diameter (*caliber*) of the bore is measured between two lands (fig. 2).

Hoops. — The tube is submitted during fire to considerable pressure (approximately 2000 kgs.

per square centimeter), which tends to split it along a line parallel to the axis of the bore.

To strengthen the tube, it is hooped, *i. e.*, strongly reinforced with steel hoops, the diameter of which is smaller than the exterior diameter of the tube. These hoops are sometimes forced on the tube by means of a hydraulic press but more often by heating and shrinking (*e. g.*, 155 H.). (Fig. 3.)

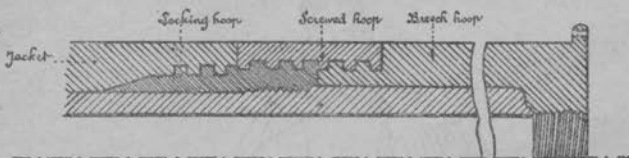


Fig. 3. — Hoops of the 75 mm. gun.

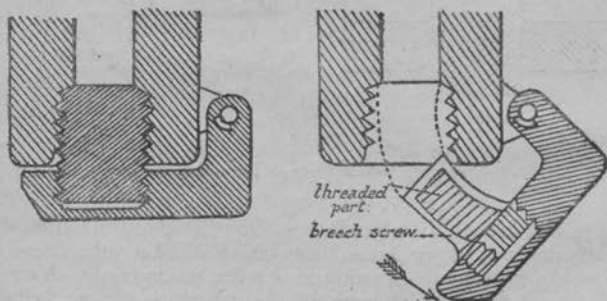
Light modern guns (75, 155, and so forth) have only one hoop of great length called the jacket or *breech hoop*.

Other hoops may be placed on the tube for special uses: (*e. g.* 75 bronze jacket, locking hoop, screwed hoop, hoop holding the muzzle rollers; 155 H. 1877 Model, trunnion hoop.)

Breechblock. — The breechblock is a piece of steel which closes the rear part of the tube.

Three models are in use:

1. *Screw breechblock.* — It is threaded and screwed into the rear part of the tube (155 H. 1917 S. Mod.) (Fig. 4).



(Longitudinal sections
along the axis of the bore.)

Opening of the breech

Fig. 4. — Schneider breechblock.

2. *Drop breechblock.* — It is made of a block of steel revolving around an axis, *e. g.*: Nordenfeld breechblock of the 75 (fig. 5), which revolves around an axis parallel to the bore.

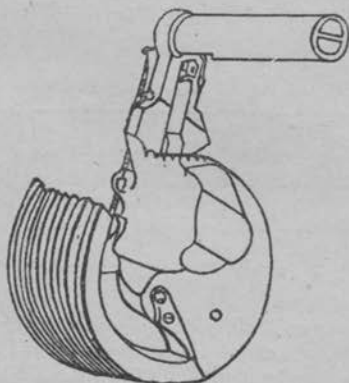


Fig. 5. — Screw of the 75 drop breechblock.

3. *Wedge breechblock.* — It is made of a block of steel which goes into a mortise made in the tube. (Breech of the German 77) (Fig. 6).

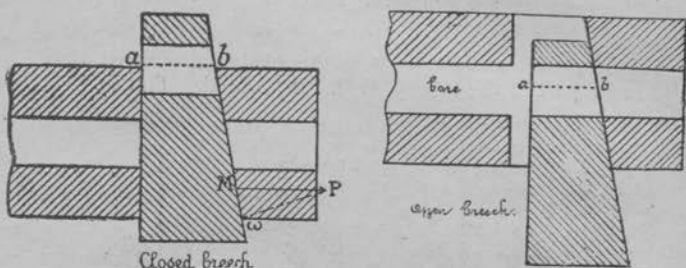


Fig. 6.

Wedge breech. (Section through the axis of the bore.)

On the breech is placed the firing mechanism and the safety devices, in particular those which will keep the breech closed to prevent its opening under the action of the charge gases, and those which prevent the cannoneers from firing before the breech is completely closed.

Obturator. — The charge gases must not escape to the rear of the tube. Such a thing would reduce the accuracy

of fire and would injure the breech and its recess. Therefore an obturator is necessary (fig. 7).

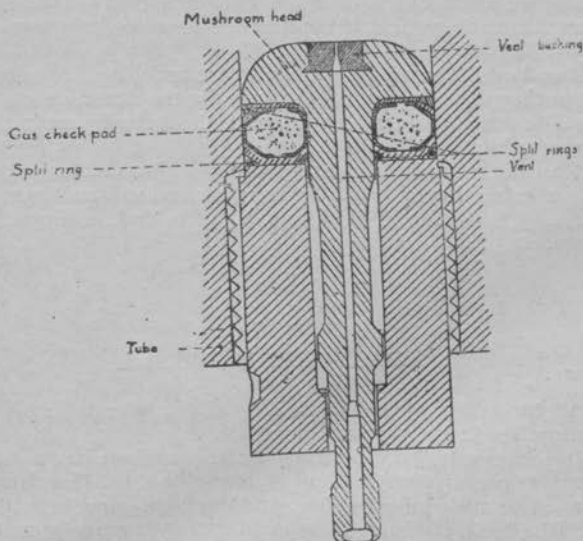


Fig. 7. — De Bange plastic obturator.

The principal types of obturators are :

a) **Plastic obturators**, *e. g.*, de Bange obturator (fig. 7), and the obturator of the 155 H. 1917 S. Mod., in which a ring of plastic matter is compressed by a mushroom head, pressing the outer split rings against the wall of the bore and the inner split ring against the spindle of the mushroom head.

b) **Obturators** consisting of a cartridge case which, when the charge gases act, swells out and fits closely against the walls of the tube.

CHAPTER III.

GUN CARRIAGES.

The carriage supports the gun when it is firing and during its transport.

The impulses which the carriage sustains while firing depend on the kind of fire which is executed.

In the case of flat trajectory fire, the direction of the impulse sustained approaches the horizontal; in the case of curved fire, the vertical. Therefore they must be built accordingly.

Two types of carriages exist; they are called *rigid carriages* when they directly support the tube by the trunnions; and *recoil carriages* when they support the tube by means of devices which recoil with it.

Most of the modern guns are fitted with recoil carriages. However, rigid carriages are still in use and will continue to be (*e. g.*, 155 L. 1877 Mod., 220 H. 1880 Mod., sliding carriage, etc.).

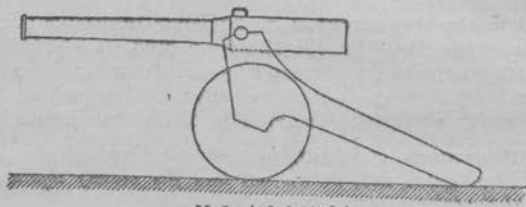
ART. I.

RIGID CARRIAGES.

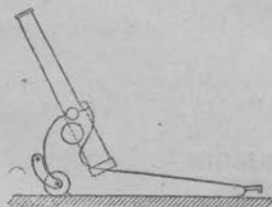
All the recoil effect due to the firing of the projectile is transmitted to the carriage directly.

In the case of flat trajectory fire, the carriage has a tendency to rise up and then to fall down; to avoid this rising, it must be made long and low. In the case of curved fire, the carriage has a tendency to be crushed, so it must be made squatty and most often, as the wheels cannot bear such a strain, they will have to be removed (fig. 8).

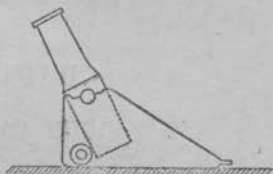
Rigid carriages.



155 L. (1878 Mod.)



155 H. (1881 Mod.)



220 M. (1880 Mod.)

Fig. 8.

In all cases, the carriage will recoil until stopped by friction and the action of gravity.

After every shot the cannoneers will have to bring the gun back to its firing position and then lay it again. All this results in fatigue and a loss of time incompatible with rapid firing.

Friction of the carriage on the ground is used to limit the recoil as much as possible, (Sliding float of the 155 L. 1877 Mod.) and also different kinds of brakes to prevent the wheels from turning.

In order to assist in checking the recoil and to facilitate the return of the gun to the firing position, inclined planes should be placed behind the wheels.

In certain cases, the recoil of the carriage is limited by means of a hydraulic cylinder (fig. 9) in which the friction of

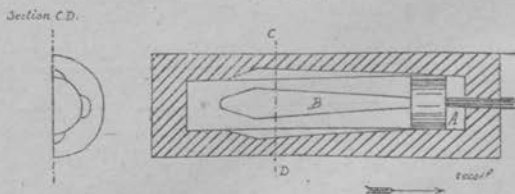


Fig. 9. — Hydraulic cylinder (recoil ended).

a liquid passing through small openings is utilized (Ex. 220 1880-91 Mod.).

In every hydraulic cylinder the size of the openings vary, being large at the beginning of the recoil and narrow at the end.

A cylinder, which is full of liquid, is fixed on a frame which is anchored to the ground. Inside the cylinder is a piston, bored with holes, the rod of which is connected to the carriage.

When the carriage recoils after firing, the liquid has to pass from A to B with great speed, which slackens and limits the movement.

It is evident that the openings through which the liquid flows cannot be of constant dimensions. At the beginning of the recoil, the velocity of motion being great, the liquid must flow easily, otherwise the reaction of the recoil apparatus would be enormous.

In this case, the recoil apparatus and the gun carriage would have to be particularly strong, therefore heavy. The reaction of the brake decreases as the speed of recoil decreases at the end of the recoil (1); if the openings made for the

(1) It can be demonstrated that if, at a given moment of the recoil, v is the velocity, and ω the total surface of the openings, the reaction F of the buffer is directly proportional to v^2 and inversely to ω^2 .

liquid to flow through were very large, the recoil apparatus would no longer have any action.

The variation of the surface of the openings is realised in different ways.

EXAMPLE: Cylinders with grooves (220 mortar) [fig. 10]. The openings consist of the space between the piston and the inner wall of the cylinder, which is grooved.

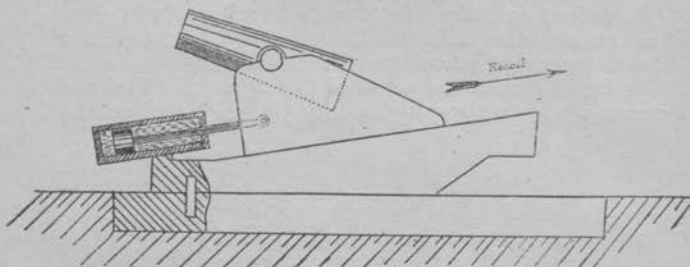


Fig. 10. — 220 m/m. Recoil apparatus.

After the recoil is ended the gun resumes its firing position, through the action of gravity, if the chassis is inclined, or by some operation of the cannoneers. At this time, the liquid does not oppose any resistance because its speed in passing through the openings is very slow.

ART. II.

GUN RECOIL CARRIAGES.

We have just seen that the rigid carriages are not convenient for rapid firing because of the time and labor necessary to bring them back to the firing position and also because they have to be laid again.

Very rapid fire with small caliber guns was obtained first.

The same principles which produce rapidity of fire have been extended to the heavier guns, as it may sometimes be useful for heavy guns to fire rapidly a large number of rounds. It also spares fatigue to the cannoneers and makes it easier to obtain greater accuracy in firing and to get the greatest efficiency out of the cannoneers.

Materiels built in this way are called *rapid firing materiels*.

CHAPTER IV.

RECOIL APPARATUS.

ART. I.

RECOIL CYLINDERS.

To obtain this rapid fire, the gun only participates in the recoil, and the carriage, being fixed on the ground by the trail spade, does not move during the fire (fig. 11).

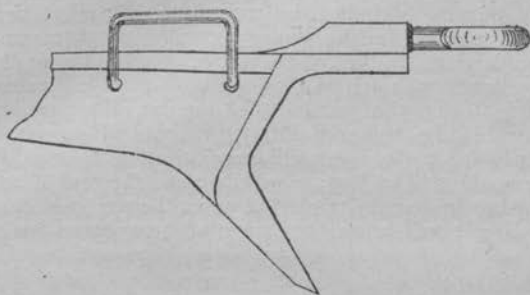


Fig. 11. — Trail spade.

The connection between the gun and the carriage is made by means of a hydraulic cylinder. The gun slides during the recoil, carrying the mobile part of the cylinder with it (piston and its rod in the 75, the cylinder remaining fixed to the carriage; cylinder in the 155 H. 1917 S. Mod., in which the piston and its rod remain fixed to the carriage).

EXAMPLE : Cylinders with a central counter rod (Schneider). — The piston rod is hollow, holes are bored through the head of the piston. A counter rod *t* of varying diameter is screwed into the bottom of the cylinder and penetrates the hollow rod; to flow from A to B, the liquid has to pass through the annular space of varying diameter between the

rod and the counter rod (fig. 12). Other devices are also used (75 cylinder).

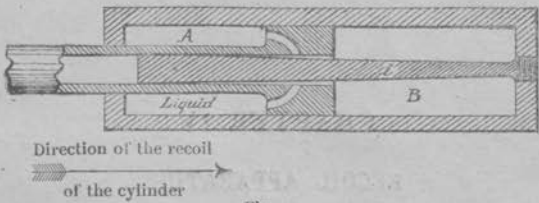


Fig. 13.

Instead of a shock, causing a considerable impulse in a very short time, the cylinder causes the carriage to undergo a continuous and diminished impulse during a much longer time.

A man can carry a weight of eighty kg., for instance, from one point to another, all at once, making a violent and short effort, or, dividing this load into certain number of parts, can carry it in several journeys which necessitate at each time a smaller effort. In the second case, the man need not be as strong as he must be in the first case, inasmuch as the number of journeys is greater and accordingly, the effort for each of them smaller. For the same reason, the effort transmitted to the carriage by the hydraulic cylinder will be smaller in proportion, inasmuch as the length of recoil is greater. It is evident that the smaller the impulse, the steadier the carriage will be, and accordingly the lighter it may be.

The long recoil cylinder will therefore allow the rapid firing of guns of small caliber; it will increase the rapidity of fire of any heavier gun by rendering easier the service of the gun (fig. 13); it will allow the firing of heavy guns having a

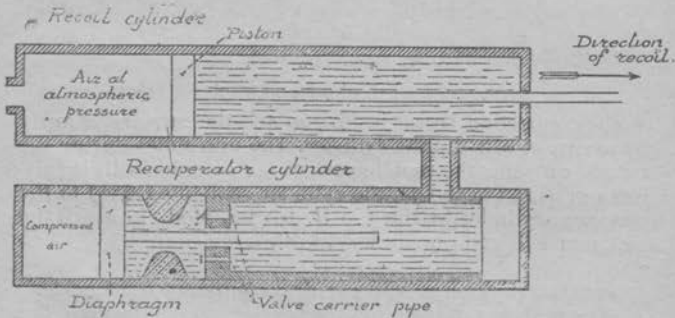


Fig. 13.

curved trajectory, without removing their wheels (e.g., to fire the 155 H Mod. 1881 rigid carriage, the wheels have to be

removed; the 155 H 1917 S is fired without its wheels being removed and the 220 QF also.)

If the length of the recoil lessens, the effort transmitted to the carriage increases; it will be necessary to build it more strongly (*e.g.*, the 155 GPF, of which the length of recoil varies according to the quadrant elevation, has on this account a very strong carriage).

The length of recoil cannot be increased over certain limits, as the gun must be sustained during the recoil without exaggerated increase of weight (muzzle rollers of the 75) and also when firing with a great elevation, the breech must not strike the ground.

The effort transmitted to the carriage must be lessened by every possible means. This is why in the 155 H 1917 S, it is the cylinder (fig. 14.) which recoils, the piston remain-

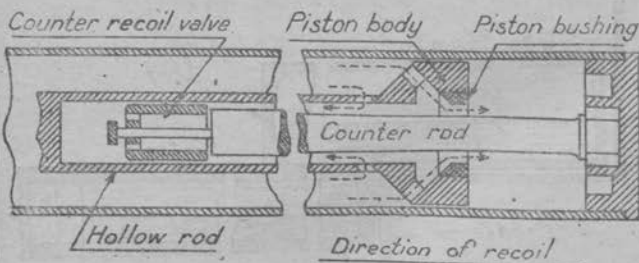


Fig. 14.

ing connected with the carriage. The cylinder mass increasing the recoiling mass, the impulse transmitted to the carriage is lessened in the same way as the shock sustained by the shoulder of a man firing a rifle is lessened in proportion to the greater weight of the rifle.

ART. II.

RECUPERATORS.

When the action of the recoil cylinder is ended the gun is drawn back completely on the guide rails. To bring it back to its firing position, the action of another device is necessary. This device is the *recuperator*. Its principles are as follows: The recoil compresses an elastic matter (air or metallic springs); at the end of the recoil, this elastic matter expands and pushes the gun back into place. The recuperator must not only push the gun back into its firing position, but keep it there during fire at any quadrant elevation as well as when travelling.

For this reason, the recuperator at rest must have a rather high initial pressure (initial pressure of the air recuperator of the 75 = 110 to 145 kg. per sq. cm.; initial pressure of the recuperator of the 155 H. 1917 S. = 31 kg. per sq. cm.).

The air recuperator may be connected with the recoil cylinder as in the hydropneumatic cylinder of the 75, or entirely apart from the cylinder as in the air recuperator Schneider (fig. 15).

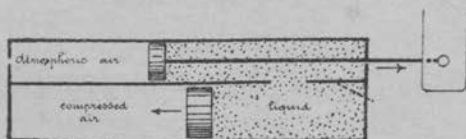


Diagram of a hydropneumatic cylinder.

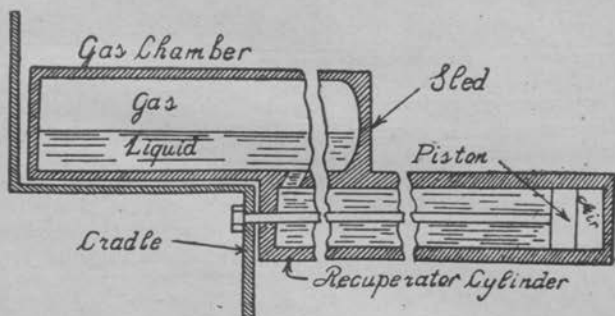


Fig. 15. — Diagram of the Schneider recuperator.
(The recoil cylinder is not represented).

In a general way, the air is not directly compressed by a piston but by means of a liquid so as to secure liquid joints which do not leak as easily as air joints.

The spring recuperators are independent of the recoil cylinder and may be placed in any part of the materiel.

ART. III.

COUNTER RECOIL BUFFERS.

The counter recoil must end without shock at zero velocity, otherwise the gun would be displaced; this would impede the service of the gun and the rapidity of fire. If the recuperator acts alone during the counter recoil, a shock will certainly occur. As the recoil has been controlled by means of the hydraulic cylinder, the counter recoil is controlled by means of the hydraulic counter recoil

buffer. In a general way, the same liquid works in the recoil cylinder and in the counter recoil buffer.

The counter recoil buffer is built in such a way that it has no action during the recoil. (Valve of counter recoil of the Schneider materiel.)

CHAPTER V.

TRAVERSING AND ELEVATING MECHANISMS.

ART. I.

ELEVATING MECHANISMS.

Laying for elevation is done by lowering the breech to increase the elevation and raising it to decrease the elevation, thus turning the gun (tube in the rigid carriages, and tube and recoil controlling parts, in the recoil carriages) around the trunnions.

The movement is produced by a hand wheel, which by means of a gear, actuates a device of the turning parts with respect to another device connected with the carriage.

In the example shown (fig. 16), the rotation of the hand

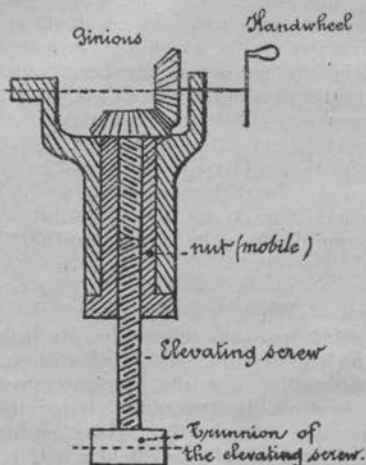


Fig. 16. — 75 gun.

wheel through a bevel gear produces the rotation of its mobile nut. The elevating screw cannot turn and the mobile nut therefore moves up or down, depending upon the direction of rotation, thus moving the breech of the gun up or down.

In certain cases, laying for elevation is done in two independent movements. One displaces a rocker with respect to the carriage, the other displaces the turning parts with respect to the rocker. The angle of site and the quadrant elevation of the firing tables are thus set separately. (Ex. : 75, 1897 Mod., 155 H 1904 Mod.).

These devices may be either screws and nuts, or racks and pinions (fig. 17). They are built so as to be reversible

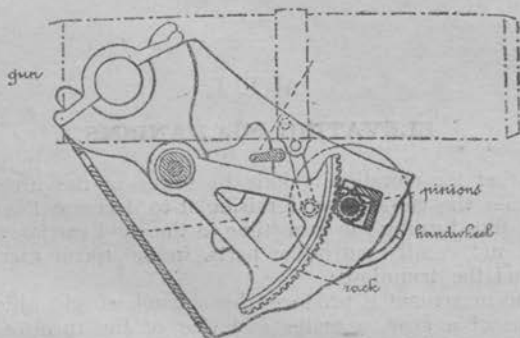


Fig. 17.

(Ex. : Devices fitted with screw and nut, nut moving with respect to its screw which is fixed : independent range setter of the 75. Devices in which the turning part is fitted with a rack and the carriage is fitted with a pinion : rocker of the 75; elevating system of the 155 H. 1917 S).

Certain guns which fire very heavy projectiles, must be brought to a loading position after each shot, and are often provided with a rapid re-elevating system. This system generally consists of a rack and a pinion, which are distinct from the devices for laying for elevation and allow the gun to move rapidly from its laying position to its loading position, and inversely.

Equalizers. — When a gun, which has a long recoil, fires with a great quadrant elevation, its breech runs the risk of striking the ground. To avoid this, a hole may be dug in the ground (A, fig. 18). In gun construction, it is avoided by elevating the trunnions (B) or by placing the trunnions near the breech (C). This last method is, in particular, used for guns of heavy field artillery. But in this case, there is in front of the trunnions, a great preponderance of weight which interferes with the operation of elevating the

gun, the gunner not having the necessary strength to elevate it to the angle of fire. It is then necessary to counter balance

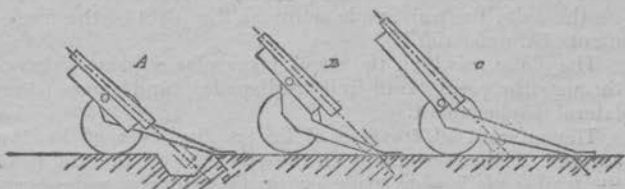


Fig. 18.

that weight preponderance by means of a special device called *equalizer*.

Two systems are used :

1. Add to the turning part in the rear of the trunnion, a certain weight, so as to equalize the weight in front of the trunnions (D, fig. 19).

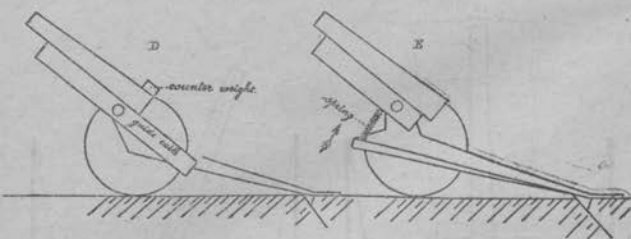


Fig. 19.

This system is used in the Schneider guns, for which the weight added is formed for the greater part by the prolongation of the guide rails at the back and accessorially by the augmentation of the weight at the rear part of the tube (Breech counter weight).

2. Use a device which has a permanent tendency to raise up the muzzle and which presses on the carriage (spring dynamic equalizer of the German 105 H., and compressed air dynamic equalizer of the 155 St-Chamond 1915 H.) [E, fig. 19].

ART. II.

TRAVERSING MECHANISMS.

With rigid carriages, the laying for direction is done by displacement of the carriage by the cannoneers.

With gun recoil carriages, two systems are in use :

1. *By traversing on the axle* (fig. 20). — The carriage slides on the axle, the trail spade acting as the pivot of the movement (Ex. : 75, 155 H).

The plane in which the shock takes place passes always through the pivot (trail and trail spade), and there is no lateral displacement.

The amount of traverse of fire is limited : *a*) by the amount of the movement on the axle ; *b*) by the width of the trail spade, a wide spade having a greater and wider bearing surface.

It is then necessary to have a trail spade as narrow as is permitted by the necessity of having a bearing surface sufficiently wide to support the gun during recoil.

2. *Rotation around a pivot*. — The carriage consists in this case of two parts : a lower carriage which bears an almost vertical pivot, and an upper carriage which can turn on the lower one about the pivot (fig. 21).

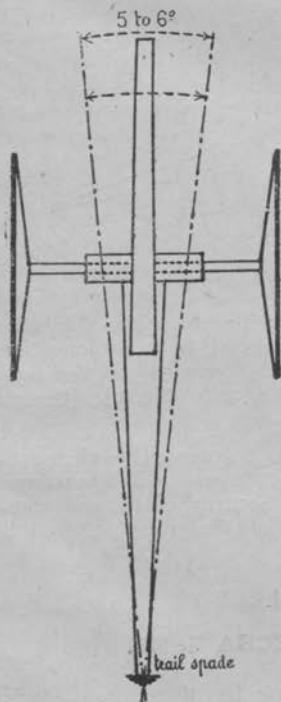


Fig. 20.

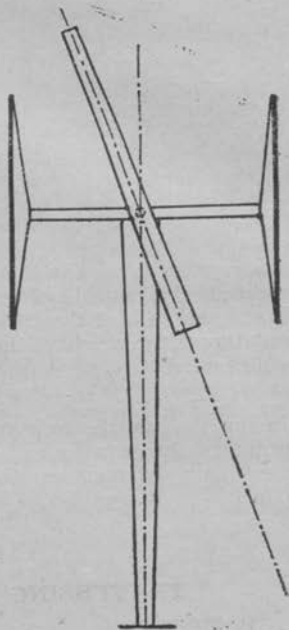


Fig. 21.

Theoretically, the traverse of fire is without limit; practically, in order to avoid any displacement in direction, it is necessary that the direction of the recoil pass through the fixed base (trail spade).

If the carriage has a single trail spade, there is a displacement as soon as the plane of fire passes outside of the fixed base or the trail spade. The amount of traverse is not greater than in the materiels which traverse on the axle. But the fixed base may be greatly increased by the use of split trails, which give a traverse of fire of 60° (155 GPF, Deport guns).

CHAPTER VI.

LAYING APPARATUS.

ART. I.

LAYING FOR ELEVATION.

It consists of setting off the quadrant elevation in one operation or by setting separately the site and the elevation.

The apparatus for laying in elevation may consist of a quadrant level (1888 Model) or of an apparatus graduated in distances or angles (range scale of the 75, range drum of the 155 H. 1917 S.) or of a combination of these two (quadrant and range drum). These devices are either fixed on the gun or independent of it.

ART. II.

LAYING FOR DIRECTION.

To lay a gun for direction, use is made of an aiming point which is generally seen through a sight apparatus fixed to the gun. It is necessary to take into account the possible inclination of the trunnions, especially if the quadrant elevation is great. For this reason, guns firing with great quadrant elevation (155 H. 1917 S) usually have their sighting apparatus provided with a cross level which allows the plane of sight to be brought to the vertical.

PART V.

CARE AND PRESERVATION OF ARTILLERY MATERIEL.

CHAPTER I.

GENERAL CONSIDERATIONS.

The care of materiel has a very great influence on the service ability of the gun and its precision. The preservation of guns and economy and good use of ammunition are possible only if constant care is given to the gun. The life of the gun is not at all in proportion to the number of rounds fired. Some 75 m/m guns were still serviceable after 20,000 rounds had been fired, some 155 m/m howitzers after 12,000 rounds. They had been given good care. Guns of the same caliber have become unserviceable after a thousand rounds, because they were not given the necessary care.

To avoid injuries and premature wear and to prevent accidents, the following precautions must be observed at all times :

1. Daily inspection of materiel between periods of firing and replacement of worn out parts in ample time. In this connection, injuries to materiel must be discovered, their importance must be estimated, precautions to prevent their recurrence must be taken, and it must also be determined whether necessary repairs can be made by the battery personnel or whether the materiel must be sent to the rear for repair.

2. Careful cleaning of parts and lubrication of rubbing surfaces. Cleanliness is so important that injuries to materiel and accidents are of most frequent occurrence in bad weather. Rust is the origin of serious damage to materiel.

The cleaning referred to not only includes the daily clean-

ing and inspection, but also the partial dismantling, inspection, cleaning and lubrication of each gun during its periodic withdrawal from service.

Batteries replace parts which are out of service by spare parts carried in the wagons belonging to the unit, but only on condition that the replacement of these parts requires neither dismantling unauthorized at the front, nor forging, nor the adjusting of any delicate or essential parts by means of a file.

Other replacements or repairs are done by repair squads or workshops. Attach to the materiel the gun book on which the injury or accident which occurred is briefly mentioned. Complete these indications, if necessary, by a written note giving more detailed explanations.

An individual book contains the past record of each gun. This record must include the number of rounds fired daily and the charge used with each projectile, as well as the date and result of every inspection by the materiel inspector. It also records any unusual incidents that may have occurred.

In this case, write down the marks relative to ammunition fired. The gun-book belongs to the gun and must accompany it wherever it goes.

Example of gun book record.

Caliber "75 m/m."

Model "1897"

Gun No. "8513" (1)

Tube No. "502 Creusot" (2)

DATE.	NO. ROUNDS FIRED.	REMARKS AND CHARGE NUMBERS.
Jan. 5	146	New firing lanyard.
6	12	
13	28	
25	57	
		Visit of inspector, tube in good condition.
Feb. 4	115	Sent to park, slight imprint. Wear + 1. Position of cone 12.5. Sent back to battery.
6		
8		

(1) Number engraved on top of breech hoop.

(2) Number stamped on rear end of tube on the inside.

Example of record of gun with variable charge.

Caliber "155 m/m. Howitzer"
Gun No. "4783".

Model "1917 Schneider"
Tube No. "1407 Creusot"

DATE.	NO. ROUNDS FIRED.	REMARKS AND CHARGE NUMBERS.
Aug. 3	22 13 5	Charge 3. " 2. " 00. New obturator.

CHAPTER II.

GENERAL PRINCIPLES APPLYING TO ALL TYPES OF MATERIEL.

ART. I.

BORES.

An inspection of the bore is best made by diffused light reflected into one end of the bore by means of a white paper reflector properly inclined. The bore is examined from the opposite end. In this manner, inspect the bore from each end.

In order more thoroughly to examine some injury detected in the bore, this injury may be more directly illuminated by means of a short length of candle introduced into the bore on the end of a narrow lath. In gun parks, a special lighting apparatus is furnished for this purpose. The use of such direct lighting is not advisable at the beginning of the inspection, as it dazzles the eye and may cause minor blemishes and injuries to be overlooked.

The diameter of the bore at any part may be obtained

with precision by the use of the star gauge. The method by which this is done is described in Ordnance pamphlets.

A certain portion of the bore may be examined by means of gutta-percha impressions. The gutta-percha is warmed in a water-bath, carefully kneaded and applied on a wooden block and the outer surface covered with graphite. A second wooden block is set in front of the former and a wedge forced between the two blocks so as to press the gutta-percha against the side to be examined. After 40 or 50 minutes the impression is cold and can be removed.

The increase of diameter, expressed in tenths of millimeters is written down under the heading of wear, in the record books. If it is over 5 for the 75 or 10 for the 155, the percentage of abnormal shots and the dispersion increase rapidly and the materiel should be submitted for reclassification.

The wear may also be seen from the progressive wearing away of the slope, so that a projectile placed in its loading position must be pushed into the bore farther and farther.

Experiments with the 155 G, 1877 Model, demonstrated that the loss in range, expressed in hundredths of the range was equal to half of the advance of the projectile expressed in millimeters.

A record of the wear and of the progressive difference in seating of the projectile should be noted in the gun book.

The first effect of wear in the action of a gun appears first in the form of a decrease in range. This is not serious, since fire for adjustment permits range errors to be taken into account. As the wear increases, abnormal shots occur and take place more and more frequently as the wear progresses, and finally the dispersion becomes greater than is permissible. The permissible limit in this connection is usually taken as 8 probable errors of the range tables, and when this is reached, the gun is put out of service unless the situation demands its continued use despite the inaccuracy of its fire.

Let us examine the principal causes of wear and injury to the tube.

Erosion and wear of lands at their origin.

Erosion consists of the wearing away of the surface of the bore and generally appears first at the forcing slope at the beginning of the rifling, particularly in the corners where the grooves and lands meet.

The injury done to the forcing slope may cause differences in the seating of projectiles with consequent loss of precision in fire. The lands of the rifling may also be eroded away. When this is great, the rotating band may not be sufficiently

engaged to secure rotation of the projectile. When this condition arises with a gun it should be considered unserviceable.

Erosion is due to the following causes :

1) The friction of the rotating band against the sides to the bore.

2) Heat. The temperature of explosion is from 3000 to 5000 degrees and the incandescent gases in contact with the bore liquefy a thin film of metal and subject the inner part of the tube to violent expansions and contractions. A part of this film is washed away by each shot and the surface of the bore is hardened by contact with the incandescent gas containing carbon. Small fissures appear first, particularly at the junctions of the lands and grooves and these become deeper with each shot.

3) The mechanical action of the gases. The latter, under enormous pressure, form eddies at the beginning of the rifling and due to their heat and high velocity sweep away a thin film of steel. This action is increased due to the expansion of the tube which increases and allows the gases to rush out between the walls of the bore and the projectile.

4) The chemical action of the gases more or less corrosive according to the composition of the powders.

For given guns and powders, erosion depends upon the condition of the surfaces in contact, the temperature of explosion, and the velocity of the projectile. It is kept down by keeping the gun as cool as possible, by washing and greasing the bore frequently, by using reduced charges whenever possible and by firing slowly.

A full pail of water should be kept near each piece, and whenever fire is suspended, even for a few seconds, the bore of the gun should be washed and greased. Too much grease should not be used however as it produces smoke which might betray the position of the battery. When time permits, at suspensions of fire and in any event when firing is discontinued for the day, the breechblock is dismantled, cleaned and oiled.

It is usually sufficient to wash and oil the bore only to a distance from the breech of 0.40 m. to 0.60 m. in the case of the 75 m/m gun and the 155 m/m II. and of from 1.50 to 2 m. in the case of the 155 m/m G. P. F. The best practice is to wash and grease the bore after each round and in any case it should be done after at least every four rounds, particularly when firing with full charges. It is also desirable to rest each gun by firing pieces alternately or by firing with 3 pieces at the same time, the fourth one being allowed to rest.

In general, at least 5 minutes' rest should be allowed after 20 shots for the 155 H. and after 100 shots for the 75 m/m gun. The rotating band should be greased particularly at its front edge. The grease used must be pure and be free from water. It is kept in waterproof boxes. The rammers, spongers and brushes must be clean.

It is desirable to use full charges only when the range or nature of the objectives makes it necessary.

Lastly, the rounds will be fired as slowly as possible. With the 155 H. not more than 2 rounds per minute should be fired. With the 75 gun, the rate of fire should not be faster than 6 rounds per minute, and this rate should not be maintained longer than 5 minutes. The 75 gun should not fire more than 100 rounds per hour.

Copper fouling.

Copper fouling is the deposit, in the bore, of copper from the rotating band. It occurs all along the rifled part of the bore and is most pronounced at the muzzle and at the beginning of the rifling. At the muzzle it is a superficial sediment of red copper, and is of little importance. The fouling at the beginning of the rifling has, on the contrary, a considerable importance as concerns the precision of fire and modification of the bore of the gun. The copper fouling mingled with powder residue tends to fill up the grooves and more copper is displaced in engraving the rotating band. This increases the resistance to the movement of the projectile and results in a greater or less increase of the pressure due to the replacement of too much copper from the rotating band. Further, the obturation farther along in the bore is not complete. This decreases the pressure and helps to increase the erosion and diminishes the accuracy of fire. Also the rotating band may not have sufficient engagement with the rifling to insure full rotation and, especially at long ranges, the projectile may tumble in the latter part of the trajectory.

This would cause the projectile to fall short. The greater the fouling, the greater is this effect.

Also copper fouling, by increasing the roughness of the interior of the bore, facilitates the heating and wear of the bore by erosion.

Fouling is ascribed to the following causes :

- 1) Mechanical action : The friction of the rotating band against the interior of the bore.
- 2) Physical action. The heat may be sufficient to melt

copper particles which are thrown violently against the walls of the bore and brazed to its surface.

3) Electro-chemical action. The electric couple of iron and copper increases the deposit of copper, directly or by electrolytic action due to acids contained in grease or released from the nitrocellulose powder. It has been observed that copper fouling varies with the nature of the charge.

In a given gun, copper fouling depends upon :

1) The condition of the bore and rotating band, being greatest when they are rough, dirty and not lubricated.

2) The muzzle velocity and the weight of the projectile.

3) The temperature of the gun being greatest when the gun is very hot.

Thus the precautions necessary to prevent excessive erosion are also effective in preventing excessive copper fouling. Greasing the rotating bands with graphite grease has given very satisfactory results.

These preventive measures are sufficient to avoid excessive fouling in guns of low muzzle velocity, like the 155 H. They serve only to delay it in the 75 gun and 155 G.P.F. When excessive copper fouling takes place steps should be taken to remove it immediately.

The use of any chemical means such as ammonia solution to remove copper fouling is absolutely forbidden, as this solution roughens the bore. Copper fouling is best removed by using an alloy of 60 parts of tin and 40 parts of lead. A certain quantity of this alloy is put inside the cartridge case (when using fixed ammunition), inside the charge bag, or on the base of the projectile. At the high temperature of combustion of the propelling charge, this alloy forms a fusible bronze with the copper deposit which is removed by the following shots.

This alloy is also used as a preventive against copper fouling. Consequently this alloy should be put inside all cartridge cases and charges used in guns. No copper fouling has ever appeared in howitzers when these have been properly cared for. Regulations concerning the use of these special cartridges or charge bags are to be issued. When this alloy is universally used, the use of grease for the projectile and the bore will be unnecessary, as the lead contained in the alloy will serve as a lubricator.

These cartridges and charge bags will be distinguished by the mark "A—n" printed below the present regulation marks, "n" represents the number of grams of alloy contained in the charge, "A" stands for the word "alloy".

The quantities of alloy used in these special cartridges, will be the following :

CALIBER.	WEIGHT PER CHARGE.
75 H. E. shell, with plate soldered on the base.....	1 gr.
Other projectiles	2 —
155 G. P. F.	20 —

To remove copper fouling the quantities of alloy to be used for each caliber can be given only approximately. They depend essentially upon the degree of fouling of the bore, the greater or lesser roughening of the surface of the bore, etc.

The following figures represent the maximum quantities not to be exceeded until further orders are given.

CALIBER.	WEIGHT PER CHARGE.
75.....	10 gr.
155 G. P. F.	50 —

Directions for use.

For removing copper fouling from a 75 gun, cartridges containing 10 grams of alloy, are issued to the batteries by the inspectors of artillery materiel in the field.

For guns of other calibers, the quantities suitable for each charge will be prepared in the following way :

The alloy is issued to the armies in the form of ribbons of 25 to 35 m/m wide, rolled up in packets of 20 grams. One or several ribbons of 20 grams or parts of these ribbons will be used. It is not necessary to make up the weight for each charge exactly; it will be sufficient to distribute over ten charges, for instance, the total weight to be used.

EXAMPLES :

For a charge of 155 G.P.F., use 2 1/2 packets of 20 grams each. Unroll entirely the ribbons constituting the quantity to be used for one charge, crumple this quantity of ribbon without crushing it, so as to shape it according to the size of the opening of the charge bag. Then place it at the top of the charge bag, so that it may be quite close to the base of the projectile when firing. Tie up the bag.

Number of rounds to be fired. Rate of fire.

Warm the piece by firing a dozen rounds, with charges without alloy, at a rather quick rate, go on firing at the same

rate with charges containing alloy, without allowing the piece to cool.

20 to 40 rounds are generally necessary for removing copper fouling from a bore of average wear and fouling.

A thorough cleaning is difficult to obtain if the surface of the bore is very rough, and copper fouling very serious.

During fire with charges containing the alloy, the piece, projectiles and rotating bands should *not* be greased.

After firing, or at the end of the day, the piece should be cleaned by the usual methods.

No attention should be paid to the yellowish or greyish tint that the bore may assume in certain cases.

Foreign bodies. — The presence of foreign bodies of any sort in the bore of the gun when it is fired is very dangerous and may cause the projectile to burst inside the bore. If the projectile clears such a foreign body without bursting, the fuse not having acted, such a body will produce in the bore scars (matages) and blemishes which may not impair the usefulness of the gun but which, nevertheless, must be avoided.

Cleanliness of the *projectiles* is the surest safeguard against accidents of this character. Consequently, thoroughly clean every projectile before it is fired and make sure that the projectiles do not come in contact with the ground either in dugouts or during handling.

Before loading the gun, it is necessary to make sure that no foreign bodies, such as cartridge case remnants, half burnt powder grains, etc., are in the bore. During night fire, use the sponge.

Splinters from enemy projectiles. — When enemy projectiles have burst near a gun, it is absolutely necessary to make sure that no splinter has struck the tube. Should a splinter cause a slight blemish to the muzzle, it may often be smoothed with a file. But should a shock outside the tube produce, as frequently happens, an *inward protrusion of the metal*, it is necessary immediately to cease fire and to send the gun to the rear for repairs. Should fire be continued, the gun would surely be rendered unserviceable owing to either a premature burst of the projectile in the bore or deformation of the tube. If the gun is immediately sent to the rear, however, it can easily be repaired at the factory and rendered fit for a further long period of service, provided it is not otherwise damaged.

Swells and bursts. — Swells and bursts, not caused by the presence of foreign bodies in the bore at the moment of fire, are due either to abnormal pressures or to defective ammunition.

1. To avoid *abnormal pressures*, only one alteration of charges is permissible, i. e., the removal of the quantity of powder necessary to pass from a given charge to a reduced one. *Other alterations are strictly prohibited* because charges are made of a mixture carefully weighed to obtain the desired muzzle velocity and the pressure the gun can bear. Powder remaining from charges which have been reduced must not be used to prepare new charges in the battery itself, but must be sent to the rear.

2. Ammunition is very sensitive to bad weather, and at the front it is exposed to it. Within a few months great changes may take place in its condition and therefore it is better not to have a larger amount of ammunition at the battery position than is necessary. Use first the older lots and replace them methodically (1). Ammunition should be sent to the front in the order of its manufacture.

Stored ammunition must be protected, not only against dampness, but also against too great a heat. In summer it is necessary to prevent sunlight from falling directly on it; therefore it must be covered with tarpaulins and boughs allowing air to move through freely.

Black metal boxes, especially, absorb a great quantity of heat if not well sheltered. The decomposition of powder may easily be detected, both by the swelling of the sides of the metal boxes, and by a characteristic odor which is detected when the box is opened.

It is strictly prohibited to load guns in advance. It is also strictly forbidden to load them for future fire at the end of a quick fire which has heated the guns.

Swelling may result also from the inflammation of the explosive charge by the flame from the propelling charge due to fissures or pipes in the base of the projectile. To avoid this accident, a copper or tin plate is welded on the base of the projectile.

The ignition of the bursting charge causes the pressure to be greatly increased and this pressure may swell or burst the tube. The explosives used for filling shells do not as a rule detonate when ignited but burn with a low order of explosion. If the detonating fuse functions, the explosion would be of a high order and the tube would almost certainly be ruptured.

Small swellings in the tube do not put a gun out of service, and fire may be continued. If they are pronounced, they are dangerous, as the projectile, meeting with less resistance

(1) In exceptional cases, this rule may be varied from. For instance, if during a period of damp weather, powder packed in wooden boxes not lined with metal is received, such powder must be used before that which has been forwarded in metal boxes.

and being insufficiently guided along a portion of its course through the tube, may strike against the lands and burst in the bore.

In case of doubt as to the advisability of firing a gun exhibiting a slight swell in the tube, consult the gun inspector.

ART. II.

BREECHES AND OBTURATORS.

Breeches should be dismantled cleaned, and greased daily. If this is done, any difficulties in their operation, and injuries which may occur to them can be avoided or remedied.

Any roughness of the threads, which might cause jams, must be filed off. Every unsound part must be replaced at once, and if the gun is fitted with an obturator, this part must be replaced immediately, if it is seen that the obturation is not sufficient, because the exit of charge gases through the breechblock might damage it severely.

In the 75 m/m gun, the cartridge case is used as an obturator. The cartridge cases must therefore be neither slit nor deformed.

During rapid fire, the obturator in separate loading guns should be frequently cooled with water.

ART. III.

RECOIL APPARATUS AND RECUPERATORS.

The description of the recoil cylinders and recuperators is given elsewhere. They should be cared for as prescribed in the Drill Regulations. They are apt to leak and should be kept filled with the prescribed liquid, to the required amount.

The recoil mechanism of the gun is so constructed as to permit a certain length of recoil and then return the tube entirely into battery without shock.

If any irregularity is noticed during the recoil or the return into battery, it shows that the parts joining the tube to the carriage are not working properly.

These parts are :

1. **A recoil apparatus** which absorbs the force of recoil, by means of the resistance offered by a liquid in passing from A (fig. 1) into B through a narrow hole.

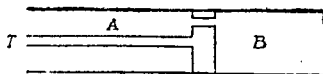


Fig. 1.

2. **A recuperator** (air cylinder for the 75 gun and the 155 H). During the recoil the recuperator absorbs a part of the force (a small part as compared with that which the recoil apparatus absorbs). The air is then compressed in C (fig. 2).

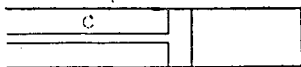


Fig. 2.

When the recoil is ended, this air expands, pushing back the piston and bringing the tube back into battery. To bring the tube back and to maintain it in the firing position, at any quadrant elevation, the air in C must have a certain initial pressure :

110 kg. per square centimeter in the 75 gun;

31 kg. — — — 155 H.

3. **A counter recoil buffer**, to limit the speed of the return, and to avoid a shock at the end. It is generally a hydraulic buffer, like the recoil apparatus, but it operates only during the return into battery.

During fire, it is necessary to watch :

1. The recoil,
2. The return in battery (counter recoil).

When they are abnormal, take the precautions prescribed by Regulations.

1. *The recoil* must be of normal length. To measure it, a special *recoil index* is placed on the gun.

When the recoil is longer than usual, it is due to the buffer not operating long enough (buffer not full enough) or the initial pressure of the return cylinder being too weak. When the recoil is too long, a torsion of the piston rod may occur, or it may even be broken because of the shock at the end of the recoil.

When the recoil is shorter than usual, it is caused by too great a resistance of the liquid in passing through the holes (dirty or thick liquid), or too high an initial pressure and an increased friction due to dirty guide-rails.

Too short a recoil may greatly damage the carriage, either through the shock caused by fire, or through the rising and falling of the carriage.

2. *Counter recoil*. — When the return into battery is not complete, it indicates that the initial pressure of the recuperator is not sufficient, or that the buffer is too full, either

on account of over filling or the heating of the liquid during fire.

The space which can be occupied by the liquid in the buffer varies on account of the volume of the piston rod. The liquid, expanded by the heat, may require a space greater than that left for it by the complete return into battery.

When the return into battery is effected with a shock, it indicates that the counter recoil buffer does not operate, or that the pressure of the recuperator is too high (this may happen on account of too great an initial pressure, or through an increase of the pressure caused by over-heating due to rapid and intense fire).

Any irregularity in the *recoil* or the *return* into battery will put the materiel out of service for a long period.

ART. IV.

GUN CARRIAGES.

The parts which need the most careful supervision are the rivets and bolts. Every loosened rivet must be reported; every unscrewed bolt must be immediately tightened. The cracks, resulting from excessive wear of the gun carriage, always appear along the lines of rivets or bolts. They are caused by either travelling or firing.

The damage done to the carriages and to the wheels by travelling may be caused by too great a speed on the march or by accidental shocks.

The greasing of the axle trunnions must be done regularly.

While firing, it is necessary to strictly observe the limits of use which have been determined for the different charges.

For example, it is forbidden to use charge 00 in the 155 Howitzer, 1917 Model, when firing at ranges less than 8000 m. because if it were used, the carriage would lack stability, and might be damaged by jumping and falling.

In general, the use of reduced charges, whenever possible, saves both carriage and tube.

Great care must be taken of the aiming and elevating mechanisms.

ART. V.

CARE OF SIGHTS.

Good care of the sights has a great influence on the precision of fire. Their adjustment must be verified frequently,

and the degree of accuracy of the various instruments of the battery studied carefully (1).

It is essential, in order to keep these instruments in good condition, that they be handled carefully. Their most important parts are made of glass and, naturally, if they are allowed to fall or strike any hard object, this glass will be shattered. These facts must be brought to the attention of the men in the battery.

Sight apparatus supports must be cleaned and oiled when necessary.

Glass surfaces must never be rubbed with fingers or gloves or anything capable of scratching them or making them dirty. To clean the glass, blow on it to remove the dust, and then wipe it with a thin, white, and soft piece of linen.

If a glass is very dirty or greasy, clean off the dirt with a piece of linen soaked in alcohol, after which, go over it with dry linen.

Avoid all shocks, which might injure or crush the planed seats, facets, and other adjusted parts of the levels and goniometers.

(1) Results obtained must be noted.

Corrections will be made when firing in order to obtain uniform results from the guns of the same battery.

PART VI

AMMUNITION.

CHAPTER I.

GENERAL CONSIDERATIONS.

I. Definitions.

Gun ammunition consists of :

- 1) *Projectiles.*
- 2) *Fuses and detonators*
- 3) *Propelling powder charges.*
- 4) *Primers.*

A round is a combination of a projectile, a fuse (and in some cases, a detonator), a powder charge, and a primer.

II. Projectiles.

Modern projectiles are hollow. Their shape is cylindrical; the top part, being ogival, is called the *ogival head*. If this ogival head is cut by a plane passing through the axis of the projectile, a section consisting of two arcs of circumference is obtained.

The plane containing the centers of these circles and perpendicular to the axis is called the *base plane of the ogival head*. The angle made by the axis of the projectile and the tangent to the ogival contour at the point B (fig. 1) is called the *ogival angle*. Except for armor piercing shells, the ogival head is truncated and the corresponding section is called the *flat*. A hole, called the *eye*, is drilled and tapped through the center of the flat coincident with the axis of the projectile.

Below the base plane of the ogival head, there is a cylindrical part called the *bourrelet*, the diameter of which is larger

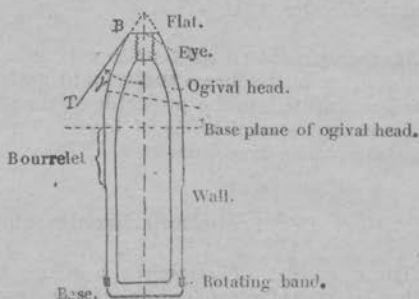


Fig. 1. — Projectile.

than that of the body of the projectile. The bourrelet diameter is only some tenths of a millimeter smaller than the gun diameter measured between *lands*; this difference of diameters is called *clearance*. The purpose of the bourrelet is to help the rotating band in centering the projectile axis in the bore of the gun.

The body of the projectile is fitted with one or several rotating bands.

The base of the projectile is cylindrical or cylindro-conical, the latter shape being better from the ballistic point of view.

Classification of projectiles. — Projectiles may be classified according to their bursting charges.

a) *H. E. Shells* are loaded with a high power explosive (for instance, melinite).

b) *Shrapnel* are loaded with balls or plates and a small bursting charge of black powder; they include *front and base charged shrapnel*, *case-shot*, etc.

c) *Special shells* are loaded with a special substance and include : *incendiary shells*, *star shells*, *tracer shells*, *gas shells*, etc.

III. Fuses and detonators.

Shells are fitted with a *fuse* and a *detonator*.

In H. E. shells with a small bursting charge as in the case of the 75 and 155, the detonator is sufficient to detonate the charge but in large caliber shells with large bursting charges, an additional amount of the detonating substance is necessary. This additional detonating substance with its container is called the *booster*.

When the detonator alone is used, it is screwed into the eye of the projectile. When the booster is used, it is screwed into the eye of the projectile and the detonator is screwed into the booster.

Shrapnel are fitted with neither boosters nor detonators, as the flame of the fuse is sufficient to ignite the black powder. The fuse is fitted on the projectile at the loading works.

There are several kinds of fuses : *Time fuses*, *percussion fuses* and *combination fuses*.

IV. Propelling powder charges.

These consist of *smokeless powder* which is contained either in *cartridge cases* or in *charge bags*. Their action is *progressive* and not sudden like that of high explosive or black powder.

V. Primers.

The propelling charge is fired by a primer. Primers are classified as percussion, friction electric, and combination electric and friction, as to method of firing, and as free or fixed depending upon whether they are used in the vent (as in the 155 S. H.) or in the cartridge case (as in the 75 G.).

CHAPTER II.

PROJECTILES.

ART. I.

GENERAL CONSTRUCTION OF PROJECTILES.

Projectiles should be so constructed as to have sufficient strength to withstand the stresses set up in them when fired. All projectiles for a particular gun and of a particular type should be as far as possible of the same weight and shape and should have rotating bands of the same hardness and area of cross section.

§ 1. Design of a projectile with a view to its resisting the stresses set up in it when fired.

It is essential to take into account the magnitude of the forces exerted on the projectile at the moment of firing. The gases of the charge exert on the base of the projectile pressures which, depending upon the gun and the powder charge employed, reach a value from 500 to 3000 kg. per sq. cm.

The amount of this pressure on the base is given by the formula $P = \frac{\pi d^2 p}{4}$ in which P is the total pressure on the base, d the diameter of the bore in cms., and p the pressure per sq. cm. The acceleration of the projectile is then.

$A = P \div \frac{w}{g} = \frac{Pg}{w} = \frac{\pi d^2 pg}{4w}$ in which A is the acceleration in cms. and w the weight of the projectile:

The force required to accelerate any element of the projectile is equal to mA in which m is the mass of the element considered.

Let ω be the weight of this elementary mass, and f the force required to accelerate it. Then $f = mA = \frac{\omega}{g} A = \omega \left(\frac{A}{g} \right)$.

$\frac{A}{g}$ is the ratio of the actual acceleration to the acceleration due to gravity and is called the coefficient of acceleration. It is then only necessary to multiply the weights of any element by the coefficient of acceleration in order to get the force transmitted to it. Bearing this in mind the magnitude of the stresses to which the various elements of the shell, fuse, and charge will be subjected can be readily determined if the acceleration is known.

NUMERICAL EXAMPLE :

When a 75 mm. projectile weighing 7.240 kg. is fired with a muzzle velocity of 535 m/s. the pressure per sq. cm. on its base will be 2400 kg. The coefficient of acceleration will then be.

$$\frac{A}{g} = \frac{\pi d^2 pg}{4 \omega g} = \frac{\pi d^2 p}{4 \omega} = \frac{\pi \times (7.5)^2 \times 2400}{4 \times 7.240} = 14,600 \text{ (approx.)}$$

Consequently the stress set up in any section of the projectile is equal to the coefficient of acceleration times the weight of that part of the projectile which is in front of the section.

Assuming that the diaphragm of the projectile under consideration supports the matrix, central tube and bullets, the

weight of which is about 3 kg. The pressure on the diaphragm due to the transmitted stress will then be:

$$3 \times 14,600 = 43,800 \text{ kg.,}$$

From the foregoing it is seen that the walls and diaphragm must have sufficient strength to withstand the great stresses produced in firing. On the other hand it is necessary to reduce the dimensions of these elements to a minimum since they constitute a dead weight.

These two opposite conditions can be met only by using high grade steel of very careful manufacture. Except in the case of armor-piercing shell, the thickness of the walls of the shell will necessarily increase gradually from the ogival head to the base, since each successive section has to withstand rapidly increasing stresses.

Safe loads for the metals employed in the manufacture of shells being much less for cast iron than for cast steel, and for the latter than forged steel, the thickness for identical calibers and total weights will decrease in the same order; the capacity of the shell, and in consequence the weight of its bursting charge will increase in the same order.

The preceding considerations show us the necessity for a very compact bursting charge, if the shell is filled with molten explosive which has left an empty space in cooling, the back layers will be thrown sharply against the forward layers on firing. The shock which results is liable to cause a premature explosion of the shell and consequently of the gun.

A similar effect is produced if a fragment of substance somewhat denser than the explosive is placed in the charge. The stress necessary to accelerate this dense portion is excessively great and the less dense explosive through which this stress is transmitted may be crushed, thus causing detonation. Charges of non-explosive materials such as sand and soft lead, have at various times caused the bursting or buckling of the body of the shell. The bursting charge of a shell, whatever its nature, presents complete security only if each section is subjected during the loading operation to a pressure at least equal to that which it will have to support at the moment of firing.

Finally, in the study of fuses, the above considerations enable one to understand how a small piece of metal weighing a few grams can compress a very strong spring and arm the fuse.

Thickness of walls. — The projectile walls must be made

thick enough to resist the stresses to which they are subjected in firing. Knowing the coefficient referred to above, it is possible to calculate the stresses corresponding to various cross sections of the projectile; the thickness of the walls is then determined by taking into account the strength of the metal used.

It stands to reason that steel walls will be thinner than semi-steel ones, and that walls made of ordinary cast-iron will be the thickest. The *dead weight* of the projectiles increases in proportion to the thickness of the walls, while the capacity of the projectile is correspondingly reduced.

As an illustration of the latter fact, the weights of explosive charges contained in 155 H.E. shells of various metals are given below. These weights are given in percentages of the total weights of the shells :

Cast-iron	5.7 o/o
Semi-steel	10.1 o/o
Steel	24.0 o/o

In loading projectiles, care must be taken to make the bursting charge compact and homogeneous, in order to avoid dangerous stresses in firing.

Design of projectiles in view of regularity of movement through the bore. — To obtain regularity of movement through the bore, it is necessary that the projectile should be properly seated in the bore, and that its geometric axis should coincide with that of the gun.

The first condition is a consequence of the fact that the initial velocity and the maximum pressure obtained with a given projectile and a given propelling charge are dependent upon the powder chamber capacity, *i. e.*, the space between the breechblock and the projectile base.

This condition is insured by the rotating band, which must come into contact with the forcing slope when the projectile is seated in position. This *seating* must be carried out very carefully. Aside from causing greater fire dispersion, a bad seating may cause very grave accidents, especially when firing at great angles. Assume that the adherence of the rotating band to the forcing slope is not sufficient to maintain the projectile in position. When the quadrant angle of elevation is increased, the projectile may fall on the powder charge from *a' b'* to *a b* (fig. 2). When the projectile is fired, it will be shot forward with a force which is increased in proportion to the greater pressure resulting

from the reduction of the powder chamber, and the rotating band will therefore strike the forcing slope violently. This

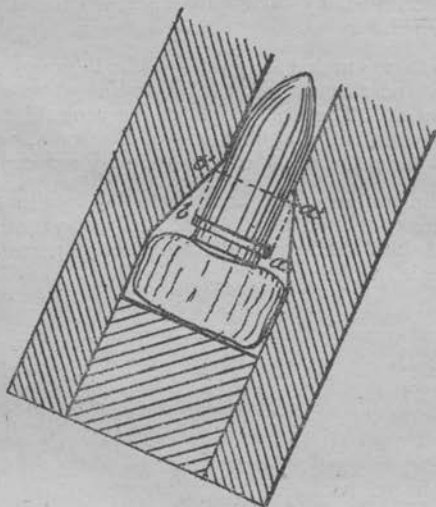


Fig. 2.

shock may cause the fuse to act on the bursting charge, but it is more likely that it would break up the explosive charge and even the projectile body, thereby causing a premature burst.

Even if the foregoing grave accidents did not happen, the rotating band might be sheared off and, instead of meshing with the grooves, might slide along the lands. The projectile, having no speed of rotation about its longitudinal axis, would tumble. Consequently it would fall at a distance which might be less than half the normal range.

An example may be given in this respect. During tests made with a 400 m/m mortar, with a projectile insufficiently seated, it was observed that there were no grooves on the rotating band, the maximum pressure was increased from 1800 to 2100 kgs. per sq. cm., the range was reduced from 11000 to 5000 meters, and the projectile body was split along a portion of its length.

The projectile tumbled during its flight and a very strong hissing sound was produced.

If such an accident were to happen with an H.E. shell, it would cause a complete destruction of the materiel. It is therefore necessary to thoroughly train the personnel with dummy shells so that accurate seating shall be insured.

It must be noted that the ramming requires an effort increasing with the caliber, because the adherence of the rotating band to the forcing slope is proportional to the length of the band, *i. e.*, to the caliber of the projectile; whereas the weight of the projectile, which has a tendency to make it fall on the propelling charge, is proportional to the cube of the caliber.

Measurements carried out at Gavres in 1916 have shown that when a 240 m/m shell is accurately seated, the rotating band adherence is about 2500 kg., that is to say, the extraction of the projectile requires a static effort of 2500 kg.

In practice, the seating can be considered as good if, in order to extract the projectile, it is necessary to strike the ogival head several times with a hollow-headed rammer.

For the projectile axis to coincide with that of the gun throughout the bore, it is necessary that the projectile should be centered in front and rear (this being obtained by means of the bourrelet and rotating band), and that the center of gravity of the projectile should be on its geometric axis.

If the latter condition is not complied with, the center of gravity will have a tendency to follow a spiral (fig. 3) of equal pitch to that of the grooves, the corresponding cylinder having a radius equal to the eccentricity e (distance between the center of gravity and the axis). The projectile will then strike against the lands which will stamp marks on the projectile body. Moreover, the initial direction of the projectile will be at an angle with the gun axis.

This phenomenon would become greater if the bourrelet clearance were to increase. It may even cause the fuse to act and produce a premature burst.

Rotating band. — The rotating band helps in centering the projectile, determines its seating in the bore and insures its rotation.

The outside diameter of the rotating band is slightly greater than that of the bore measured between groove bottoms. This difference is called *forcing*, and varies from some tenths of 1 m/m to 2 or 3 m/m.

The rotating band is made of a metal easily cut by the lands

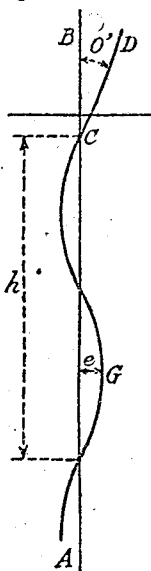


Fig. 3.

without wearing them and of sufficient strength to prevent its being torn off. Copper is generally used for these reasons.

It is the reaction of the groove flanks against those cut in the rotating band which insures the rotation of the projectile (fig. 4). But by inertia, the latter offers a resistance which is proportional to :

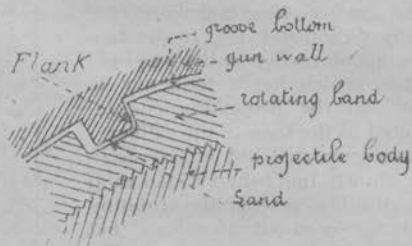


Fig. 4.

1. The projectile's weight ($M K^2$),
2. The rotational acceleration.

If the depth of the grooves cut in the rotating band is too small (fig. 5), the resistance of these grooves will not be

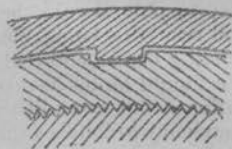


Fig. 5.

sufficient; the band will be torn off, and there will be no rotation.]

This is what happens with an old gun. With the 75, the wear may come to a point when shrapnel will not be rotated whereas shell will still rotate on account of their smaller moment of inertia ($M K^2$).

In order that the rotation of the band should cause the projectile to rotate, it is necessary that its adherence be sufficient. The rotating band is therefore pressed in a groove of

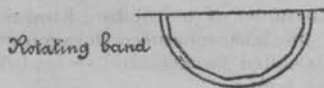


Fig. 6.

the dove-tail type. The depth of this groove is reduced as much as possible so that the projectile body may not be weakened too much. There are sometimes longitudinal and transversal corrugations on the groove surface in which the copper is jammed (fig. 7).

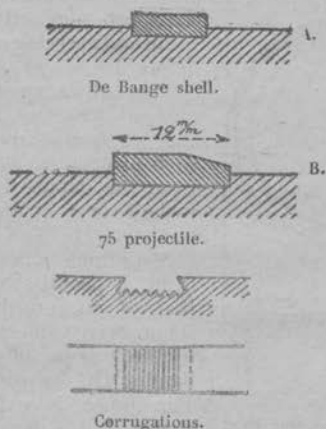


Fig. 7.

The cross section of the rotating band is such that the forcing and the bearing surface will be sufficient.

Usually the rotating band is thinner in front than in rear so that there will not be a sudden shock when it comes in contact with the lands in ramming or in firing (fig. 7 B).

Some rotating bands have a groove in which the metal cut by the lands lodges (fig. 8).

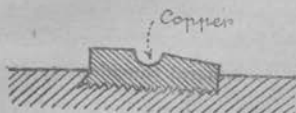


Fig. 8. — 155 m/m D shell.

Many projectiles have two or three bands (fig. 9) in order to obtain more accurate centering, this being only possible when the groove pitch is constant.



Fig. 9. — Navy shell.

The resistance offered by the forcing is essentially dependent on the state of the gun, and varies between 200 and 300 kg. per square cm. for a new gun. It is about 10 tons for the 75 shell.

The foregoing explanations show the importance of the protection of rotating bands during transportation and the inspection, filing and greasing of rotating bands before fire.

The adjoining sketch shows a type of rotating band protector (fig. 10) consisting of a rope. If such protectors cannot be obtained from the depot, it is necessary to make some with straw, hay, briar, etc.

Sometimes when a projectile is fired, a peculiar noise, similar to that of an intermittent outlet of steam occurs and is often attributed to the tearing off of the rotating band. The reason for this peculiar noise is explained in Ballistics, but it is certainly not due to the tearing off of the band, as experiments have shown.

The tearing off of rotating bands is extremely rare. When it occurs it always leads to considerable reduction of range.

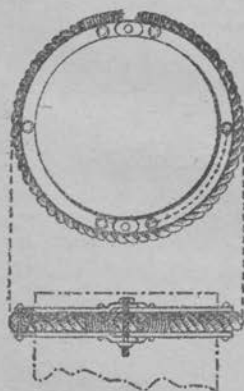


Fig. 10. — Rotating band protector of the Lardin type for 155 shell.

ART. II.

H. E. SHELLS.

A. General considerations.

H. E. shells are made of either semi-steel or steel and are loaded with an explosive which may be melted or pressed into the shell.

A booster is screwed into the eye of the projectile at the loading works. It contains a melinite train.

A detonating fuse is screwed into the booster just before firing.

Semi-steel H. E. shells. — Semi-steel is obtained by purifying ordinary cast-iron in a special furnace. It contains from 2.75 to 3.25 o/o of carbon and is much more resistant than ordinary cast-iron although less resistant than steel.

It is used extensively on account of its lower cost and easier manufacture.

Semi-steel H. E. shells are moulded in one piece and machined all over; the eye is tapped and a groove is cut for the rotating band.

The shells are tested under a hydraulic pressure of 400 kg. per sq. cm. for strength to resist bursting and for gas-tightness.

Steel H. E. shells. — The steel is cut into billets, stamped, drawn out and forged in one piece; it is then water-hardened, annealed and tested by means of hydraulic pressure. The latter is equal to 1400 kg. per sq. cm. for a 75 shell.

If, as a result of the test, the diameter of the shell has increased over a certain limit, the shell is rejected. It is also rejected if water percolates through cracks at the base. A plate made of copper or tinned iron is welded to the base in order to prevent the propelling gases from getting inside the shell through pores in the base and igniting the explosive.

The walls of shells are generally varnished or tinned inside owing to the chemical action of some explosives on semi steel and steel.

B. Loading of H. E. shells.

The projectile body is then loaded with an explosive which must be powerful and at the same time not sensitive to shocks.

Explosives in use. — They may be classified as follows.

A) **Nitrogen explosives** proper obtained by action of nitric acid on hydrocarbons derived from coal-tar products or their derivatives. The most important are melinite D, cresylite No 2, melinite O, cresylite No 1, troto, and tetryl.

Melinite D or picric acid, called lyddite by the British, is obtained by the action of nitric acid on phenol and appears in the form of fine, straw-colored crystals. It detonates relatively easily and has an acid action on metals. In a pulverized state, it is used as an *intermediate detonator*.

Cresylite No. 2 is pure cresylite obtained by the action of nitric acid on cresol and appears in small amorphous fragments. It is easily loaded by pressure, has an acid action on metals and requires an intermediate detonator of pulverized melinite D to insure its detonation.

Melinite O is obtained by mixing a large percentage of melinite D and a small percentage of cresylite No. 2. It

appears in fine crystals. It also requires melinite D as an intermediate detonator.

Cresylite No. 1 is a mixture of a small percentage of melinite D and a large percentage of cresylite No. 2. It is in the form either of amorphous lumps or dust mixed with grains.

Trotol or T. N. T. (trinitro-toluene) is obtained by the action of nitric acid on toluene. It is in the form of either small amorphous fragments or small white crystals.

It has no *acid action* on metals and does not require an intermediate detonator even though it is less sensitive to shocks than melinite D.

Tetryl is obtained by the nitration of a methylaniline. It appears in the form of a very fine powder, light yellow in color. It is sensitive to shock, blow or pressure, and should be handled with extreme care. Its principal use is as an intermediate detonator (booster charge), in the shells manufactured in the States.

The nitrogen explosives may be used either pure or mixed with one another or with some other substance so as to make the loading easier, safer or more economical.

All the nitrogen explosives give out on detonation *black smoke* (carbon) which is more or less visible according to the background.

B) **Crystallized salts or a mixture of salts.** — Of these the most used are amatol and sodatol but schneiderite, ammonium perchlorate and ammonium picrate are also used.

Schneiderite is a mixture of 87.5 o/o of ammonium nitrate and 12.5 o/o dinitronaphthaline.

It is an amorphous, yellow powder and has an acid action on metals, except lead or tin.

It is either pressed in the shell and provided with a core of melted trotol (S. C. P. T. : Schneiderite compressed with a press and provided with a core of trotol) or poured in as small grains, the interstices being filled with melted trotol (S. T. F. : schneiderite with a core of melted trotol).

It gives a white smoke when the shell bursts, owing to phosphorus having been mixed with it.

Ammonium perchlorate is used in the A. L. 75 shell and has an intermediate detonator of trotol.

It gives a white smoke when the shell bursts.

Ammonium picrate, called explosive D in the States, is a fine crystalline powder, clear orange in color. It is neutral, insensitive to shock, friction or pressure. It is largely used in the States for the filling of large caliber shells, especially armor piercing shells.

When detonating under good conditions, it gives a black smoke with carbon deposit and an ammonia smell.

Amatol. — Is a mixture of ammonium nitrate and of tolite, in varying proportions. It is to be used as the bursting charge of the shells now being manufactured in the States. It is also used in French ammunition, where it is known as nitrate tolite (N. T.).

Sodatol. — Is a mixture of sodium nitrate and tolite. It will also be largely used in the States for the filling of shells.

Process of loading explosives. — The explosive can be either pressed into the shell or melted and poured in.

Melting the explosive is easily and quickly done and does not require a costly outfit. On the other hand cavities may be formed in cooling in the case of some explosives which might lead to a break-up of the charge and a premature burst, as previously explained.

Pressing the explosive consists of packing the charge first with a mallet, after which a steel bar is forced into the explosive by means of a powerful hydraulic press (fig. 11). The density of the charge is thus increased and a hole is formed which is filled by the addition of melted or pressed explosive.



Fig. 11.

The process has the advantage of making the bursting charge very compact, thus preventing a settling of the explosive by inertia. Its disadvantage lies in the use of costly presses in isolated buildings, the walls of which must be very thick (several meters for big shells) on account of possible explosions during loading.

There is a limit of density for explosives above which they detonate incompletely or not at all.

Marks relating to explosives (French system) :

C ₂	Cresylite No. 2.
M D or D ...	Melinite D.
M O or O....	Melinite O.
T.....	Trotol.
N T.....	Ammonium nitrate and trotol.
S.....	Schneiderite.
M D N.....	Melinite and dinitronaphtaline.
M M M.....	Melinite and mononitronaphtaline.
D D.....	Melinite and dinitrophenol.
M T T C.....	Melinite, trotol, trinitrocresol.
M D P C.....	Melinite, dinitrophenol, trinitrocresol.
A M S.....	Pressed ammonal.
P.....	Ammonium perchlorate.
A M L.....	Melted ammonal.
X.....	Xylite or trinitroxylene.
N X.....	Ammonium nitrate and xylite.

The following marks relating to explosives are used for the shells manufactured in the States :

A. M. (n/n^1) [1]

Amatol.

A. C.

Melted tolite.

The other marks have not yet been given.

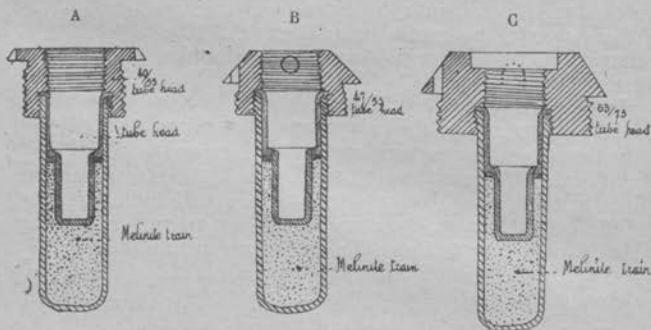
C. Boosters. — Adapters.

The loading of the H. E. shell being completed, the shell is immediately closed by screwing a booster into the eye.

A booster tube consists of three parts.

There are two kinds of boosters :

1. Boosters consisting of a simple steel tube and used in connection with fuses and detonators fitted separately.



Boosters for detonating fuse 1915 Model.

Fig. 12.

2. Boosters used in connection with detonating fuses, where the fuse and parts of the detonator are fitted together.

Boosters of the second type are used in connection with the 24-31 detonating fuses. They consist of three parts :

a) A tube body made of steel which is varnished inside and contains a powder train of pressed pulverized melinite ;

(1) The numerator of the fraction represents the percentage of ammonium nitrate and the denominator that of tolite.

b) A tinned tube plug made of brass and steel, which is driven into the powder train ;

c) A tube head made of steel which assembles body and plug, and permits the fitting of the complete booster into the projectile eye.

The various types of this kind of booster are shown by the adjoining sketches (fig. 12). They only differ in the dimensions of the head.

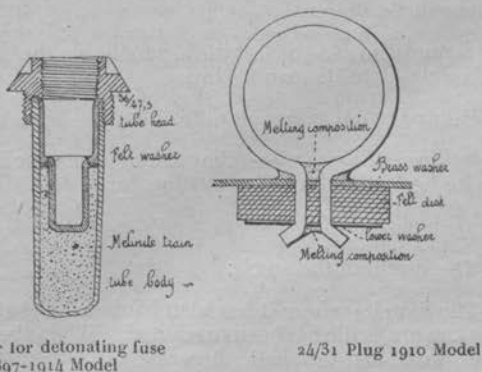


Fig. 13.

As soon as a booster is screwed into a projectile eye, a locking pin is driven into the hole provided so as to lock the booster to the projectile and a brass plug with a felt washer screwed into the hole in the booster. This plug is of the 24/31 1910 Model ; it must not be removed until the shell is about to be loaded into the gun.

The seating of boosters is done by specialists at the loading works.

If, by accident, a booster is unscrewed, it is strictly forbidden to try to screw it back or to unscrew it completely, as this might cause the bursting of the shell owing to the friction of explosive particles between the booster thread and that of the projectile eye.

If the booster is unscrewed, the shell must not be fired because the booster would be screwed back by inertia. A premature burst would be even more likely to occur than in the former case on account of the speed with which the booster would rotate.

Shells with the unscrewed booster should be destroyed as soon as possible.

Some big shells have an eye the diameter of which is too large for the booster to be directly screwed into it. In this case, an *adapter* is fitted between the eye and the booster.

D. Marks on H. E. shells.

1. ALL SHELLS EXCEPT 75 M/M SHELLS.

These shells bear :

a) Stamped marks made with a punch on the projectile body, referring to its manufacture ;

b) Painted marks referring to loading.

a) **Stamped marks.** — They are on one line and generally to be found above the rotating band.

They indicate :

1. The origin of the steel ;

2. The foundry where it has been hardened and the works where the projectile has been machined. When the foundry has also machined the shell, there is, of course, only one mark ;

3. The series number and the year.

The letter B placed after the series number means Bessemer steel. Example : fig. 14.

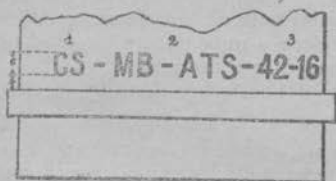


Fig. 14.

1. The steel comes from Le Creusot ;

2. The machining has been carried out at Montbard and also at the " Atelier de construction de Tarbes " ;

3. The shell series is number 42 and was manufactured in 1916.

(These marks are covered by paint which must be scratched off if the marks are to be seen.)

b) Painted marks. — Generally speaking, they refer to loading.

Besides these marks, some shells bear special marks.

H. E. shells special to a particular gun. — Some 155 m/m. steel shells which can only be fired in the 155 Howitzer (except Schneider) bear the white mark *canon court*, which is repeated three times around the cylindrical part of the projectile body.

H. E. shells made of Bessemer steel. — The letter “B” (fig. 15) is painted in white on the cylindrical part of

STEEL SHELLS (1).

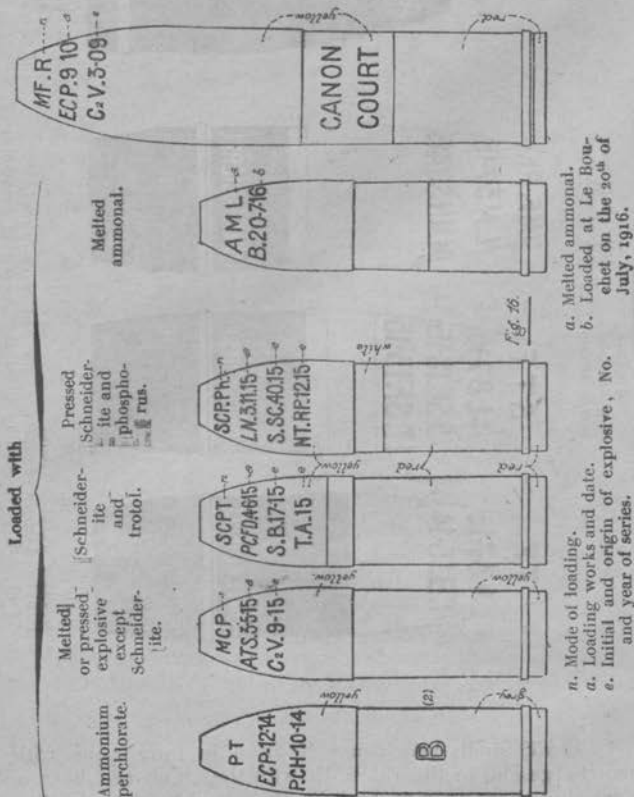


Fig. 15.

(1) Shells assembled to cartridge cases are not painted below the rotating band.

the projectile body at both ends of a diameter. If the letter "B" is larger than 25 mm in height, Bessemer acid steel is indicated.

Semi-steel shells. — The mark "fonte aciérée" is painted above the rotating band (fig. 16).

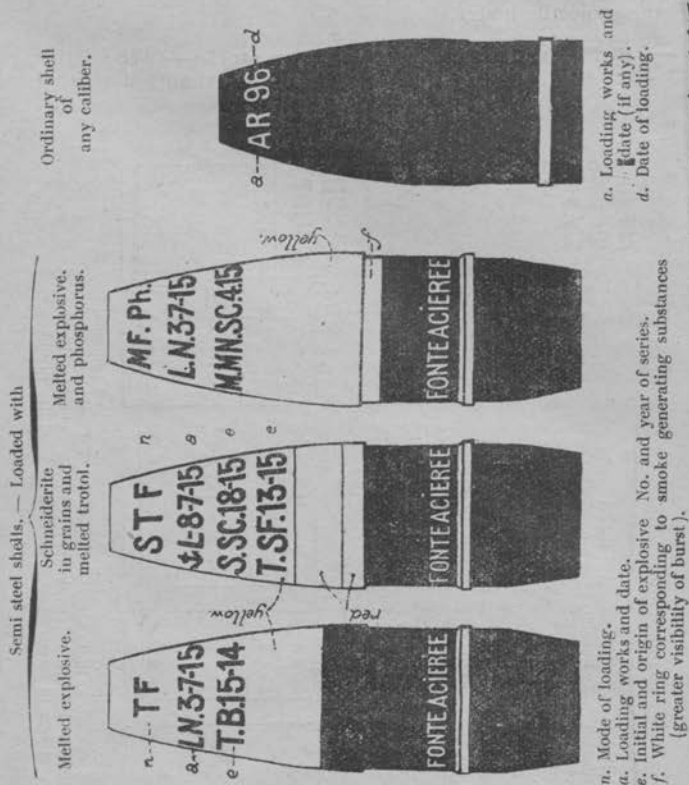


Fig. 16.

F. A. 155 shells which may be fired in long guns with 000 charge and in the 155 S. H. with the 00 charge have a black ring about 10 mm. high on the ogival head under the loading marks.

Shells fitted with fuses at the loading works. — Sometimes, in exceptional cases, very big shells are fitted with

fuses at the loading works. In such a case, the shell is painted black between the upper flat of the booster and the loading marks (fig. 17). The lower edge of the band thus

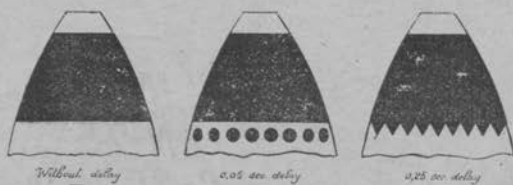


Fig. 17.

formed is straight for fuses without delay, bordered with small black circles for short delay (0.05 sec.), and indented for a long delay (0.25 sec.).

Weight marks. — Shells of 270 m/m. or smaller caliber are classified in series according to their weight after loading.

The mean weight of a series is painted in white on the projectile body for shells up to 190 m/m. in caliber, and on the ogival head for shells of greater caliber than 190 m/m.

2. MARKS SPECIAL TO 75 H. E. SHELLS

1. *Shells originating from Etablissements de l'Artillerie* (State Works), shells of the 1900 Model.

a) **Stamped marks.** — These are to be found on the cylindrical part as shown by adjoining sketch. They indicate (fig. 18):

1. Origin of the steel ;
2. Foundry where the projectile was hardened and the works where it was machined ;
3. Number of series and year of manufacture ;
4. Shell type.

b. **Painted black marks on ogival head** (fig. 19). —

1. Method of loading ;
2. Loading works ;

3. Day, month and year of loading ;
4. Kind of explosive ;
5. Origin of explosive ;



Fig. 18.



Fig. 19.

6. Number and year of explosive series ;
7. Monobloc shell of "Etablissements de l'Artillerie".

c) **Painted marks above rotating band.** — One L or small black crosses give information as to the weight of the shell :

L	= Very light ;
+	= Light ;
++	= Normal
+++	= Heavy ;
++++	= Very heavy.

These marks are also to be found on the boxes.

A white cross near the stamped marks means that a plate has been welded on the shell base. This cross is also painted on the boxes.

2. *H. E. shells originating from private works, [1914, and 1915 shells (fig. 20).*

a) **Stamped marks.** — In column, above rotating band, as shown on sketch :

1. Type of shell ;
2. Origin of steel ;
3. Foundry and works ;
4. Series number and year.

b) **Painted marks.** — Numbers (1) to (6) (fig. 21) are the same as for shells originating from State Works.



Fig. 20.

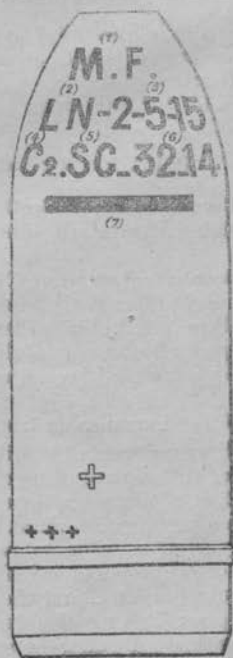


Fig. 21.

One black line (—) means monobloc shell from private works. Two black lines (==) mean : screwed ogival head (now abandoned).



Fig. 22.

c) **Painted marks above rotating band.** — The same as for shells originating from State Works.

3. *H. E. shells made of Bessemer steel.* (Fig. 22).

Stamped marks and black ones as already mentioned but in addition :

a) **Stamped marks.** — The series number is followed by letter B.

b) **White marks.** — On the cylindrical part there are two "B's" 5 cm. high at each end of a diameter.

Marks on H. E. shells (American system).

The rules followed by the U. S. Ordnance Department for the marking of shells are similar to those followed in the French Army.

They are the following :

Paint for the exterior of projectiles.

a) **Common steel shell.** — Common steel shell filled with high explosive are painted yellow.

b) **Semi-steel shell.** — The color to indicate the character of the shell filler is the same as for "Common steel shell", *i. e.*, yellow. To indicate that the shell is semi-steel, the part of the projectile in rear of the bourrelet is painted black.

Markings on shell are either stamped or stencilled markings.

The following rules are applied :

1. All components of artillery ammunition are given lot numbers at the place of manufacture. The lot number and the initials of the manufacturer are stamped on the component in a conspicuous place.

Every effort is made to insure that the entire number in any lot of a component are uniform throughout as to method of manufacture etc... and therefore it may be expected that results given by one of a lot will be duplicated to a great extent with all others of the same lot.

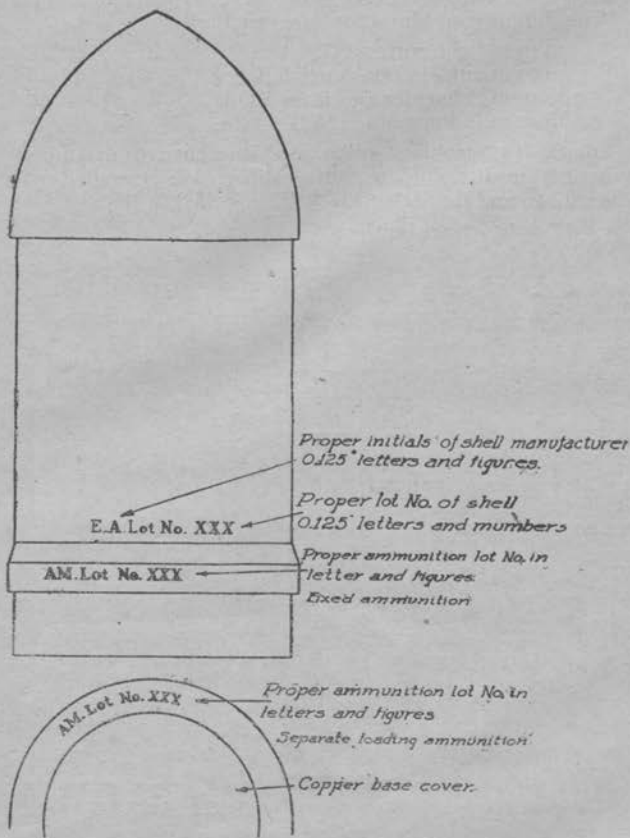
2. In addition to the lot numbers assigned to the various components, assembled rounds of all types of ammunition,

the essential components of which are packed together, are given what is termed "ammunition lot numbers".

This means that all rounds of ammunition bearing a given lot number contain the same lot of smokeless powder. In the case of loaded projectiles which are packed separately from the other components, a similar ammunition lot number is given to the loaded projectiles.

Stamped marks.

a) **Shell data.** — The lot number and initials of the manufacturer are stamped on the body of the shell in 1/8 inch letters and figures immediately above the rotating band. (See fig. 23.)



b) **Ammunition lot number.** — In the case of fixed ammunition, the ammunition lot number is stamped on the rotating band, in 1/8 inch letters and figures. (See fig. 23.)

In the case of separate loading ammunition, the loaded projectile ammunition lot number is stamped on the base in 1/8 inch figures and letters.

Stencilled markings.

a) **Colors.** — The stencilling is done with paint of the following colors: black on yellow or white back ground, white on black, blue or red background.

b) **Indication of caliber.** — The caliber of the gun or howitzer is stencilled on the part of the body of the shell corresponding to its center of gravity. (See fig. 24 a.)

The following abbreviations are used:

- 75 m/m field gun, 75 G.
- 75 m/m anti-aircraft gun, 75 A. A.
- 155 m/m Schneider Howitzer, 155 H.
- 155 m/m Filloux gun, 155 G.

In case a projectile is to be used interchangeably in both gun and howitzer of the same caliber, it is stencilled with the caliber and the letters "G", "H", e. g., 3.8 G. H.

c) **Weight of projectiles:**

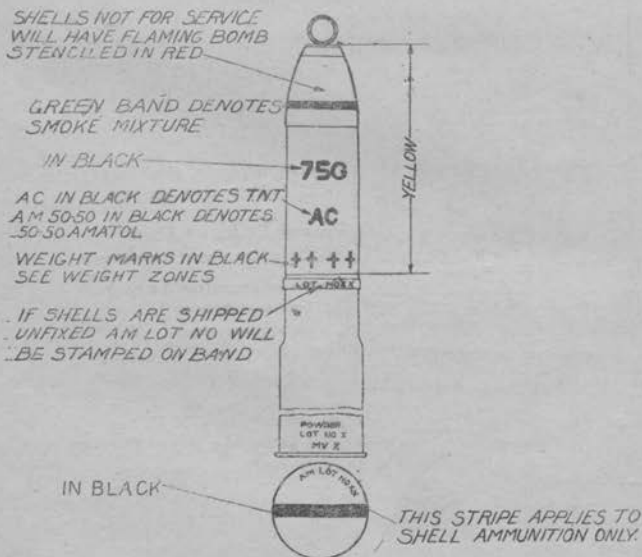


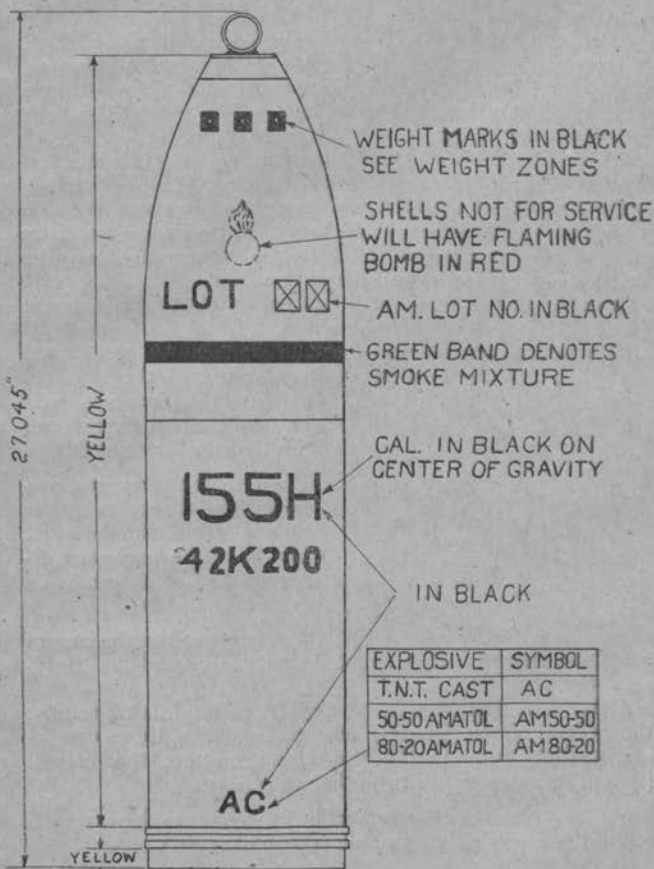
Fig. 24 a.

75 m/m gun. — The weight variations of the lot are indicated by the same marks as those used for French shell (*i. e.*, L or crosses) stencilled just above the rotating band. (See fig. 24 A.)

155 m/m howitzer and gun. — The weight variations are indicated:

1. By prick and punch marks, one, two, or three on the ogival head, surrounded by a square of black paint. (See fig. 24 a.)

2. By the stencilling of the mean weight of the lot, on the body of the shell, immediately below the markings relative to the caliber. (See fig. 24 a.)



155^m COM. STEEL SHELL MARK IV

Fig. 24

d) **Character of shell filler.** — Initials indicating the kind of explosive used are stencilled just above the rotating band. (See fig. 24 b.)

ART. III.

SHRAPNEL.

A. General remarks.

Shrapnel is used as a rule against unprotected personnel and horses.

A shrapnel consists of a steel case, balls of hardened lead, a fuse and a bursting charge, generally of black powder, which is intended to break the forward part of the envelope and which is placed either in front of or behind the balls or mixed with them.

When, by the action of a time fuse or of a combination fuse, the shrapnel bursts, the balls are shot along various trajectories which are contained in a cone, the angle of which is called *the opening of the spray*. It depends essentially on the relative position of balls and charge and may be calculated with sufficient accuracy as follows:

Assume that a shrapnel is caused to burst when at rest (fig. 25). A ball E is shot along EM with a velocity U which may be considered as resulting from two component velocities; the first called u being parallel to the shrapnel axis, and the second called u' perpendicular to the axis and meeting the latter in O.

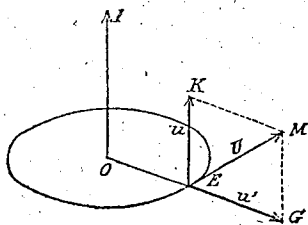


Fig. 25.

u is in the forward direction if the charge is at the base or mixed with the balls, and is in the backward direction if the charge is in front of the balls.

u' is greater in the case of a central charge. It is about 40 m. per second for the 75 shrapnel.

When a shrapnel bursts at a given point of its trajectory, the action of the bursting charge remains the same as above, but owing to the projectile's motion, the ball E (fig. 26) is subjected to two other velocities:

a) The velocity of the projectile V (which has the same direction as u when the shrapnel is base charged).

b) A tangential velocity u'' due to the rotation of the projectile.

The latter velocity is proportional to the distance EO from the ball to the axis of the projectile, and does not vary materially with the position of the shrapnel on its trajectory, as the velocity of rotation of the projectile is very nearly the same all along the trajectory. Velocity u'' is perpendicular to u' and represented by EF.

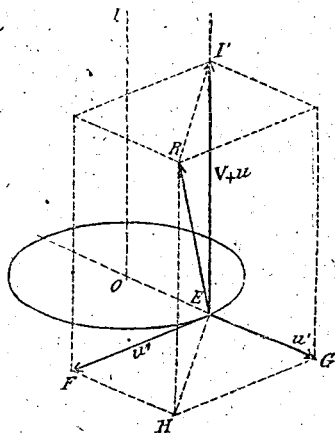


Fig. 26.

The ball will follow the diagonal ER of a rectangular parallelepiped the sides of which are $V + u$, u' and u'' . This direction ER makes with the axis of the projectile an angle which is smaller than or equal to $1/2$ of the opening of the spray above referred to.

This angle (and therefore the opening of the spray) increases :

- a) When velocity u' increases (central charge);
- b) When velocity u decreases,

and this is particularly true in the case of a front charge, when u is in the backward direction. It is evident that the velocity ER of the ball is reduced. From this it is apparent that for balls of a given weight, the effect is greatest with a base charge as compared with a front charge or a charge mixed with the balls.

c) When velocity V of the projectile decreases the opening of the spray increases as the range increases, as is shown by the following data for the 75 shrapnel :

Ranges	1000	2000	3000	4000	5000	6000
$1/2$ opening of the spray.....	7°38'	8°57'	10°	10°51'	11°35'	12°9'

d) When the velocity of rotation u'' (i.e., that of the projectile) increases.

Notice that when the initial velocity of the shrapnel is reduced, there are two contrary consequences :

a) The reduction of velocity tends to increase the opening of the spray ;

b) The reduction of velocity of rotation tends to reduce it. The latter tendency is the most important above a range of 2000 m., the opening of spray being reduced by 2 % to 3 %.

The envelope should not be thicker than is necessary to

support the shock of discharge, in order to keep the dead weight as low as possible.

The balls must satisfy the following conditions :

1. They must be strongly packed so as not to be crushed by inertia when the projectile is fired. With this end in view, the balls are made of lead mixed with 10 % antimony and when loaded, they are fixed in position by resin, sulphur or black powder and the whole strongly pressed;

2. The balls must possess a sufficient weight and velocity to put out of action a man fitted with his winter equipment. The force of impact must consequently be equal to or greater than 20 kilogrammeters. Therefore the front charged shrapnel must contain heavier balls than the base charged one in order to have the same effect, the velocity of the projectile being the same in both cases.

B. Principal types of French shrapnel.

a) **Front charged cast-iron shrapnel :** They consist of a cast-iron body (fig. 27), of balls mixed with melted sulphur, and of a charge of black powder (MC30). Ex.: the 155 shrapnel of the 1879 Model (or 1879-1915) shown by fig. 27.

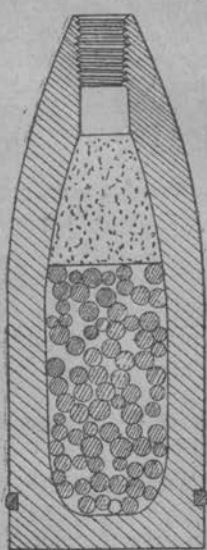


Fig. 27.

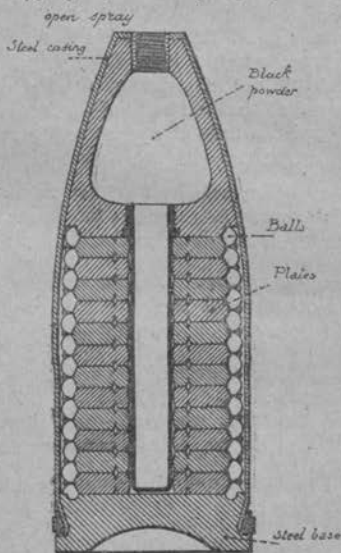


Fig. 28.

Number of balls : 270 .
Weight of one ball : 26.1 gm.

These projectiles are easily and quickly made, but their effect is limited. The walls being made of cast-iron are very thick, and the dead weight is therefore great. The bursting of the shrapnel is bad and sometimes a great number of balls remain stuck in the sulphur.

Case shot. — In this special kind of projectile, the walls are as thin as possible (fig. 28), and most of the shell is burst into splinters.

With this object in view, the shell is made as follows :

12 cast-iron plates are planed on both faces and then piled up on a steel base. A cast-iron grenade is fitted on top of these plates and contains the bursting charge. The lower face of this grenade, both faces of each plate, and the upper plate of the base, have hemispherical sockets where the balls are placed.

The plates are furrowed so as to facilitate their breaking up, and these furrows are filled with powdered charcoal, the action of which is to make the burst more visible.

It can be seen that, owing to the design of this projectile, the shock of firing is supported by the plates and base and not by the walls of the projectile. The thickness of the envelope may therefore be reduced; it consists of a thin sheet of stamped steel which surrounds the grenade and the plates, and is pressed into a groove of the base of the projectile where it is locked by the rotating band.

When the case shot is fired, the shock at departure is sufficient to insure the breaking up of the plates. The action of the charge is simply to burst the envelope.

These projectiles have the following advantages :

1. The dead weight is reduced to a minimum.
2. They break up well.

On the other hand, their drawbacks are the following :

1. The bursting charge being in front, the weight of the balls has to be increased in order to increase their effectiveness, and their number is therefore reduced;
2. To keep their velocity as high as possible, the bursting charge is reduced, which brings about a decrease of visibility.

The 155 case shot has the following characteristics :

Weight of projectile.....	40.800 kg.
Weight of ball.....	0.025 kg.
Number of balls.....	416.
Number of splinters.....	288.
Weight of bursting charge.....	0.560 kg.
Opening of spray.....	22°.

c) **Base charged shrapnel.** — The drawbacks of the case shot were particularly evident when used for howitzers. The remaining velocity of the projectile was smaller in this case, and this, combined with the front charge, gave

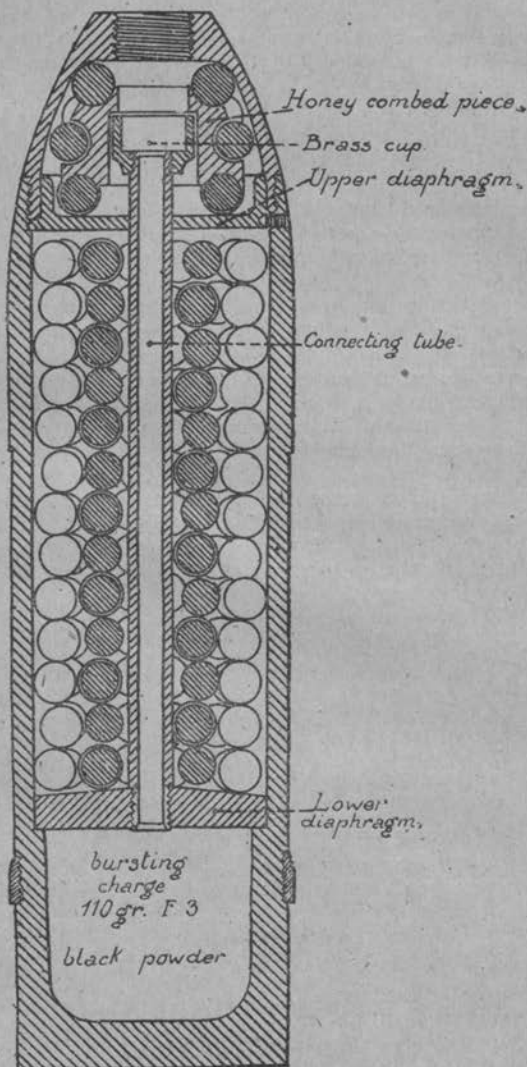


Fig. 29. — 75 ^m/_m Base charged shrapnel.

the balls so small a velocity that the effects of the projectile were insufficient.

For this reason, base charged shrapnel were designed in 1891 for use with the 120 Howitzer.

The projectile body is made of steel and stamped (fig. 29).

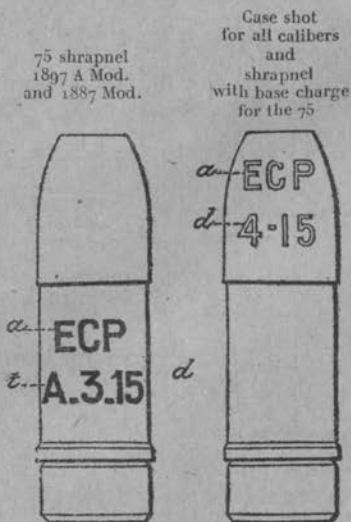
The connecting tube is made of soft drawn steel, and is fitted at the top with a brass cup which receives the fuse base. There are 640 balls, each weighing 12 grams.

The spaces between the balls are filled with a mixture of resin and yellow wax so as to insure compact loading. The balls rest on a diaphragm which separates them from the bursting charge.

Another diaphragm shaped like a cup is in front of the balls. Its circumference is fitted against the joint between the body of the projectile and ogival head. The latter is empty.

The 75 base charged shrapnel is similar to the 120, but the ogival head contains a honeycombed piece of wood in which balls are fitted. The 75 shrapnel contains a total number of 261 balls.

These projectiles have the following advantages over the case shot :



SHRAPNEL AND CASE SHOT
Fig. 30.

1. Since a base charge increases the velocity of the balls,

the weight of the latter may be reduced and their number increased.

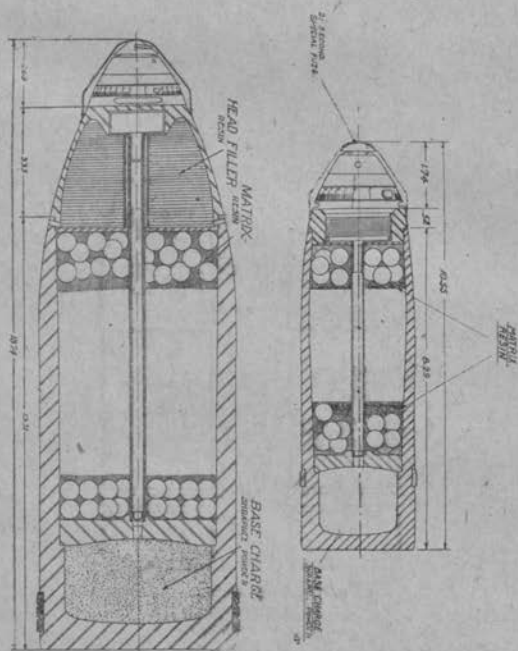
The effect of the projectile is much better.

2. Owing to the above action of the base charge, there is no objection to increasing the weight of the latter, thereby giving an improved visibility of burst.

The drawbacks are as follows :

1. The projectile body must be resistant enough not to be broken before the balls are ejected. The dead weight is therefore increased.

2. The diaphragm supporting the balls must be very thick, so that the heat caused by the pressure of the balls and connecting tube against it when the shrapnel is fired will not be transmitted to the bursting charge and cause



155 m/m shrapnel
for howitzer and gun.
95 LBS.
Mark 1.

Fig. 31 a.

Assembled view.
75 m/m
anti-aircraft shrapnel.
Mark 1.

Fig. 31 b.

premature bursts. The increase in thickness of the diaphragm tends also to increase the dead weight.

3. The fuse being fitted on the ogival head, a connecting tube is necessary between the ogival head and the base charge, so that the dead weight is again increased, and there is a smaller space for the balls.

Notwithstanding these drawbacks, base charged shrapnel are better than case shot of the same caliber.

All projectiles containing black powder are incendiary.

C. Marks on shrapnel.

a) **Stamped marks.** — Similar to those stamped on H. E. shells (fig. 14). Besides these marks, the number of the projectile is marked on the upper part of the body and the series number of the ogival head as well as the number of the latter are marked on the ogival head.

D. The only type of shrapnel manufactured nowadays in the States is the base charged one, both for the 75 m/m gun and the 155 m/m Howitzer (see fig. 31).

This shrapnel is painted red.

The stamped marks are the same as those for H.E. shell (see above).

The only stencilled marks are those relative to the caliber, and the same system as for the shells is followed.

ART. IV.

SPECIAL SHELLS.

A. Incendiary shells.

These shells are loaded with incendiary cylinders, the spaces between the cylinders being filled with black powder.

The incendiary cylinder (fig. 32) consists of a pack of slow-



Fig. 32. — Incendiary cylinder.

burning linstock for primer, strengthened by several spirals of string containing some saltpeter and primed by ordinary

linstock inside and outside. This pack is surrounded by a rectangular piece of stout cotton cloth which is impreg-

Loaded with P 3.
type N.

- t. Projectile type.
- a. Loading works and date.
- p. Marks relative to the weight.

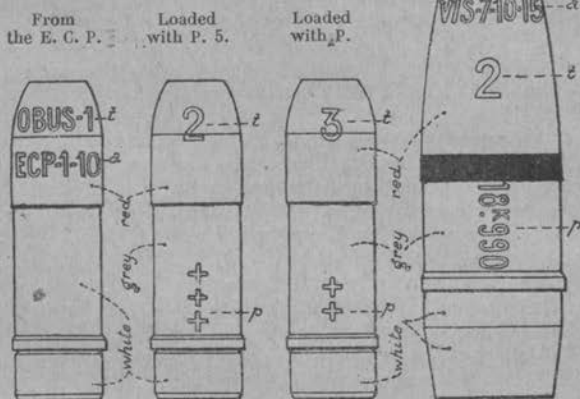


Fig. 33. — Incendiary shells.

nated with an incendiary substance. The whole of the cylinder is tied up by an annealed brass wire.

The cylinder weighs 30 grams and its duration of combustion is about 2 minutes.

American incendiary shells have the ogival head and bour-relet painted red, the body light gray, and the word «INCEN-DIARY» stencilled in white, lengthwise on the body.

Marks on incendiary shells : see fig. 33.

B. Illuminating-shells.

The star shell (fig. 34) used in connection with the 155 H. contains 8 stars similar to those used for fireworks. These stars are fitted with silk parachutes.

The shell also contains a small charge of black powder, the action of which is to set fire to the stars and propel them backward, together with the base of the projectile which is kept in position by a thread of small resistance.

The stars descend very slowly and for about 45 seconds illuminate surrounding objects brightly.

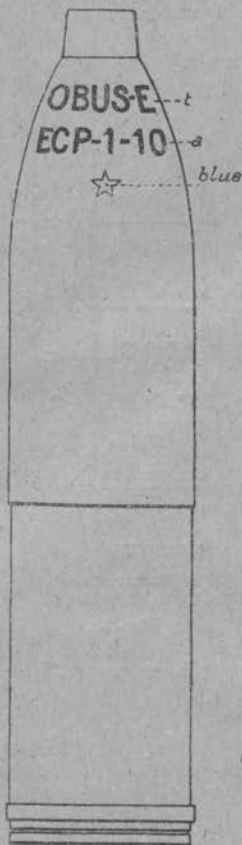
The most efficient height of burst is about 300 meters and

the burst interval on the trajectory must not be over 300 meters. The direction must be accurate within 150 meters.

When these conditions are complied with, it is possible to observe up to 1200 meters.

The trajectory of star-shells is the same as that of case shot and there are special firing tables to determine the height of burst. Star shells are also incendiary.

Marks on star-shells. — They are marked with an E and a star (see fig. 34).



- t. Projectile type.
 - a. Loading works and date.
- Star shell for the 155.

Fig. 34. •

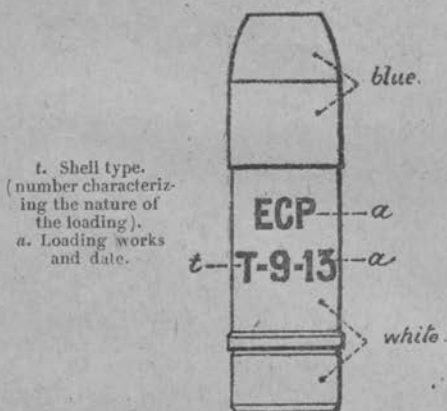
American illuminating shells are painted white.

C. Tracer shells.

This shell is loaded with a readily combustible substance and its ogival head has several holes. It is fitted with a 30/55 time fuse which ignites the inside charge, the flames of the latter going through the holes of the ogival head so that the trajectory is made visible. Fire for adjustment on aircraft is thereby rendered easier.

These shells are of course incendiary.

Marks on tracer shells. — Tracer shells (fig. 35) are painted *blue* from eye to base plane of ogival head and *white* below that plane. The letter T is marked on the body.



Tracer shell
for the 75, from the E. C. P.

Fig. 35.

American tracer shells are painted blue.

D. Gas shells.

a) Description :

§ 1. Different types of poison gas and tear gas shells.

Gas shells may be divided, from the stand point of their properties, into three principal classes.

1. Shells loaded with violent but volatile poisons, lethal gas.

2. Shells loaded with poisons of persisting action and immediate effectiveness.

3. Shells loaded with poisons of persisting action but with delayed effects.

Shells loaded with volatile poisons. — The chemicals enclosed in these shells are very volatile; they entirely vaporize at the moment of the bursting of the projectile, forming a cloud capable of bringing about fatal effects, but which loses its efficacy more or less quickly on being diluted with the air.

This kind of shell includes the French shells, No. 4, No. 4B, No. 5 and No. 8, and the American shells loaded with V.N. and C.G. .

The marks on these shells are the following :

Shells No. 4. — 2 white bands No. 4.....	} Shell painted green.
No. 4B. — 1 white band No. 4B.....	
No. 5. — 1 white band No. 5.....	
V.N. Shells 1 white band	} Shells painted light gray.
C.G. Shells 2 white bands.....	

Shells loaded with poisons of persisting action but of immediate effectiveness. — The chemicals enclosed in these shells having a high boiling point, vaporize only partly at the moment of the burst.

The cloud produced on burst is not likely to cause death, but it immediately gives effects irritating the eyes and the respiratory system, or even caustic and vesicant effects.

The greater part of the contents is atomized and scattered in the shape of small droplets which cover the ground and surrounding objects and continue to give forth emanations prolonging the action of the initial cloud.

This kind of shell includes the French shells Nos. 7, 9, 12, 14, 16 and 21 and the American shells loaded with N.C., P.G. and B.A.

The marks on these shells are as follows

No. 7. — One yellow orange band No. 7.
 No. 9. — One yellow orange band No. 9.
 No. 12. — One yellow orange band No. 12.
 No. 14. — One yellow orange band No. 14.
 No. 16. — One yellow orange band No. 16.
 No. 21. — One yellow orange band No. 21 (1).
 N.G. shells, 1 white band, 1 red band, 1 yellow band.
 P.G. shells, 1 white band, 1 red band, 1 white band.
 B.A. shells, 1 red band.

(1) Shell No. 21 does not contain smoke producing chemicals.

The persistence of these chemicals is from 6 hours to several days for No. 7, No. 16 and P.G. shells,

2 days for shell No. 9; 5 days for shells Nos. 12 and 14,
15 days for shell No. 21.

3. Shells loaded with poisons of persisting action but with delayed effects. — The chemical (yperite) enclosed in these shells has a very high boiling point. It is atomized at the moment of burst into small droplets which cover the ground and surrounding objects. Its weak vapour tension and resistance to the atmospheric agents gives it a very long persistence.

The action of the chemical is not immediate, appearing after a few hours or a few days. It acts on the mucous membranes (eyes, larynx) or on the skin itself, penetrating the clothing and producing burns.

Food contaminated by the chemical become poisonous.

The only type of shell of this kind existing for the present is the French shell No. 20, marked with 2 yellow orange bands and No. 20.

The average persistence of the chemical is 15 days.

Constitution of gas shells. — Gas projectiles are steel or semi-steel shells, having the same outer shape as the H.E. shells of the same caliber.

Gas projectiles are now manufactured and supplied for the following guns :

French : 75 m/m. gun, 105 m/m. gun, 120 m/m. gun, 145 m/m. gun, 155 m/m. gun and howitzer, and trench-mortars. The latter being provided for firing at objectives lying close to our own lines, are only loaded with volatile poisons.

U. S. guns : 75 m/m. gun, 4".7 gun, 5" gun, 6" gun, 155 m/m. gun and H., 8" H. and trench-mortar.

Most of the gas projectiles (except No. 20 and No. 21) contain a smoke producing chemical which makes adjustment fire easier and which in some cases, is also used to absorb and carry the poisonous chemical, so as to avoid too rapid a dissipation.

On account of the difference in the expansion coefficients of liquid and metal, an empty space is left in all projectiles loaded with liquids, which allows the liquid to expand to the volume corresponding to the maximum temperature which the projectile may be submitted to.

Fusing. — The explosive charges which break up the poison gas or tear shells are enclosed in tubes. They break the projectile open and atomize the liquid.

The above charges vary from 25 grams of melinite for the 75 shell, to 92 grams for the 155 m/m F. A. shell and 190 grams for the 155 m/m steel shell. They are too weak to project splinters of the projectile with a sufficient velocity to be effective against personnel.]

To secure the maximum efficiency, poison gas or tear shells must be fitted with an instantaneous fuse. Fuses without delay or with zero delay cause the projectile to burst when it has already penetrated the ground. Under these conditions a portion of the liquid is absorbed by the earth and the efficiency is lowered.

75 shells are fired with I or Instantaneous Schneider fuses; for other calibers, there is an advantage in using I. A. fuses.

To ensure the gas cloud forming on a level with the ground, it is advantageous to use the charge that produces the largest angle of fall, so as to diminish the chances of a ricochet of the partly fragmented shell.

§ 2. Smoke projectiles.

These projectiles are intended for the creation of curtains to conceal the advance of attacking waves, or as signals for the troops in the course of barrage fire.

They are No. 3 special shells, loaded with phosphorus and should be fired with I or S. R. fuses.

b) Storage of gas shells :

Storage. — The cartridges and shells must be arranged by classes and by numbers and so disposed as to make supervision easy.

Gas shells may be handled without danger because of their weak bursting charge.

The store-rooms where they are kept must be well ventilated.

A leaky shell may be detected by the vapor which escapes or by perceptible leakage at the eye. Every leaking shell should be taken away from the store-room or caisson to be fired or destroyed. If circumstances are such that it should not be fired, it should be carried away to an isolated and well ventilated spot, all necessary precautions being taken against emissions of gas, and destroyed by means of petards. During transport and at the moment of explosion, care should be taken to keep on the windward side. As a temporary expedient, the shell may be rendered harmless by burying it or immersing it in water.

The store-room guards should have their gas masks at hand at all times. They must put them on before entering a room in which gas can be smelled.

The proportion of shells that leak tends to increase with the length of time they are kept; the parks should supply the batteries from the oldest lots.

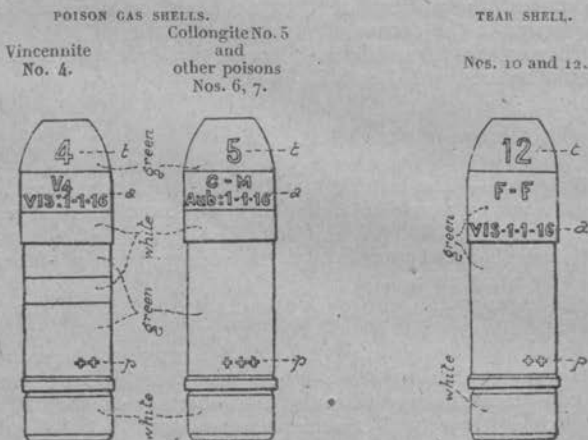
Special additional rules for No. 20 projectiles.

The personnel put on gloves and masks before handling No. 20 projectiles which show traces of leakage. They also put on the special overalls or blouse when because of the weight of the projectile or the work to be done, the clothing might be rubbed by the projectile.

As soon as received, the projectiles should be inspected to discover any leakage, the booster joint being especially examined (1). The gloves and the mask should be worn during the inspection.

The boxes or projectiles should be kept out in the open preferably, and are arranged in small piles.

Near each pile place some loose earth to be used for covering the projectiles broken by enemy fire. Every depot must be provided with shovels and chloride of lime in water-tight containers.



GAS SHELLS.

Fig. 36.

(1) The inspection of 75 m/m projectiles is made when the boxes are opened to distribute them.

When a pile is hit, withdraw the personnel to the windward, give the alert to all personnel less than 200 m. to the leeward, cover the broken shells, the liquid that has spilt out and the neighboring projectiles with chloride of lime and a layer of earth 10 cm. thick. Wear mask and gloves.

c) Marks on gas shells :

1. French system. — For all calibers, the number appearing on the shell corresponds to a certain chemical which can be mixed with different smoke-producers. The letters placed above the number of the shell are the abbreviations for the chemicals used. The marks placed on the third line indicate the loading works and the date of manufacture. The poisonous shells are painted green.

The shells containing volatile liquids have one or two white bands and those containing persistent liquids, one or two orange bands (1).

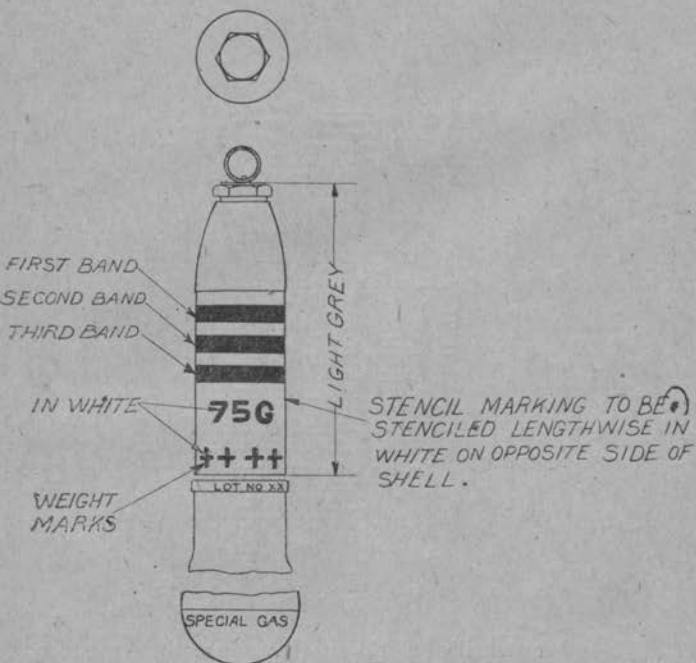


Fig. 37 a.

(1) The shells for persistent gases loaded before January 1, 1918 have no orange band.

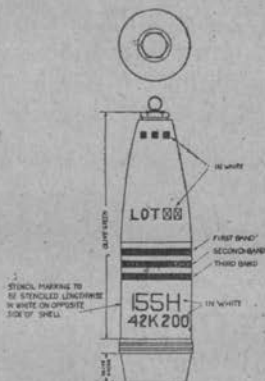
The marks relative to the weight are the same as those for H. E. shells, but they appear on the white or orange portion.

American system. — The shell is painted light gray. Bands around the body, half an inch wide, and half an inch apart, are used to differentiate the nature of the filling.

White bands are used for lethal but not persistent gases.

Red bands are used for gases which are persistent. Therefore a combination of white and red bands indicates a filling which is both lethal and persistent.

In addition, the words "SPECIAL GAS" are stencilled in white and lengthwise of the body (fig. 37 a).



155mm COM STEEL SHELL MARK II

TABLE OF SHELL FILLER MARKINGS

SHELL FILLER	COLOR OF BANDS			SPECIAL MARKINGS
	1ST BAND	2ND BAND	3RD BAND	
VN	WHITE	NONE	NONE	SPECIAL GAS
W	WHITE	WHITE	NONE	SPECIAL GAS
PS	WHITE	RED	NONE	SPECIAL GAS
HS	RED	RED	NONE	SPECIAL GAS
BA	RED	NONE	NONE	SPECIAL GAS
PD	WHITE	RED	WHITE	SPECIAL GAS
UC	WHITE	RED	YELLOW	SPECIAL GAS
WP	YELLOW	NONE	NONE	SPECIAL
SMOKY SHELL	NONE	NONE	NONE	SPECIAL
INCENDIT	NONE	NONE	NONE	INCENDIT
OL	NONE	NONE	NONE	OL
CHOKED SHELL	NONE	NONE	NONE	CHOKED SHELL
P. 22	YELLOW	YELLOW	NONE	SPECIAL

OTHER SPECIAL TYPES OF CHEMICAL SHELL, WHOM FUNCTION IS NOT INDICATED BY THE COLOR OF THE PAINT WILL HAVE STENCILED ON THE SHELL A WORD TO INDICATE ITS FUNCTION

WEIGHT ZONES FOR 155MM HOW SHELL			
NOT INCLUDING FUSE WEIGHTS			
FROM	TO	WEIGHT MARK	WEIGHT SYMBOL
10	12	10	10/100
12	14	12	12/100
14	16	14	14/100
16	18	16	16/100
18	20	18	18/100

Fig. 37 b.

The other stencilled marks are the same as those used for H. E. shell.

CHAPTER III.

FUSES.

ART. I.

GENERAL REMARKS.

A. Definitions.

A *fuse* is an appliance giving a flame which ignites or detonates the charge inside the projectile.

If this charge consists of black powder (shrapnel, etc.), the flame is sufficient to cause the explosion directly. If the bursting charge consists of explosives other than black powder (melinite, trolol, etc.), a detonating fuse is required to ensure detonation.

A *detonator* consists mainly of a cap containing some fulminate of mercury.

When a detonator is fitted on the fuse, the appliance is called a *detonating fuse*.

Fuses are divided into the three following classes :

1) **Percussion fuse.** — This fuse functions on impact either by inertia, or by a striker being driven inside like a nail.

The principle of construction of fuses operated at moment of impact by inertia is shown in the following figure (fig. 38).

2) **Time fuse.** — This fuse functions at a time after firing determined by a time train and may be so set as to cause the projectile to burst in the air before impact.

3) **Combination fuse.** — This fuse functions [either in the air or on impact.

B. General principles.

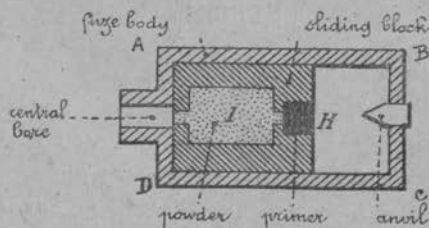
As the projectile does not always strike the ground exactly on its point, a fuse cannot be relied upon to function at

the moment of impact by a striker being driven inside like a nail.

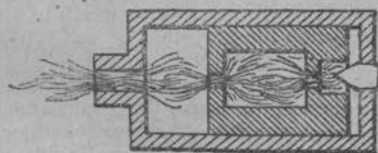
Most fuses are operated by inertia.

The principle of their construction is as follows (fig. 38):

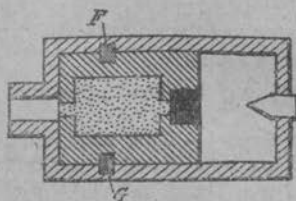
Before departure.



At point of impact.



Before departure and during flight of projectile.



At point of impact.



Fig. 38.

A box ABCD is connected with the bursting charge by a tube

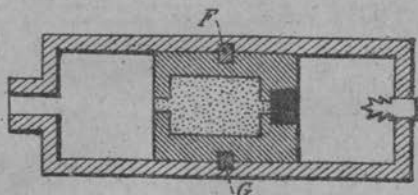
A block, containing fulminate H and powder I, is driven forward in the box by inertia when the projectile strikes the ground. The fulminate H strikes against an anvil fitted in the box and, by its detonation, ignites the powder I. The flame of the latter passes through the tube and causes the detonation of the bursting charge. On the model shown in the figure, the block is kept in position by two pins F and G made of lead which break under the shock of impact when the projectile strikes the ground.

This type of fuse will not function if the remaining velocity is not great enough to produce a sufficient shock on impact to break the lead pins.

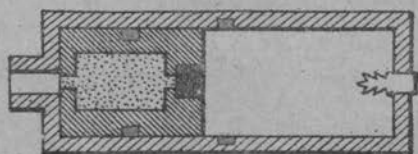
This difficulty is overcome by fixing the sliding block at some point between the rear face of the box and the anvil, where it is held by lead pins. These pins are broken by the shock of discharge and the block moves backward.

On impact the projectile and the box, which is solid with it, are suddenly stopped. The block moves forward and strikes against the anvil. This will take place even though the remaining velocity is small, because the block is free.

Before departure.



After departure.



At point of impact.

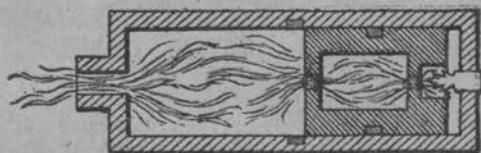
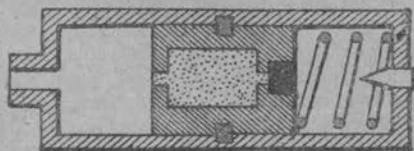


Fig. 39.

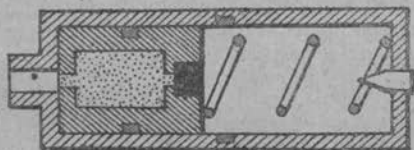
The block tends to slide forward when the projectile is retarded by the air and also because of the rapid oscillations of the axis of the projectile to the right and left of the tangent to the trajectory, at the moment of departure.

This movement is checked by the small *safety spring* (fig. 40) fitted between the front part of the box and

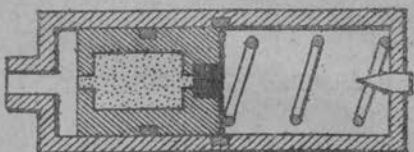
Before departure.



At departure.



During flight of projectile.



At point of impact.



Fig. 40.

the block, which however, is not strong enough to prevent the block from sliding forward by inertia at the point of impact.

The shock of the block against the rear face of the box at the moment of firing has a tendency to cause the block to rebound and possibly strike the anvil. In order to prevent

this, a lead or card-board washer P (fig. 41) is fitted to the rear face of the box so that the shock is deadened.

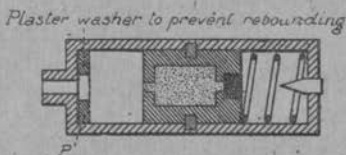


Fig. 41.

This type of fuse shown in fig. 41 is called *friction fuse* and is used by the French Navy.

These fuses are quite safe during transportation due to their resistance to arming and consequently they are not likely to arm when dropped accidentally. They are used only in connection with high velocity guns, as only with these is the shock of discharge sufficient to arm them. When armed, they are sufficiently sensitive.

The conditions required of fuses are :

1. Safety during transportation;
2. Sensitiveness when armed.

The latter condition is realized by one of the three following systems :

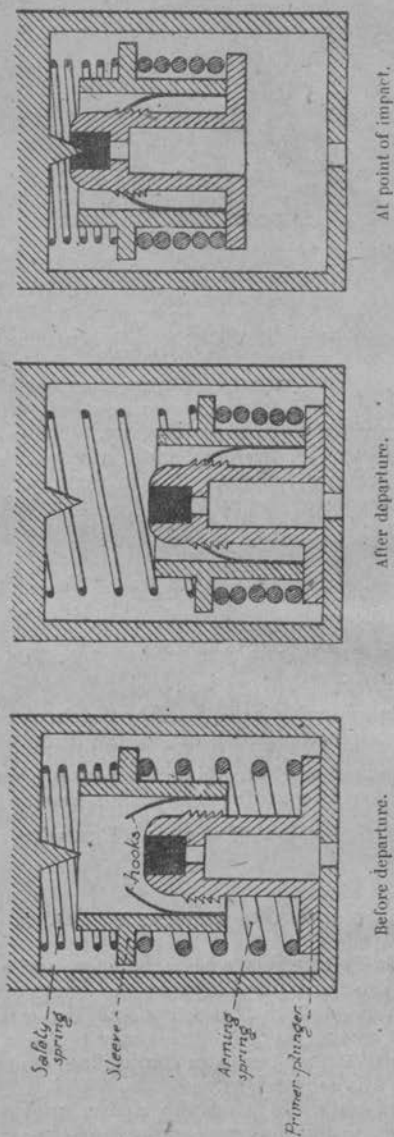
1. A sleeve or ring is displaced by the shock of discharge, thus freeing a plunger which carries the firing pin.
2. The rotation of the projectile causes a device in the fuse to function by centrifugal force thus freeing the plunger.
3. The combustion of a grain of powder releases the plunger.

1) RING OR SLEEVE RESISTANCE FUSES.

The fuse body contains a *primer-plunger* and an *anvil*. A strong spiral spring is fitted between the flange of the *primer-plunger* (fig. 42) and that of the *sleeve* (also called *retaining ring*). This *spring*, by keeping primer plunger and sleeve apart, prevents the primer from coming into contact with the anvil before it is so intended.

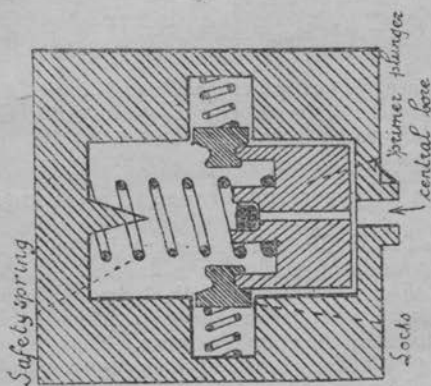
At the moment of firing the sleeve moves backward with reference to the plunger compressing the spring. Clasp-hooks, which are fitted inside the sleeve, then engage notches on the primer-plunger.

The sleeve, the spring and the primer-plunger are then

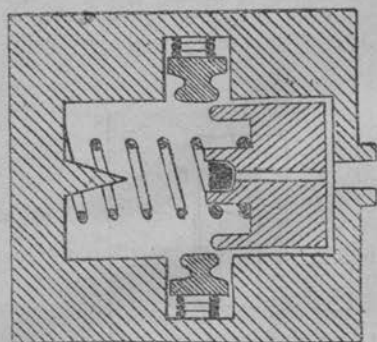


Fuses working by inertia of a sleeve.

Fig. 4a.

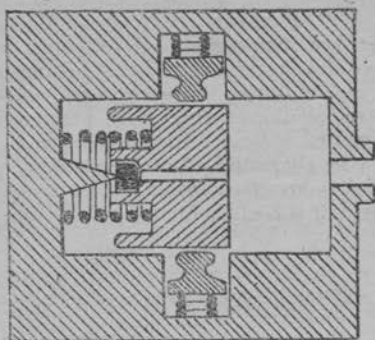


Before departure.



After departure.

(The locks thrown aside by centrifugal force have freed the primer plunger.)



At point of impact.

Sketch of a fuse working by centrifugal force.
Fig. 43.

linked together in one piece which is thrown forward by inertia at the moment of impact, overcoming the pressure of the safety spring, causing primer to strike against the anvil.

This system provides a relatively light primer-plunger, which makes for safety during transportation, and gives a heavy mass (sleeve, arming spring, and primer-plunger) after arming, which makes for sensitiveness on impact.

These fuses may be characterized by the *smallest coefficient of acceleration which ensures their arming at the moment of departure*; for example, this coefficient is equal to 2500 for the fuse 1899 Model.

2) FUSES ARMED BY CENTRIFUGAL FORCE.

The sketches in figure 43 show a fuse of this kind.

The primer-plunger is fixed during transportation by locks which are themselves held in position by springs. These locks are thrown outward when the speed of rotation of the shell is great enough (fig. 44) to overcome the resistance of the springs.

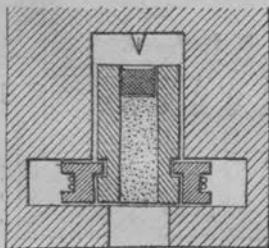


Fig. 44.

For a given fuse, the force exerted on the locks is directly proportional to the square of the velocity of rotation and inversely to the distance between the locks.

3) FUSES ARMED BY COMBUSTION OF A GRAIN OF POWDER.

As shown in fig. 45, the primer-plunger is fixed by a bar resting against a grain of powder.

An anvil is thrown backward relatively by inertia by the shock of discharge and strikes against a primer, thereby causing the ignition of the grain of powder. The combustion of the grain of powder frees bar and primer-plunger; they are thrown forward on impact, compressing the safety-spring, and bringing the fulminate cap in contact with a fixed anvil.

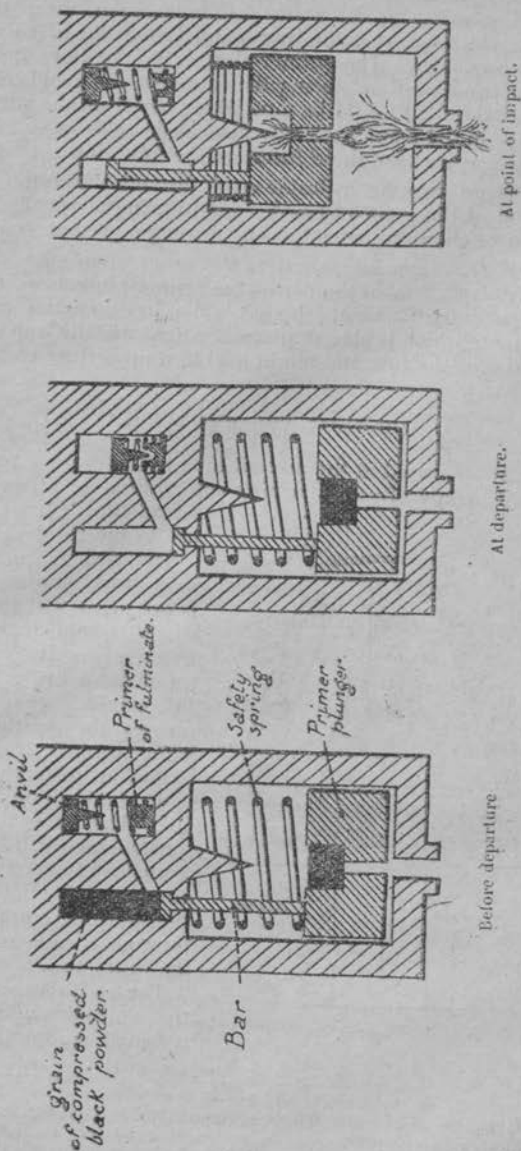


Fig. 45.

Most German fuses are of this type. The advantage is that the combustion of the grain of powder takes some time, during which the projectile travels along about the first 100 m. of its trajectory. The primer-plunger is therefore held in the unarmed position during the time that the rapid oscillations of the shell would be most likely to act on the primer-plunger in the manner already described.

The drawbacks of these fuses are the following :

1. There may be an inside crack through which the combustion of the grain of powder would bring about the detonation of the fulminate, thereby causing a premature burst.
2. If they are put in water, the grain of powder might be dissolved, so that the bar of the primer-plunger would be free to move forward, whereas water has no action on the fulminate which is placed in a water-tight metallic cap. This would arm the fuse and might lead to a premature burst.

4) TIME FUSES AND COMBINATION FUSES.

Time fuses used at the present time in the French Artillery consist mainly of a slow-burning composition (1) pressed into a lead tube. It is set on fire by means of a striker.

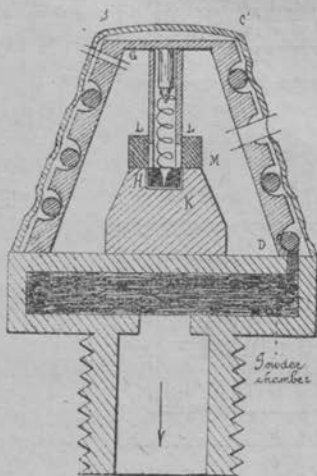


Fig. 46.

The striker, contained in a tube, consists of a pellet pointed at the base which is kept in position by a safety spring. At the moment of firing, owing to inertia, the pellet presses the spring, and being thrown backward, strikes against the fulminate composition H (fig. 46). The latter then detonates and with the help of a small charge of pressed powder M, ignites the slow-burning composition through a hole made by the fuse setter.

The lead tube containing the slow-burning powder is wound in a spiral groove

(1) This powder has the following composition : 75 o/o saltpeter, 10 o/o sulphur, 13.5 o/o carbon, 1.5 o/o pulverized gumlake. The lead tube in which this powder is to be pressed has been drawn out several times so as to have the required diameter and is then wound round the fuse. The speed of combustion is about 1 m. per 76 sec.

around the casing of the fuse, which is itself covered by a brass cap. This cap is graduated according to the rate of burning of the powder.

One end of the lead tube is fixed to the top of the fuse, the other end to a powder chamber at the base.

The flame from this powder is communicated to the bursting charge through the tube leading to the latter.

The hole made by the fuse setter goes through the brass cap at a division of the scale which indicates the time of burning from the hole to the powder chamber. If the projectile were fired without being set, the striker would act and the gases produced by the fulminate composition and the small charge of pressed powder might cause the bursting of the fuse head at the moment of departure. In order to prevent this, a small hole *G* is drilled at the top of the fuse, through which the gases above referred to find an outlet.

Combination fuses. — They consist of a percussion fuse and a time fuse fitted together.

In the U. S. combination fuse the upper part of the fuse contains the time elements, the lower part the percussion elements.

The time elements consist of the plunger *b*, the firing pin *c* and the time train. The plunger carries the percussion composition and a small igniting charge of black powder.

The plunger is held out of contact with the firing pin by a split resistance ring *a*. The shock of discharge causes the plunger to be thrown against the firing pin; the inertia of the plunger acting through its surface, in contact with the split ring, expands the latter, and the plunger carries the percussion composition to the firing pin.

The time train of the fuse is composed of two rings of powder *f* and *h* contained in grooves cut in the two time train rings *m* and *n*. The grooves are not cut completely around the rings, but a solid portion is left between the ends of the grooves in each ring.

The lower time ring *n* may be rotated around the axis of the fuse, so as to displace with respect to the position of the powder pellet *e*, another powder pellet which is contained in the vent *g* shown in dotted lines on the figure and which is used to ignite the lower time train *h*.

The displacement of the lower time ring *n* is the setting of the fuse.

The flame from the percussion composition ignites the powder pellet *e*, which, in turn, ignites one end of the upper time train; the latter burns counterclockwise. The flame reaches then the powder pellet *g*, ignites the lower time ring *h*, which burns clockwise. The flame reaches the powder pellet *i*, which ignites the powder contained in the

powder magazine *h*, and thus, the bursting charge of the shrapnel.

The percussion elements consist of a plunger *r* with a firing pin, a friction composition, a small igniting powder charge, and a vent filled with powder and communicating with the powder magazine.

NOTES. — *a*) Time fuses and combination fuses are not absolutely water-tight, however careful their manufacture.

Moisture may get through the joints after a time and reach

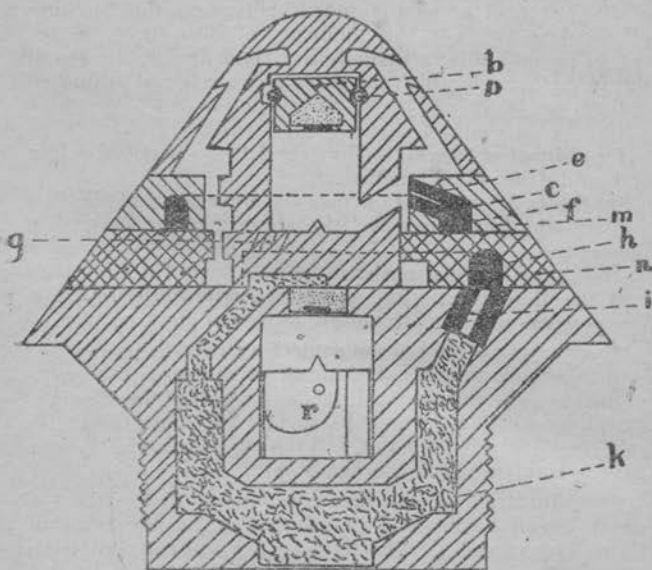


Fig. 47.

Schema of U. S. comb. fuse.

the powder chamber from which it gets to the powder contained in the lead tube. This is the reason why heights of burst vary greatly in some cases.

155 case shot are sometimes fitted with 30-55 fuses of the 1889 Model. These fuses have a cap which should not be removed until the projectile is about to be fired.

b) The rate of burning of powder in the tube is dependent on atmospheric conditions, and is proportional to :

1. *The atmospheric pressure* (an increase of 1 m/m causes an increase of speed of $\frac{1}{1100}$);
2. *The temperature* (an increase of 1° causes an increase of speed of $\frac{1}{1400}$);
3. *The velocity of wind.*

On the contrary, it *decreases with the humidity.*

The probable error in range of a 75 fuse is about twice the probable error in range of the projectile for a given quadrant angle of elevation.

In mountainous country, the speed of combustion is reduced when the altitude increases, and it is therefore necessary to reduce the length of the lead tube by increasing the corrector. For this reason special formulas are given for mountain guns. For ordinary ground, corrections of altitude are not to be taken into account.

From these considerations it is seen that adjustment of height of burst is always necessary, its object being to determine the *height of burst of the moment* (and not of the day as it is sometimes called).

It is well to note that hot and dry weather calls for a reduction of corrector while, for cold wet weather it is the reverse.

ART. II.

DESCRIPTION OF THE PRINCIPAL FUSES IN USE.

A) Percussion detonating fuses.

1) 1899 MODEL FUSES.

There are five types of 24/31 percussion detonating fuses 1899 Model, actually in use (1) :

1. 1899 fuse (without powder delay) *white head.*
2. 1899-08 fuse (0.05 sec. powder delay) *black head.*

(1) The two dimensions which are mentioned in referring to a fuse are the diameter of the thread and the base diameter of the bevelled part of the head. For instance in a 24/31 fuse, the thread diameter is 24 m/m and the bevel diameter 31 m/m.

3. 1899-1915 fuse (without powder delay) *white head*.

4. 1899-1915 fuse with short powder delay (0.05 sec.) *black head*.

5. 1899-1915 fuse with long powder delay (0.15 sec.) *black head and violet shank*.

Only fuses 2 and 3 will be described, the small differences which characterize the other fuses being given at the same time.

The above mentioned fuses are now manufactured in the States.

The fuse 1899 or 1899-1908 Model is called detonating fuse.

Mark V. — The French system is adopted for the marking of this fuse, that is to say :

White head for the fuse without delay,

Black head for the fuse with delay.

The fuse 1899-1915 Model is called detonating fuse *Mark IV*, and, as in the French fuses :

White head means no delay,

Black head means short delay,

Black head and violet shank means long delay.

1899-1908 fuse. — It is shown by a sketch on the following page and consists of :

a) A percussion system R (Robin).

b) A 0.05 sec. powder delay.

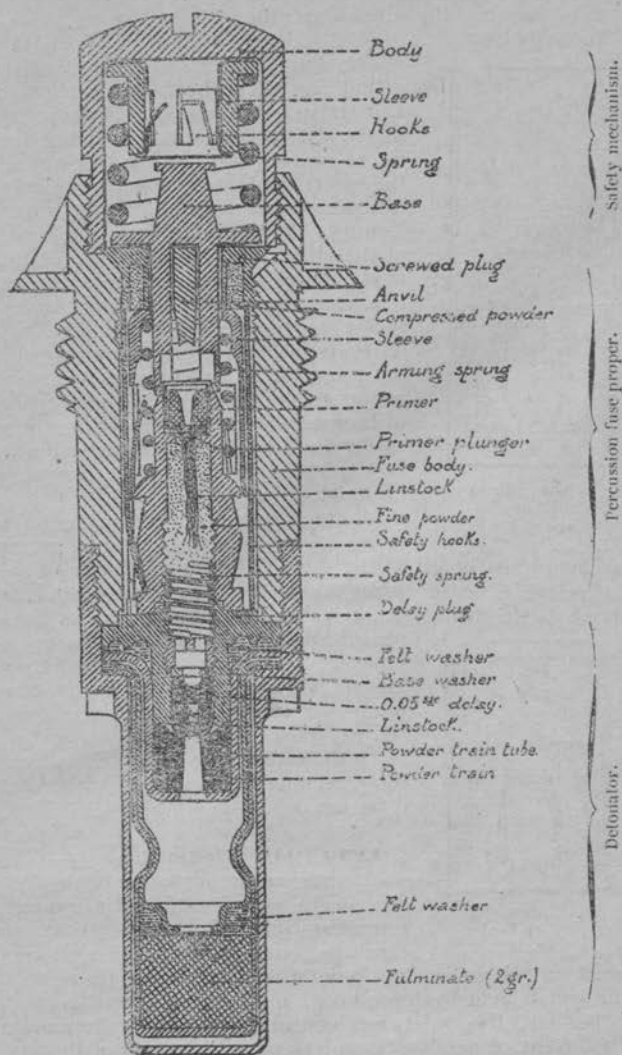
c) A cylinder similar to that of the detonator already described and containing 2 gm. of fulminate.

d) A supplementary safety mechanism fitted in a steel cylinder which is screwed on the fuse head. This safety mechanism consists of a base piece, a sleeve and a spring between the two latter parts. Hooks are cut in the sleeve.

The lower branches of the base piece (fig. 48) are on both sides of the anvil and their ends are close to the upper part of the primer plunger, which is thus prevented from moving forward and striking against the anvil.

The percussion mechanism of the fuse works as follows :

During transportation, the primer-plunger is held not only

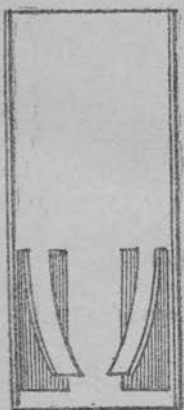


24/31 Percussion detonating fuse 1899-1908 Model.

Fig. 28.

by the arming spring but also by three safety hooks (fig. 49) cut in a brass cylinder. These hooks are fitted against the base of the primer-plunger and the upper end of the brass cylinder

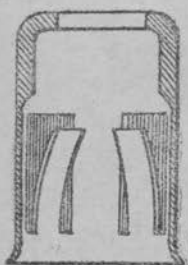
resting against the fuse plug; the primer-plunger therefore cannot move.



Brass cylinder
Safety-hooks.

Fig. 49.

backward, its hooks fitting against the upper flange of the base piece. Sleeve, spring and base piece are united and are free to slide forward as the velocity of the projectile is diminished by the resistance of the air or on impact.



Sleeve
and clasp hooks.

Fig. 50.

The sleeve (fig. 50) also consists of a cylinder in which hooks are cut but in a direction opposite to that of the safety hooks. At the moment of departure, the sleeve goes backward and its base pushes the safety hooks away from the primer-plunger which is then free to move forward. At the same time, the hooks of the sleeve fit themselves against the upper flange of the primer-plunger, so that primer-plunger, sleeve and arming spring are connected together. They are prevented from moving forward while the projectile is travelling along its trajectory by means of a safety-spring made of bronze. The top part of the safety spring is fitted in the primer-plunger hole and the lower part in the base plug of the fuse.

At the moment of departure, the sleeve of the safety mechanism moves backward, its hooks fitting against the upper flange of the base piece. Sleeve, spring and base piece are united and are free to slide forward as the velocity of the projectile is diminished by the resistance of the air or on impact. The base piece, having moved forward, no longer prevents the primer-plunger from striking against the anvil.

1899 Model fuse. — It differs from the preceding fuse only by the fact that it has no delay.

1899-1915 Model fuse. — The safety mechanism at the top of the fuse described above, is intended to prevent premature detonation due to shocks in case the other safety devices do not

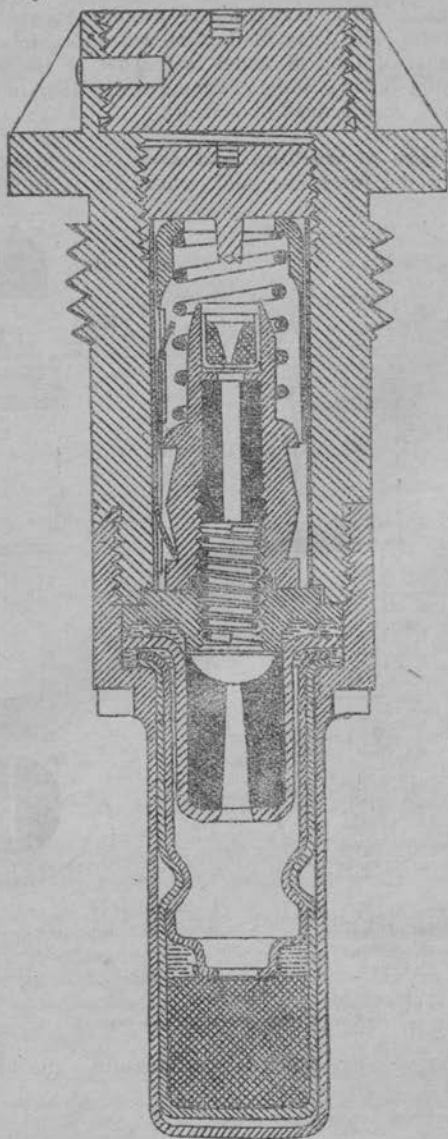
work. Such an accident is not probable, because the primer-plunger is held by three hooks and the arming spring.

Besides, this safety-mechanism works for a minimum coefficient of acceleration of 2500, whereas that of the fuse itself is 1900. It therefore jeopardizes the working of the fuse when small propelling charges are used.

Furthermore, the head is likely to be deformed when striking the target, especially with *heavy shells*, and might then cause the base piece to be forced back, thus blocking the primer-plunger.

For all these reasons, the safety-mechanism has been done away with in 1899-1915 fuses.

Fig. 51 shows a fuse 1899-1915 Model or mark IV *without powder delay*.



Percussion detonating fuse 1899-1915 Model (without delay).
Fig. 51.

The fuses of this model with short or long powder delay differ from that shown in the sketch by the fact that they are fitted with a delay between the primer-plunger and the powder train: the delay of the fuse with short delay is identical to that of 1899-08 Model fuse. That of the fuse with long powder delay is longer, having a duration of combustion of 0.15 sec. instead of 0.05 sec.

Conditions of working and use. — 1899 Model and 1899-08 Model fuses (fig. 52) work for a coefficient of

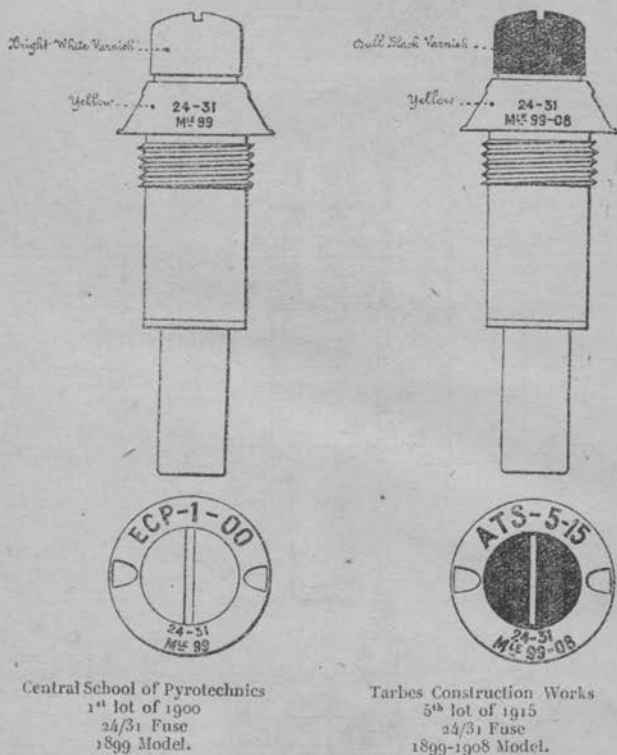


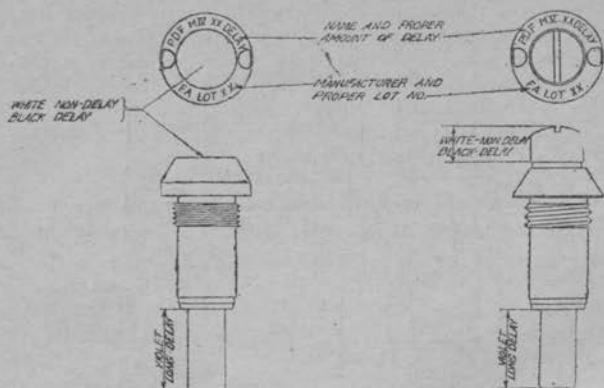
Fig. 52.

Marks on 1899 and 1899-1908 fuses.

acceleration of 2500 which is reached under the following conditions :

75.....
155 H. Schneider...

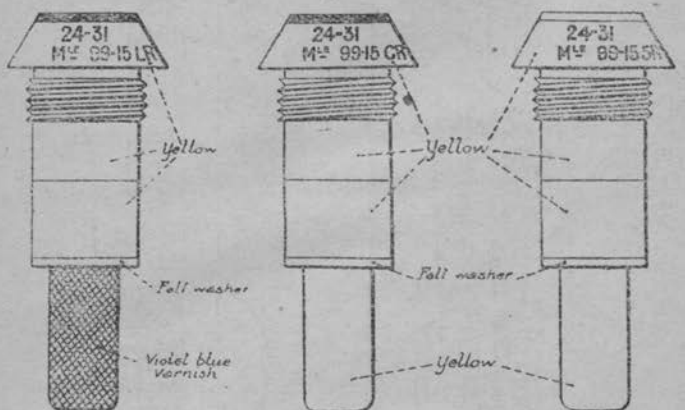
With all charges.
Charges : 00, 0, 1, 2, 3.



Detonating fuse mark IV.

Detonating fuse mark V.

Fig. 53.



Central School
of Pyrotechnics.
12th lot of 1915
24/31 fuse
1899-1915 Mod.
with long delay of 0.45 sec.

Central School
of Pyrotechnics
12th lot of 1915
24/31 fuse
1899-1915 Mod.
with short delay of 0.05 sec.

Central School
of Pyrotechnics.
12th lot of 1915
24/31 fuse
1899-1915 Mod.
without delay.

Fig. 54.

Marks on 1899-1915 fuses.

1899-1915 Model fuses (fig. 54) work for a coefficient of

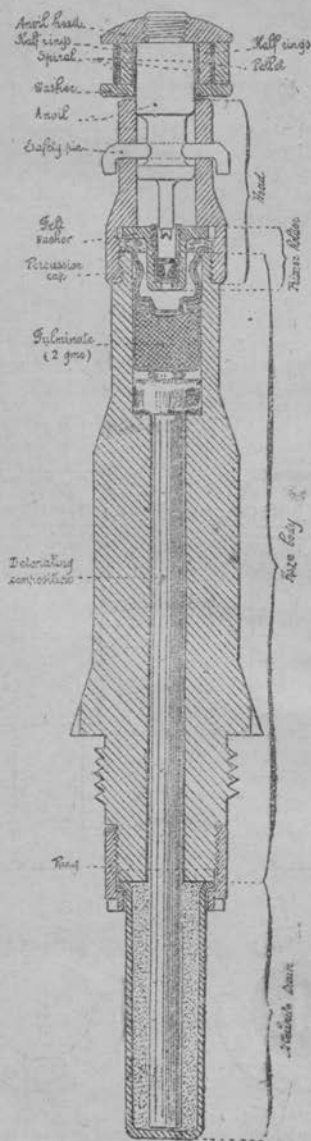


Fig. 55.

I. A. 24/31 Percussion deto- nating fuse 1915 Model.

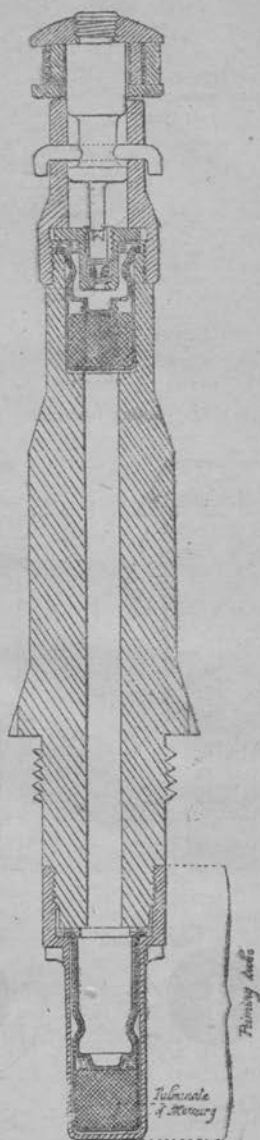


Fig. 56.

I. A. L. 24/31 Percussion deto- nating fuse 1916 Model.

acceleration of 1900 which is reached with all charges for the 75 m/m gun to 155 m/m Howitzer :

1899-1915 Mod. fuses are now reserved for 155 howitzers of all types.

All 24/31 detonating fuses 1899 Mod. are screwed on boosters by hand. They must be fitted with stabilizing felt washers.

2) I. A. FUSE 1915 MODEL (fig. 55 and 58).

3) I. A. L. FUSE 1916 MODEL (fig. 56 and 59).

I. A. fuse (1) 1915 Mod., invented by General Sainte-Claire Deville, and I. A. L. fuse 1916 Model, invented by André Lefèvre, cause the shell to detonate before the ogival head strikes the ground. The surface effects of the projectile are thus the maximum.

This result is obtained by the great length of the fuse, the head of which, being 12 centimeters in front of the projectile, strikes the ground $\frac{1}{2000}$ of a second before the ogival head. The inside mechanism is very sensitive and the detonation of the fuse is transmitted very rapidly to the bursting charge.

I. A. fuse. — The I. A. fuse is designed as follows :

A steel anvil, ending in a flat head, is held in the fuse head by a safety pin made of steel; when the anvil head strikes a resistant obstacle, this steel pin is at once broken and the anvil strikes a small primer. The flame thus produced, brings about the detonation of a primer consisting of two gm. of fulminate of mercury. The latter detonation is transmitted through a tin tube filled with melinite (2), a powder train (explosive) at the base of the fuse body, to the booster and bursting charge. The safety pin cannot be designed so as to resist accidental shocks or the shock of discharge, because if this were done, the fuse would not be sufficiently sensitive at the moment of impact. Therefore the safety-pin is given a small diameter in order to rupture easily at impact, and another safety-device is provided to insure safety during transportation and handling. It consists of two half rings made of steel, fitted together by a brass spiral which goes round the rings first inside and then outside, there being three

(1) I means instantaneous and A means "allongée", i. e., increased in length, L means Lefèvre.

(2) The detonation is transmitted through this tube at a velocity of 7000 m. per second, i. e., 10 to 39 times the remaining velocity of the projectile. The detonation therefore reaches the bursting charge at a moment when the shell is about to strike the ground, the fuse alone being in the ground.

complete turns round the rings. The spiral is ended by a pellet solid with it.

The winding of the spiral (fig. 57) is counter to that of the rifling.

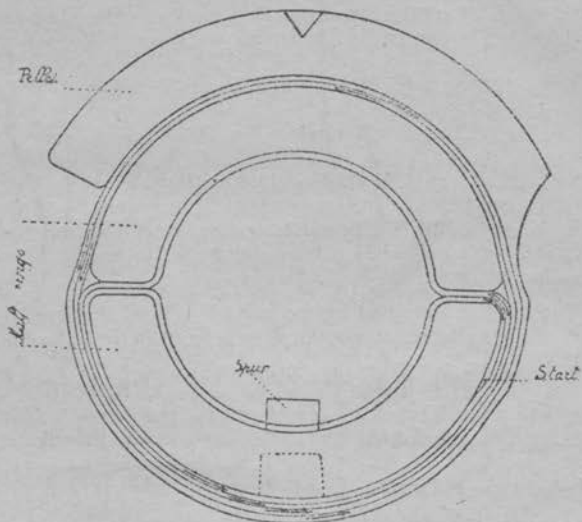


Fig. 57. — Cross section of spiral (as seen from base of fuse).

The two half rings are fitted between the anvil head and a washer placed on the head of the fuse, so that the two latter parts are prevented from coming into contact.

When the speed of rotation of the projectile is sufficient (1), the pellet is driven outward from the axis by centrifugal force thus unrolling the spiral. At the end of unrolling, the two half rings are drawn away by the spiral so that the anvil is now held in position only by the safety-pin.

At the moment of impact, the anvil-head is pushed backward by the shock, the safety-pin is broken, and the anvil strikes against the primer.

If the spiral does not overlap the washer on which it is resting, the premature tearing off of the half ring is not to be feared, but if the spiral does overlap the washer, the pellet will go backward by inertia at the moment of departure.

(1) The unrolling cannot start before the speed of rotation has reached 1800 rotations per minute. There is a certain amount of friction between the spiral edge and the washer underneath, and by inertia of rotation the spiral tightens itself up at moment of departure. For all these reasons, the half rings are set free only at about six meters from the 75 gun.

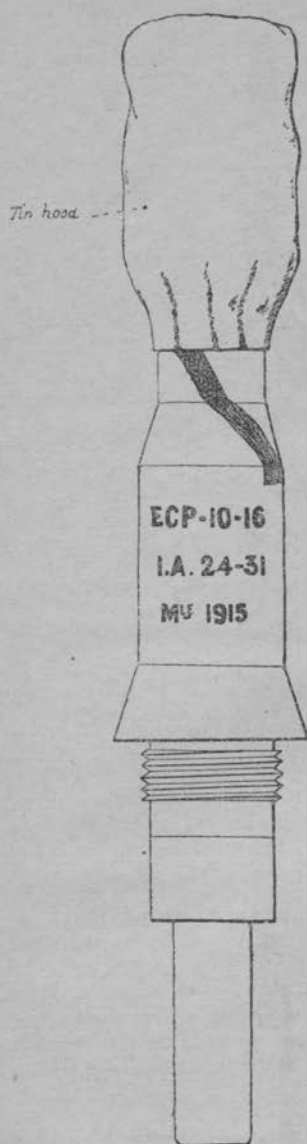


Fig. 58.

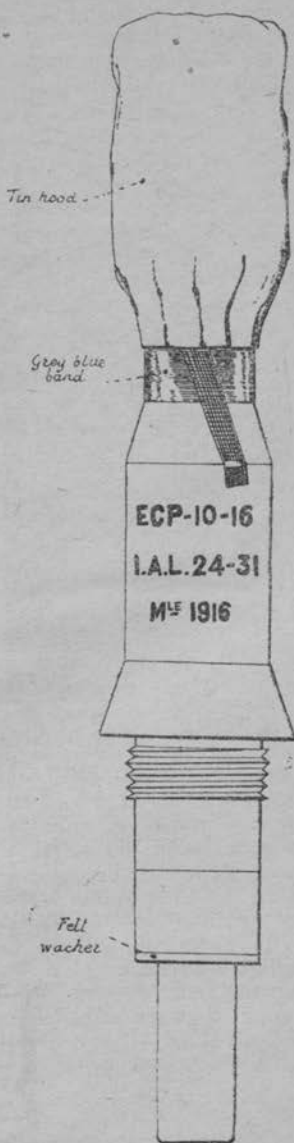


Fig. 59.

Marks on I. A. and I. A. L. fuses.

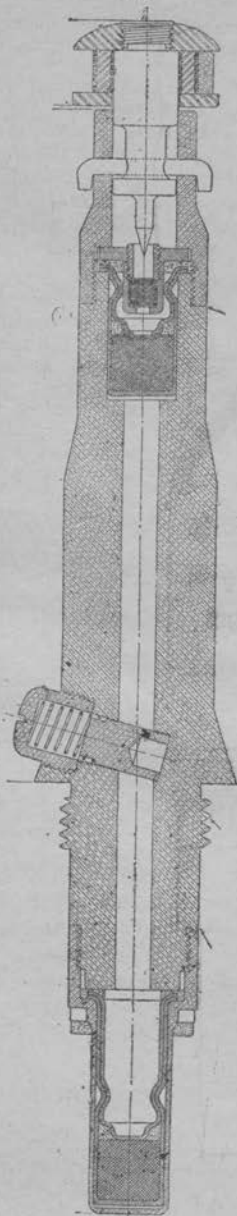


Fig. 6c.

The consequences may be either a breakage of the spiral or an *immediate* unrolling of the spiral in the gun.

In the first case, the half rings will remain in position and prevent the fuse from detonating at the moment of impact. In the second case, that of the unrolling of the spiral in the gun, the anvil-head may be able to break the safety-pin by inertia if the acceleration of the projectile is sufficient, and a premature burst would then occur in the bore of the gun.

The above remarks indicate the *great importance of the spiral and the absolute necessity for avoiding its unrolling during transportation and handling.*

In view of this, a tape of tarred canvas is wound round the spiral so as to keep it tight, and the head is covered by a thin hood made of tin. The hood and the tape are removed by pulling the free end of the tape.

When using I. A. fuses, the following directions must be adhered to :

1. Never remove the tin hood before having first screwed the fuse on the booster.

2. After removing the tin hood, be sure that the spiral is in its right position. *Never use an I. A. fuse without its spiral: such a fuse must be sent back to the depot (1).*

3. See that the ring which connects the powder train to the fuse body cannot be unscrewed. If it can be unscrewed by hand the fuse should be sent back to the depot.

4. If it is necessary to take a shell fitted with an I. A. fuse out of the gun, the anvil head must not be subjected to the shock of the rammer. To avoid this a cylindrical piece of wood is placed in the bore between the shell and the rammer.

I. A. L. fuse. — This fuse differs from the I. A. fuse in the following particulars :

1. There is no tin tube containing a melinite train.

2. Instead of a powder train at the base, there is a primer similar to that of other detonating fuses which contains a second cap with two grn. of fulminate.

A fuse similar to the I. A. L. fuse and called detonating fuse Mk. III, is now manufactured in the States. It differs from the I. A. L. fuse by a safety shutter (see fig. 60), which separates both detonators as long as the centrifugal force is not sufficient to compress its spring.

(1) The battery personnel must be thoroughly trained in the handling of the I. A. fuses. It has happened that gunners, accustomed to I. T. or R. T. fuses fitted on bombs for trench mortars, in which a safety ring has to be removed before fire, thought the spiral to be also a safety ring and removed it, thereby causing premature bursts.

24'31 percussion detonating truncated A. L. fuse.

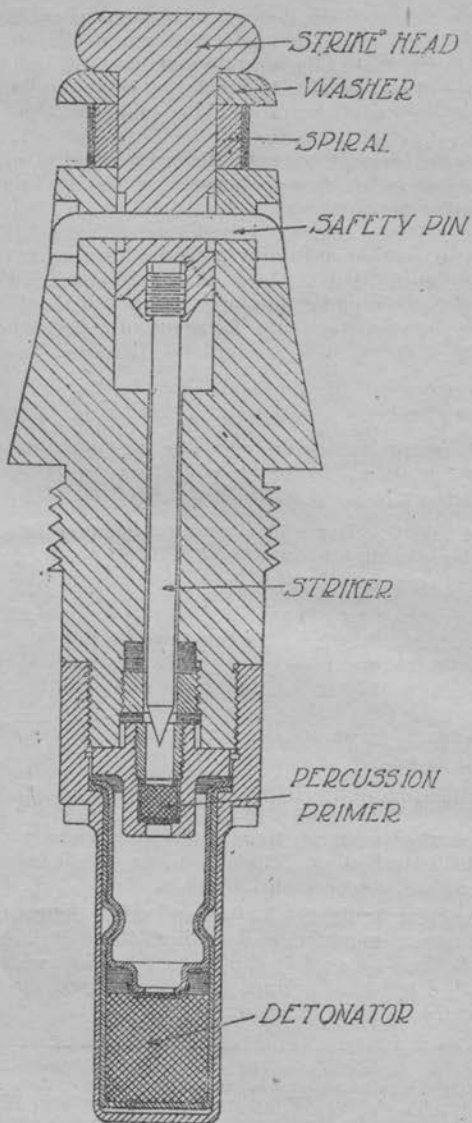


Fig. 61.

Conditions of use. — The I. A. and I. A. L. fuses may be used with all charges for the 155. With regard to the 75, these fuses must not be used with reduced charges owing to abnormal bursts taking place. As the fuse must fall on the head for the steel pin to be broken, I. A. and I. A. L. fuses must not be used for trajectories, the angle of impact of which is less than 10° .

Truncated A.L. fuse. — In order to obtain a fuse with better ballistic properties than those of the I.A.L. fuse, a new fuse called "Truncated A.L. fuse" has been designed and is now in use.

Figure 61 shows a section of this fuse.

The mechanism of this fuse is quite similar to that of the I.A.L. The safety device is however somewhat different. One of the two half rings has the shape of a U, as shown in figure 62. Moreover, in order to delay the unwinding of the

Spiral roll.

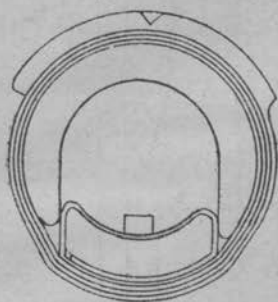


Fig. 62.

spiral, a washer is inserted between the head of the striker and the top of the spiral. As long as the acceleration of the projectile is positive, this washer, owing to inertia, presses on the spiral. The fuse is provided with a tin foil cap which is to be removed before the fuse is fired.

I. A. and I. A. L. fuses with red head. — In these fuses (which are not to be used for the 75, 155 S. H. and 155 G. P. F.) the spiral (fig. 63) is wound in the same direction as the grooves of the gun. The pellet therefore goes away from the axis by the loosening due to inertia of rotation, this action taking place for a much smaller speed of rotation than in the preceding case.

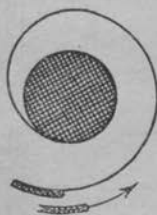


Fig. 63.

It follows that such fuses are particularly suited to projectiles having a small initial velocity. This is the case with the

155 Howitzer 1891 Mod. for velocities less than 200 m. per second.

In these fuses, the anvil head and the top of the hood are painted red.

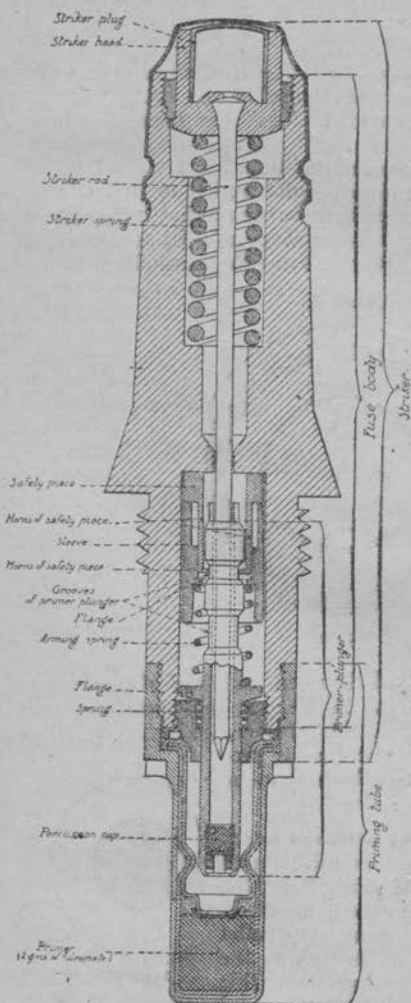


Fig. 64.

Before departure.

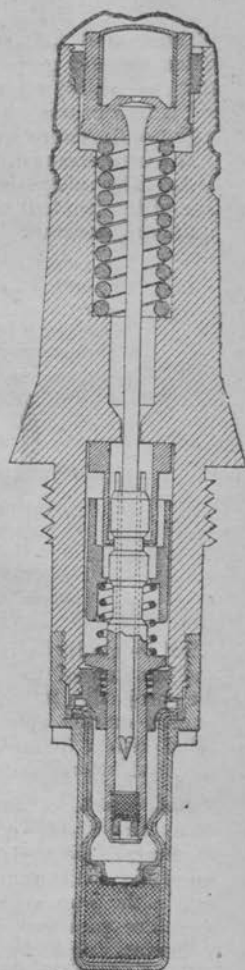


Fig. 65.

During travel through bore (1st stage).

The fuses are also used for guns which are rifled to the left.

I. A. and I. A. L. fuses of the first kind would not be suitable in this case, because the spiral, being also wound to the left, would be unrolled too quickly and would cause premature bursts.

4) INSTANTANEOUS PERCUSSION DETONATING FUSES.

24/31 R Y 1917 Model.

This fuse has been so designed by Commandant Remondy as to be absolutely safe during transportation and handling as well as very sensitive at the moment of departure and at the moment of impact.

The fuse body contains :

1. *A striker* made of bronze, the top of which is fitted inside with a head closed by an aluminium plug. The whole is held in position by a long spring.

2. *A primer-plunger* which is a kind of tube with two grooves and a flange outside. Through this tube the striker is able to slide. A cap containing fulminate of mercury is at the base of the tube.

3. *A sleeve* with a hollow and a flange inside.

4. *An arming spring* fitted between the flange of the sleeve and that of the primer-plunger.

5. *A safety-piece* fitted against the sleeve and in which six clasp-hooks have been cut; these hooks are fitted in the upper groove of the primer-plunger.

6. *A small spring* fitted between the flange of the primer-plunger and the plug supporting the whole mechanism.

A detonator similar to those already described is fitted at the base of the tube.

Working.— 1. At the moment of departure (fig. 64), the striker goes backward by inertia pressing the long spring, but its point cannot reach the primer because the distance is too great. At the same time the sleeve goes backward by inertia compressing the arming spring (fig. 65).

2. As soon as the sleeve has gone backward, the clasp-hooks of the safety piece are no longer held in the upper groove of the primer plunger. The safety piece is therefore free to go backward by inertia (fig. 66) and the hooks fit themselves in the lower groove of the primer plunger (fig. 67).

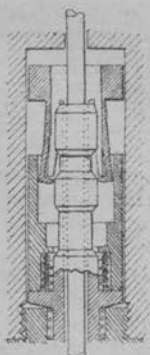


Fig. 66.

During travel
through bore
(2nd stage.)

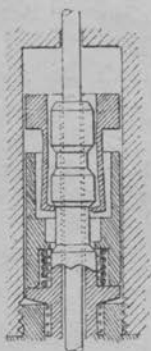


Fig. 67.

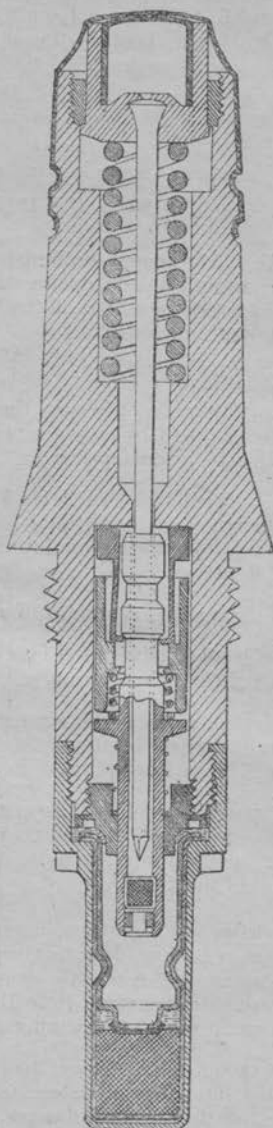


Fig. 68.

On the trajectory.

3. When the shell is at the muzzle:

a) the striker goes forward, owing to the action of its spring.

b) the sleeve goes forward also and the hooks of the safety-piece are then held in position by the sleeve in the lower groove of the primer-plunger.

c) primer - plunger, arming spring, sleeve and safety piece are connected together and slide forward owing to the action of the small spring behind. The primer is then at about 0.5 m/m from the end of the striker (fig. 68).

4. At the moment of impact, the striker is suddenly stopped while the other parts of the fuse continue forward. The consequence is that the primer is hurled against the striker.

On hard ground, the R. Y. fuse (fig. 69) is not as sensitive as the I. A. fuse on account of its smaller length.

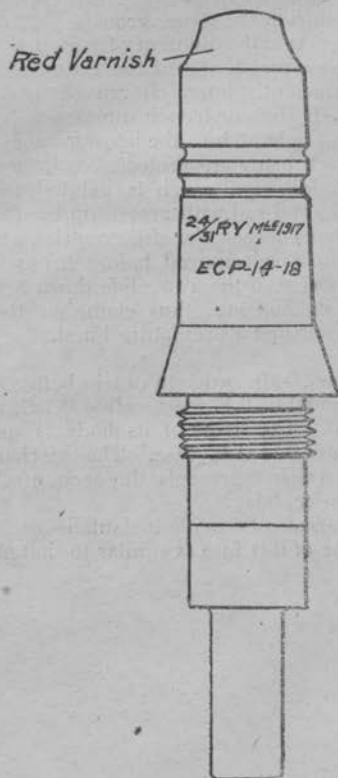


Fig. 69.

On soft ground, both fuses act in the same way. But on very soft ground, the R. Y. fuse is more sensitive, because the effort necessary to drive its striker in is 15 kg., whereas it is 300 kg. for the I. A. fuse.

Safety. — 1. Falling on its point cannot make the fuse act because the striker cannot reach the primer.

In order to increase the effort necessary to drive the striker back, a washer has been recently inserted between the base of the striker spring and its rest in the body of the fuse.

The necessary effort is thus increased to 18 kg. and this fuse may be used for :

$$V_0 < 750 \text{ m.s.}$$

2. Falling on its base may cause the sleeve to go backward, but the safety piece is freed too late for the inertia to act upon it, its weight not being great enough to make the hooks jump outside the upper groove.

This fuse works at the moment of departure for a coefficient of acceleration equal to 340 if the action of the propelling gases lasts sufficiently long. It can be used in connection with all modern guns or trench mortars.

It is screwed by hand into the booster tube; the head of the striker and its housing are protected against dust and moisture by a tin foil cap, which is painted red for the first model of fuse, and red with green top for the fuse with the washer inserted between the striker spring and its rest.

This cap must be removed before firing as otherwise it might, at discharge of the gun, slide down between the striker head and its housing, thus clamping the striker in its position, and causing a premature burst.

R.Y.G. Fuse. — In order to obtain better ballistic properties, a new model of R.Y. fuse, called R.Y.G. 1918 Model has been designed. The shape of its body is quite similar to that of the truncated A.L. fuse. The mechanism is shown by figure 70 which represents the section of an R.Y.G. fuse with long powder delay.

This fuse can also be made instantaneous.

The working of this fuse is similar to that of the R. Y. fuse.

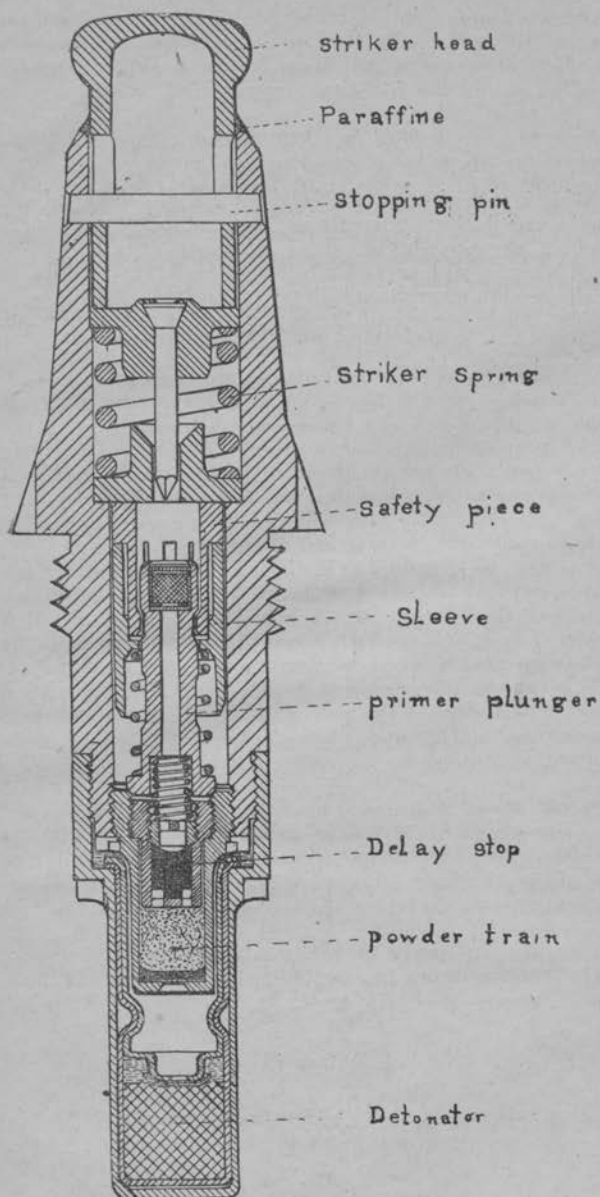


Fig. 70.

5) SCHNEIDER FUSES.

24/31 fuse 1916 B Model.

This fuse works by centrifugal force and is designed so as to be safe during transportation and not to function in the gun. The principle has already been explained.

It is made with or without delay. The latter kind is specially used in connection with 75 gas shells.

The lateral surface of the cap is painted black when the fuse is with powder delay (0.05 sec.) and white when it is without powder delay.

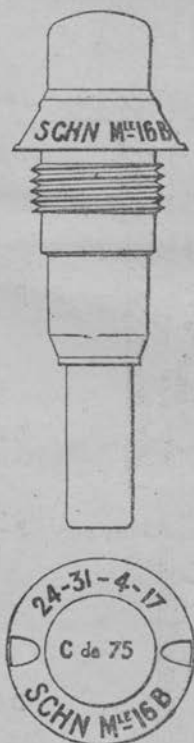


Fig. 71.

Marks on Schneider
fuse 1916 B Model.

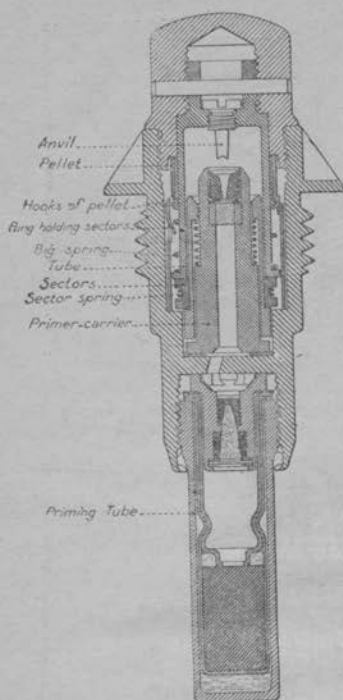


Fig. 72.

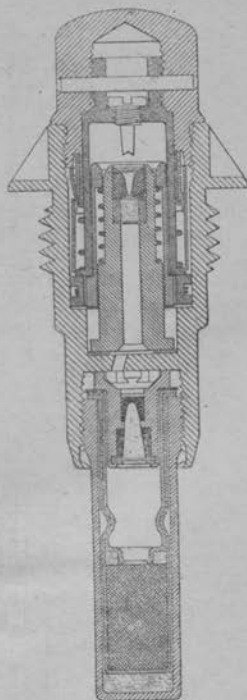


Fig. 73.

It will not operate for a speed of rotation under 12000 rotations per minute, the latter limit being reached only by the 75 gun fired with a normal charge. (17000 r. p. m.)

It is screwed by hand into the booster.

B. Time fuses and combination fuses of French design.

All these fuses are now provided with a tin foil cap which entirely covers the cone of the fuse and is pressed in a groove cut in the lateral surface of the powder chamber.

The color of this cap varies with the nature of the fuse.

It must be removed before the fuse is set.

1) FOB SHRAPNEL:

a) **22/31 combination fuse 1897 Model.** — It consists of a time mechanism and a percussion mechanism (fig. 74-75).

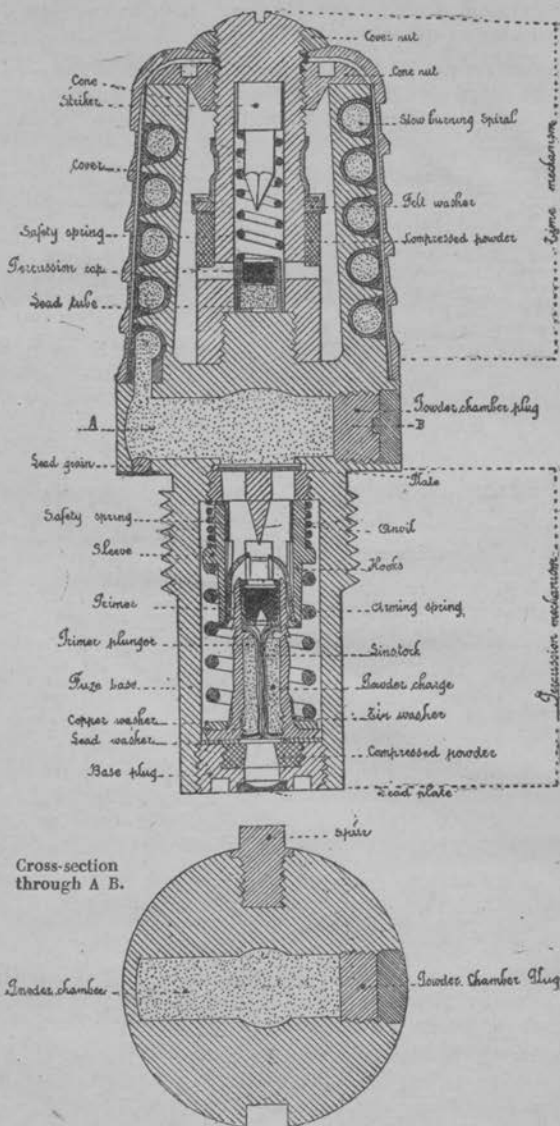
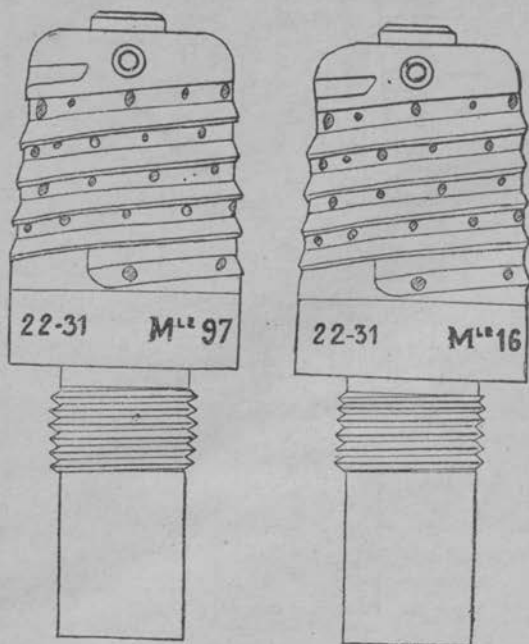


Fig. 74.

22/31 Combination fuse 1897 Model.

The operation of the former has been described previously : the working of the latter also.

The maximum time of burning is *24 seconds*. These fuses may be fitted (for the 75) on base charged shrapnel 1897 Model; on projectiles 1897 A and 1897 M Models.



22/31 Combination fuse 1897 Model.

22/31 Time fuse 1916 Model.

Fig. 75.

Marks on 22/31 fuses.

Their minimum coefficient of acceleration is about *2800*. The tin foil cap of this fuse is painted white.

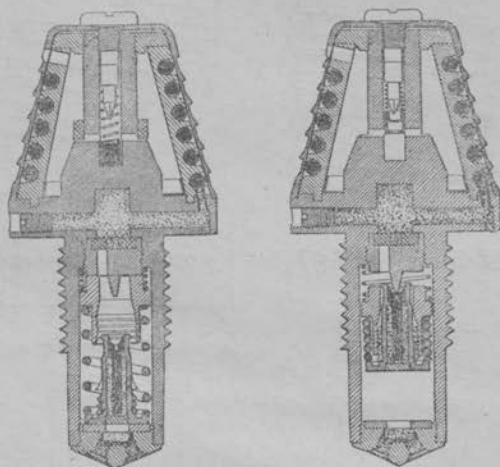
b) 22/31 time fuse 1916 Model. — This fuse differs from the preceding one only by the fact that it is not fitted with any percussion mechanism. The tin foil cap of this fuse is painted blue. It is especially used for anti-aircraft shrapnel.

22/31 time fuse A 1917 Model. — This fuse is similar

to the preceding one, but its maximum time of burning is 32 seconds instead of 24.

Its tin foil cap is painted black with a blue ring at the lower part.

c) **30/55 combination fuse 1889 Model.** — This fuse, shown in fig. 76-77, is similar to the preceding one. The



Before departure.

At moment of impact.

30/55 Combination fuse 1889 Model.

Fig. 76.

maximum duration of combustion is 49 seconds. It is used with shrapnel or case-shot, for the 155 gun and others.

Its minimum coefficient of acceleration is about 2800.

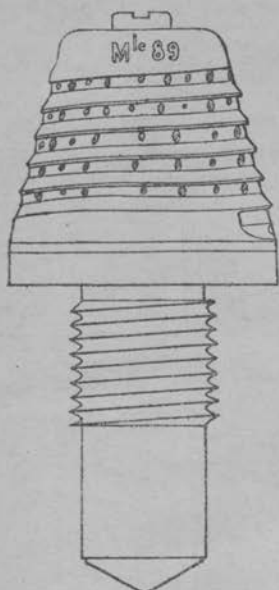
The tin foil cap of this fuse is painted white.

d) **30/55 time fuse 1913 Model.** — This fuse (fig. 78) differs from the preceding one *only by the fact that there is no percussion mechanism*. The base of the fuse is therefore shorter.

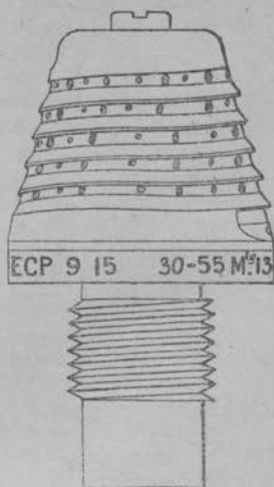
It is fitted on tracer shells for 75 and 105 guns as well as on 75 shrapnel 1907-1911 A Model, used against aircraft. Its minimum coefficient of acceleration is about 2800.

The tin foil of this fuse is painted blue.

Marks on 30/55 fuses.



30/55 Combination fuse
1889 Model.
Fig. 77.



30/55 Time fuse
1913 Model.
Fig. 78.

2) FOR H. E. SHELLS :

Detonating fuses (time and combination). — These fuses are designed like those already described, but they are fitted with a detonating system consisting of a cap which contains two grams of *fulminate*. The combination fuses are also fitted with the percussion mechanism of the 24/31 fuse 1899-1908 Model (with short delay). There are six types:

1. 24/31 time detonating fuse 1915 Model (fig. 81), with blue cap.
2. 24/31 time detonating fuse A 1916 Model, with black cap and blue ring on the lower part of it, maximum duration 31 seconds.
3. 24/31 combination detonating fuse 1916 Model, with white cap (fig. 79 and 83).
4. 24/31 combination detonating fuse A 1918 model with black cap, and white ring on the lower part of it. Maximum duration = 31 seconds.

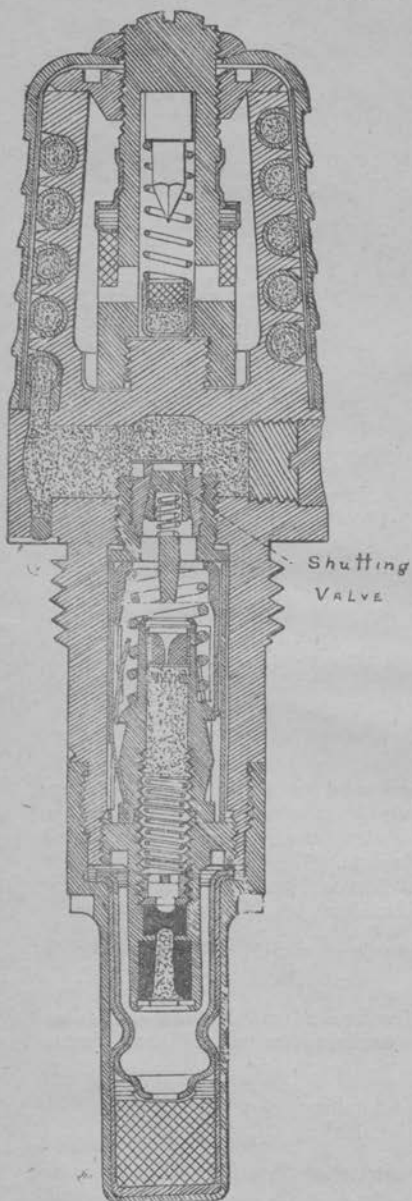


Fig. 79.
[24/31 Combination detonating
fuse 1916 Model.

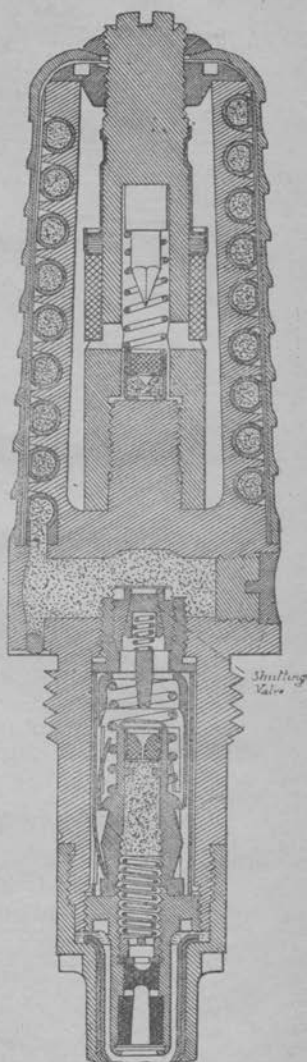


Fig. 80.
24/31 Combination detonating
fuse L. D. 1917 Model.

5. 24/31 combination detonating fuse L. D. 1917 Model with white cap. Maximum duration = 51 seconds.
6. 24/31 combination detonating fuse L. D. A. 1918 Model with black cap and white ring on the lower part of it.



Fig. 81.

24/31 Time detonating
fuse 1915 Model.

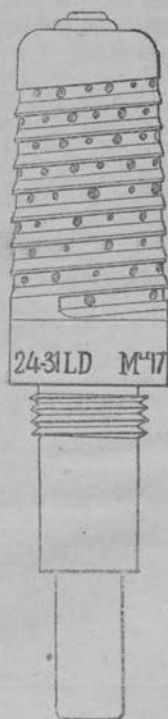


Fig. 82.
24/31 L. D.
Combination detonating
fuse 1917 Model.



Fig. 83.

24/31 Combination
detonating
fuse 1916 Model.

7. 24/31 combination detonating fuse, 1916 Model.
8. 24/31 combination detonating fuse, 1917 Model (fig. 80 and 82) with long duration of combustion (L. D.).

The 1915 Mod. fuse differs from the 1917 Mod. fuse only by the fact that it has no percussion mechanism.

The 0.05 sec. delay is introduced in order to prevent premature bursts which might be accidentally caused by the direct

transmission of the detonation of the fulminate to the powder chamber at the moment of departure. In such a case the combustion of the delay would give the shell sufficient time to leave the gun. The premature burst would then take place at some distance from the gun.

In the 1916 and 1917 combination detonating fuses, a valve is fitted between the powder chamber and the anvil of the percussion mechanism. The action of the valve is to insure a constant speed of combustion of the delay by preventing the outside air from getting inside. When the powder in the chamber detonates, its gases push the valve backward, but when the powder delay is ignited the resulting gases push the valve forward, thus preventing the air from getting inside.

The duration of combustion of 1915 Model and 1916 Model fuses is *24 seconds*.

That of the 1917 Model fuse is *51 seconds*. The minimum coefficient of acceleration is about 2800.

These fuses are screwed by hand into the booster in the same manner as other detonating fuses (*felt washer*).

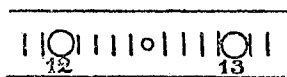


Fig. 84.

With the exception of the L. D. fuse 1917 Model, the heads of combination fuses are now scaled in seconds, half seconds and in some cases tenths of a second (fig. 84). The figures indicate the duration of combustion.

The head of the L. D. fuse 1917 Model is scaled in seconds

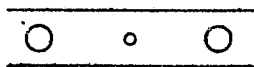


Fig. 85.

and half seconds, the seconds and half seconds being indicated by holes (fig. 85). In the near future, this scale will be completed by figures indicating the duration of combustion, as in the case of other fuses.

Time and combination fuses of American design.

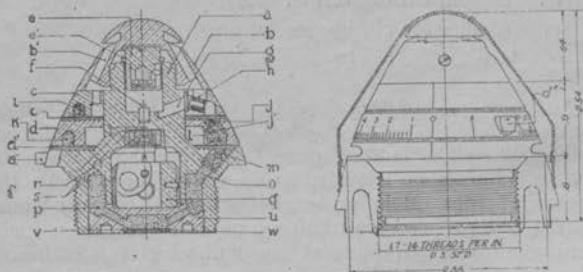
The only type of fuse used is similar to that explained in the chapter :

“Combination fuses of U. S. manufacture”.

The models used are the following ones :

For the 75 m/m shrapnel, 21 sec. combination fuse
M. 1907 M.

21 sec. combination fuse
M. 1915 M. (see fig. 86.)



21 second combination fuse model of 1907 M.

Fig. 86.

This fuse consists of the following parts, assembled as shown in the drawing (fig. 86) :

- a. Body, bronze.
- a'. Stop pin, brass.
- b. Closing cap, brass.
- b'. Vents in closing cap.
- c. Upper time-train ring. Tobin bronze.
- c'. Washer for time-train ring, graduated, felt cloth.
- d. Time-train ring, graduated, Tobin bronze.
- d'. Washer for body, felt cloth.
- d''. Rotating pin, brass.
- e. Concussion plunger.
- e'. Concussion resistance ring, brass.
- f. Firing pin, brass.
- g. Vent leading to upper time-train.
- h. Compressed powder pellet.
- i. Upper time-train, compressed powder.
- j. Compressed powder pellet, in vent leading to lower time-train.
- j'. Compressed powder pellet in lower time-train vent.
- k. Lower time-train, compressed powder.
- l. Brass disk, crimped in place.

- m. Compressed powder pellet in vent c.
- o. Vent leading to magazine.
- p. Powder magazine.
- q. Percussion plunger.
- r. Percussion primer.
- s. Vents leading from percussion primer to magazine.
- u. Bottom closing screw, brass.
- v. Washer for closing screw, muslin.
- w. Washer for closing screw, brass.

The body "a" of this fuse is machined from a bronze casting. The time-train rings "c" and "d" are turned from hard-rolled rods of Tobin bronze. An annular groove in the shape of a horseshoe is milled in the lower face of each of the time-train rings. Meal powder is compressed into these grooves under a pressure of 66,000 pounds per square inch, forming a time-train, the total length of which is 9 inches.

The time element of this fuse is composed principally of the following parts: The time or concussion plunger "e", the concussion resistance ring "e'", the firing pin "f", the vent "g", leading to the upper time-train, the compressed powder pellet "h", the upper time-train "i", the vent "j", the lower time-train "k", the compressed powder pellet "m" in the vent "o", leading to the powder magazine "p".

The plunger "e" is cylindrical in shape and contains the percussion composition in a recess at its base. The weight of the plunger rests upon the concussion-resistance ring "e'", which keeps the primer from contact with the firing pin. At discharge of the gun the resistance of the ring is overcome and the primer is exploded by contact with the firing pin.

As stated above, the annular grooves into which the meal powder of the time-train is pressed are in the shape of a horseshoe, a solid portion being left between the ends of the groove in each ring or disk.

The upper time-train ring "c" is prevented from rotating by pins which are halved into the fuse body and the inner circumference of the ring.

The vent "g" is drilled through the walls of the concussion-plunger chamber and is exactly opposite a hole in the inner surface of the upper time-train leading to the end of the train from which the direction of burning is counter clockwise.

The hole "j" is drilled through the upper face of the lower time-train ring "d" to the end of the lower time train groove, from which the direction of burning is clockwise. The lower time-train ring is movable and is graduated on its outer edge in a clockwise direction from 0 to 21.2, each full division corresponding to one second time of burning in flight; these divisions are subdivided into five equal parts corresponding to one-fifth second. A radial pin "d'" is provided in the lower

ring for engagement with a notch in the fuse setter for setting the fuse. A line on the lower flange of the fuse stock is the datum line for fuse settings.

The vent "o" is drilled through the flange of the fuse stock to the powder magazine "p", and leads to the same end of the lower time-train as the vent "j"—that end from which the direction of burning is clockwise when the fuse is at its "zero" setting.

The action of the fuse as a time fuse is as follows :

Assume first the "zero" setting as shown on the figure.

At discharge of the gun the time plunger arms and fires its primer. The flame through the primer passes out through the vent "g", igniting the pellet "h", the end of the upper time-train "i", down through the vent "j", to the end of the lower time-train "k", and thence through the vent "o" to the magazine "p", the flame from which is transmitted to the base charge in the shrapnel. It will be seen that for the "zero" setting of the fuse the origins of both upper and lower time-trains are in juxtaposition. Assume any other setting, say 12 seconds. The vent "j" has now changed its position with respect to the vent "h", leading to the beginning of the upper time-train and the vent "o", leading to the powder magazine "p", both of which points are fixed by the angle subtended between the 0 and the 12-second settings. The flame now passes out through vent "g" and burns along the upper time-train in a counter clockwise direction until the vent "j" is reached, where it passes down to the beginning of the lower time-train and burns back in a clockwise direction to the position of the vent "o", whence it is transmitted by the pellet of compressed powder "m" to the powder magazine "p".

For the 21.2 second setting the vent "j", leading to the beginning of the lower time-train, is opposite the end of the upper time-train, and the end of the lower time-train is opposite the vent "o" leading to the powder magazine. It will now be seen that to reach the magazine "p" and burst the shrapnel, the entire length of time-train in both rings must be burned.

As already stated, the annular grooves in the lower face of each ring for the powder trains do not form complete circles, a solid portion being left between the ends of the grooves in each. This solid portion is utilized to obtain a setting at which the fuse cannot be exploded, known as the "safety point".

This point is marked by a line on the outer edge of the movable time-train, surmounted by an "S", and is located about halfway between the zero mark and the 21.2 second graduation. When this point is brought opposite the line on

the lower flange of the fuse body, the vent "j" is covered by the solid metal between the ends of the upper train, and the vent "o", leading to the powder magazine "p", is covered by the solid metal between the ends of the lower or movable time-train.

At the safety setting it will be seen that the upper train may burn entirely out in case of accidental firing of the time plunger, or in case it may be desired to burst the shrapnel by impact or percussion, without the flame being able to reach the magazine "p".

The cloth washers "c'" and "d'" are glued to the upper face of the graduated time-train ring and to the upper face of the flange on the fuse stock. These surfaces are corrugated, as shown, to make the washers adhere more strongly. The function of the washers is to make a gas check and prevent premature action of the fuses.

The compressed pellet "j'", in the vent leading from the outside to the beginning of the lower time-train, is to release the pressure of the gases due to the burning train. The gases from both time-trains escape into the outer air through the annular spaces shown in the illustration and the vents "b'", in the closing cap.

The percussion element of this fuse as shown in the plate consists of a percussion plunger "q" and an ordinary percussion primer "r".

The system of vents through the walls of the fuse shown in the figure conduct the flame from the percussion primer to the magazine "p".

The bottom closing screw closes the percussion-plunger recess and keeps the powder in the magazine. The muslin washer "v" is coated with shellac and held in place by the brass washer "w", over the outer edge of which a projecting lip is crimped.

These fuses are issued assembled in shrapnel. For transportation in limbers and caissons the fuse should always be set at the safety point.

The fuse is provided with a waterproof hood of thin brass, hermetically sealed. The hood should be stripped off before an attempt is made to set the fuse.

For the 75 m/m H. E. shell 21 sec. special fuse.

For the 155 m/m S. H. shrapnel 45 sec. combination fuse M 1907 Model, mechanism similar to that of the 21 second fuse.

For the 155 m/m H. E. shell 45 sec. special fuse.
21 second combination fuse M. 1907 Model.

Directions relative to use of fuses.

The following rules concerning fuses are of such importance that they cannot be emphasized too strongly. *They must be rigidly observed.* They have often been put in Army Orders, but despite this, hundreds of needless deaths have been caused because of their infringement.

1. It is absolutely forbidden to disassemble a fuse.
2. Any fuse which has been accidentally disassembled must be destroyed at once. If fired it may cause a premature burst in the gun. If handled, a grave accident may happen.
3. Any fuse which has been fired is dangerous because it is then able to detonate under the action of a slight shock. It is absolutely forbidden to touch it whether it is fixed on the projectile or not.

CHAPTER IV.

PROPELLING POWDER CHARGES.

ART. 1.

GENERAL NOTES ON POWDERS.

Propelling powder charges now in use belong to one of the following classes:

1. Black or mechanical powders,
2. Smokeless or chemical powders (*e. g.*, B or US powders).

1. — Black powders.

Black powders are mixtures of saltpeter, *i. e.*, potassium nitrate (KN O_3) sulphur and charcoal. The proportions of

these substances, which vary with the various powders, are close to 75 % saltpeter, 12.5 % sulphur and 12.5 % charcoal.

Charcoal is used to burn the saltpeter, and sulphur facilitates the ignition.

Black powders may deteriorate either by the formation of powder dust or by moisture.

Dust increases the quickness of the powder, causing sometimes abnormal pressures during firing. Dusty powder must be fanned to remove the dust.

The effect of moisture is that a coat of saltpeter is formed on the surface of the powder which then becomes pasty and cannot be used. This is the reason why all appliances containing black powder must be carefully kept free from atmospheric moisture.

Black powder is very easily ignited by contact with a burning body or by a spark.

Its ignition, even in the open air, may cause a very dangerous explosion.

Uses of black powders. — They are no longer used as propelling powders because they are not progressive enough, give a great amount of smoke and leave so much residue that the gun would have to be cleaned after every shot.

A small percentage, 1 % as a maximum, of black powder, is mixed with smokeless powders in order to ignite the smokeless powder.

Black powder is also used for the loading of shrapnel, case shot, etc., as the visibility of burst is thereby increased.

Primers, time and combination fuses, powder trains and powder delays in percussion fuses and detonators contain some black powder.

2. — Smokeless powders.

They are chemical powders, *i. e.*, they consist of only one chemical body instead of being a mixture as in the case of black powder.

They burn without smoke and without leaving any solid residue.

They are obtained by the action of nitric acid on cotton.

It is essential that a lot of smokeless powder should be as homogeneous as possible, both as to the ballistic standpoint and as to the life of the powder.

Lots are obtained by mixing methodically several layers of powder so as to comply with given conditions of initial velocity and maximum pressure.

The French B powders are generally delivered in the shape of flat and regular grains when used for rifles and of flat ribbons when used for guns.

Their color varies from light yellow to dark brown according to the series; this is due to their mixture, as explained above; but the color of one layer must be uniform.

Some powders are artificially colored red in order to be distinguished from others.

The thickness of bits of powder varies from some tenths of a m/m. to 5 m/m.

The quickness varies approximately in reverse ratio to their thickness.

American US powders are also used. Their chemical formula is very similar to that of the French powders, but they are delivered in the shape of small cylinders in which one or more, usually seven, holes are drilled (fig. 87).

Smokeless powders burn with a characteristic greenish flame and are not so easily ignited as black powder. As previously stated, black powder is mixed with them to facilitate ignition.

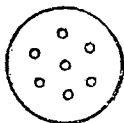


Fig. 87.

Smokeless powders are progressive in action. Their combustion is comparatively slow and there is generally no explosion if the combustion takes place in an open space.

Smokeless powders gradually decompose, several gases being formed (CO_2 , CO , N , N_2O , NO , H).

This decomposition, which is due to loss of nitrogen, is very slow at an ordinary temperature but is much quicker when the temperature increases or under the action of moisture.

This is the reason why smokeless powders must be kept in watertight boxes (metallic boxes with rubber joints or boxes lined with zinc). These boxes must not be subjected to heat or moisture and as far as possible they must be opened only in dry weather and not in the sun.

Bad powders are characterized by:

1. A special smell of nitrous gases when the boxes are opened.

2. Binding strings which are eaten or have become yellow or brown.

3. A soft and oily condition, the acid on top, light yellow spots with darker edges, and some parts more transparent than others.

Powders suspected of decomposition should be isolated, and sent back to the rear for examination and possible destruction.

ART. 2.

CHARGE BAGS. — CARTRIDGE CASES.

The powder charge may be contained in :

a) either a *charge bag* which is fired by means of a *free primer* (for instance : 155 S).

b) or a metallic *cartridge case* fitted with a *primer*. The case may or may not be fitted to the projectile.

The bundles of powder must never be modified nor the powders mixed.

A. — Charge bags.

Bags. — They are generally made of silk or baize (fig. 88). Being made of animal matter, they do not leave any unburnt residue after the projectile has been fired.

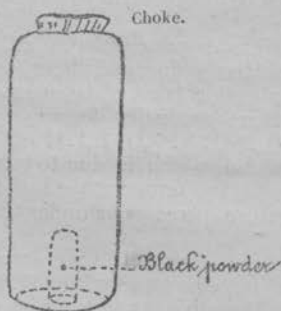


Fig. 88. — Charge bag.

The bag is put into the gun with the black powder igniter in the rear so that flame of the free primer may easily reach the igniter.

Inside loading. — Black powder. — A small charge of black powder is put at the center of the base of the bag, as shown in the sketch. However, the smokeless powder may not be immediately ignited and, for this reason, one should wait from 30 seconds to two minutes before repriming or opening the breech in case of a misfire.

The flat ribbons of B powder are generally tied in small bundles which are placed parallel to the axis of the bag, one bundle resting on top of another.

Reduced charges. — It is sometimes necessary to fire

with reduced charges. In such cases, a determined number of bundles should be taken out of the bag, the figure inscribed on the topmost bundle indicating the whole charge that remains. The length of the bag is therefore reduced but its diameter remains unaltered.

The charge bags manufactured in the States are made of a base section, containing the lowest charge, and several increment sections. The latter are fastened on the top of the base section by means of ribbons of the same material as that of the charge bag sewed on the base of the base section bag, and tied over the top of the increment sections. The reduced charges are obtained by the removal of one or several increment sections.

B. — Cartridge cases.

Primed cartridge cases permit rapid loading and firing and provide a simple obturation system. However these cases are expensive. They may be altered in shape by shock, they increase the dead weight, they must be concealed at the battery position and they make it difficult to verify the condition of the powder.

Cartridge cases are made of brass. Their shape is shown in fig. 89 and 90.

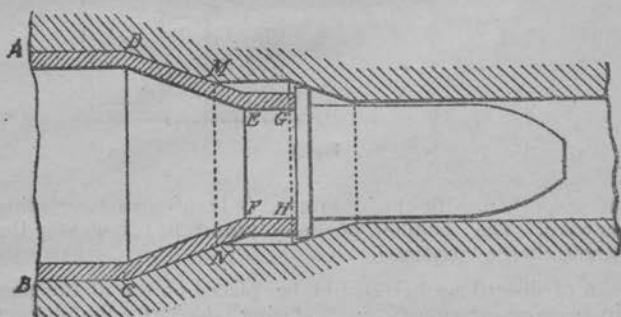


Fig. 89.

A B C D is slightly bevelled to facilitate the case being put into and extracted from the gun. C D M N is part of a cone which is fitted against a corresponding bevel of the gun.

E F G H is fitted on the base of the projectile. The base of the cartridge case has a flange against which the extractor arms operate.

The extra thickness K L (fig. 90) of the cartridge case base brings forward the pressure of the propelling gases, which is therefore rendered smaller in the vicinity of the extractor

recess where the gun walls are less resistant. This extra thickness also facilitates priming.

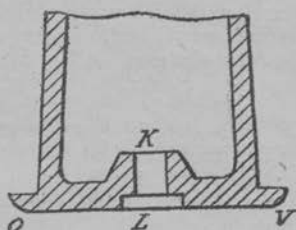


Fig. 90.

When varying charges are put in the cartridge cases (155 H 1915 and 155 H St-Chamond), they are put up in small flat bags (fig. 91). These bags are set one on top

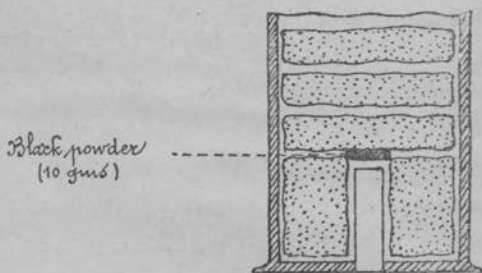


Fig. 91.

of the other, with the numbered side of each bag facing upward. The number of the topmost bag indicates the whole charge contained.

A cardboard washer should be placed on top of the bags in any case for compactness. Firing tables give the charges to be used for each particular gun.

C. — Marks on charge bags and cartridge cases
(French system.)

a) **Charge bags.** — There are two kinds of marks, one referring to the bag itself, the other to the charge.

i. *Marks relative to the bag proper.* — The color of the bag varies according to the powder it contains.

The marks referring to the bag itself are found on a line parallel to the axis of the bag and indicate :

- a) type of gun.
- b) nature of powder.
- c) works where the bag has been made and year of manufacture.
- d) nature of projectile; this mark exists only when the preceding marks may apply to bags for different uses.

FOR EXAMPLE : Obus O means ordinary shell,

Obus A — long shell,

Obus R — Armor piercing shell.

2. *Marks referring to the charge.* — They are put under the preceding or at right angles with them.

They indicate :

- a) type of gun.
- b) weight and nature of powder,
- c) powder lot.
- d) works where charge has been completed together with the month and year of manufacture.

b) **Cartridge cases.** — Black marks on the body of the case indicate :

- a) type of gun,
- b) weight and nature of powder,
- c) powder lot,
- d) works where the case has been loaded and date of loading.

Special marks on 75 cartridge cases (fig. 92).

1. Weight of powder charge (variable weight),
2. Nature of powder (B S P or U S₃ for normal charges B C for reduced charges),
3. Diphenylamine,
4. Percentage of diphe- { Sometimes mixed with the B
nylamine. } powders in order to increase
their stability.
5. Number and year of manufacture of powder lot.
6. Initials of factory which manufactured the powder

In case of foreign powder, marks 5 and 6 are replaced by a lot mark which varies with the powder origin.

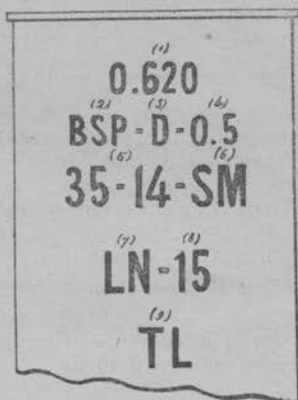


Fig. 92.

7. Works where the powder has been loaded in the cartridge case.

8. Year of loading.

Marks (2) (5) and (6) are necessary for firing data.

Marks on charge bags and cartridge cases, American system.

a) Stencilling on bags for Howitzers. — The words "INC. ZONEX" are stencilled on each increment of the powder charge in three positions on sides 120° apart.

On the base charge are stencilled lengthwise the caliber and model of Howitzer, powder lot, weight of powder in base charge, initials of loading plant and date of loading.

b) Stencilling on base for guns. — The bags for each section for powder charge for guns are stencilled to show the fractional part of the complete charge contained in the section, the caliber and model of the gun, the powder lot number, the muzzle velocity of the gun given by the complete charge, the initials of the loading plant.

c) Stencilling on cartridge cases.

1. On base, for H. E. shells, normal charge, a black stripe $3/8$ inch wide across the center of the base.

For H. E. shell reduced charge, 2 black stripes $3/8$ inch wide across the center of the base, and perpendicular to each other.

For shrapnel, no stencilled marks.

2. *On body*, for all cartridges, the words :

POWDER LOT No. X

stencilled in black immediately above the base.

For reduced charges, two black stripes are stencilled immediately below the shoulder, with the words :

REDUCED CHARGES

between them.

CHAPTER V.

PRIMERS.

A. — Fixed primers.

When smokeless powder is put in a cartridge case, the latter is fitted with a primer (fig. 93) which consists of a tube loaded with black powder. This tube, placed inside the

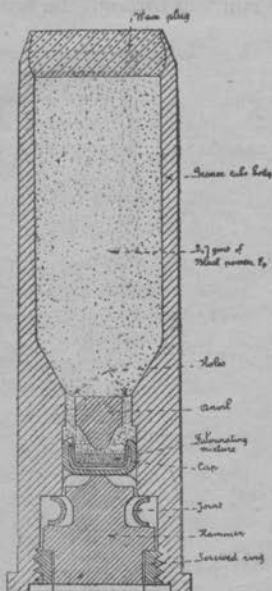


Fig. 93. — Primer tube.

cartridge case, protrudes inwards and is capped with a layer of B powder.

At the lower end of the primer is an anvil, a cap of fulminate of mercury, and a small hammer. The latter is held in position on top by an elastic joint or a pin and at the base by a ring screwed on the primer body.

The small hammer is acted upon by the firing pin and pushes the cap of fulminate against the anvil, thereby causing the ignition of the black powder and smokeless powder.

The type of fixed primer which is to be used in the States for all 75 m/m gun ammunition is the 49 grain percussion primer mark II.

It consists of a brass body approximately 2 inches in length and 5/8 in diameter, loaded with 49 grains of black powder, battery cup, firing plug, retaining bushing, cap, percussion pellet and anvil. The principle of working is the same as that of the French fixed primer.

B. — Free primers.

A free primer (fig. 94) is used in the 155 S. H. to ignite the powder when the latter is in bags. The free primer is placed in the hole running through the breechblock.

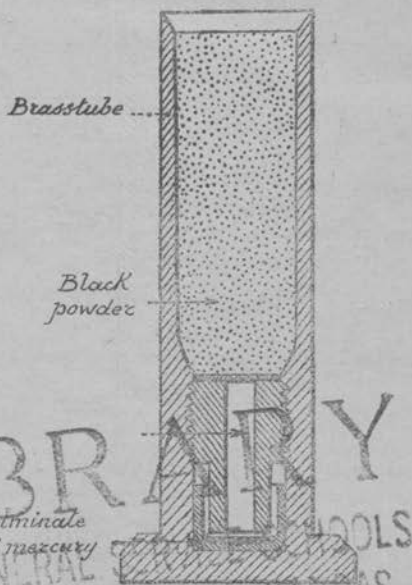


Fig. 94. — Free primer.

The firing pin forces the base of the tube inwards, thereby causing the cap of fulminate to strike against the lower face of a ring screwed inside the free primer. The top part of the latter is filled with black powder.

The upper edge of the free primer expands under the action of the propelling gases and is pressed against the walls of the hole running through the breechblock. The propelling gases are therefore prevented from passing outside through that hole.

The American type of free primer now used is the 21 grain percussion primer mark I.

It consists of a brass body approx. $3/8 \times 1/2$ inch in length and loaded with an igniting charge, 21 grains of black powder.

The principle of working is the same as that of the French free primer.

CHAPTER VI.

HANDLING, TRANSPORTATION AND STORAGE OF AMMUNITION.

ART. I.

PROJECTILES.

a) When travelling, the projectiles must be kept in special boxes or must be fitted with rotating band protectors and carefully kept under cover.

b) When in dumps, they must never be in the open air.

c) Whenever possible, the projectiles should be placed vertically on planks in order not to come into contact with the ground. They should be separated from each other by separators.

If it is necessary to place the projectiles horizontally, the various layers should be separated by planks or branches so as to isolate the rotating-bands. There should not be more than 5 layers of 75 projectiles resting upon each other; the limit is 3 for the 155.

d) *Shells must never be kept with their fuses on, because they might explode under the action of neighboring explosions. Fuses are to be fitted on when the shell is about to be fired. The bat-*

tery personnel must therefore be perfectly familiar with the fitting on of fuses.

The central tubes must be shut by plugs until the fitting-on of the fuses.

e) Piles of projectiles should not contain more than 50 projectiles. They should be separated by intervals of 5 meters to 10 meters if possible.

f) Projectiles must be carefully cleaned; dirt might cause premature bursts. In this respect, it is advisable to fire a shrapnel before starting H. E. shell fire in order to clean the gun in case it were soiled; this is called the *drying shot*.

g) Rotating bands must be examined before firing and any roughness smoothed off.

h) It is advisable to put some grease on the rotating band and on the bourrelet when the projectile is about to be fired. This precaution insures a longer life to the gun.

i) When firing, it is necessary to examine, to sponge and slightly grease the bore as often as possible (for instance every four rounds for heavy guns).

ART. II.

FUSES.

a) Fuses in general and combination fuses in particular must be carefully kept dry; covers for the 30-55 fuses must be removed only when fire is going to start.

b) I. A. 1915 Model and I. A. L. 1916 Model fuses have tin hoods which must not be removed before the shell is about to be fired. If, by accident, this hood has been ripped off, the fuse must not be used but must be sent back to the rear.

b) Fuses and particularly I., I. A. and I. A. L. fuses are very sensitive to the shock of branches, even of small diameter. It is therefore necessary when the battery is in position in a wood to see that no branches are close to possible trajectories, as the wind might make them cross these trajectories at any moment.

d) **It is strictly forbidden to disassemble a fuse or a detonator. If, for any reason, any fuse or detonator has been disassembled, it must be destroyed at once.**

ART. III.

CHARGES.

a) Powder charges must be stored in dugouts separate from those of projectiles. For each gun there should therefore be :

1. Dugouts for projectiles ;
2. — for powder charges ;
3. — for fuses.

If these rules are not followed, heavy explosions are likely to occur which, in addition to the damage they do, may draw the enemy's fire.

b) Charge bags must be kept in metallic boxes which should be kept closed until the last minute and should be stored in dry dugouts.

c) These boxes must never be exposed to the sunlight and generally speaking, powders must not be subjected to great differences of temperature. The heating of powders causes dangerous pressures and differences of velocity, the latter causing considerable variations of range.

d) For the same reason, it is strictly forbidden to put a projectile in the gun before the order to do so; any projectile which has been introduced into the bore must be fired at once.

e) Fixed powder charges must not be modified or mixed.

ART. IV.

PRIMERS.

They must be kept free from moisture.

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