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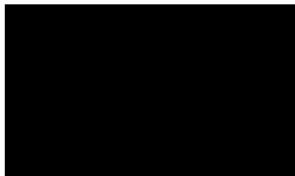
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ARTILLERY COURSE

BOOK 2

INFORMATION ON EXPLOSIVE SUBSTANCES  
INFORMATION FROM INTERIOR BALLISTICS

Under the General Editorship of

Maj. Gen. of the Engineering

Artillery Service

A. D. BLINOV

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Armed Forces

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ARTILLERY COURSE

BOOK 2

INFORMATION ON EXPLOSIVE SUBSTANCES

INFORMATION FROM INTERIOR BALLISTICS

The book consists of two parts :

The parts are written By :

1. Information on Explosive Substances -

Colonel STOLBOSHINSKI, A. P.

and

Colonel NIKIFOROV, N. N.

2. Information from Interior Ballistics -

Colonel NIKIFOROV, N. N.

This book is intended as a Manual for Students

of Artillery Schools and may be used as a

Guide Book for Officers of the Artillery of the

Soviet Army in their independent studies.

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## P A R T O N E

## INFORMATION ON EXPLOSIVE SUBSTANCES

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## CHAPTER ONE

## GENERAL FEATURES OF EXPLOSIVE SUBSTANCES

## 1. BRIEF INFORMATION ON THE HISTORY OF EXPLOSIVE SUBSTANCES

The first explosive substance (BB) known to man from the earliest times was the smoky (black) powder of saltpetre, Sulphur and carbon. <sup>1</sup>

Who and when this powder was discovered is still in doubt; its origin is the subject of a whole series of legends, but there is reason to suppose that it was invented in CHINA or INDIA. The oldest written records of these peoples are proof of that powder was familiar to men several centuries before our era (i.e. before the birth of Christ - T).

The ARABS adopted powder from the CHINESE who, commencing from VIII century of the Christian era, were in close trading relations with the Chinese; it is interesting to note that the two Arab words for saltpetre are Chinese Salt and Chinese snow. Using powder to begin with merely as a combusive means, the Arabs soon discovered its propellent propensities and started to make wide use of it for practical purposes. A special literature made its appearance among them on how to manufacture and use black (smoky) powder.

Early in the XIV th. Century Europeans became acquainted with powder through the Arabs. The first to make its acquaintance were the Spaniards who were engaged in wars with the Arabs over the domination of the Iberian Peninsula.

In Russia powder was beginning to be used from the second half of the XIV th century.

In a NOVGOROD Year Book for the year 1382 there is mention of the names for fire weapons :-

"Self Shooters," "tyufyaki" (modern "matress, palliasse idlers, drones, good-for-nothing-T), "let-offs" and push-offs ("pushki" - guns, T).

The ALEKSANDROV Year Book for 1382 gives an account of the siege of MOSCOW by the armies of the TARTAR KHAN TOKHTAMYSH. The Chronicler states:

"The citizens defending the city and opposing the TARTARS, some shot arrows from the palliasades, others cast stones upon them, others let off guns against them and others "Self Shooters," filling the fire weapons and firing the powder, yet others let off very great guns." \*

<sup>1</sup> Powder is here considered as one of the variations of explosive substances.

\* The above from Old Slavonic - T.

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This means that in 1382 powder was already in use in RUSSIA.

Powder was already being produced in MOSCOW by the end of the XIV th. Century and as a result of the careless handling of it a fire broke out in 1400: "Of powder was MOSCOW burnt - at midnight did it burn," so says the Chronicler. The first powder works were opened in MOSCOW in 1494. Other towns also began powder production apart from MOSCOW.

Powder manufacture greatly developed under Ivan VASIL'EVICH THE DREAD (alias Ivan THE TERRIBLE-I) on whose order powder works were built in the vicinity of MOSCOW and specially under PETER I who built the PETERSBURG, OKHTA and SESTRORETSK powder plants which in their productive capacity exceeded the WEST EUROPEAN powder factories of the time. Later, in 1761, SHUVALOV introduced to the technology of smoky powder serious improvements which considerably increased the quality of smoky powder and heightened its stability when stored and in transport.

The great Russian scientist M.V. LOMONOSOV, apart from other works, also applied himself to the study of the laws of the combustion of powder. He provided a series of outstanding theoretical conclusions in his work "Of the nature of powder."

Black (smoky) powder ruled supreme and unchallenged for more than half a millennium, until in the second half of the XIX th century it was replaced by another and more potent explosive substance.

An exception to this is fulminating mercury (lit. T.) which has been known since 1799 and fulminating salts were known even earlier but found no practical application. Fulminating mercury represented that class of explosive substances which are now-a-days, because of their effect, known as High Explosives ('brizantnyi' from the French word 'brizer' to destroy, cursh), and among these it belongs to the category of initiating explosive substances used for initiating explosive processes.

The discovery of fulminating mercury (and what is even more important, the methods of making percussion caps with it) revolutionized warfare. Up to the time when percussion caps were introduced charges in the rifles were fired by sparks generated by a flint striking against steel. This system of firing charges did not increase the quick firing propensities of rifles beyond one to two shots a minute; in this process flints failed to strike in 15% of cases and were only for 40-50 shots; fire in strong winds, in rain and in snow was greatly impeded.

The introduction of percussion caps increased the quick firing qualities of rifles, helped in firing in any weather, introduced much that was new in the technology of musketry and strongly influenced the tactics of battle.

The next stage in the history of explosives was led in by the discovery of gun cotton in 1833.

From the close of the sixties of the XIX th Century gun cotton begins to oust black powder (smoky) powder), first in blasting and then in explosive charges (principally in sea mines and torpedoes), and from the early eighties it is being used as the main substance (for powder charges), as at that time a way of manufacturing smokeless powder from gun cotton had been discovered, which in its ballistic qualities was found superior to black (smoky) powder.

Following the appearance of gun cotton came another High Explosive substance - nitro-glycerine, accidentally discovered in 1876 while processing glycerine with a blend of nitrogen and sulphur acids in one of the laboratories. Owing to the dangers attending the preparation and processing of nitro-glycerine, this substance received no practical application at that time.

The first to point to the possibility of using nitro-glycerine blended with additional substances as an explosive for projectiles, was the celebrated Russian chemist - N.N. ZININ, the creator of aniline and organic dyes.

During the defence of SEBASTOPOL (SEVASTOPOL' - T) (1854) ZININ personally worked on the preparation of nitro-glycerine for projectiles.

The experiments carried out by N.N. ZININ and V.F. PETRUSHEVSKI lead to concrete results, but owing to the conservative tendencies of Czarist bureaucrats their results were not exploited in RUSSIA. From 1860-1863 PETRUSHEVSKI produced 160 puds (5760 lbs - T) of various dynamites from nitro-glycerine.

A. NOBEL was well acquainted with the experiments of ZININ and PETRUSHEVSKI. He happened at that time to be in Russia and received the information personally from ZININ.

Using the results of the work of the Russian chemists, A. NOBEL took out the patent for the invention of dynamite and built a plant in Germany for its manufacture.

Nitro-glycerine explosive substances known as dynamite were begun being used for blasting operations.

At the moment nitro-glycerine and gun cotton are the basic materials in the preparation of smokeless powders.

In 1886 the high explosive qualities of picric acid became known, which from 1783 had been used as yellow paint.

5 Picric acid entered military technology as melinite in Russia and France, liddite in England and Shimoze in Japan etc.

The Russian gunner S.V. PANUSHKO devoted much labour to the problem of using picric acid for explosive charges. He perished in 1892 from an accidental explosion during an experiment on melinite projectiles.

6 Following melinite, an explosive substance was found with better qualities than any preceding it - this was trinitrotoluol or trotil (tol); in using melinite it was found (fairly often) that there were premature explosions of projectiles, while trotil proved nearly harmless in this connection.

In a short period of time trotil became for this reason the main explosive substance to be used for equipping artillery projectiles, mines, air bombs etc. This is to be explained as follows: first, trotil has not a high degree of sensitivity to mechanical influences, a fact which contributes to safety in firing; secondly, when coming in contact with the metal sides of projectiles, trotil does not generate sensitive combinations as melinite might create.

From 1906 trotil became widely used. At the moment trotil is the main explosive substance being used in the manufacture of detonators for fuzes and for detonator caps.

In the first World War ammoniac - saltpetre explosive substances were in wide use. These were explosive blends of ammonium saltpetre and high explosive substances, for instance - trotil.

The period following the first imperialist world war expressed itself by the appearance of new high explosive substances -

hexogene and 'taena' (sic).

For a very long time the only initiating explosive substance was fulminating mercury in spite of some of its defects. Among the newly discovered initiating explosive substances the most widely used in practice is leadazid. Lately two new initiating explosive substances have come to be used: lead stifnat (sic) and tetrazene.

With the introduction of rifled guns the requirements from powder still further increased. All efforts to improve the ballistic qualities of black

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(smoky) powder failed to produce any effective results. A more powerful powder was needed.

The idea to turn the powerful high explosive substances of gun cotton into a propelling agent proved tempting so that a succession of scientists devoted themselves to its possibilities.

After steadfast experimental work a means was found of adapting gun cotton to a smokeless powder by diluting it in a blend of alcohol (lit. spirits) and ether (1884).

In Russia smokeless gun cotton powder was being manufactured in 1891. D. I. MENDELEEV worked much over its perfection. Soon after the discovery of gun cotton powder, smokeless powder went into production. Thus nitro-glycerine smokeless powder made its appearance.

I. M. CHELISOV and other Russian scientists did much towards the research and preparation of smokeless nitro-glycerine powders.

7 The period commencing with the XX th. Century up to the present time expresses itself by further research into explosive substances, their perfection and the improvement in their use for military purposes.

Artillery is based on the wide use of explosives. Arty fire alters its features in accordance with the discovery of new explosives and their use. Every artillery officer must be familiar with the main features of explosive substances in order to use them safely and rationally.

## 2. THE APPEARANCE OF THE EXPLOSION THE EXPLOSIVE SUBSTANCE AS A SOURCE OF ENERGY.

An explosion in the wider sense of the word is the phenomenon of a very rapid physical or chemical alteration of a substance accompanied by an equally rapid transformation of its potential energy into mechanical function. The mechanical function on an explosion is always produced by gases streaming towards expansion which were created in the process of the explosion. Thus an explosion always expresses itself by the three following factors:

- the short duration of the process;
- creation of gases;
- the exoteric phenomenon (discharge of heat), increasing the resilience of gases.

The main feature of an explosion is the sharp increase of pressure on the environment surrounding the focus of the explosion. Evidence accompanying an explosion is a more or less powerful sound.

7 Depending on the chemical substance of the Explosive substance and on the conditions of the detonation the explosive transformations flow with varying speeds. The greater the speed of the explosive transformation, the quicker pressure grows. The speed in the growth of the pressure determines the character of the mechanical function accompanying the explosion. Where the process of the explosion is steady, pressure will also grow steadily. In this case the mechanical function of the gases will express itself in the movement of the surrounding environment whenever sufficient pressure has formed in order to overcome the resistance of the environment, for instance in the motion of the obstacle opposing the spreading of the gases (diag. 1). When, however, the process of the explosion occurs in so brief an interval of time that it may be considered as being almost instantaneous (the chemical transformation at once embraces the whole body of the Explosive charge), pressure will be so sharp, that the mechanical function of the gases will express itself

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in a very powerful vibration of the environment surrounding the focus of the explosion, and where an obstacle is in the way - in its destruction (diag. 2).

In military matters the qualities of Explosive substances are used depending on their components and on which different kinds of mechanical function the explosion is capable of. In artillery Explosive substances are used as a source of energy essential for propelling projectiles.

(propelling charges) and for detonating them (detonating charges).

A conception of an Explosive substance as a source of energy is provided by calculating the force of a propelling charge, i.e. a computation of the amount of energy and time in the course of which this energy becomes transformed into mechanical function on a shot. The energy of a propelling charge

Diag. 1

gradual formation of gases or an explosion: gases knock off the lid of a vessel.

Diag. 2

Instantaneous formation of gases. On an explosion gases destroy the nearest objects.

is spent on: providing the projectile with muzzle velocity, overcoming opposition in the bore impeding the motion of the projectile, on expanding and heating the sides of the bore, on blow back (all. recoil - T) etc., part of the energy remains unused when gases issue from the barrel. The amount of energy spent on giving the projectile its muzzle velocity can be found as the quantity of kinetic energy of a body in motion from formula

$$E = \frac{M V^2}{2} = \frac{g V^2}{2g}$$

- E - is the amount of energy in kgs;  
 M - is the mass of the body in motion, equating  $\frac{g}{g}$ ;  
 g - is the weight of the body (projectile) in kgs;  
 V - is the speed of the body (projectile) in m/sec.

In the case of a gun with which (when the rifled part of the barrel has a length of 1.6 m) the muzzle velocity comes to 400 m/sec. and the projectile weighs 40 kgs, we get:

$$E = \frac{40 \cdot 400^2}{2} = \frac{320.000 \text{ kgs}}{2 \cdot 10}$$

In order to compute how much energy must be produced by a charge on a shot it is sufficient to multiply the quantity found by 3<sup>\*\*</sup>, because it is known that in order to provide the projectile with its muzzle velocity only  $\frac{1}{3}$  of the total amount of the energy of the propelling charge is spent. Consequently, the amount of energy to be produced by the charge must approximately equate 320,000.3 = 960,000 kgs.

Here one to disregard the negligible time interval in the course of which gas pressure increases up to the moment when the projectile starts moving, the time of function of the propelling charge will equate the time of the movement of the projectile in the interior of the barrel. Computing this time, we will find the time interval in the course of which the amount of mechanical energy which we have already found, will have been transformed into mechanical function. Let us assume that the motion of the projectile in the bore of the

\* See para. 15 "Potential of an Explosive Substance."

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barrel is of equal acceleration, i.e. the projectile is moving at an average velocity

$$V_{cp} = \frac{0 + 400}{2} = 200 \text{ m/sec}$$

Dividing the length of the course of the projectile along the bore of the barrel (the length of the rifled section), which in the case of the piece selected as an example, amounts to 1.6 m, by the velocity, we will get the time sought for, namely  $t = 1.6 : 200 = 0.008$  sec. These two data determine the peculiarity of an Explosive substance as a source of energy - the ability to transform in an insignificantly brief space of time a great amount of energy into mechanical function, i.e. the Explosive substance as a source of energy expresses itself in a very considerable force. In order to obtain an equally great amount of energy (960,000 kgs) in the same space of time, one would need an engine disposing over a force of

$$\frac{960,000}{75.0,008} = \underline{1,600,000} \text{ h.p.}$$

### 3. CLASSIFICATION OF EXPLOSIVE SUBSTANCES ACCORDING TO THEIR COMPONENTS.

Explosive substances are usually divided into the following three groups according to their component:

- A. Explosive chemical combinations.
- B. Explosive components and blends from non-explosive substances.
- C. Explosive components and blends from explosive substances.

A. Explosive Chemical Combinations are characterized by the following factors:

- (a) by the presence in them of molecules of special atomic grouping, conditioning the insolidity of the connections within the molecules (lit. inner molecular connections - T); each class of Explosive substances has corresponding to it its own atomic combination which forms the basis for the further classification of Explosive substances
- 9 (b) propensity to inner molecular combustion, resulting in the creation of a great amount of heat from the presence in the molecules of the Explosive substance of the atoms of burning substances and of the hydrogen atom;
- (c) by the endothermocity of creation, i.e. by the presence of energy (heat), accumulated (absorbed) by the Explosive substance during its formation from elements.

10 The first factor is common for all Explosive substances of the group in question, the second and third, on the other hand, is not peculiar to all Explosives belonging to the group of explosive chemical combinations.

The group of explosive-chemical combinations: can be broken up into a series of sub-groups of which the following are most generally used in artillery practice:

1. Nitrates, or compound ethers of azide acid. High Explosives of this sub group are obtained by processing alcohols or carbo-hydrates with azide acid. This process is called nitration.

\* cp = medium, average - T

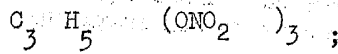
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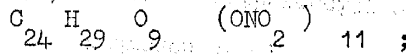
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The most important representatives of such Explosives are:

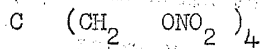
- (a) Nitro-glycerine, or glycerine-nitrate:



- (b) Pyroksiline (Alt. pyroxile, gun cotton - T)



- (c) Taen, or Pentaeritrittetranitrate



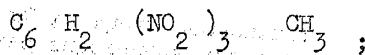
From these formulae it can be seen that nitrates express themselves by the presence of group  $ONO_2$ .

Nitrates (apart from taen) are generally used in the preparation of other explosive substances (smokeless powders and dynamites).

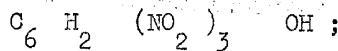
2. Nitro compounds obtained as a result of processing nitrogen acid with carbo-hydrates.

The most generally used in practice are:

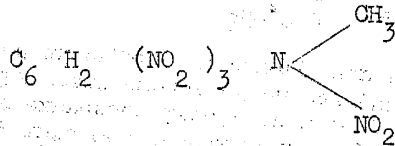
- (a) Trotil, or trinitrotoluol (tol)



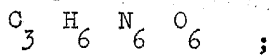
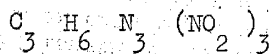
- (b) Melinite, or trinitrophenol, or Picric Acid



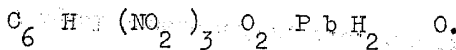
- (c) Tetril, or trinitrophenyl-metlnitramin



- (d) Hexsogen, or tsiklotrimetilentritramin



- or (e) stipnat (sic) of lead, or trinitrorezortsinat  
of lead



All of these express themselves by the presence of group  $NO_2$  and are used as independent explosive substances; in particular trotil is used for the manufacture of explosive charges for a great number of modern artillery projectiles.

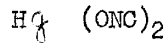
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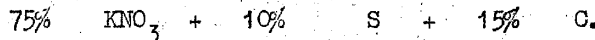
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3. Fulminates, or salts of fulminating<sup>\*</sup> acid. These explosives are obtained from the reaction of alcohol and the solution in nitrogen acid of some heavy metals (mercury, silver etc). In practice the most generally used are fulminate of mercury or fulminating mercury (lit.-T):



A characteristic feature of fulminates is the presence in their composition of the very unsteady atomic combination of ONC. Fulminating mercury requires very little action for producing an explosion and is therefore used for initiating the detonation of steadier Explosive substances.

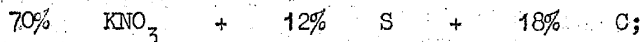
4. Azides, or salts of nitro-hydrogen acid. Azide of lead  $\text{Pb N}_6$  is used in practice. This is obtained by the reaction of the solution of azide of sodium (alt. natrium - T) on the solution of nitro acid of lead. Azides like fulminating mercury are used for initiating detonations of other Explosives. The most important representatives of the Explosives of this group are powders of saltpetre - carbon, for instance the military powder.



#### B. Explosive Compounds from non-explosive substances

Explosive substances of this group represent a compound of two or more substances not possessing their own explosive attributes, nor being chemically linked with each other. They are formed of substances which are fairly rich in oxygen, and from the substances of fuel, and therefore they burn through the oxygen of the former.

Mining Powder:



To this group of Explosives may also be related:

- (a) compounds of oxygen with combustible gases, petrol vapours, spirits, pulverized crude oil, flour, coal dust soot etc. Some of such compounds are used for interior combustion motors.

#### C. Explosive Substances and Compounds of Explosive Substances:

The Explosive attributes of this group express themselves by the features of those Explosives which belong to their number; Explosives of this group are very many, but the following have the greatest practical application:

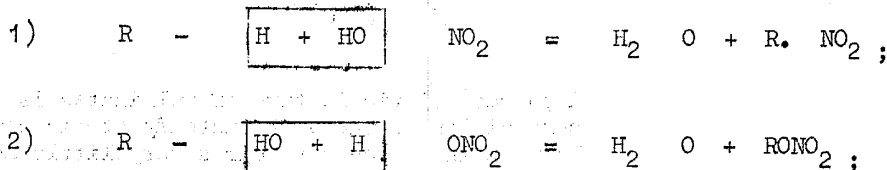
1. Smokeless powders made from a compound of two kinds of gun cotton (alt. pyroxiline - T) (pyroxyline powder) or from a compound of pyroxyline and nitro-glycerine (nitro-glycerine powder).
2. Ammonium - Saltpetre compounds whose main component is ammoniac - saltpetre; this has explosive attributes of its own, though these are not strongly expressed.
3. Dynamites, or nitro-glycerine explosives are compounds of nitro-glycerine with various substances which are as a rule, explosives (for instance fulminating gelatin contains: 88 - 93% of nitro-glycerine and 7-12% of colloid cotton).

\* is the word for fire-damp-T

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4. NITRATION

The majority of explosives are products of nitration. Nitration consists of the reaction on the organic combination of nitrogen acid ( $\text{HNO}_3$ ) in the presence of sulphuric acid ( $\text{H}_2\text{SO}_4$ ); depending on the chemical structure of the molecules of the organic combination, nitration pursues the following course:



R stands for the organic root:

In the first case occurs a combination of nitrates whose intrate group  $\text{NO}_2$  is directly connected with carbo-hydrate; in the second case occur compound ethers of nitrogen acid whose group  $\text{NO}_2$  is connected with carbo-hydrate by means of the oxygen atom.

In both cases water ( $\text{H}_2\text{O}$ ) forms in the process of nitration. As this weakens the reaction of the nitration, it is essential to eliminate its influence and in order to achieve this, nitration should be effected in the presence of some substances which absorb water effectively. A substance of this kind is sulphuric acid ( $\text{H}_2\text{SO}_4$ ): it not only absorbs water but at the same time strengthens the nitration capacities of  $\text{HNO}_3$ , hence the significance of sulphuric acid is very considerable indeed in the entire process of nitration.

Experiments show that in some cases no nitration takes place without sulphuric acid. Thus nitration is the action on organic combination of the compound between nitrogen and sulphuric acids.

12 The composition of the nitrate compound is determined by the nature of the materials of which an explosive substance is prepared and by the required degree of nitration.

Nitrogen and sulphuric acids may in the process of nitration be used not in a compound but in succession, one after the other. In such circumstances only sulphuric acid reacts on the organic combination (this process is called sulphurization) and then the sulphuric products are processed with nitrogen acid.

13 Nitrogen and sulphuric acids, used for nitration, must be very strong and as pure as possible. Admixtures in nitric acids entering Explosive substances lower their chemical stability.

5. Aspects of Explosive Transformations

It has already been said that the reactions of explosive transformations occur with varying speeds and that the magnitude of these speeds determines the nature of the mechanical function of gases which are found among the products of an explosive transformation. That is why one must place the velocity with which the reaction of an explosive transformation spreads over the body (lit. mass - T) of an explosive substance, at the foundation of the determination of an explosive transformation:

Depending on this velocity one distinguishes between the following three aspects of explosive transformations: rapid combustion, the explosion proper and detonation.

Rapid Combustion of an Explosive substance is the process of explosive transformation which occurs with a velocity not exceeding several metres per second, and is considerably influenced by exterior conditions.



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Where this process occurs in the open air, it is not generally accompanied by any considerable effect and is sometimes called deflagration. In an enclosed space, however, for instance the powder chamber of a piece, this process takes place far more energetically and is accompanied by a sharp sound. The character of the function in the latter case expresses itself in the more or less rapid growth of the pressure of gases and the execution by these of functions in shifting or casting aside the least opposition. A typical example of rapid combustion is to be found in the combustion of a propelling (alt. powder - T) charge of smokeless powder in the bore of a gun barrel. In this case the operation of gases expresses itself in the rapid accretion of pressure in the bore as the result of which the gases fulfil their function of propelling the projectile.

The Explosion proper is the process occurring with the alternative of velocity measured in hundreds or even in thousands of metres per second and depending to a lesser degree on extraneous factors. The feature of the function of gases expresses itself in a sharp increase in pressure at the focus of the explosion, in the shock of gases against the surrounding milieu, the increase of temperature of the surrounding object to white heat and in their breaking up, but at comparatively short distances from the focus of the explosion. Example - explosion of a charge of black powder in a "shpur"\* (sic - T) with a plug.

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Detonation is a process spreading over a substance with the maximum velocity possible for the given conditions, generally measured in thousands of metres per second. The magnitude of this velocity is constant for the circumstances in question and for the given explosive. The character of the function on a detonation shows itself in a very sharp jump in the pressure and in shock produced by the gases accompanied by the maximum destructive effect allowed by the given conditions. For instance, the velocity of a detonation of pyroxyline (all gun cotton - T) reaches up to 6,800 m/sec. and of nitro-glycerine - up to 8,200 m/sec.

## 6. DETONATION

The phenomenon of detonation was first observed during experiments with nitro-glycerine. It was found that when initiating nitro-glycerine with a capsule of fulminating mercury the destructive effect is considerably stronger than where the explosion is effected by a jet of fire. The practical significance of this discovery was so obvious that it led to the research into the detonations of all explosive substances.

Research into the processes of the detonations of various explosives showed that the amount of heat produced on a detonation and the quantity of gases formed are nearly identical with those aroused by an ordinary explosion. Hence the destructive effect accompanying detonation can only be explained by the unusually great velocities in the development of a detonation. As the result of such velocities there occurs an exceptionally rapid and almost instantaneous shock from gases. The force of this shock from the gases or a detonation is explained by the fact that in the first place the gases occupy in the early stage a volume of the charge up to the moment of explosion and in the second place - by the fact that the heat generated by the reaction, not being able to escape either by radiation or, by direct transmission, entirely spends itself on heating the gases. These two facts then determine the highest degree of the manifestation of the resilience (alt. vibration - T) of the gases and their maximum destructive effect on detonation.

As the result of the violent blow from the gases on detonation, a destructive effect occurs also in a case where the charge is placed not inside of the object to be blown up but outside it. This attribute of detonation is widely used in blasting, for the destruction of railways, bridges etc.

\* SHPUR - an opening driven into a rock for blasting.

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Theory of Detonation. The process of arousing and developing a detonation has not yet been fully established and there is still much in it which is not clear. Of all the theories put forward on detonation, the most complete explanation of this phenomenon is offered by the theories of the percussion wave and the explosive wave. According to theory of the percussion wave, detonation is aroused by a mechanical percussion inflicted by some object (for instance by a striker) or by molecules of gas which are rich in energy and dispose over rapid movement, forming on the explosion of the detonator. Provided the force of the percussion is sufficient there occurs a disintegration of the molecules of that part of the charge of the explosive which has received the blow. Apart from the purely mechanical reaction on the explosive charge, the charge becomes heated as the result of a part of the mechanical energy passing to thermal energy (alt. being transformed into or becoming thermal energy - T), a fact which strengthens the explosive transformation of the surface layer of the explosive charge at the focus of the percussion. The combination of these two factors gives rise to the percussion wave which begins spreading with immense velocity from one layer to another over the entire mass of explosive charge until it entirely transformed into the final products of the explosion.

The theory of the explosive wave explains the phenomenon as follows.

As the result of the percussion on the explosive substance located at the very place of the percussion, the layer of this substance contracts; the mechanical energy of the percussion thereon turns into heat energy and the compressed layer becomes heated. As the result of this heating the compressed layer explodes. This explosion knocks against the neighbouring layer which becomes heated in its turn and then blows up. This explosion deals a blow on the next layer etc. (percussion - heating - explosion). An explosive wave spreads with tremendous speed, which is by no means less than that of a percussion wave. The magnitudes of these speeds can be judged from the speed with which a percussion spreads in, let us say, a steel tube: this speed equates 5,100 m/sec and is very close in its extent to the velocity of a detonation, found in experiments.

Percussion waves, spreading over a medium incapable of explosion, constantly grow weaker losing their initial energy. In contrast to these purely physical waves, percussion waves passing over the mass of an explosive charge do not become extinguished as their energy is constantly being maintained by the explosive reaction of the layer of the explosive which the wave envelops.

Thus the velocity of the detonation depends upon the velocity of the percussion wave aroused by the initial impulse and on the speed of the explosive reaction.

The theory of the percussion wave is proved by the following experimental data:

1. The initial thermal impulse does not as a rule cause a detonation of an explosive charge as the mechanical percussion is absent during the heating process and no percussion wave arises. Exception to this are very few partly initiating explosive substances whose detonation may be aroused by heating. This can be explained by the fact that all these explosive substances are very sensitive and endothermical in their origin, i.e. they include in themselves, even before the explosion, a great amount of accumulated thermal energy, which as the result of heating becomes freed in a very brief space of time, which in itself is equivalent to percussion.
2. The velocities of a detonation grow with the increase of the force of percussion of the initial impulse as in this case the quantity of energy increases and thence also the velocity of the percussion wave.

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- 16 3. With the increase of the density of the explosive substance, the velocity of the detonation also increases, as the denser and more compact medium aids the transmission beams of the percussion wave.
4. The detonation velocities of various explosive substances, all other conditions being equal (initial impulses, physical conditions, casing etc), are not identical, as the velocity of a detonation depends upon the speed of the explosive reaction of the layer enveloped by the percussion wave and this velocity is determined by the chemical nature of the explosive substance.

Methods of Determining Detonation Velocities.

The following method is the simplest:

16 The explosive to be tested is placed in a small cylindrical tube A (diag 3). The ends of detonating cord 6 have been inserted into this tube at two points 'a' and 6. The detonating cord is loop shaped and with its central part is packed (alt. laid-T) and fastened on a thin leaden or tin disk B; the centre of the cord is carefully marked on the disk by line K.

The detonation of the explosive to be tested, simulated by the detonator II will subsequently cause the detonation of the ends of the cord. As end 'a' of the cord will detonate a little earlier than end 6 the two percussion waves spreading from

the terminals of the primacord towards its centre will not meet at point K but at some point  $K_1$ , which will be the further from point K the later terminal 6 of the primacord was detonated in comparison with terminal a, i.e. the less was the speed of the detonation of the explosive substance to be tested. Point of encounter  $K_1$  is obtained with sufficient accuracy on the disk.

Diag. 3 Method of determining the velocity of a detonation

By measuring the distance 1 between points a and 6 and  $KK_1$ , between points K and  $K_1$  and knowing the velocity of the detonation of the detonating cord -  $v$ , one can compute the velocity of the detonation of the explosive to be tested by the following:

$$D = \frac{v l}{2 KK_1}$$

D - is the velocity of the detonation of the explosive.

In the time interval  $t = \frac{l}{D}$  the waves will pass along the primacord

along various paths. The path travelled from point 'a' will be greater than the length of half the cord by  $KK_1$ , while the path travelled from point 6 will be less than this length by the same dimension. Hence the difference between the paths equates  $2 KK_1$ , while time  $t = \frac{2 KK_1}{v}$

The two dimensions, separately (alt. each or one by one - T) equal to the third dimension, are equal to each other, hence,

$$\frac{l}{D} = \frac{2 KK_1}{v}$$

Whence

$$D = \frac{v l}{2 KK_1}$$

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Example: The velocity of the detonating cord equates 7,200 m/sec. and the distance between its terminals - 0,3 m; in determining the velocity of the detonation of intro-glycerine, the distance between points K and K<sub>1</sub> has come to equate 0,13 m.  
Thus the sought for velocity

$$D = \frac{7,200 \cdot 0,3}{2 \cdot 0,13} = 8308 \text{ m/sec.}$$

Thus, this method is based on a comparison of the velocities of the detonation of a primacord and of the explosive to be tested. The velocity of the detonation of the primacord, however, may also be found by experiment.

The method of determining the velocity of the detonation of the primacord consists of the following measures.

One takes two sections of the prima-cord, differing in their length by 8-10 m. Some ends of these sections are fastened to the common detonating cap A (diag. 4) while the others are inserted to an identical depth into the narrow open apertures of the steel pig B (alt. block-T) Drum C turns over these apertures with a constant speed.

On a simultaneous initiation of the sections of the prima-cord the percussion wave travelling along the shorter section will reach the turning drum earlier and will make an earlier impression (alt. mark-T) on its surface than the percussion wave spreading along the longer section.

Knowing difference  $l$  of the lengths of the sections of the prima-cord, distance  $h$  according to the length of the circumference between the marks on the surface of the drum, the length of its circumference and the speed at which it turns  $n \cdot s / \text{сек} / \text{сек}^*$ , one can find the velocity of the detonation of the prime cord  $v$  from formula

$$v = \frac{n \cdot s \cdot l}{h}$$

In fact, the linear velocity of the movement of the point on the surface of the revolving drum equates  $n \cdot s$  m/sec, consequently, path  $h$  along the circumference of the drum will be traversed in time

$$t = \frac{h}{n \cdot s}$$

The speed of detonation of the prima-cord

$$v = \frac{l}{t}$$

Substituting to the equation

$$v = \frac{l}{t} \text{ instead of } t,$$

the quantity found, we get

$$v = \frac{n \cdot s \cdot l}{h}$$

\* Possibly recs/sec = T

Diag. 4 Determining the velocity of detonation of a prima-cord

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- 17 Example: The difference in the lengths of the prima-cord is 8 metres, the length of the diameter of the drum is 0.6 metres and the velocity of its revolution is 300 revs/sec. As the result (one word illegible-T) the distance between the marks has come to 0.2 metres. Thus the velocity of the detonation of the prima-cord will be

$$v = \frac{300 \cdot 0.6 \cdot 8}{0.2} = 7200 \text{ m/sec.}$$

More accurate methods of determining detonation speeds are based on the use of special instruments - chronographs marking the time in which the detonation spreads along the length of the charge of the explosive substance under test.

- 18 Table 1 shows the velocities of detonation of the more widely used explosives:

<u>Type of Explosive</u>	<u>Velocity of Detonation in m/sec.</u>
Gun Cotton (pyroxyline)	5200 - 6300
Nitro-glycerine	8200
Melinite	7480
Trotil	6990
Ammonites	5100 - 5300
Tetril	7740
Fulminating Mercury	4490
Azide of Lead	4500

Influenced Detonation. The detonation of a, so called, active explosive charge can cause a detonation in another, a passive, charge, which is at some distance from the first. Such a detonation is known as influenced detonation. An influenced detonation has no special practical value as a means of initiating an explosive, but in order to eliminate danger in the manufacture, storing and use of an explosive, this phenomenon must be reckoned with, for instance when planning the distance at which workshops and stores for explosives should be from each other.

- 18 Causes of influenced detonation are:

- (a) action of the percussion wave from the active charge which continues spreading, after the explosion of the latter, over the surrounding milieu;
- (b) direct percussion of gases from the active charge;
- (c) percussion from the splinters of the envelope (alt. container-T) of the active charge or of any other objects thrust aside by the force of the explosion of this charge.

The main cause is the action of the percussion wave, as the two other causes can bring about detonation or destruction only over a short space from the site of the explosion of the active charge.

Detonation through influence is considered to reach its maximum effect, i.e. to be at its extreme, at a distance where the explosion of the active charge is still capable of causing the detonation of a passive charge. The extent of the maximum distance depends:

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- (a) on the power and density of the active charge (with their increase, the distance of transmission also increases),
- (b) on the qualities of the passive charge;
- (c) on the qualities of the medium separating the charges.
- (d) on the nature of the containers housing the charges.

The dependence of the extent of the limiting (alt. extreme, maximum - T) distance on the weight of the active charge is fairly well expressed by the following empirical formula:

$$z = z_1 \sqrt{c}$$

- z = the extent of the maximum distance in metres;
- c = the weight of the active charge in kg;
- z<sub>1</sub> = the coefficient depending upon the conditions enumerated above.

The value of coefficient z<sub>1</sub> fluctuates within the limits of 0,05 - 0,54. For instance for an active melinite charge with a density of 1,25 and for a passive charge of trotil with a density of 1,0, coefficient z<sub>1</sub> = 0,3. At distances exceeding maximum distances, percussion waves no longer cause the detonation of passive charges, but may all the same, bring about mechanical destruction. This raises the very important problem of the so called safe ranges, i.e. distances at which a distinction caused by an explosion has no real significance.

Safe ranges are computed by formula:

$$R = R_1 \sqrt{c}$$

- R = the extent of the safe range in metres;
- C = the weight of the charge in kgs;
- R<sub>1</sub> = the coefficient.

When calculating safe ranges, use is made of the following values of coefficient R<sub>1</sub> (table 2).

TABLE 2

Type of Explosive	Magnitude of Coefficient	
	For Unencased * (?) charges	For Encased * (?) charges
Nitro-glycerines and Dynamites .....	16,6	2,9
Other H.Es and Smoky powder .....	10	1,75

7. Reaction of Explosive Transformations

As the result of the reaction of the explosive transformation, as in fact in any chemical reaction, new chemical combinations are formed as the products of this reaction, or as products of the explosion.

\* Russian: neobvalovannyi - obvalovannyi zaryad - T

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19 In their physical composition the products of explosion may be hard, liquid or gaseous. In their chemical composition these products of explosion can vary greatly, and their chemical composition is principally determined by the chemical nature of the explosive substance in question.

Moreover, various factors may considerably influence the composition of the products of an explosion, as, for instance, the method of arousing the reaction, temperature and pressure in which the reaction occurs, the degree of homogeneousness of an explosive in its chemical composition etc. The quantitative and qualitative composition of the products of an explosion are determined by the following methods.

20 Method of theoretical calculations, the essence of which is based on the assumption that on an explosion its products are formed according to the laws of chemical equilibrium and conformity in a strictly determined sequence. Thus, for instance, the elementary method for computing the composition of the products of the explosion of an explosive with a positive oxygen balance (more than sufficient for the full combustion of carbon) is based on the assumption that the whole carbon and hydrogen burn up completely at the expense of the oxygen. It is assumed that the oxygen which remains unused as well as the nitrogen is to be found in a free state among the composition of the products of the explosion.

20 The method of Chemical Analysis consists of taking samples from the gases which have formed in the explosion and by processing them with different kinds of absorbants. A decrease in the volume of the gas compound provides in this experiment the approximate contents of the gaseous products in question. For instance, in order to determine the presence of a relative quantity of CO<sub>2</sub> one uses a solution of corrosive potash in water (1:2). It is known that one cubic centimetre of this solution absorbs 40 cm<sup>3</sup> of CO<sub>2</sub>.

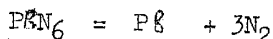
Knowing the composition of the products of the explosion one can draw up an equation of the reaction of the explosive transformation of the explosive substance.

Study of these equations is most important as it allows one to compute such basic features of explosive transformation as the heat of an explosion radiated on an explosion, volume of gases and their temperature and from these - the energy and force of the explosion.

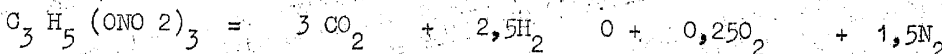
In the chemical sense all reactions from explosive transformations can be related to the following two basic aspects.

- (1) to the reaction from the disintegration of the molecules of the explosive substance;
- (2) to reaction from combustion or the combination of burning substances capable of supporting the combustion; - mainly - the combination of oxygen as the chief acidifying agent, with carbon, hydrogen, sulphur etc.

Reactions of the first kind are very simple but are met with fairly rarely. As an example of a reaction of this kind may be taken the reaction from the disintegration of azide of lead on an explosion:



Reactions of the second kind are far more complex but more interesting inasmuch as they are shared by nearly all explosive substance in use. As an example of a reaction of the second kind may be taken the reaction from the explosive transformation of intro-glycerine

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Reactions of combustion, depending on the oxygen contents, are classified into:

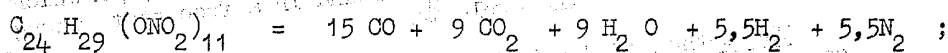
- (1) reactions of explosive substances with a positive oxygen balance, i.e. with oxygen contents in a quantity sufficient for full oxidation (alt. acidification - T) of the hydrogen contents of the molecules of the explosive substance into carbonic acid and of hydrogen into water, as an example of a reaction of this kind may be taken the reaction already mentioned.

of the explosive transformation of intro-glycerine containing only the products of full oxidation;

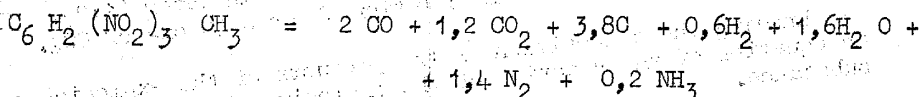
- (2) reactions with a negative oxygen balance, i.e. with oxygen contents in such a quantity which is not sufficient for obtaining fully oxidized products of explosion.

Among reactions with a negative oxygen balance are usually counted the following:

- (a) reactions of explosives containing oxygen sufficient for full gasification (lit. formation of gas - T), for instance, the reaction of the explosive transformation of pyroxyline (alt. gun cotton - T)



- (b) reactions of explosives containing insufficient oxygen for a full formation of gases, for instance, the reaction of the explosive transformation of trotil where carbon in its amorphous state (soot) is



found side by side with the gaseous products of the explosion.

Reactions of explosive substances having a positive oxygen balance are usually known as reactions of full combustion and those with a negative balance - as reactions of incomplete combustion.

Full and partial (alt. incomplete - T) combustion must be differentiated from the negative conceptions of complete and incomplete explosion.

A complete explosion is one in which the entire body (lit. mass - T) of charge is transformed into the final products of the explosion. In an incomplete explosion only part of the explosive charge is affected, while the rest remains unaffected by the explosion and does not participate in the function of the explosion. Causes of an incomplete explosion are the insufficient force of the initial impuls, humidity of the charge etc. Evidence of incomplete explosion is the presence of dense smoke accompanying the explosion of even those explosives which usually occur without any smoke (smoke in such cases is caused by the pulverization of the unexploded part of the explosive charge), or a change in the colouring of the smoke; thus for instance trotil is accompanied on explosion by dense black smoke; the colour of smoke is in this case determined by the presence among the products of the explosion of carbon in the amorphous state (soot; see the equation for the reaction of the explosive transformation of trotil - already mentioned); while an incomplete explosion of trotil is accompanied by smoke which is partly black and partly yellowish brown in colour from the pulverized unexploded part of the trotil.

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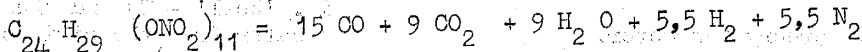
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8. Volume of the Gaseous Products of anExplosion

21 The volume of the gaseous products of an explosion can be computed by the equation on explosive transformation or it can be measured by a gasometer.

22 Computation by the reaction equation. According to AVOGADRO's law 1 grammolecule of gas at 0° and a pressure of 760 mm occupies a volume of 22,4 litres. Therefore, in order to determine the volume of gases it is necessary to calculate the amount of gas grammolecules, multiply it by 22,4 and divided by the weight of the grammolecules of the explosive substance in kilograms, in order to bring the volume of gases to 1 kg of the explosive substance.

Example. Reaction of the explosive transformation of pyroxyline (alt. gun cotton - T) (consisting of eleven azotes)



According to this computation the quantity of gas grammolecules (will be ?-T)

$$N = 15 + 9 + 9 + 5,5 + 5,5 = 44 ;$$

Then from 1 grammolecule of an explosive the volume of gases (will be ?-T)

$$w = 22,4 \cdot 44 = 985,6 \text{ litres,}$$

and of 1 kg of pyroxyline

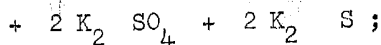
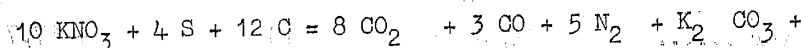
$$w_o = \frac{985,6}{1,143} = 862,3 \text{ litres}$$

as 1 grammolecule of pyroxyline weighs 1,143 kg (see table 3).

In this calculation it has been assumed that water is in a vaporous condition as the result of the high temperature of the explosion.

Should the water be in a liquid state, the quantity of gas molecules will decrease down to 35, and  $w_o$  to 685,9 litres.

22 Example 2. Smoky powder containing 78,9 %  $\text{KNO}_3$  + 9,9 % S + 11,2 % C reacts approximately as follows in an explosive transformation:



then

$$N = 8 + 3 + 5 = 16 \text{ and } w_o = \frac{224 \cdot 16}{1,283} = 279,3 \text{ litres.}$$

Measuring in a Gasometer. The explosive to be weighed is placed in a special thick walled steel container

(diag. 5) - known as a "calorimetric (sic - T) or manometric (sic - T) shell" (manometer = pressure gauge - T), - and is then exploded electrically.

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After the explosion the gases are allowed to cool. They are then let into the gasometer through tube T.

The gasometer consists of two "bells" (cylinders - T) - one movable  $\Pi$  and one rigid H. the movable cylinder (lit. bell - T) is immersed in a bath A filled with mercury; the interior of the rigid cylinder is filled with water.

The gases entering below the movable cylinder from "Shell" B through tube P, lift the cylinder (lit. 'bell' - T) and thus oust the water from the rigid cylinder (lit. bell - T)

Diag 5. Mercury Gasometer.

22 From the amount of the water thus ousted, one determines the quantity of the  
23 gaseous products of the explosive transformation.

TABLE 3

Head of Formation and Molecular Weights

Name of Substance	Chemical Composition	Molecular Weight in grams	Heat of Formation in Kal / mol
Methane .....	CH <sub>4</sub>	16	+ 18,4
Acetyline .....	C <sub>2</sub> H <sub>2</sub>	26	- 58,1
Cyanic Hydrogen .....	HCN	27	- 30,5
Ammonia .....	NH <sub>3</sub>	17	+ 10,5
Sulphur-Hydrogen .....	H <sub>2</sub> S	34,1	+ 4,8
Cyanogen .....	C <sub>2</sub> N <sub>2</sub>	52	- 73,9
Vaporous Water .....	H <sub>2</sub> O	18	+ 57,7
Liquid Water .....	H <sub>2</sub> O	18	+ 67,5
Oxide of Carbon .....	CO	28	+ 26,4
Carbonic Acid gas ...	CO <sub>2</sub>	44	+ 94,5
Nitro-glycerine .....	C <sub>3</sub> H <sub>5</sub> (ONO <sub>2</sub> ) <sub>3</sub>	227	+ 82,7
Fulminating Mercury .....	Hg (ONC) <sub>2</sub>	284	- 65,4
Pyroxyline .....	C <sub>24</sub> H <sub>29</sub> O <sub>9</sub> (ONO <sub>2</sub> ) <sub>41</sub>	1143	+ 639
Smoky Powder .....	Mechanical Compound	1283	-

One can take gas samples from the gasometer through the tube for their chemical analysis. This is done by means of special dropping tubes; as has already been explained. Table 4 sets out volumes of gases which form on the explosion of some explosives.

Volumes of Gases forming on the Explosion of  
Some Explosive Substances

Name of Explosive	Litres to 1 kg
Fulminating Mercury .....	315
Azide of Lead .....	231
Pyroxyline cont. 11% <sup>of NITROGEN</sup> azotes .....	860
Nitro-glycerine .....	715
Trottil .....	685
Melinite .....	683
Tetril .....	742
Smokeless Pyroxyline Powders .....	910 - 970
Smokeless	
Nitro-glycerine Powders .....	810 - 880
Smoky Powders .....	234 - 307

9. Quantity of Heat Generated in an Explosion

The amount of heat generated in an explosion may be calculated by the equation of the reaction of an explosive transformation by calorimetrical measurement.

24. Computation of Heat from an Explosion by Reaction

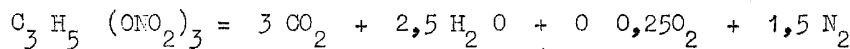
This method is based on GESS's <sup>1</sup> Law.

According to this law the quantity of heat generated or absorbed in the course of chemical reactions, depends only on the initial and final state of the bodies participating in these reactions and not on the path along which the system of the bodies passed from the initial to the final state.

By applying GESS's law to the reaction of explosive transmutations, one can reach the conclusion that the heat from the explosion equates the algebraic difference between the heats generated in the formation of the products of an explosion, and of the explosive substance itself.

The heat of an explosion is generally computed at a constant Volume <sup>Q<sub>v</sub></sup>.

Example: Let us use the already familiar reaction of the explosive transformation of nitro-glycerine



The heat from the formation of the products of the explosion is made up of the heat from the formation of 3 CO<sub>2</sub> and 2,5 H<sub>2</sub>O (of the heat from the formation of O<sub>2</sub> and N<sub>2</sub> as there are no simple substances)

<sup>1</sup> GESS G.G. (1802 - 1850) Russian Scientist, Professor of the PETERSBURG Technological Institute.

Table 3 sets out the heat from the formation of various substances. According to the data of this table the heat from the formation of the products of the explosion equates.

$$94,5 \cdot 3 + 57,7 \cdot 2,5 = 427,75 \text{ K.}$$

After subtracting from this figure the heat from the formation of 1 gram-molecule of nitro-glycerine, we will obtain the heat which is generated on the explosion of this gram-molecule

$$427,75 - 82,7 = 345,05 \text{ K.}$$

In order to bring the heat from the explosion up to 1 kg of the explosive substance, the quantity of heat for 1 gram-molecule must be divided by its weight in kilograms:

$$\frac{345,05}{0,227} = 1520 \text{ K.}$$

Example 2: Equation of the reaction of the explosive transformation of fulminating mercury



then

$$Q_w = \frac{26,4 \cdot 2 + 65,4}{0,2846} = 415,3 \text{ K}$$

It must be pointed out that fulminating mercury has, as an endothermic explosive, a heat of formation with symbol minus, i.e. in the formation of fulminating mercury heat is not generated but absorbed (expended) and accumulates in the molecule of the explosive (- 65,4 K), therefore one must not subtract but add 65,4 K.

#### Method of Calorimetric Measurement

The explosive for weighing (?) is placed in the calorimetric container (lit. bomb) which is arranged as follows (diag. 6).

25 The thick walled steel container A is hermetically closed by screwing on lid B

The following are inserted in the lid:

(a) a metal rod 'a' which is insulated from it;

This rod serves as a contact for initiating the sample of the explosive by electricity;

(b) a small metal tube 'b' for filling the container (lit. - bomb-T) with nitrogen or oxygen. This tube serves at the same time as the second contact; a platinum cup 'e' is attached to this tube for holding the explosive sample;

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Diag 6. The Calorimetric "Bomb".

Diag 7. Calorimeter.

- (C) two vents - one inlet valve (vent ? - T) 'c' for filling the "bomb" (? container - T) with nitrogen or oxygen and one outlet valve 'd' for exhaust gases which form on the explosion of the explosive sample; by this vent the container can be connected to the calorimeter.

The calorimetric container (lit. 'bomb' - T) is placed in the calorimeter (diag. 7) (one word perforated by binding hole - T) (containing ?) a propeller mixer (ventilator ?) and a thermometer.

The amount of heat generated by the explosion of the sample is established by the heating of the water in the calorimeter; for this the sum of the specific heat (alt. coefficient of heat absorption - T) of the water and of the apparatus is multiplied by the difference between the final and initial water temperature.

Table 5 shows the heat from explosion of the most commonly used explosive substances.

TABLE 5

Name of Explosive	Amount of heat generated by the explosion of 1 grammolecule, in cal.
Pyroxyline cont. 11 azotes .....	1040
Nitroglycerine .....	1490
Trotil .....	1000
Melinite .....	1030
Tetrit .....	1090
Fulminating Mercury .....	414
Azide of Lead .....	367
Smokeless Pyroxyline Powder .....	765-809
Smokeless Nitroglycerine Powder .....	1096-1173
Smoky Powder .....	570-807

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10 Temperature of an Explosion

The temperature of an explosive transformation  
is called maximum temperature of explosion

The temperature of an explosion is not established by experiment as the exceptionally short duration of its development almost excludes the use of instruments, although there have been several attempts to measure this temperature. Thus a number of metal wires were placed in the calorimetric container ( - 'borb' - T), each with a different melting temperature and from these wires the temperature of the explosion was judged.

The temperature of an explosion is as a rule determined by calculating the reaction of the explosive transformation by its reaction equation. This computation is based on the known dependence between the heat of the body, its specific heat \* and its temperature.

In conditions of explosive transformation this dependence can be expressed by the following equation:

$$Q_w = C_w \cdot t,$$

$Q_w$  = heat of explosion on a constant volume in small calories;

$C_w$  = coefficient of heat absorption (alt. specific heat - T) of the explosion at a constant volume in small calories;

$t$  = temperature of explosion sought.

But the specific heat (alt. coefficient of heat absorption - T) itself depends upon the temperature of the explosion; for practical computations this dependence expresses itself like this:

$$C_w = a + bt,$$

26 a and b are the coefficients found by experiment, changing in dependence on the nature (alt. character ?) of the products of the explosion.

27 Table 6 sets out the numerical values of these coefficients.

TABLE 6

Products of Explosion	a	b
Single Atom Gases .....	2,98 .....	0
Two Atom Gases .....	4,8 .....	0,00045
Carbon Acid Gas CO <sub>2</sub> .....	9,0 .....	0,00058
Vapours of Water H <sub>2</sub> O .....	4,0 .....	0,00215
Four Atom Gases .....	10,0 .....	0,00045
Five Atom Gases .....	12,0 .....	0,00045
Vapours of Mercury Hg .....	3,0 .....	0
Carbonic Acid Potassium K <sub>2</sub> CO <sub>3</sub> .....	30,0 .....	0
Carbonic Acid Natrium Na <sub>2</sub> SO <sub>4</sub> .....	29,0 .....	0

\* Alt. 'its coefficient of heat absorption' - T

/(Contd.)

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TABLE 6 (Contd.)

Products of Explosion	a	b
Sulphate Potassium $K_2 SO_4$ .....	32,2 .....	0
Sulphuric Potassium $K_2 S$ .....	17,8 .....	0
Chloric Potassium $KCl$ .....	12,9 .....	0
Sulphate Natrium $N_{a_2} SO_4$ .....	32,4 .....	0
Cyanic Potassium $KCN$ .....	10,5 .....	0
Sal ammoniac $NH_4 Cl$ .....	12,0 .....	0
Aluminium Oxide $Al_2 O_3$ .....	22,4 .....	0
Silica $Si O_2$ .....	11,4 .....	0
Carbon $C$ .....	2,9 .....	0
Lead $Pb$ .....	7,0 .....	0

Let us solve this system of the two equation in relation of

t :

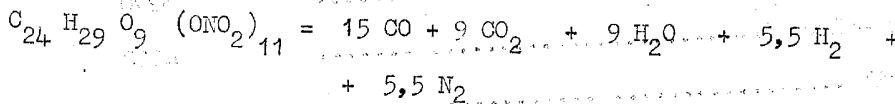
$$Q_w = (a + bt) t = at + bt^2$$

or  $bt^2 + at - Q_w = 0$

Whence

$$t = \frac{-a \pm \sqrt{a^2 + 4 \cdot b \cdot Q_w}}{2 \cdot b}$$

Example 1. Reaction of the explosive transformation of pyroxyline



Let us calculate the quantity of heat for 1 grammolecule using the data in table 3.

$$Q_w = (15 \cdot 26,4 + 9 \cdot 94,5 + 9 \cdot 57,7) - 639 - 11 \cdot 6,8 K,$$

or 1 126 800 cal.

Let us compute the specific heat (alt. coefficient of heat absorption - T) of the products of explosion.

According to the reaction we have 26 grammolecules of two atom gases ( $15 + 5,5 + 5,5 = 26$ ), 9 grammolecules of  $CO_2$  and 9 grammolecules of  $H_2 O$ .

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Then we will get by using the data in table 6:

$$26(4,8 + 0,00045t) + 9(9,0 + 0,00058t) + 9(4,0 + 0,00215t) = 241,8 + 0,03627t = C_w$$

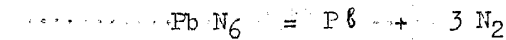
Consequently

$$a = 241,8 \text{ and } b = 0,03627.$$

The temperature sought

$$t = \frac{-a \pm \sqrt{a^2 + 4 \cdot b \cdot Q_w}}{2 \cdot b} = \frac{-241,8 + \sqrt{241,8^2 + 4 \cdot 0,03627 \cdot 1126800}}{2 \cdot 0,03627} = 3160^\circ.$$

28 Example 2. Equation of the Reaction of the Disintegration of Azide of Lead



Heat of Explosion  $Q_w = 107.000 \text{ cal.}$

$$C_w = 7,0 + 3(4,8 + 0,00045t) = 21,4 + 0,00135t.$$

Consequently,

$$a = 21,4 \text{ and } b = 0,00135.$$

$$t = \frac{-21,4 + \sqrt{21,4^2 + 4 \cdot 0,00135 \cdot 107000}}{2 \cdot 0,00135} = 3963^\circ.$$

TABLE 7

Name of Explosive	Temperature of Explosion in °C
Pyroxyline with 11 azotes (sic) .....	3270
Nitro-glycerine .....	4250
Trotil .....	3150
Melinite .....	3540
Tetrit .....	3530
Fulminating Mercury .....	3530
Smokeless Pyroxyline .....	2300-2850
Smokeless nitro-glycerine Powder .....	2900-3550
Smoky Powder .....	2200-2500

11. Initial Impulse and Sensitivity of Explosive Substances

In order to arouse the explosion of an explosive charge, one must spend some quantity of outside energy spent on percussion, heating etc. This outer energy is known as initial impulse, while the process of arousing the explosion of the explosive charge is called initiation.



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28 In the initial impulse one must distinguish between its form (kind of energy) and force (amount of energy). In order to initiate an explosive substance, usually the following kinds of energy are used: mechanical, thermal, electrical and the energy from the explosion of some other explosive substance. The amount and kind of the essential energy for an initial impulse is expressed in the so called sensitivity of an explosive substance, i.e. its greater or lesser capacity at the beginning of an explosive transformation. Under the influence of this or the other exterior reaction.

The form and force of an initial impulse have an extremely important practical significance both when using an explosive substance and when handling it.

29 The following has been established by experiments:

1. The sensitivity of various explosive substances to the effect of an initial impulse of one kind or another is not identical and fluctuates within very wide limits. Even in the case of an identical explosive, one must alter the force of the initial impulse according to the physical condition of the explosive substance, by admixtures etc. (alt. by adding compounds-T). For instance, in order to arouse an explosion of identical charges a percussion (lit. blow-T) of the following force is required:
  - for dry pyroxyline - 0,40 kg/cm<sup>2</sup>;
  - for pyroxyline with 15 % of moisture - 1,8 kg/cm<sup>2</sup>.
2. An identical explosive has different sensitivities to the action of initial impulses of different kinds. Thus of the two explosives - azide and pyroxyline - the first is more sensitive to a blow (alt. percussion - T) and the second - to heat; smoky powders are more sensitive to thermal influence (alt. action - T) than to mechanical action (though they are also very sensitive to mechanical influences).
3. On the alteration of the force and form of the initial impulse, the character of the development of the process of explosion undergoes a change and thence also the character of the action (alt. effect - T) of the explosive substance. For instance, trotil, when the heating process is slow, burns up and produces an explosion in the converse case; the speed of the explosive transformation of nitro-glycerine increases 6-8 times and its force by 2-3 times where instead of using a flame one uses a charge (cap) of fulminating mercury.

The examples quoted prove sufficiently clearly how essential it is to select for each explosive substance an initial impulse which in character and power suit it best. This choice ought to guarantee the best performance by an explosive charge, also absence of failure in bringing about an explosion, safety in handling, in transport, storing etc.

For the selection of an initial impulse of the kind, which would correspond to the peculiarities of the explosive substance in question and to the conditions of its use, one must know the numerical data expressing the sensitivity of the explosive to the influence (alt. action - T) of the initial impulse of a different kind.

29 Mechanical Initial Impulse (blow, prick, friction).

To arouse an explosion by percussion, special percussion mechanisms are used whose action are based on a very rapid displacement of a massive striker. On an encounter between the striker and the charge, the explosive receives a powerful blow, the mechanical energy of which is concentrated on the comparatively small surface of the pin at the narrowed end (alt. tip - T) of the striker. Part of this mechanical energy is spent on arousing the explosion by a direct blow, bringing about the disturbance of the atomic connections and the disintegration of the molecules of the surface layer of

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30 the explosive charge at the place where it encounters the blow. The other part of the energy transforming itself into heat, heats this layer to a temperature at which the explosive transformation begins. The combined action of the mechanical and thermal energy arouses the explosion through the agency of the blow.

The sensitivity of an explosive charge to a blow is usually tested on an instrument known as a "pile driver."

This (diag. 8) is arranged as follows:

30 Weight P, weighing from 0,5 to 20 kgs, slides freely between two vertical and mutually parallel laths - K. This weight can be dropped from the required height marked on scale H, with the aid of a block transmission and a spring circuit breaker (lit. excluder, switch - T) M. A massive steel anvil is mounted on a concrete base A - below the laths. A "stamping" device is mounted on the anvil. It consists of striking base (lit. anvil - T) a, striker pin b and a guide (lit. directing - T) sleeve C (diag. 9).

Diag 8. "Pile Driver."

Diag 9. "Stamping" Device.

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About 0,03 gr. of explosive substance is placed between the striker and the anvil (alt. striking base - T) of the stamping device. The sensitivity of the explosive to percussion is assessed either at the minimum height at which the weight is dropped causing an explosion, or by the force of the blow to a unit of the area in  $\text{kg}/\text{cm}^2$ , or, finally, by the percentage of the explosions which occur when the weight is dropped from a definite height. Table 8 sets out the data <sup>1</sup> expressing the sensitivity of some explosive substances to percussion. Sensitivity is manifested by the force of a blow to a unit of the area essential for obtaining an explosion out of six experiments.

These numerical characteristics of explosive substances are of considerable practical importance as they permit

- (1) Break down all explosives into group (classes) according to the degree of their sensitivity to mechanical reaction;
- (2) determine the rules of safety when handling them, in transport and storing;
- (3) calculate the force of the percussion mechanism for initiating the explosive charge in question.

31

TABLE 8

Name of Explosive	Force of Percussion in $\text{kg}/\text{cm}^2$
Fulminating mercury .....	0,08
Lead Azid .....	0,12
Liquid Nitro-glycerine .....	0,16
Fulminating Galantine .....	0,40
Dry Pyroxyline (alt. Gun cotton - T) .....	0,50
Taen (six - T) .....	0,80
Hexogen .....	1,30
Tetрил .....	1,60
Melinite .....	2,00
Ammatoles (Ammataly, sic - T) .....	2,5 - 3,0
Tetрил .....	3,0 - 4,0
Smoky powders .....	1,2 - 1,8
Smokeless Powders .....	1,0 - 2,0

Initiation of an explosion by pricking does not essentially differ from initiating an explosion by percussion, as in this case, too, there is a concentration of a great amount of mechanical energy on the very small surface of the striker. Initiation by pricking is used in the case of a few explosives (the more sensitive explosives to mechanical reaction), and in particular in the case of fulminating mercury and lead azide.

31

<sup>1</sup> For an identical explosive the data expressing sensitivity to a blow (table 8) and other peculiarities (subsequent tables) may differ somewhat in extent, a fact which is to be explained by the difficulty of observing identical conditions in the course of experiments.

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31 When arcing an explosion by friction, heat accumulates, in the various particles of the explosive substance subjected to friction as the result of the mutation of the mechanical energy into thermal energy and as the result of the heating of these particles up to a temperature at which the explosive mutation commences.

In the process of their manufacture and in their further service all explosives are subjected to friction - when they are being pressed, packed, transported etc. Therefore testing explosives for sensitivity to friction (specially of "t e r o c h n y k h s o s t a v o v 1" - (first word - not known, second word - compositions - T) is of great practical value.

The most accurate data expressing the sensitivity of explosives to friction are obtained in cases where they are tested with the aid of a friction pendulum.

Diag. 10 Friction

The friction pendulum (diag. 10) consists of a pivot Pendulum (pendulum) which has a length of 2 metres. This is suspended from a special device. A steel shoe, weighing 2 kgs is attached to the lower end of the pendulum. When the pendulum is being swung, the convex lower surface of the shoe rubs against the explosive laid on a special anvil - H - for the test. Before the test, the pendulum can be fixed at the required height along a graduated (alt. milled - T) arc.

32 The sensitivity of the explosive substance to friction expresses itself through the initial height of the drop, in the number of swings of the pendulum and the weight of its shoe. Thus, for instance, fulminating mercury explodes after 3-10 swings at an initial height of 25 cm, while azide of lead explodes after 12 swings at an initial height of drop of 37,5 cm, the weight of the shoe being increased by 0,15 kgs.

Sometimes the sensitivity of explosive substances to friction is tested by pounding them (alt. rubbing - T) in a small china mortar with glazed pestle. Table 9 sets out data found for some explosives in this way (by pounding).

TABLE 9

Name of the Explosive	Result of Test
Nitro-glycerine .....	Explodes
Fulminating Mercury .....	Explodes
Tetрил .....	Slight Crackling
Picric Acid .....	Slight smell of burning
Trotil .....	Non-reactive
Pyroxyline .....	Non-reactive
Black Powder .....	Non-reactive

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INITIAL THERMAL IMPULSE - heating or jet of flame.

In both cases there is a direct transmission of thermal energy to a part of the explosive charge, which causes an explosive transmutation.

The reaction of an explosive to heating is determined by the temperature of the flash, i.e. by the minimum temperature to which part of the explosive charge must be heated in order to cause in itself expansion of the explosive transformation at a speed which is sufficient for obtaining at least a sound effect. It must be stressed that the temperature of the flash is not the temperature of the initial explosive transformation of the explosive substance, as this transformation may begin also at a lower temperature, but in this case it will occur at a slow pace and will not be in the nature of a flash.

Nickel covering  
of an electric heater

Iron bath

Wood's Alloy  
(A l l o i V u d a)

Tin Casing

11. Instrument for establishing the temperature of the flash from an explosive substance.

The temperature of a flash is usually determined in a special bath (diag 11) heated by electricity and filled with a special alloy. When the temperature of the alloy comes close to the temperature of the flash, a container holding a small quantity of the explosive substance to be tested is lowered into the melted alloy. At the moment of the flash, the temperature is determined by thermometer which has also been lowered into the same alloy.

33 Table 10 shows the temperature of flashes determined in this way:

TABLE 10

<u>Name of Explosive</u>	<u>Temperature of Flash in °C</u>
Fulminating Mercury .....	175 - 180
Azide of Lead .....	330 - 340
Smoky Powders .....	290 - 310
Smokeless Powders .....	180 - 200
Pyroxyline .....	195
Nitro-glycerine .....	200
Tetril .....	195 - 220
Trottil .....	290 - 295
Picric Acid .....	290 - 300

33 The Initial Electric Impulse. For initiating an explosive charge by electricity one generally uses the so called igniting bridge fuzes in which a thin metal wire is brought to white heat through an electric impulse and ignites the explosive charge surrounding it.

From this it follows that the essence of electric initiation is identical with thermal initiation.

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An initial impulse aroused by the energy from the explosion of another explosive substance. For initiating an explosive substance with a low degree of sensitivity one needs a very powerful initial impulse. Direct application of a very powerful mechanical initial impulse to an explosive charge is connected with considerable technological difficulties.

The year 1864 brought the realization of the possibility of detonating one explosive through the explosion of another. The initiating charge is in this case known as detonator and the process as detonation. Thus, the problem of initiating an explosive with a low reaction is solved by exploiting the energy from the explosion of a considerably more sensitive detonator requiring a comparative weak initial impulse. For arousing an explosion, one generally uses a whole system of detonators combined in one whole (for instance in the fuze) which are stored, transported and used by observing special safety measures. Direct mechanical or thermal actions (percussion, pricking, flame) are reacted to by the most sensitive (primary) detonators (percussion cap detonators) which is generally made from fulminating mercury or azide of lead with various admixtures. The explosion of a detonating cap is passed to another less sensitive secondary detonator (intermediate detonator) and through this to the main explosive charge. There may be several intermediate detonators. A method of this kind of detonation has been accepted for modern artillery projectiles. The need for several detonators is caused by the fact that detonating caps are made very small for reasons of safety and therefore its power is insufficient for direct initiation of the main charge.

The essence of arousing an explosion by the action of a detonator consists in the main of a very sharp and intensive shock (alt. blow - T) from gases which form on the explosion of the detonator, i.e. this scarcely differs from arousing an explosion by means of mechanical percussion.

The sensitivity of an explosive substance to the action of a detonator is determined by its minimum weight at which the detonation of the main charge occurs. Table 11 sets out the minimum weights of detonators which are sufficient for exciting the explosion of identically weighing explosive charges most frequently used in artillery.

TABLE 11

Detonator	<u>Explosive to be tested - grams</u>		
	TETRII	MELINITE	TROTIL
Of Fulminating Mercury	0,29	0,30	0,36
Of Azide of Lead	0,025	0,025	0,09

The energy from the explosion of one explosive substance can be used not only for detonation but also for igniting another explosive substance and specially for igniting powder compounds. For this one uses ignitor caps<sup>#</sup> of fulminating mercury with admixtures which weaken its explosive tendencies, lengthen the flame and provide on the explosion of the cap hard particles which heated to white heat, contribute towards better ignition.

#### Factors influencing the sensitivity of Explosive Substances

Of all the factors influencing the sensitivity of explosive substances the following are the most important in practice:

1. The Physical composition of an Explosive. When passing from the solid to the liquid condition the sensitivity of an explosive increases and decreases in the converse transition. Nitro-glycerine is a typical example in this connection. It is more sensitive in its liquid state than in its solid (frozen) condition.

<sup>#</sup> Alt. percussion caps, pull fuzes - T.

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A dependence of this kind is usually explained by the fact that, when passing from the liquid to the solid state, some amount of heat is generated which must be compressed by increasing the force of the initial impulse when initiating the explosive substance in its solid state. Among other examples expressing the influence of the physical composition of the substance on its sensitivity, one may quote the following: Friable pyroxyline is considerably more sensitive than gelatinized (dissolved) pyroxyline; pressed nitro-compounds are considerably more sensitive to an explosion being excited in them with the aid of a detonator cap than liquid (melted) nitro-compounds.

2. Degree of Trituration. The dependence of the sensitivity of an explosive on the degree of trituration, i.e. on the size of the crystals is not identical in the case of all explosives and the data on this dependence are contradictory in the extreme. None the less, it is possible to establish for the majority of explosives that a higher degree of trituration corresponds to greater sensitivity.

3. Density of Explosive Substances. With the increase in the density of an explosive substance, its sensitivity decreases, as in this case the energy of the initial impulse is spread over a large mass and a smaller amount of energy reaches particles of the explosive.

An increase in the density of explosive is usually reached by pressing them. Even so sensitive an explosive as fulminating mercury may by pressing it be brought to a state where it very nearly loses all its sensitivity.

35

4. Initial Temperature of Explosives. With an increase in the initial temperature of an explosive substance, its sensitivity grows a situation which may be explained by the weakening of the connections within the molecules of the explosive, as the result of which a lesser amount of outside energy is required for the beginning of the explosive transformation. This assumption is proved by a number of experiments with initial impulses of various kinds.

Table 12 shows data establishing the dependence of the sensitivity of fulminating gelatine to the shock of a falling 2 kg weight or its initial temperature.

TABLE 12

Initial Temperature in °C	5	25	50	75
Necessary height of the weight (in cm) at which an explosion occurs .....	20	13	11	10

Table 13 sets out the influence of the change in the initial temperature on sensitivity to the heating of trotil and picric acid. The higher this temperature, the less is the time required for obtaining a flash.

TABLE 13

Required duration of heating in minutes	10	7	5	3	2	1	0,5
Trotil	210°	275°	285°	297°	310°	320°	330°
Picric Acid	283°	295°	302°	310°	315°	325°	330°

36

5. Admixtures to Explosive Substances. Most admixtures to explosive substances can be broken down into the following groups:

- (a) Admixtures increasing the sensitivity of explosives to mechanical action: sand, finely crushed glass, particles of metal and other objects harder than the explosive in question, having sharp edges. The increase in sensitivity in this case is explained in the concentration of the energy of the initial

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impulse - pressure, blow, friction - on the sharp edges of the particles of these admixtures. Table 14 gives a clear picture of their influence on the sensitivity of explosives. This table has been drawn up with basis of experiments with trotil.

TABLE 14

Sand contents in Trotil in % .....	0,01-0,05	0,10-0,15	0,20-0,25
Percentage of Explosions on the shock from a 10 kg weight dropped from a height of 25 cm .....	6	20	29

It can be seen from Table 14 that with increased sand contents the sensitivity of the explosive grows.

- (b) Inert Admixtures, lowering the sensitivity of explosives as part of the energy of the initial impulse spreads to them; in themselves they do not participate in exciting the explosion.

To the category of such admixtures belong porous earths, magnesium etc. Thus, for instance, the sensitivity of nitro-glycerine containing 25 % of the porous mineral specie - k i z e l'g u r (sic - T), decreases by three times in comparison with pure nitro-glycerine.

- (c) Phlegmatizing Admixtures considerably lower the sensitivity of explosives even if they are introduced in comparatively small quantities. To phlegmatizing admixture or phlegmatizers belong: paraffin, vaselin, castor oil and other substances able to envelope separate particles of explosives. By enveloping individual particles of an explosive, phlegmatizers as it were create defensive screens around these particles and thus lower the receptiveness of explosives to exterior actions.

Water also possesses phlegmatizing qualities a fact which is used for storing pyroxyline.

The part played by phlegmatization is very considerable indeed. When firing with armour and concrete piercing projectiles it is essential to obtain an explosion when the projectile has already penetrated the obstacle. As at the moment when the projectile encounters the obstacle, a shock of such violence occurs that it can excite a premature burst of the projectile, projectiles are in some cases fitted with a phlegmatized explosive substance.

37

## 12. DENSITY OF EXPLOSIVE SUBSTANCES

One distinguishes between the actual density of an explosive and its density measured in weight (lit. g r a v o m e t r i c h e s k a y a p l o t n o s t' - T) as well as the density of the charging (loading - T)

Actual density or simply density of an explosive substance is the specific gravity of the substance itself, i.e. actual density is determined by the amount of the explosive substance, consisting of the unit of the volume of its grain\* (lit. translation of "z e r n o" - T), and is measured by the weight of the unit of the volume of its grain.\* Knowing the weight of the grain\* and its volume one is in a position to compute actual density. The greater the actual density of the explosive, the more of it is contained in the given volume.

Gravimetrical (sic-poss measured by weight - T) Density (density of packing of crystalline and granular (granulated ? - T) explosive substances in the relationship of their weight in a definite space ( ? volume ) 'o b, e m' - T) to that space ( ? volume) which the explosive occupies

\* Alt. kernel - T



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(together with the air spaces between the grains or crystals and their interiors).

If the true density of explosive substances depends on their nature, then gravimetric density depends on the shape and size of the grains or particles of the explosive; by triturating an explosive substance, its gravimetric density undergoes a change (decreases). In the case of moulded and liquid explosive substances the gravimetric density equates actual density where the charge is one whole entity.

E.g. 1,8 kg of an explosive substance of grains of some specific shape is placed in a container having a volume of 3 litres. The gravimetric density of this explosive substance in the grain of the specific shape equates

$$\frac{1,8}{3} = 0,6.$$

Owing to the fact that in the packing of powder grains it is important to avoid leaving spaces between them which are occupied by air, the gravimetric powder density is always less than the actual density, and fluctuates within the limits of 0,7 - 0,9, while the true density of, for instance, pyroxyline powder equals 1,6.

Density of Loading (Alt. Charging - T). Very often explosives do not fill the whole volume (powder chamber) in which the explosion occurs but only part of it. The relationship between the weight of the charge to the volume of the powder chamber is known as the density of charging (the weight of the explosive substance to a unit of the volume of the powder chamber).

Thus the density of charging equates

$$\Delta = \frac{W}{V}$$

$\Delta$  = density of charging in  $\text{kg/dm}^3$ ;

$W$  = weight of explosive charge in kg;

$V$  = volume of the powder chamber in  $\text{dm}^3$  (in litres).

Having already the weight of the charge as well as the volume of the powder chamber it is not difficult to compute the density of loading.

Example The weight of the propelling (Alt. powder - T) charge is 2,25 kg, while the volume of the powder chamber is 5,5 litres; then

$$\Delta = \frac{2,25}{5,5} = 0,4 \text{ kg/l, or } 0,4 \text{ kg/dm}^3$$

37 If the explosive substance fills the whole volume of the powder chamber then the density of loading will equate the gravimetric density of the explosive substance.

### 38 13. STABILITY OF EXPLOSIVE SUBSTANCES

Stability of explosive substances is called their quality of retaining their physical and chemical, and therefore also their explosive faculties when stored, unaltered in the course of time.

The stability of explosives determines the possibility of creating large reserves of them necessary for securing the constant preparedness of the country for mobilization.

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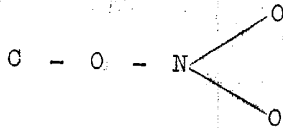
We will have to differentiate between physical and chemical stability.

Physical stability of Explosive substances consists of their mechanical soundness (alt. durability, solidity, endurance, stability - T), non-hygroscopic nature, lack of volatility etc. Explosives not possessing these attributes are in one respect or another unstable. For instance, smoky powders have little physical stability as the result of the insufficient mechanical solidity of their grains and because of their hygroscopic nature; the physical instability of smokeless pyroxyline powders is conditioned by the (alt. depends on -T) the volatility of the solvent; ammonites have insufficient physical stability due to the hygroscopic nature of saltpetre, etc.

Physical stability is retained in proper conditions of the storage of explosives and the proper handling of them: hermetic sealing, inner linings (alt. interlayers - T) protecting the explosives from knocks and thus from being damaged in transport, when being carried etc.

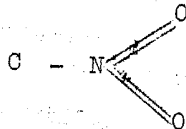
38. Greater or lesser chemical stability of explosive substances depends on many causes. The most important of these is the chemical quality (Alt. nature - T) of the explosive substance itself; the more solid are the molecular links (alt. connections - T) and the less the reactive capacity of the explosive, the greater is the chemical stability over which it disposes.

Nitrates have the least solid links (pyroxyline and nitro-glycerine) as in the atomic grouping which is characteristic of them, -ONO<sub>2</sub>, the nitro-group NO<sub>2</sub> is not directly linked to the carbon of the molecule but by the atom of the hydrogen whose connection with nitrogen is unstable (alt. not solid, firm - T):



Hence pyroxyline and nitro-glycerine are chemically the least stable of explosive substances.

In nitro-combinations group NO<sub>2</sub> is directly linked to carbon (trotil, melinite etc.)



This connection is sufficiently steady and nitro-combinations possess great chemical stability.

39. Unrelated (alt. foreign, outside, casual, accessory - T) admixtures exercise a considerable influence on the chemical stability of explosive substances. Some of these admixtures lower the chemical stability of explosives, playing the part of positive k a t a l i z a t o r y (sic), i.e. they promote the acceleration of slow molecular transformations of explosives in conditions, for instance, of prolonged storage and specially where the temperature in the stores is raised.

Among positive catalyzators (Translator's license) the most important in practice are the remains of nitrate acids which have not been washed off and which are the main agents for lowering the chemical stability of explosives. Therefore the elimination of acids is a most important function in the preparation of explosives. It is specially important to pause and consider the so called a v t o k a t a l i z ( ? autocatalysis) the essence of which consists of the following.

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Explosive substances, as systems lacking chemical stability, are capable of slow molecular transformations without any visible exterior reactions in the usual conditions of their treatment. Resulting from such transformations, intermediate products form from the disintegration of the molecules of the explosives, which play the part of positive catalyzators, speeding the process of these transformations; catalyzators of this kind are usually oxides of nitrogen (alt. azote oxides - T). The phenomenon of autocatalysis sharply increases in force on an increase in the temperature of the explosive substance which, in the final instance, may lead to a spontaneous explosion of the explosive substance. One has to reckon with this situation quite particularly when storing explosives in a hot climate (Trans Caucasian and Central Asiatic Republics).

From what has been said it follows the main measures guaranteeing the greatest possible chemical stability of explosives are chemical purity in their preparation, a strict regime in temperature and measures preventing humidity in storing (alt. anti-damp precautions).

STABILIZATION OF EXPLOSIVE SUBSTANCES. Apart from positive catalyzators lowering the chemical stability of explosives, there are admixtures which may fulfil the function of negative catalyzators, i.e. they may slow down the processes of slow molecular transformations of explosives and thus raise their chemical stability. Admixtures of this kind are known as stabilizers; they are widely used in the manufacture of those explosives which in their chemical nature dispose over little chemical stability, particularly in the manufacture of smokeless powders. The importance of stabilizers consists of this, that they combine with nitrate acids and azote oxides which have not been washed off, forming in the course of the process of the slow molecular transformation of the explosives and neutralize their activity without, however, halting the disintegration of the molecules of the explosives. The simplest example of a stabilizer is provided by triturerated chalk which is added (up to 2 %) to pyroxyline in order to increase its chemical stability. For stabilizing smokeless powder one employs d i f e n i l a m i n -  $(C_6 H_5)_2 NH$ , which not only keeps smokeless powders from disintegrating but at the same time improves them when disintegration has already begun. Use of d i f e n i l a m i n increases the permitted period of storage of smokeless powders by several times.

#### 14. TESTING AND CHECKING THE STABILITY OF EXPLOSIVES

Chemical Stability of Explosives. The essence of a test of the chemical stability of Explosives consists of this, that the test is carried out at such increased temperatures at which it is possible to discover and evaluate an alteration in the chemical condition of the explosive, which would otherwise, in ordinary conditions of storing, be unnoticeable. The faster and stronger explosives react at increased temperatures the less chemically stable they are considered.

The methods for testing the chemical stability of explosives can be classified into two groups;

1. Tests of the qualitative order are based on the application of various indicators showing by the change of their colour (alt. dyes, stains, hues, tinta - T) either the beginning or definite degree in the decomposition of the explosive substance.

As an example of this may be taken the test which is usually employed for checking the chemical stability of nitro-glycerine or nitro-glycerine powders. This test is based on the very sensitive reaction of potash (alt. kali - T) containing iodine together with starch in the presence of oxides of nitrogen (alt. azote -) this is done as follows:

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A sample of the explosive to be tested is inserted into a test tube with a cork, from which an iodine and starch paper has been suspended (indicator 5 diag. 12). This is steeped in a solution of glycerine in water. The test tube is inserted into an aperture (? housing T) of a basin containing water with a temperature of 75°

### Diag. 12. Qualitative test.

A. Sample of Explosive:

Indicator:

B. Water bath.

The temperature of the water in the bath leads to a molecular transformation of the explosive substance which is accompanied by the secretion of nitrogen oxides, while a small coloured brown stripe forms on the border between the dry and the moist part of the indicator (paper). This stripe corresponds to the colour of the combination which has occurred between the iodine and the starch. The chemical stability is considered normal when the small stripe has appeared on the indicator not earlier than after 18-20 minutes.

The other qualitative tests are very similar to the test which has been described and mainly differ from it in the indicators used and in the degree of heating, as, for instance, in the case of the basic test where a (Russian word: l a k m u s o v a y a b u m a z h k a - T) laquered (?) paper is used as indicator.

2. Quantitative tests consist of determining loss of weight by the explosive substance while it is being tested, and in determining the amount of nitrogen oxides which form.

41 As example of a test of quantity is a test by weighing. This is used for the determining the chemical stability of smokeless powders. This test is conducted as follows.

The explosive sample is placed in a water bath heated to a temperature of 95°. After 24 hours this sample is weighed; loss of weight is entered on a graph in percentages (diag. 13). The process of a sharp decomposition of the powder is indicated by a sharp upward bend of the curve.

41 The chemical stability of an explosive substance is assessed by the time which has elapsed from the commencement of the heating of the powder up to the moment corresponding to the bend of the curve. It will be seen from the diagram that this moment of the bend A and B has for one powder I occurred at the 15th hour of the 24 hours, while in the case of the other II only at the 24th hour; consequently the chemical stability

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of the second powder is much higher than of the first.

Time of heating in hours

Diag 13. graph of the weighing test

The Physical Stability of Explosives requires periodical checking, as in the case of chemical stability. This check consists of the exterior inspection of the explosive, in determining presence of humidity, of volatile solvents etc. In determining the hygro-metricity of explosives and the volatility of the solvent contained in them, one uses the ordinary physical methods.

#### 15. STRENGTH OF POTENTIAL OF EXPLOSIVES

41 A. Strength of Explosive Substances. The strength of an explosive is usually assessed by the maximum pressure which is developed by the explosive in question in its explosion in an enclosed space, as an enclosed space corresponds best to the conditions of the usual employment of an explosive (powder chamber of an artillery piece, the interior cavity of a projectile etc). It is considered that the higher this pressure the greater will be the force possessed by the explosive substance in question.

Maximum pressure in an enclosed space is found by computation on the basis of theoretical consideration or by direct measurement in a pressure container (lit. manometric bomb).

The more gases form on an explosion and the greater their temperature, the more will be the pressure developed by them and the stronger the explosive in question.

According to BOYLE - MARIOTT's - GEY (HEY ?) - LYUSSAK (LUSSAC ?)'s Law, the dependence between pressure, quantity amounting on 0° to a pressure of 760 mm) and the temperature of gases forming on the explosion, can be expressed by the following equation of the state (alt. condition - T) of gases

$$p \omega = p_1 \omega_1 \left( 1 + \frac{1}{273} t \right) = p_1 \omega_1 \frac{273 + t}{273}$$

42 p stands for the maximum gas pressure on an explosion;

$\omega$  stands for the space in which the explosion occurs;

$p_1$  stands for the initial pressure in 1 a m;

$\omega_1$  stands for the volume of gases on the explosion of 1 kg of explosive on 0° and a pressure of 760 mm;

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- $\frac{1}{273}$  - stands for the temperature coefficient of gas expansion;  
 $t$  - stands for the temperature of gases taken as equating the temperature of the explosion.

When expressing this equation in absolute temperature

$$T = t + 273, \text{ we get}$$

$$p \omega = \frac{p_1 \omega_1}{273} T. \quad (1)$$

Quantity  $\frac{p_1 \omega_1}{273}$  is a constant for the amount of gases under consideration and is expressed by letter R.

Thus  $p \omega = R T \quad (2)$

RT, containing the two most important characteristics of the explosive function of the given explosive substance, is called the force of the Explosive Substance and is expressed by symbol f

$$f = RT = \frac{p_1 \omega_1}{273} T.$$

It is necessary to stress that this is a conventional nomenclature as it does not correspond to the physical essence of RT, which does not express the force of an explosive but only its mechanical ability to function, i.e. the theoretical function which would be carried out by  $\omega_1$  l (litres ? - T) of gases expanding under atmospheric pressure when heated from 0° to T°. Hence f has a dimension not in units of force, but in units of function which is carried out by 1 kg of explosive, for instance, in litro-atmospheres. As 1 litro-atmosphere equates 10,33 kgm, then

$$f = \frac{10,33 \cdot 1}{273} T = 0,038 \cdot T \text{ kgm.}$$

Usually the true force of a given explosive substance is expressed by quantity f (the conventional force of the explosive.)

Let us, in order to compare some explosive, compute this conventional force for them.

Example 1. Nitro-glycerine:

$$\omega_1 = 715 \text{ l and } T = 4250^\circ + 273^\circ = 4523^\circ$$

then

$$f = 0,038 \cdot 715 \cdot 4523 = 122890 \text{ kgm.}$$

Example 2. Smokeless pyroxyline powder:

$$\omega_1 = 928 \text{ l; } T = 2350^\circ + 273^\circ = 2623^\circ;$$

$$f = 0,038 \cdot 928 \cdot 2623 = 92497 \text{ kgm.}$$

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Example 3. Smoky Powder:

$$W_1 = 279 \text{ kg}; \quad T = 2473^\circ;$$

$$f = 0,038 \cdot 279 \cdot 2473 = 26\,219 \text{ kgm.}$$

B. Potential of Explosives. If we assume that the whole heat of an explosion -  $Q_w$  - is transformed into mechanical energy, then the magnitude of this energy -  $W$  - will, according to the law of thermodynamics, equate

$$W = 427 Q_w \text{ kgm.}$$

The greatest possible amount of mechanical energy related ( ? expressed in - T) to 1 kg of an Explosive, is called the potential or the potential energy of an explosive substance.

Name of Explosive	W Kgm:	Table 15
Pyroxyline (azotes) ...	446	200
Nitro-glycerine .....	649	000
Trottil .....	431	300
Melinite .....	439	800
Tetрил .....	467	600
Fulminating Mercury ...	177	200
Lead Azide .....	156	700

The potential of an explosive, as also force  $f$ , is one of the most important features of the efficiency of an explosive.

Table 15 shows the potentials of the most commonly used explosive substances.

In reality, however, the whole heat of the explosion does not turn into mechanical energy and the whole mechanical energy does not fulfil a really useful function.

A considerable amount of heat and mechanical energy is spent on heating the medium, escapes with the heated gases, is spent on harmful resistances, etc.

As an example of the correlation between the potential of an explosive and a truly useful function, may be cited the computation of the expenditure of the thermal energy of a charge consisting of smokeless powder on a shot from an artillery piece (see p. 142).

16. HIGH EXPLOSIVE AND BLAST EFFECT OF EXPLOSIVE SUBSTANCES

A. High Explosive effect, or high explosivity of an Explosive Substance, is called its propensity towards (splintering) fragmentation effect. This effect will be the greater, the more energy is transformed into mechanical energy in a unit of time; hence the dimensions expressing the amount of energy which are released on an explosion and the speed of the explosive transformation, must enter into the mathematical expression of the high explosivity. It has already been proved that the velocity of an explosion increases on an increase in the density of charging;

44 consequently, high explosivity depends on such density of charging. Hence high explosivity (alt. tendency towards splintering - T), when related to 1 kgm of an explosive, is generally expressed by the following formula:

$$B = f \cdot D \Delta,$$

B - stands for - high explosivity of an explosive in units of function to a unit of time;

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44. f - stands for the force of an explosive  $\left( \frac{P_1 W_1}{273} T \right)$  ;

D - stands for the velocity of a detonation;

Δ - stands for the density of charging.

Already knowing quantity f, D and Δ, one can compute the magnitude of the high explosivity of an explosive substance.

Example 1. For trotil: f = 89 100 kgm; D = 6690 m/sec ;

Δ = 1,5; we get

$$B = 89\ 100 \cdot 6690 \cdot 1,5 = 894\ 118\ 500 \text{ units of}$$

function a second

Example 2. For Fulminating Mercury: f = 45 522 kgm ; ...

D = 4490 m/sec and Δ = 4,0; we get

$$B = 45522 \cdot 4490 \cdot 4,0 = 817\ 575\ 120 \text{ units of}$$

function a second.

For an experimental assessment of the high explosivity of explosive substances, various methods are employed; let us consider some of these GESS's Test (HESS ? - T). This method is used for determining the explosive tendencies of an explosive substance according to the degree of compression of a small lead cylinder from the explosion of a cartridge containing the substance to be tested (diag 14).

Lead

Capsule

Disc

Diag. 14. GESS's Test by compression of a lead cylinder

Diag. 15 Test by penetration of a lead disc.

45 Test by Penetration of a Lead Disc. This is employed for testing detonator caps it consists of the following.

A thin lead disc is placed over a section of a gas pipe. The detonating cap to be tested is placed vertically over the centre of the disc and is fastened by a steel arc (diag 15). A properly functioning cap should pierce the disc; in this process the diameter of the penetration should be no less than the diameter of the cap with regular radiation around the aperture (diag 16)

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45 The most accurate assessment of the high explosive tendency of an explosive are practical tests of ammunition equipped with it. In this case one determines high explosivity (alt. splinter effect - T) according to the degree and character of the splintering of the metal body of a projectile (mine).  
 Groove before explosion      Diag. 16 Lead Disc after the explosion of a detonator cap on it.

B. Blast Effect of an Explosive

Blast effect of an explosive is its ability of effecting the destruction of some solid body, for instance - soil. Blast effect depends on the magnitude of gas pressure forming on the explosion and on the speed with which this pressure develops; apart from this, the result of blast effect also depends on the peculiarities of the medium. This latter has no mathematical expression.

Diag 17. Lead cylinder for testing an explosive for splinter effect (alt. high explosive effect-T)

Groove after Explosion

Diag. 18 Lead cylinder after the explosion of an explosive sample with cylinder.

To measure blast effect one often uses the dimensions of a crater forming on the explosion of the charge of a given explosive substance. But this is a very inexact way of measuring.

The following method provides more accurate data on the blast effect of an explosive.

45 An explosive sample (generally 10 gr) is inserted into a cylinder (bomb) with a central bore with no openings to it. The explosive is enclosed in a foil cartridge into which one inserts the detonating cap (diag 17). After the insertion of the small cartridge, the bore of the container (bomb) is filled with dry sand.

On the explosion of the sample the bore of the container (bomb) expands and the force of the blast effect of the given explosive is assessed from the extent of the increase of the bore (diag 18).

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Name	Volume in
Nitro-glycerine	550
Pyroxyline	420
Trotol	295
Melinite	305
Tetril	390
Fulminating Mercury	150
Azid of Lead	115
Smokeless Pyroxyline Powder	350
Smoky Powder	30

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17. DIRECTED (AIM. GUIDED) EFFECT OF AN EXPLOSION (CUMULATIVE EFFECT)  
AND ITS PRACTICAL EXPLOITATION

The energy of an explosion from charges of the usual kind cannot always be easily exploited with the best effect, because it disperses itself equally in all directions from the site of the explosion. However if one were to give the explosive charge a special shape and to place the detonator in a definite way, one will be able to give a guided effect to the wave of the explosion and thus considerably increase the destructive effect from the explosion in the set direction.

In order to obtain a guided effect from the explosion, it is sufficient to make a cup like or conical cavity on the side of the charge which will have to contact the obstacle to be destroyed, and to place the detonator at the opposite side to this cavity (diag. 19). In this case the detonation wave will travel from the detonator in the direction towards the cavity in the charge of the explosive substance, and the presence of the cavity will help the cumulation (collection, concentration) of the percussion on waves when they meet in the empty space of the cavity in the charge. Thus the special feature of the function of hollow charges is connected with the diffusion from the surface of the cumulative cavity of the descending jets and waves.

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Diag. 19. Cumulative armour  
melting Shell <sup>\*</sup>

Section:

1. Body of Shell;
2. Explosive charge  
(alt. bursting charge-T);
3. Cumulative cavity;
4. Detonator.

46 almost perpendicular to the surface of the cavity ("cumulative surface") and allows the jets to gather on a "cumulative focus."

Consequently the essence of the occurrence of cumulation consists of the concentration and direction of the energy of the explosion and the creation of a condensed current of gases in the space of the cumulative cavity (diag. 20). Resulting from the collision and compression of the products of the explosion, the cumulative current expresses itself by a high degree of density, velocity, temperature and pressure. The speed of the cumulative jets in some cases is greater than the speed of detonation of high explosives (alt. fragmentation-T), reaching dimensions of 10-15 thousand m/sec at an enormous pressure in the region of 1 00 000 kg/cm.<sup>2</sup>

The percussion from a force of this kind is sufficient for piercing armour whose thickness is close on the diameter of the cumulative aperture in the charge or even one and half to two times greater. Hence the cumulative effect is widely used in special charges, which have come to be known as armour melting charges (See book 5 of the Artillery Course)<sup>1</sup>

#### 18. CLASSIFICATION OF EXPLOSIVE SUBSTANCES ACCORDING TO THEIR USE.

Explosive substances are usually divided, according to their employment, into initiating, fragmentation, propelling and pyrotechnical structures.

Diag. 20. Diagram of a guided effect from an explosion wave where the explosive charge has been equipped with a crater like cavity:

C - jet of strongly heated gases, acting with increased force in the direction from the crater-like cavity.

\* Lit. Shell piercing armour by melting it - T.

<sup>1</sup> These shells have been named armour melting as the result of the point of view which prevailed at one time to the effect that the cumulative gas jet on an explosion causes metal to melt with the consequent scooping out of the liquid metal through the pressure of the jet. Experiments have, however, to a great extent proved another point of view, whose adherents consider the main factor leading to the destruction of armour, to be the dynamic blow from the cumulative jet.

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47 Initiating Explosive Substances are distinguished by the following peculiarities:

1. The usual form taken by the explosive transformation of initiating explosive substances in normal conditions is their full detonation, which in their case is easily aroused by all aspects of the initial impulse.

2. From the moment when the Explosion has been aroused up to the moment when the maximum speed of the explosive transformation has been developed a very short time elapses, consequently initiating explosives taken in small quantities, for all practical purposes explode instantaneously.

These features of initiating explosives make them most useful for initiating explosions in other fragmentation (alt. high explosive) explosive substances with secondary detonation.

To the group of initiating explosives in common use belong:

fulminating mercury, azid of lead, stiniate (sic) of lead.

48 High Explosive Substances. This name is given to explosive substances with whom the explosive transformation is not always a complete detonation and which differ by a considerably less sensitivity to exterior influences than initiating explosive substances. As the result of their lesser sensitivity they are safer to handle. They are generally exploded by percussion caps of initiating substances. High explosive substances are used for demolition charges and mines in demolition work. Pyroxyline belongs to high explosive substances, also nitro-glycerine, trotil, melinite, hexogene (lit. gegsogen - T) and others.

Propellent Explosives, or Powders. Propellent explosives are called those, the character of whose explosive transformation in an unenclosed (not immutable) space allows them to be used for propelling projectiles (mortar bombs).

Propellent explosives are mainly used in propelling charges of guns and mortars. Their explosive transformation expresses itself partly in the rapid combustion brought about by the combustive contents. Powders are divided into two great sub groups: those which consist of mechanical compounds and those which are chemical combinations of the colloid type. The first sub group contains smoky powders (or black powders) and the second - smokeless (pyroxyline and nitroglycerine) powders.

48 Pyrotechnical compositions (incendiary, illuminating, signalling and tracing) are used for special purposes ammunition (among this signalling rockets) and consist of mechanical compounds from oxydes and fuels. When burning they give the required pyrotechnical effect (illuminating, incendiary etc). However, many of these compounds have also explosive characteristics and in certain conditions may also detonate (for instance, compositions for signalling purpose, containing chlorates as oxidizers).

It must be pointed out that the division of explosive substances into propelling and high explosive has a somewhat conventional character, as the explosive transformation of powders depending on the conditions in which it occurs, may have the character of an explosion. It was rightly said in the course of five centuries that smoky powder both "blasted and propelled", i.e. was used both as bursting and propelling substance.

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## CHAPTER TWO

## INITIATING EXPLOSIVE SUBSTANCES

## 19. FULMINATING MERCURY

Chemical Composition and Formation. In its chemical composition Fulminating Mercury Hg (ONC) is a mercury salt of fulminating acid (HO·NC) and forms as a white deposit, as the result of the action of alcohol on a solution of metallic mercury in nitrogen acid.

One first dissolves mercury in nitrogen acid; in this process the solution of nitrogen acid-mercury - Hg (ONO<sub>2</sub>)<sub>2</sub> forms as a dark green liquid. This solution is then processed with alcohol.

Features and Use. Fulminating acid is a white or grey powder consisting of small crystals. It has a sweet taste; as a combination of mercury it is poisonous. The specific gravity (density) of fulminating mercury is 4,42; It is one of the heaviest explosive substances and lends itself for this reason to very compact charging. Its gravimetrical density amounts to 1,5. By pressing this density can be brought to 3,9.

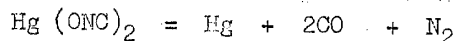
The chemical stability of fulminating mercury is not very great, but quite sufficient for its practical use. During prolonged heating up to 50° fulminating mercury does not decompose, but when heated to 90° decomposition becomes noticeable after 35 hours. When heated to 175-180° fulminating mercury explodes.

In water it scarcely dissolves at all, but dissolves well in water solution of ammonia and cyanic potash (alt. kali - T). Strong Alkali and mineral acids decompose fulminating mercury; concentrated sulphuric acid causes it to explode.

Fulminating acid reacts scarcely at all on nickel or lead. It cooperates with difficulty with copper, reacting slightly to aluminium, specially in the presence of moisture. Hence it is never used in aluminium cases.

50 Fulminating mercury is very sensitive to all aspects of the initial impulse, therefore it is very dangerous to deal with.

This sensitivity can be reduced by moistening and pressing; the first is used for storing and the second for use. The reaction of the explosive transformation can be expressed by the following



Because of its high sensitivity and good explosive faculties fulminating mercury is widely used in the manufacture of the means of ignition: igniter caps (mainly compound with potassium chlorate salt and antimony), detonator caps and primacords (alone or in compound with tetril).

*Hydrogen*  
20. AZID of LEAD

*no!!*  
*баропола*  
Chemical Composition and Formation. Azids are called salts of azote - <sup>*nitrogen*</sup>hydrogen acid (HN<sub>3</sub>). This acid is an extremely explosive and sensitive substance. When not exposed to water it is a transparent and malodorous liquid. The following azids are used in practice: natrium (alt. sodium - T) azid Na N<sub>3</sub> and azid of lead, Pb N<sub>3</sub>; the first has no explosive faculties and is a half part product in the manufacture of the second.

The reaction of the formation of natrium azid can be broken down into the following phases:

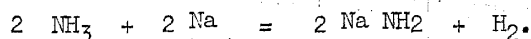
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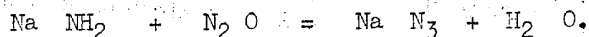
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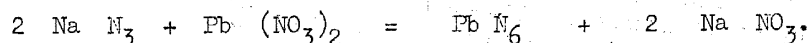
1. The formation of amidin of natrium through heating natrium in the atmosphere of dry ammoniac:



2. Formation of azid by the action of protoxide of azote on the amidin of natrium:



3. Formation of azid of lead occurs as the result of the interaction of water solutions of azid of natrium and azote acid lead:



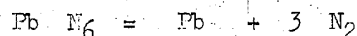
Azide of lead comes out as a deposit in the water solution of azote - natrium salt.

Features and Use. Technical azide ready for use consists of small granules of tiny crystals whose shape it is impossible to observe even with the aid of a microscope. Azide of lead is white with a yellowish hue. Its specific gravity (density) is 4,8. By exposing it to a pressure of 800 atmospheres the gravimetrical density of azide of lead can be brought to 3,1. Azide of lead is almost indissoluble in water.

51 Acids, even those which are weak, decompose azide of lead. This brings about the secretion of azote - hydrogen acid. Azide of lead interacts easily with copper, it is for this reason used in copper casings.

It does not interact at all with nickel and aluminium as a result of which it is usually employed in aluminium casings.

Azide of lead becomes grey - brown (lit. - T) when exposed to light and to carbonic acid gas and loses its explosive qualities. It is however chemically very stable in the conditions with which we are concerned. The reaction of the explosive transformation (decomposition) may be expressed by formula



Possessing good explosive features and high sensitivity, azid of lead is an excellent initiating explosive, considerably surpassing fulminating mercury in its initiating faculties; it is being increasingly used in the manufacture of detonator caps.

Its advantages in comparison with fulminating mercury:

(1) less sensitive to various kinds of mechanical reactions (percussion, pricking, friction) and therefore not as dangerous;

(2) More powerful than fulminating mercury; in the manufacture of detonator caps of lead azide approximately three times less is required than in the case of fulminating mercury;

(3) More stable;

(4) Does not lose susceptibility to detonation in severe conditions of moisture (30 %).

Possessing a very high flash temperature (3100°), azide of lead find it hard to ignite, and for faultless functioning its surface is always covered in detonator caps with a thin layer of stinote (sic) of lead, which ignites much easier.

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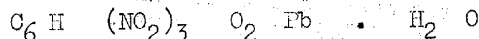
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21. STIFNATE OF LEAD (TRINITROREZORCINATE OF LEAD, TNRS).

Chemical Composition and Formation. Stifnate (sic) of Lead, of trinitrorezorcinate of lead (TNRS), is a salt of stifnic (sic) acid (trinitrorezorcinate); it is expressed by the following formula:



and is related to the group of initiating explosive substances.

The initial material in the preparation of stifnate of lead is stifnic acid  $C_6 H (NO_2)_3 (OH)_2$ , a hard crystalline substance yellow in colour, astringent when tasted. In order to obtain stifnate of lead, soda ( $Na HCO_3$ ) is added to a water solution of stifnate acid, resulting in the formation of stifnate of sodium (alt. sodium) in the water -  $C_6 H (NO_2)_3 (O Na)_2$ .

One then adds to the water solution of stifnate of sodium - a solution of azote - acid lead, resulting in a deposit of stifnate of lead which is not soluble in water.

52 Peculiarities and Use. Stifnate of Lead is a hard substance of small crystals, dark yellow in colour. Its specific gravity is 3,08.

Stifnate of lead is of slight hygroscopicity, does not dissolve in water nor in organic dissolving agencies, decomposes under the influence of acids, darkens and decomposes when directly exposed to the sun. It does not interact with metals. The flash temperature of stifnate of lead is approximately  $270^\circ$ , i.e. higher than in the case of fulminating mercury, but lower than in the case of lead azide.

It has a lesser sensitivity to percussion than lead azide, but its sensitivity to friction is the same as with lead azide. A distinguishing feature of this substance in comparison with the other initiators is its propensity to electrification on friction and a great sensitivity to electric charges. Altogether, however, the initiating capacity of stifnate of lead is considerably less than that of the other explosives of this kind.

Stifnate of Lead is used:

- (1) In azide detonator caps for facilitating ignition of lead azide;
- (2) As a substitute for fulminating mercury in some percussion compositions.

22. TETRAZEN

Tetrazen is the newest among initiating explosive substances: it was first obtained in 1910 and came into practical use in 1922.

52 Tetrazen is one of the products of unlimited (lit. - T) azote - hydrogen  $NH_2 - NH - N = NH_2$ , in which the extreme hydrogen atoms are replaced by radicals (lit. translation). Its empirical formula is:  $C_2 H ON_4O$ . Tetrazen is obtained from aminoguanidinnitrate (sic) from the action on its water solution by the water solution of nitric acid of sodium  $Na NO_2$ .

Tetrazen is a hard powder of small crystals and is yellowish in colour; its specific gravity is 1,65, its gravimetrical density is approximately 0,5. When exposed to a pressure of  $2000 \text{ kg/cm}^2$  its density can be brought up to 1,47.

In water and in organic solvents tetrazen is practically indissoluble; it has a small hygroscopicity; it decomposes in boiling water. It possesses alkalic qualities and with weak acids, produces salts, which hydrolyze easily. ( ? dissolve easily in water - T). On the action of strong acids and alkalis tetrazen decomposes.

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53 Chemically tetrazen is less steady than other initiating explosive substances; its slow decomposition is already noticeable during prolonged heating at above 50°; its flash temperature is about 140°.

In its reaction to percussion tetrazen is like fulminating mercury, but is less sensitive to friction than fulminating mercury.

The initiating faculty of tetrazen is approximately two times less than in the case of fulminating mercury and thus it is insufficient for employment in its pure form. Tetrazen is used in the percussion compositions of ignitor caps, principally compounded with stiftate of lead as a substitute for fulminating mercury. In this capacity it fulfils the task of increasing the sensitivity of the stiftate. Such compositions in comparison with compositions of fulminating mercury and chlorate have a less corroding effect on weapons (i.e. cause less rust).

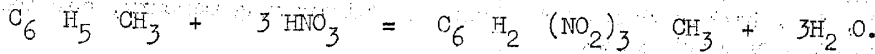
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## CHAPTER THREE

## HIGH EXPLOSIVE SUBSTANCES

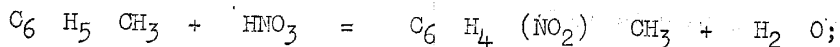
## 23. TROTIL (TOL)

Chemical composition and Formation. In its chemical composition trotil or trinitrotoluol (abbreviation - TOL or TNT) belongs to the group of nitrocompounds of the aromatic series and is obtained by nitration of toluol ( $C_6H_5CH_3$ ). The reaction of the formation of trotil can be expressed by the formula:

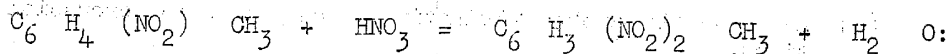


There are periodic and continuous processes for obtaining trotil. Of the periodic processes the most widely used is trotil obtained in three nitrations. In this case the reaction in the formation of trotil can be broken down into the three following phases.

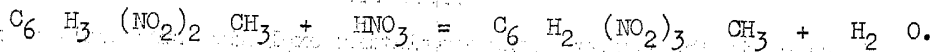
1st nitration of toluol into mononitrotoluol:



2nd nitration of mononitrotoluol into dinotrotoluol:



3rd nitration of dinotrotoluol into trinitrotoluol:



According to the general rule, nitration in all three cases occurs in the presence of sulphuric acid.

The indispensability of nitration in several phases arises due to the fact that on nitration in one phase there occurs a partial oxidation of toluol with the formation of benzoic acid and this leads to a decrease in the secretion of trotil and to a considerable expenditure of acids.

54

55 Initial materials Toluol and azote (alt. nitric - T) and sulphuric acids are the basic materials. Toluol is a colourless, transparent and movable liquid having a definite odour; boiling temperature of toluol is 110, 6°; its specific gravity is about 0,87 (at 20°); it does not dissolve in water:

The following are used in the preparation of toluol:

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- (1) rock coal toluol, obtained by coking coal, from which it is possible to extract about 0,1 % of toluol.
- (2) rock oil toluol, obtained from oil products (oil sometimes contains approximately 1,8 % of toluol, and from the products of its processing - pyrogenization - about 5 % of toluol is added).

Thus the raw material foundation of trotil is very wide, all the same it is not sufficient for satisfying the requirements of modern armies, a situation which forces one to use together with trotil also other high explosive substances.

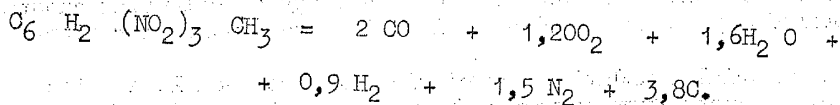
Features and Use. Trotil is a crystalline substance light yellow in colour. It has a bitter taste. Trotil melts easily; the melting temperature of technical trotil is approximately 81°, the solidifying temperature is about 80°. Its specific gravity is 1,66. The gravimetric density of crystalline trotil is 1,6. The gravimetric density of crystalline trotil is 0,8 - 1,0; the density of cast trotil is 1,56 - 1,60. It is almost indissoluble in water; its hygroscopicity is very slight. It is best dissolved in spirits and even better in benzole and acetone. With metals trotil does not interact by itself; it reacts to water and spirits alkalis by forming metallic products, which are sometimes erroneously called trotilates which have a higher sensitivity in comparison with trotil.

On ignition by a jet of fire trotil ignites and even when in considerable quantities, it quietly burns with a strongly smoking flame. It is moderately sensitive to mechanical reactions: when pierced by a bullet it does not, as a rule, produce explosions.

In its pressed form trotil is most receptive to detonation - easily explodes with the acid of a two-gram detonating cap: in its cast form trotil is less receptive to detonation and needs the use of an interval detonator of tetril or of pressed trotil.

Not reacting to light (exterior darkening of its colour has no significance), moisture, variation of temperature etc, trotil is a very steady explosive substance and in normal conditions of storage does not change its qualities in the course of an indefinitely long duration of time.

The reaction of the explosive transformation of trotil can be expressed by this equation:



The gaseous products of the explosion are poisonous (there is much CO). As the result of its slight sensitivity, neutrality, chemical stability, comparatively great force of explosion and in view of its comparative cheapness, trotil is at present the main high explosive used for the manufacture of explosive charges for artillery projectiles, mines, air bombs etc. Trotil is also widely used in military demolition work. Trotil has ousted pyroxyline and melinite which used to be used for explosive charges. In combination with hexogene, trotil is also used for the explosive charges of armour melting shells.

#### 24. PICRIC ACID

Chemical composition and formation. According to its chemical composition picric acid is related to the group of nitro compounds of the aromatic series and is a product of nitration of phenole (C<sub>6</sub> H<sub>5</sub> OH). Its chemical nomenclature is trinitrophenole; in technology picric acid is known by various names: melinite<sup>1</sup> (USSR, FRANCE); liddite (ENGLAND); pertile (ITALY), SHIMOZE (JAPAN).

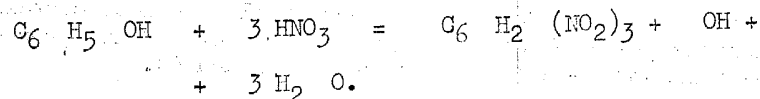
<sup>1</sup> Melted picric acid has been called melinite (from the Latin for honey - mel, as it resembles honey in its exterior aspect).

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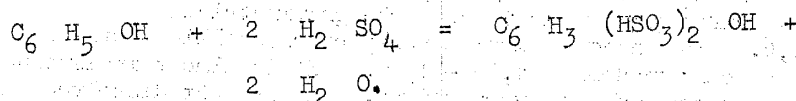
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The reaction of the formation of picric acid may be expressed by this equation:

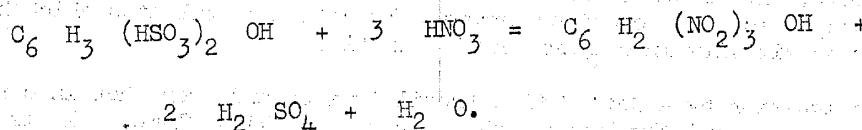


But as direct nitration of phenole occurs violently and is accompanied by losses, phenole undergoes a preliminary process of sulphurization and is then nitrated and the reaction of the formation of picric acid assumes the following form:

1. Sulphurization of phenole.



2. Nitration of disulphophenole:



**Basic Materials.** Basic materials in the preparation of picric acid are phenole whose solution in water is known as carboic acid, nitric and sulphuric acid.

56 Phenole is a product of benzole ( $\text{C}_6 \text{H}_6$ ) in which the hydrogen atom (H) has been replaced by the hydroxyl group (OH). Chemically pure phenole unadulterated by water is a colourless crystalline substance with a strongly characteristic odour.

Phenole obtained by a distilling process from coal tar or synthetically from benzole.

57 Apart from phenole, as basic material in the manufacture of picric acid benzole or dinitrochlorbenzole  $\text{C}_6 \text{H}_3 (\text{NO}_2)_2 \text{Cl}$  may be directly used. The latter is an intermediate product of the technology of colouring substances obtained from benzole by means of chlorination with subsequent nitration.

Thus the raw material foundation for picric acid are phenole and its by-products, i.e. products from coking coal and processing crude oil.

**Features and Use.** Picric Acid is a crystalline substance and is light yellow in colour. It has a bitter taste; its specific gravity is 1,8. Its melting temperature is 122,5°. Technical picric acid solidifies at 119,5 - 122,5°.

Picric acid does not easily dissolve in water. It is best dissolved in spirits and ether and best of all in benzole and in concentrated nitric acid. As in its essence it is a fairly powerful acid it is able to replace its hydroxyl hydrogen by metals, forming salts known as picrates. Picrates of heavy metals are very sensitive to exterior reactions and often explode from percussion on a shot. Metal picrate is capable of forming on the inner surface of the body of a projectile, a situation which makes it necessary to cover this surface with a layer of tin or to polish it. When it ignites in the open air, picric acid burns up quietly with a strongly smoking flame. When igniting in an enclosed space, it explodes. *scat*

In a powdered state, picric acid is fairly sensitive to mechanical reactions; in the melted state, they scarcely affect it and it requires

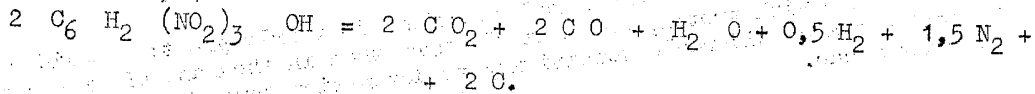
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for its initiation, apart from a detonator cap, an interval tetril or pressed picric acid detonator.

The reaction of the explosive transformation of picric acid can be expressed by the equation:



The gaseous products of picric acid are, as in the case of trotil, poisonous, (there is much C O).

As it possesses good explosive qualities, picric acid is a powerful high explosive. Till the appearance of trotil, picric acid was widely used in all countries in its cast state (under the name of melinite, liddite, shomoze etc), in the manufacture of explosive charges of artillery projectiles.

At present picric acid is used in the manufacture of demolition blocks, anti-tank mines, land mines etc.

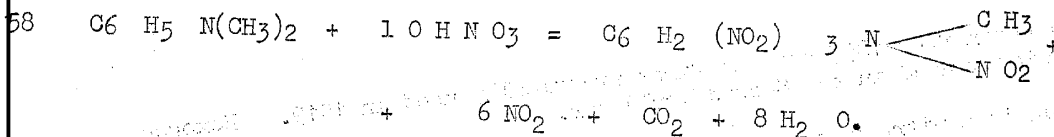
For marine mines and air bombs one uses a compound of picric acid and dinitronaphthaline.

The chief defect of picric acid is its great sensitivity to mechanical reactions and its tendency to interact with metals (picrates).

## 25. TETRIIL

58 Chemical Composition and Formation. In its chemical composition tetril belongs to the group nitrate combinations of the aromatic series and is a product of the nitration of dimethylaniline [C<sub>6</sub> H<sub>5</sub> N(CH<sub>3</sub>)<sub>2</sub>]. Its full chemical nomenclature is - t r i n i t r o p h e n i l m e t i l n i t r a m - i n .

The reaction of the formation of tetril may be expressed by the following equation:



As the reaction is very fierce, it is necessary in order to obtain tetril with sulphuric acid, first to process dimethylaniline with sulphuric acid it is then neutralized and then one nitrates (it is processed with nitric acid) the sulphuric acid salt of dimethylaniline which has formed.

Basic Materials. Basic materials are dimethylaniline, sulphuric and nitric acids.

Dimethylaniline, being a product of aniline (C<sub>6</sub> H<sub>5</sub> NH<sub>2</sub>) and of methylated spirits (CH<sub>3</sub>OH), is a transparent liquid which can have various colours, ranging from light yellow to brown. Dimethylaniline has a specific tarry odour. It is soluble in spirits.

Features and use. Tetril consists of small crystals and has a light yellow colouring. Its specific gravity is 1,725, its melting temperature is 131°,5. It solidifies at a temperature of 127°,7. It does not lend itself easily to solution in water but is easily soluble in benzole, acetone, aniline, is easily pressed and its density can be brought by compression to 1,65.

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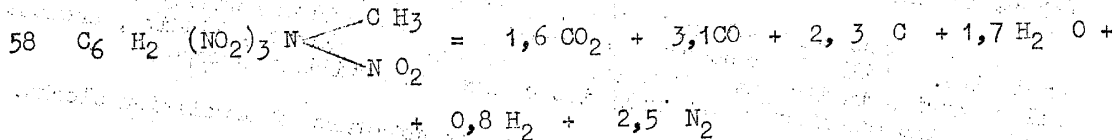
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Industrial \* tetril is less stable than trotil and picric acid, but for normal conditions of storage temperatures its stability is entirely sufficient. It starts to decompose when heated up to 100 - 110°C; at a melting temperature its decomposition can be easily observed with the naked eye.

Its sensitivity to mechanical reactions is fairly great: considerably more so than with trotil, and a little more than in the case of picric acid. Tetril has a considerable sensitivity to detonation through the medium of a detonator cap.

The reaction of explosive transformation of tetril may be expressed by this equation:



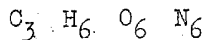
59 Tetril surpasses trotil and picric acid (see table 18) in its explosive features and is a powerful H.E.

It is used in the manufacture of various kinds of detonators and in particular for detonators in artillery projectile fuzes; apart from this, it is used in the role of a secondary charge in detonating caps and when blended with fulminating mercury - in primacords.

The obstacle to its wider use for instance in explosive charges is mainly its expense and high sensitivity.

## 26. HEXOGEN

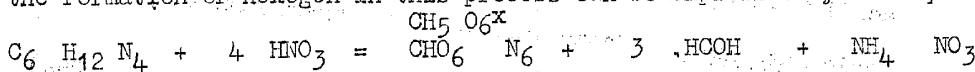
Chemical Composition and Formation HEXOGEN (Russian in text - GEKSOGEN - T) is the abbreviation for a high fragmentation (literary translation) Explosive substance, having the empirical formula.



Hexogen is known from 1897 but was first practically used in 1919. Hexogen was first widely used in the Second World War.

Hexogen is a nitro compound; its chemical name is cyclotrimethylenetrinitramin.

In order to obtain hexogen, ground, dried and sifted urotropine is nitrated in nitric acid only (concentrated nitric acid). The reaction of the formation of hexogen in this process can be expressed by the equation:



(Translator's note: Some of the figures are illegible in the photostat

- CAUTION

\* lit. - technical - T

x Illegible in text.

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59. This reaction is accompanied by the secretion of heat, through the partial decomposition of urotropine and through the acidifying processes.

As the result of nitration, hexogen forms as a solution with used up nitric acid. In order to extract hexogen from this solution, the contents of the nitrator<sup>2</sup> are emptied into cold water where the hexogen sets.

Basic Materials. In order to produce hexogen the necessary basic substances are utropine and nitric acid.

Utropine or hexomethylenetetramin ( $C_6 H_{12} N_4$ ) are obtained by saturation with ammoniac of *formalin* phosmaline. It is a white crystalline substance and has a sweet taste.

Peculiarities and Use. Hexogen is a hard crystalline substance and is white in colour. Its specific gravity is approximately 1,8, it is compressed to a density of 1,66. Its melting temperature is at  $201^{\circ}$  and when it reaches this temperature it decomposes.

Hexogen is non hygroscopic and practically indissoluble in water. It dissolves badly in spirits, but dissolves comparatively well in acetone.

60. Hexogen is very steady in so far as the action of various reacting agents are concerned. Alkalis do not affect it; in concentrated nitric acid it dissolves without decomposing, but it does decompose with sulphuric acid. Hexogen does not interact with metals.

Hexogen reacts very steadily to temperature, surpassing considerably tetril in this respect and is only slightly less steady in this connection than trotil.

60. Its flash temperature is  $230^{\circ}$ . When ignited it burns with a bright flame and part of it melts, leaving a yellowish peel.

Its sensitivity to mechanical actions, also its sensitivity to detonation is greater than tetril.

Hexogen is used for secondary charges in detonator caps and in primacords, also as an intermediary detonator. When blended with trotil, it is used for equipping projectiles.

In spite of the unlimited nature of its basic raw materials (as the basic materials for urotropin are coal, water and air), hexogen has not yet come into sufficiently wide use. This is to be explained by its high sensitivity to mechanical actions when compared with trotil, and, secondly, by the fact that it has not yet been sufficiently studied, and that is why it was not manufactured on a large scale before the Second World War.

## 27. TAEN

Like hexogen taen is one of the more powerful high explosives.

Chemical Composition and Formation. Taen is a nitric acid ether of pentaeritrite [ $C(CH_2OH)_4$ ] and therefore may be counted among the nitrates.

1 The expense of crystallized tetril is for instance five times greater than that of trotil.

2 Nitrotor is a special vessel for nitration.

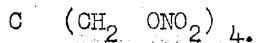
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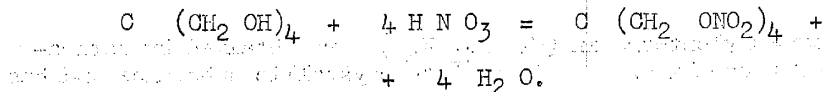
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Its chemical name is tetranitratpentaeritrit and its formula is



To produce taen, pentaeritrite is nitrated in nitric acid alone (in concentrated form).

The reaction in this process may be expressed by:



60 The technological process of producing taen scarcely differs in anything  
61 from the production of hexogen. Pentaeritrite (4 atoms spirit) is a white  
crystalline substance with melting temperature of 260°. The raw material  
basis of taen is very wide, as the fundamental sources for its production are  
coal, water, air and lime.

Features and Use. Taen is a small grained white powder. Its specific gravity is 1,77; it is compressed to a density of 1,6. The melting temperature of industrial taen is 138-140°. Its melting process is accompanied by a slow decomposition. Taen is non-hygroscopic and is indissoluble in water, and practically indissoluble in spirits.

Taen does not interact with metals and is sufficiently steady when exposed to reacting agents. When exposed for a long duration of interaction with strong alkali solution it becomes soapy.

A properly purified taen possesses a satisfactory chemical stability; its stability is not less than that of tetryl but it is less than that of hexogen. An insufficiently purified taen has slight chemical stability and long storage may lead to its explosion. Its flash temperature is 215°. Taen is very sensitive to mechanical actions and to detonation; in this respect it occupies one of the foremost places among other high explosive substances which are in use to-day. In so far as its explosive characteristics are concerned it scarcely differs from hexogen.

Taen is used in the role of a secondary charge in detonator caps and in detonators of special purposes ammunition.

It is also possible to use taen for charges of special purpose ammunition. In the Second World War the Germans made wide use of it for small calibre A/A shells and for A/Tk grenades.

## 28. DINITROBENZOLE, XYLIL (Lit. KSILL), DINITRO-NAPHTHALINE.

These nitroaromatic explosive substances are mainly used in compounds and blends with trotil or picric acid, as well as in the so-called synthetic explosives blended with ammoniac - saltpetre.

DINITROBENZOLE. Chemical formula



Dinitrobenzole is a nitric product of benzole.

Benzole is a colourless, transparent and volatile liquid. It is a product of the coking - benzole industry and of the processing of crude oil. When coking coal in old fashioned coking furnaces twice as much benzole is obtained than toluol, and in the case of modern plant - seven to eight times more.

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In the pyrolyzation (lit. - T) of crude oil one obtains (according to weight of the basic raw material) 6, 6 % of benzole and 4,4 toluol. Thus the raw material basis of dinitrobenzole is broader than that of trotil.

Dinitrobenzole is obtained from benzole by means of a two phased nitration.

In view of the cheapness of the basic material and the simplicity of production dinitrobenzole is approximately one and a half times cheaper than trotil. The peculiar feature of dinitrobenzole, which is an obstacle to its manufacture and use, is its comparatively high degree of volatility and the poisonous nature of its vapours (which can be eliminated by proper ventilation).

Features and Use. Denitrobenzole is a hard, crystallic substance, yellow in colour; its melting temperature is about 90°. Its specific gravity is 1,5; its density when moulded is approximately 1,45.

62 Denitrobenzole does not dissolve in water, but dissolves well in organic solvers. It does not interact with metals. It possesses an excellent chemical stability. Its flash temperature is more than 300°. When ignited it burns quietly with a strongly smoking flame. It is less sensitive to mechanical reaction (nearly twice less) than trotil. It is little receptive to detonation, specially in its cast form, as the result of which it needs a special detonator.

In its explosive qualities it is inferior to trotil. Dinitrobenzole can be used for ammunition charges both in its pure form (with the addition of a sufficiently powerful special detonator) as well as blended with other explosive substances (e.g. with picric acid) and, above all, as a blend with ammoniac - saltpetre (e.g. a blend of 80 % of ammoniac - saltpetre with 20 % of dinitrobenzole has been used under the name of bellite).

In the first world war, in view of the great expenditure of explosives and lack of trotil, dinitrobenzole was much used by the Germans; it found no application in the second world war.

XYLIL (lit. KSILIL), like dinitrobenzole was used in the first world war as a high explosive substance to replace the shortage of trotil. It was mainly produced in RUSSIA and FRANCE and was used in compounds with other explosive substances, also as a blend with ammoniac - saltpetre.

The basic material for producing xylil is xylol which is obtained by processing coal and crude oil. This process gives five times less of xylol than toluol.

Xylol is a colourless and transparent liquid. Two nitrations are essential to produce it.

62 It consists of a hard crystallic substance which has a yellowish colour. Its melting temperature is about 180°; its specific gravity is 1,65; its gravimetrical density is approximately 0,6. Its hygroscopicity is slight, it does not dissolve in water, not well in spirits, considerably better, however, in benzole and acetone. It does not interact directly with metals, is steady in heating and melts without decomposing; its flash temperature is about 330°.

It is more sensitive to mechanical actions than trotil; in this connection it resembles picric acid, in its sensitivity to percussion and to bullet penetration it does not differ from trotil.

Its susceptibility to initiation considerably fluctuates depending on the degree to which it has been ground and on the contents of oil admixtures. (? lubricants - T) acting as phlegmatizers. It is slightly inferior in its explosive qualities to trotil.

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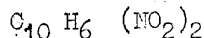
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Xylil is not used in its pure form; when blended with trotil it possesses good explosive qualities and reacts well to detonation. It can be used for ammunition charges, also when blended with ammoniac - saltpetre.

DINITRONAPHTALINE is a product of nitration; its chemical formula:



The basic material for dinitronaphtaline is naphthaline ( $C_{10} H_8$ ), produced from coal tar at about 1% of coking coal.

Naphtaline is a white crystalline substance with a characteristic odour and melting point of  $80^{\circ}$ . Dinitronaphtaline is obtained from naphthaline through two nitrations.

Dinitronaphtaline is a hard substance of small granules. Its colour ranges from yellow to brown. Its melting-temperature is not below  $150^{\circ}$ . Its specific gravity is 1,5. Its hygroscopicity is slight, and it is almost indissoluble in water and spirits, but dissolve in acetone. It does not interact with metals, is stable in heating and is not sensitive to mechanical actions.

63 The explosive qualities of dinitronaphtaline are very weak, hence it cannot be used independently, and is exclusively used in admixtures and alloyed with other explosives. The best known alloy is 88 % of ammoniac - saltpetre with 12 % of dinitronaphtaline, known as SHNEIDERITE. It was widely used in the first world war.

Apart from this, dinitronaphtaline is used as a blend with picric acid (80 % of picric acid, 20 % of dinitronaphtaline); this alloy is known as "French Blend."<sup>1</sup>

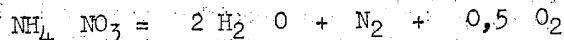
#### 29 AMMONIA - SALTPETRE EXPLOSIVES

AMMONIA - SALTPETRE explosive substances are those whose basic part is ammoniac - saltpetre; apart from this some fuel and most often explosive components form part of them.

63 AMMONIA - SALTPETRE ( $NH_4 NO_3$ ) is a hard white crystalline substance. It is strongly hygroscopic and dissolves very well in water. Dry ammoniac - saltpetre melts and decomposes at a temperature of  $150-170^{\circ}$ . Dry ammoniac - saltpetre not slightly interacts with metals, but when it is moist - it does so considerably more, and causes oxidation of metal.

Ammoniac - saltpetre is in itself an explosive, but a very weak one. In order to arouse an explosive transformation, special conditions are required, and a sufficiently powerful initial impulse.

The reaction of decomposition is expressed by this equation:



When it decomposes it secretes free oxygen; hence it is used alloyed with fuels. Among the latter are used:

- (a) explosives not having sufficient oxygen for the total combustion of all products of decomposition, as, for instance, trotil;
- (b) non-explosive substances: organic, for instance, wood or peat dust, wood shavings, charcoal etc; non-organic, for instance, alumina, silico-aluminium, ferro-silicia etc.

Ammoniac - Saltpetre divides into the following types, according to the components which enter into it;

<sup>1</sup> Sometimes it is called "French compound."



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1. AMMOTOLS - explosive components containing trotil in the capacity of a combustible substance in a quantity of 20-60 %.
2. AMMONALS - explosive substances containing trotil in the capacity of a combustible substance (or xylil) and aluminium powder; the latter increases the temperature of the cases of burning.
64. 3. Dynamones. These are explosive compositions with non explosive fuel admixtures.

All these compositions ( ? compounds - T) surpass trotil in their blasting effect (they provide more gases) while in their high explosive effect (bursting) they are inferior to trotil because they take longer to detonate.

Ammonia - saltpetre explosive substances are, as a rule, powdery alloys whose colour depends on the composition of the fuels which are added to them and therefore their colours may differ.

The principal defect of ammonia - saltpetre explosives is their hygroscopicity, also their tendency to absorb moisture (?), which lowers their susceptibility to the initial impulse, which may lead to incomplete explosions or to explosions which pass to ordinary combustion.

The sensitivity to percussion of ammonia - saltpetre explosives is slightly higher than that of trotil, but is less to friction. Their sensitivity to fire is slight: they do not ignite from a spark, and with difficulty from fire.

Ammonia - saltpetre explosives are widely used for all kinds of demolition work, for anti-tank and anti-personnel mines and for demolition charges. In order to prevent them from being affected by moisture, they are placed in damp - proof casings.

Ammonia - saltpetre explosive have a number of names depending on their composition. The most widely used are set out in table 17. Explosive and technical data for the most commonly used among them will be found in table 18.

TABLE 17

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The most Commonly Used Ammonites

Components	Ammonia-Saltpeure	Trinitro-toluol	Trinitro-xylene	Dinitro-naphthaline	Denitro benzole	Picrate Ammonia	Alumina	Tar	Baked Coal	Flour of wood Tar
Ammonites										
Amnotole 80/20 ...	80	20	-	-	-	-	-	-	-	-
Amnotole <sup>1</sup> 40/60 ...	40	60	-	-	-	-	-	-	-	-
Russian										
Amnotole										
(Russian Blend) .....	50	38	12	-	-	-	-	-	-	-
American										
Amnotole <sup>1</sup> .....	50	50	-	-	-	-	-	-	-	-
Shneiderite .....	88	-	-	12	-	-	-	-	-	-
Bellite .....	35	-	-	-	65	-	-	-	-	-
	87 or 80	-	18	-	13 or 20	-	-	-	-	-
Amnoxye .....	82	-	12	-	-	-	-	-	-	-
Ammonal .....	82	-	-	-	-	6	-	-	-	-
Maisite .....	72	-	-	-	-	23	5	-	-	-
Ammonpek .....	95	-	-	-	-	-	-	5	-	-
Dinaumon .....	90	-	-	-	-	-	-	-	-	10

<sup>1</sup> Were used in World War I

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TABLE 18

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Explosive and Technical Data for some H.E.s.

NAME	Volume of Gaseous Products 2/kg	Heat of Explosion Cal/kg	Temperature of Explosion °C	Velocity of Detonation m/sec	At normal density mm	At a density of 1,2 mm	At a density of 1,3 mm
Trotill	685	970-1010	3200	6990	13	16-18	-
Melinite	690	1000	3570	7100	15-16	-	19
Tetril	740	1090	3770	7740	19	-	22
Hexogen	900	1300	3400	8380	-	-	24
Rfaen	800	1400	3900	8400	-	-	24
Dinitrobenzole	717	850	2770	6160	10	-	-
Xylil	700	1000	3000	6600	10	-	-
Amnotole	896	970	2890	5300	12-13	-	-
Ammonal	836	1180	3380	5300	12-14	-	-
Shneiderite	918	921	2870	5100	9-14	-	-

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## PYROXYLINE (alt. Gun Cotton - T)

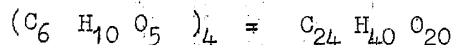
Chemical Composition and Formation. In its chemical composition pyroxyline belongs to the group of complex ethers of nitric acid and is a nitrate of cellulose or cellular tissue (?) (more exactly, it is a compound (alt. blend - T) of such nitrates).

As a product of nitration, pyroxyline is very non-homogeneous and represents, as experiments prove, a blend of various nitrates of cellulose.

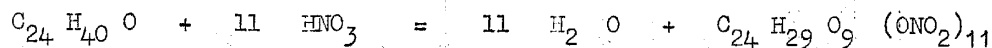
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The elementary particle of cellulose, called a glucose remnant, is expressed by formula  $C_6H_{10}O_5$ . This elementary particle has, taken by itself, no physical or chemical significance, and does not exist by itself. Only when joining with other such particles, it forms a so called elementary body which consists of four elementary particles.

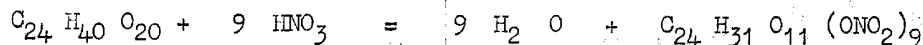
Hence the formula for this elementary body looks like this:



This formula is used for computing the reactions in the formation of nitrates of cellulose. Thus for instance:



The nitrate of cellulose, obtained as the result of this reaction - i.e.  $C_{24} H_{29} O_9 (ONO_2)_{11}$  is called, according to the number of its atoms, 11 azotes. By altering the quantity of  $HNO_3$ , one can obtain nitrates of cellulose with other azote contents, for instance:



By comparing these two equations one can draw the conclusion that the greater the azote contents are in nitrate of cellulose, the more oxygen is added to it, and the greater will be the degree of its nitration: the degree of nitration is determined by the quantity of groups  $ONO_2$  contained in the molecule of pyroxyline.

It has been noted above that pyroxyline represents a blend of nitrates of cellulose at various degrees of nitration. Hence the problem of classification of nitrates of cellulose is of very great importance.

The most acceptable classification is set out in Table 19.

TABLE 19

Classification of Nitrates of Cellulose

<u>Name of Nitrates of Cellulose</u>	<u>Chemical Formula</u>	<u>Azote Contents in %</u>
12 azotes	$C_{24} H_{28} O_8 (ONO_2)_{12}$	14,14
11 "	$C_{24} H_{29} O_9 (ONO_2)_{11}$	13,47
10 "	$C_{24} H_{30} O_{10} (ONO_2)_{10}$	12,75
9 "	$C_{24} H_{31} O_{11} (ONO_2)_9$	11,96
8 "	$C_{24} H_{32} O_{12} (ONO_2)_8$	11,11
7 "	$C_{24} H_{33} O_{13} (ONO_2)_7$	10,18
6 "	$C_{24} H_{34} O_{14} (ONO_2)_6$	9,15

TABLE 19 (Contd.)

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TABLE 19 (Contd.)

<u>Name of Nitrates of Cellulose</u>	<u>Chemical Formula</u>	<u>Azote Contents in%</u>
5 azotes	$C_{24}H_{35}O_{15}(ONO_2)_5$	8,2
4 "	$C_{24}H_{36}O_{16}(ONO_2)_4$	6,76
3 "	$C_{24}H_{37}O_{17}(ONO_2)_3$	5,36
2 "	$C_{24}H_{38}O_{18}(ONO_2)_2$	3,79
1 "	$C_{24}H_{39}O_{19}(ONO_2)_1$	2,00
Non-nitrated Cellulose	$C_{24}H_{40}O_{20}$	0

67 12 azote nitrate of cellulose has not yet been produced, though nitrates have been obtained which are close to it.

11 azote nitrate of cellulose is produced by the action on cellulose of an acid mixture containing 22 % of  $HNO_3$ , 66 %  $H_2SO_4$  and 12% of  $H_2O$  at 30 minutes nitration and at a temperature of 30°C. This nitrate of cellulose

67 dissolves badly in spirit and ether mixture, it belongs with its composite part to industrial pyroxyline (pyroxyline No 1) and is a powerful H.E.

10 azote nitrate of cellulose is obtained through the action on cellulose of an acid mixture containing 21,5 %  $HNO_3$  (page perferated here - T)? 5%  $H_2SO_4$  and 15%  $H_2O$ . It forms the so called No 2 pyroxyline.

11 and 10 azote nitrates of cellulose are thus called pyroxylines: pyroxyline contains not less than 12% of azote.

9 azote nitrate of cellulose can be obtained through the action of an acid mixture upon the cellulose, containing 21%  $HNO_3$ , 63%  $H_2SO_4$  and 17%  $H_2O$ . It dissolves well in a spirit and ether mixture, acetone, nitro-glycerine and belongs, as was already indicated, to pyroxyline No. 2.

Eight azote nitrate of cellulose is produced by the action of cellulose of an acid mixture, containing 20% of  $HNO_3$ ; 60% of  $H_2SO_4$  and 20% of  $H_2O$ . It dissolves well in spirit and ether mixture. It is widely used in the manufacture of celluloid, synthetic leather, lagness etc.

9 and 8 azote nitrates are known as K o l l o x i l i n e s. This contains less than 12% of azote.

7 azote nitrate of cellulose and nitrates of a lower degree of nitration are not used industrially, as they dissolve poorly in the usual solvents, while 3-2 and 1 azote nitrates have not been produced up till now.

67 Thus one has to deal in practice with mainly two kinds of pyroxylines which differ from each other by their ability to dissolve in spirit and ether mixture. Hence pyroxyline No 1 is sometimes called indissoluble while pyroxyline No. 2 is known as - dissoluble.

Basic Materials. The basic materials for the production of pyroxyline are cellular tissue and nitric and sulphuric acid.

Cellular tissue, or cellulose, is the structural material and basic substance from which the sides of vegetable cells are formed.

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68 Fibrous substances form the main contents of cellular tissue, as for instance - flax, cotton, hemp etc. For this reason pyroxyline used for a long time to be exclusively produced from cotton which contains cellular tissue to the amount of 87-91%. From the 1914 - 1918 onwards the production of pyroxyline tested to be based on wood as the more economic product; dry wood contains cellular tissue to the amount of from 45, 3% (birch) to 57, 8% (fir tree).

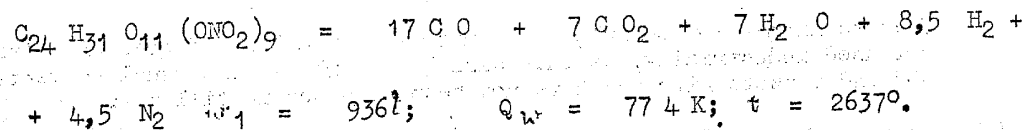
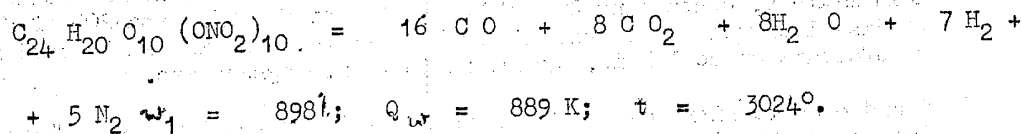
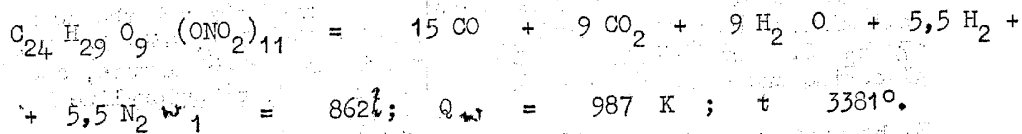
Features and Use. Pyroxyline is an almost white mass and in its exterior appearance scarcely differs from the material from which it is made. It has neither smell nor taste. The true density of pyroxyline is 1,65 - 1,66. The gravimetrical density of friable pyroxyline (sap) is about 0,2 - 0,3, this density can be raised to 1,25 by pressing moist pyroxyline.

68 Pyroxyline is very hygroscopic but does not dissolve in cold or hot water, which is why it is stored in its moist condition. Moist pyroxyline scarcely reacts at all to a mechanical initial impulse while dry pyroxyline is most sensitive to it. In order to produce an explosion the height of drop of a 2 kg. weight on an 'anvil' must amount to 20 cm in the case of dry pyroxyline, and 180 cm - for moist pyroxyline.

Its flash temperature is 195°. When ignited in the open air, dry pyroxyline, in small quantities, quickly burns up without exploding. Dry pyroxyline detonates from a detonator cap. Moist pyroxyline detonates from the detonation of dry pyroxyline.

It dissolves well in acetone and in artificial ether; its dissolution in spirit - ether mixtures depends, as has already been said, on azote contents (soluble and indissoluble pyroxylines). Collodionial cotton (9 and 8 azote nitrates) dissolves well in nitro-glycerine. The ability of pyroxyline to dissolve satisfactorily through the action of various kinds of solvents is widely used in the manufacture of smokeless powders and dynamites.

The reactions of the explosive transformation of pyroxyline may be expressed as follows:



The volume of gases  $W_0$ , heat of explosion (secreted on the explosion)  $Q_w$  and the temperature of the explosive  $t$  have been computed from the above equation for 1 kg of pyroxyline.

69 From a study of these reactions and the  $W_0$ ,  $Q_w$  and  $t$ , corresponding to them, it follows that by a decrease in the azote contents, i.e. on a lowering of the degree of nitration of pyroxyline, its explosive faculties will drop.

The explosive reactions of pyroxyline manifest themselves by incomplete combustion (presence of CO and H) and by complete gasification (smokelessness).

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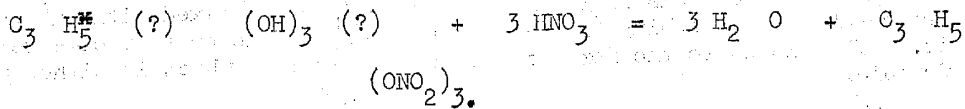
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At present pyroxyline is scarcely used at all as an explosive substance. In spite of this, however, the importance of pyroxyline is very considerable indeed, as it possesses good explosive qualities and the ability to turn to gelatine (to become transformed into a gelatinous mass) through the action of various solvents; - it is reckoned the basic initial material in the manufacture of smokeless powders and dynamites.

### 31 NITRO-GLYCERINE and DYNAMITES

Chemical Composition and Formation. According to the chemical composition, nitro-glycerine or glycerinenitrate, the same as pyroxyline, belongs to the group of complex ethers of nitric acid and is a product from the nitration of the three atom spirit of glycerine [C<sub>3</sub> H<sub>5</sub><sup>#</sup> (OH)<sub>3</sub>].

The reaction of the formation of nitro-glycerine may be expressed as follows:



For holding (lit. tying, binding, connecting, joining - T) the water which forms during nitration, the latter is passed through in the presence of sulphuric acid.

Initial Materials These are glycerine and nitric and sulphuric acids.

Glycerine is a colourless and oily liquid with a sweetish taste, but odourless. The quality of glycerine affects to a considerable degree the safety of the process of nitration and the result of the finished product. Hence glycerine used for the manufacture of nitro-glycerine, otherwise known as dynamite glycerine, must be pure. The test of glycerine consists of its chemical analysis and a test nitration in laboratory conditions.

Features and Use. Nitro-glycerine consists, in the same way as glycerine, of an oily and odourless liquid with a sweetish taste. Its colour depends on the colour of the basic material (of glycerine). Nitro-glycerine may have several colours ranging from light yellow or almost colourless to brownish - yellow. Its specific gravity is 1,6 at 15° C. Nitro-glycerine dissolves well in the majority of organic solvents. It dissolves poorly in glycerine, petrol, liqroine and kerosene (paraffin - T). In water, - in 1 litre at 20°, it dissolves at a ratio of 1,8 grammes and at 50° - at about 2,5 grammes of nitro-glycerine.

Strong sulphuric and nitric acids dissolve nitro-glycerine. Strong alkalis make it soapy (?) when heated. Nitro-glycerine is in itself a good solvent for

70 the combination of the aromatic group and what is specially important, it gelatinates coloxylines.

Nitro-glycerine has volatile qualities on an increase of temperature and freezes easily.

Chemically pure nitro-glycerine is very stable; A test sample produced in 1874 has still not lost its qualities: but acids which have not been washed away (alt. wasted off - T) lower the chemical stability of nitro-glycerine and cause its self-decomposition, a situation which may lead to explosion. In its sensitivity to mechanical actions nitro-glycerine is very close to initiating explosive substances; hence it is dangerous to handle. It reacts considerably weaker to heating and produces an ordinary explosion only on intensive ignition. It detonates from a detonator - cap.

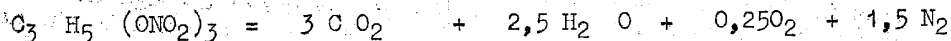
\* T - Caution, illegible figure.

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The reaction of its explosive transformation can be expressed by this equation:



Nitro-glycerine is poisonous. When working on it, it penetrates by suction into the pores of the skin, where hands are not protected, and causes violent headache.

As nitro-glycerine has a very high temperature of explosion and a very great speed of detonation, and on exploding secretes a great amount of heat and gases, it is one of the most powerful explosive substances, but as the result of its sensitivity and its liquid condition is not used directly as a high explosive and is only employed in the production of smokeless powders and dynamites.

DYNAMITES. Dynamites, as has already been stated, are called high explosive substances whose basis is formed by nitro-glycerine mixed with substances which are capable of absorbing (retaining) nitro-glycerine or to become gelatinized by it. This leads to the formation of a plastic mass which is either hard or friable.

Dynamites, retaining in the main all the explosive qualities peculiar to nitro-glycerine, do not, however, possess such an excessive sensitivity to mechanical actions and are a plastic mass. Hence they are widely used for blasting.

At temperatures commencing from + 8° and lower, some dynamites freeze and in this state are very dangerous to handle.

Depending on the character of the substances with which nitro-glycerine is mixed, dynamites are grouped into those with non active and active foundations. Its name shows that in the first instance the foundation does not participate in the operation of the explosion, and that in the second instance - it does. A classical example of dynamites with a non-active (alt. passive - T) foundation is the so-called gurdynamite which consists of porous (one word ?\*) earth (pebble ?\*), saturated with nitroglycerine (25% of kizel'gur and 75% of nitro-glycerine). Apart from kizel'gur magnesia, chalk etc. can be used for passive dynamite.

At present dynamites with non-active foundations are not in use.

The manufacture of dynamites with an active basis is founded on the qualities of nitro-glycerine, as has already been stated, of dissolving some kinds of pyroxyline, resulting in the formation of a uniform elastic mass resembling gelatine; this process is called gelatinization.

A weakly gelatinized nitro-glycerine possesses the quality of retaining firmly some admixtures (saltpetre, wood and meal flour) without losing its plasticity.

The following are the most widely used dynamites with an active basis: fulminating gelatine, or explosive gelatine (approximate composition: 7-13% collodionic cotton and 93 - 87% nitro-glycerine) and plastic dynamites (approximate composition: 3-6% collodionic cotton, 9-27%, potash sulphur or sodium sulphur, 2-8% wood flour and 62 - 83% nitro-glycerine).

\* Russian "n i f u z o r n a y a z e m l y a" - T)

\* Russian "k i z e l' g u r

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To the group of dynamites with an active foundation belong grisutines<sup>‡</sup> (approximate composition: 12-30% nitro-glycerine, 70-88% ammonia-saltpetre, about 0,2-1% collodionic cotton and any non-active absorbant, e.g. chalk). For some types of work, for instance in hard rocks, these dynamites are indispensable. Apart from this, when giant mines are exploded, dynamites are also used as powerful detonators for other explosive substances.

## CHAPTER FOUR

## PROPELLING EXPLOSIVE SUBSTANCES (POWDERS)

## 32. SMOKELESS POWDERS

Gelatinization and composition. The main defect of smoky powder consists of its insufficient force, which was found unable to satisfy the requirements set by the demands in the second half of the XIXth century for artillery, in so far as its long range aspect was concerned.

At that time many powerful explosives were known, but it was found impossible to adapt them for propulsion of projectiles in view of the great velocities developed by them in their explosive transformation.

In order to exploit H.E. substances for the propulsion of projectiles it was imperative to solve the task of lowering the velocities of their explosive transformation to the velocity of rapid combustion and at the same time to maintain their force. This task was solved by the gelatinization of pyroxyline.

Gelatinization is based on the fact that pyroxyline changes its physical nature through the action of some solvents and changes into a uniform congealed mass, and after being condensed it assumes a corniculated form (hard colloid). Due to the great density and viscosity of this mass its explosive transformation now occurs as a rapid combustion. The process of the passage of pyroxyline to a congealed condition is known as gelatinization.

Depending on the character of solvents and on their influence on the explosive features of smokeless powders, the latter are divided into the two following groups:

1. Smokeless pyroxyline powders, among which the solvents have no explosive qualities and are intended only for gelatinizing the pyroxyline, after which they are removed from the gelatinized mass with the exception of a very small amount, which guarantees the colloidal condition of this mass.

73 2. Smokeless nitro-glycerine powders, among whom nitro-glycerine is the solvent remaining after the gelatinization among the constituent parts of the mass of powder. It together with pyroxyline forms a solid combination.

Smokeless pyroxyline powders are prepared from an alloy of two kinds of pyroxyline - No. 1 and No. 2, possessing different explosive qualities. By altering the proportion between these two kinds of pyroxyline, one can select the required force and speed of combustion of the smokeless powder in relationship to the type and calibre of the gun in question.

In the manufacture of smokeless powder from these two kinds of pyroxyline, the solvent used is a mixture between spirit and ether. Under the influence of this spirit and ether mixture, pyroxyline No. 2 dissolves and forms a sticky and dense liquid - known as collodium, while pyroxyline No. 1 swells. Colloidal solutions, when thoroughly stirred, penetrate into the particles of pyroxyline No. 1, glue them together and thus form one uniform plastic mass - gelatine. When removing the solvent, the gelatine condenses and in this process of condensation are formed powder grains of the required sizes and shapes.

‡ Unknown expression - presumably from the French word "grison" - fire damp - T

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Smokeless nitro-glycerine powders are of two main types:

- (1) ballistites - powders from a mixture of pyroxyline No. 2 (colloxyline) with nitro-glycerine; here nitro-glycerine is taken in a quantity which is sufficient for the full solution of pyroxyline;
- (2) Cordites - powders from a mixture of pyroxyline No. 1 with nitro-glycerine.

The essence of gelatinization in the manufacture of smokeless nitro-glycerine powders remain the same as in the case of pyroxyline powders; only not two kinds of pyroxyline, but pyroxyline with nitro-glycerine, combine and form gelatine in the presence of the solvent. Were one in this connection to take as foundation of the powder pyroxyline No. 1 (cordites) the solvents will be acetone and nitro-glycerine, but if colloxyline (ballistites) are chosen as foundation, only nitro-glycerine will be the solvent.

On an increase in the nitro-glycerine contents, the force of nitro-glycerine powders increases, as nitro-glycerine in comparison with pyroxyline is the more powerful explosive. But there is a limit to the increase (about 60%) as when the nitro-glycerine content is considerable the viscosity and density (? compactness - T) of the gelatine decrease to such an extent that they cease to be an obstacle to the spreading of the reaction of the explosive transformation at a speed approaching to the speed of detonation and a gelatine of this kind ceases to be a propelling explosive substance. This can be observed in fulminating gelatines and gelatindynamites, whose colloidal cotton contents do not exceed 5-10%.

74 Types of Powders. A definite type of powder must correspond to a gun of a definite type and calibre. The type of smokeless powder is determined by:

- (1) the chemical contents of the powder, i.e. by the correlation of indissoluble (No. 1) and dissoluble (No. 2) pyroxyline and the relationship between pyroxyline and nitro-glycerine - for nitro-glycerine powders (the chemical contents of the powder express its force and the speed of its combustion);
- (2) the shape of the powder grain, which may be ribbon shaped, tube shaped, disc shaped etc determines (lit. characterizes - T) the progressiveness of the combustion of the powder. (see part two, pages 113-120);
- (3) the dimensions of the powder grain - the length and thickness (diameter) of the ribbons, tubes etc (dimensions of powder grains express the duration of the full combustion of a powder (alt. propelling - T) charge.

These features are considered in greater detail in the second part of this book as they are connected with the problem of inner ballistics.

A definite mark of powder corresponds to each kind of powder. This mark is included in the mark of powder charges.

### 33. FEATURES OF SMOKELESS POWDERS.

Physical and Chemical Peculiarities. In their outer appearance smokeless powders greatly resemble a horny substance or carpenter's glue. In thin strips and discs they are almost transparent. Powders may be of different colours from light yellow to dark green and brown depending on the stabilizer and the kind of powder. Small grained powders when processed with graphite have a shiny grey or black colour.

When examined through a microscope one can spot in smokeless powders separate filaments (alt. fibres - T) of non-gelatinized pyroxyline, and in nitro-glycerine powders - tiny nitro-glycerine drops.

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74. Smokeless powders long retain the odour of solvents, stabilizers and other admixtures which are used in the course of their manufacture (ether, camphor etc.). The shape of the grains of smokeless powders is very variegated: powder grains may be disc shaped, they may have the appearance of small tubes, threads, ribbons, small cylinders with one or more small grooves etc.

This diversity also applies to the dimensions of powder grains; the smallest in size is hunting powder (T - i.e. shot gun powder), the diameter of whose grain amounts to 0,5 - 1,0 mm; the dimension of the grains of tubular powders used for propelling charges for heavy artillery pieces, reaches one metre in length and 2,5cm in diameter. Smokeless powders are fairly stable as the result of which they neither alter their shape, nor crumble or turn to powder when transported or shaken.

75. The specific weight of smokeless powders fluctuates from 1,55 to 1,63; their grainmetrical density, even of specially heavy powders, is always less than a unit.

In normal conditions smokeless powders contain a certain amount of moisture - pyroxyline powders 1-2% and nitro-glycerine powders - 0,5 - 1%. When kept in a damp atmosphere the contents of moisture in them grow, which lead to a deterioration of their ballistic qualities. Pyroxyline powders possess greater hygroscopicity in view of their porous nature; their moisture contents may reach from 2-2, 5%; but moistening scarcely influences these powders as after drying to their normal moisture content, they restore their ballistic qualities.<sup>1</sup> Nitro-glycerine powders when compared to pyroxyline powders are less porous and consequently less hygroscopic, but when moistened and then dried, they alter their ballistic qualities, as water is able to oust the nitro-glycerine from the contents of the mass of powder. Therefore one ought not to use damp charges. They must be sent to the stores. It has already been pointed out that the least chemically stable explosives are the compound ethers of nitrogen acid; hence the chemical stability of smokeless powders is comparatively slight even in normal conditions of storage. On an increase and in fluctuation of temperature in the place of storage, smokeless powders undergo a sharp decrease in their chemical stability, a situation which may lead to their spontaneous combustion (lit. self ignition - T). In order to avoid this and to remove powder with a lowered stability (below the norm), it is subjected to periodic tests.

The explosive transformation of pyroxyline and nitro-glycerine expresses itself in a full formation of gas; hence the products of combustion of smokeless powders are only gases, which explain the absence of smoke.

Explosive and Ballistic Qualities. The sensitivity of smokeless powders to mechanical reactions is fairly high, but not so high as to render them dangerous to handle. This sensitivity increases with an increase of indissoluble pyroxyline in nitro-glycerine powders and nitro-glycerine - in nitro-glycerine powders (grains (- T), and to a lesser extent, in powder grains. The flash temperature of smokeless powders fluctuates within the limits of 180 - 200°. Under the short-duration action of the ignitor cap flame, these powders ignite in view of their compactness, with difficulty and often fail to act. That is why smoky powder is used for igniting smokeless powder charges.

76. In the open air smokeless powders burn with an intensive yellow flame; in great quantities and in conditions of strongly increased pressure this combustion may pass into detonation.

The main characteristic of the ballistic qualities of smokeless powders are the force and speed with which they burn. The speed with which smokeless powders burn is also known as their vitality. Both these characteristics are determined by the magnitude of the maximum pressure and the speed with

<sup>1</sup> Pyroxyline powders are dried in the shade and in no case in the sun.

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which this grows in a "manometric bomb" (alt. ? pressure gauge container - T) during the combustion of a powder sample.

Nitro-glycerine powders secrete slightly less gases in the process of combustion than pyroxyline powders, but burn up at a higher temperature, hence they are stronger than pyroxyline powders. The result of higher temperatures of combustion is the great vitality of nitro-glycerine powders.

The powder and vitality of pyroxyline powders increase with the increase of insoluble pyroxyline and of nitro-glycerine in the case of nitro-glycerine powders.

Smoke and Flash on a Shot. A slight amount of smoke is caused when a shot is fired by the smoky powder contents of the ignitor on the latter's combustion. On the increase of these contents in the ignitor the amount of smoke naturally also increases when a shot is fired.

Smoke also forms when a shot is fired from water vapours which enter the contents of the products of combustion of smokeless powders; another cause for smoke may be the incomplete combustion (explosion) of part of the powder grains of the propelling charge. Smoke appearing on a shot causes fouling which must be removed by cleaning the bore of the barrel.

When a shot is fired a flame (alt. flash - T) forms apart from smoke. The following three kinds of flashes are distinguished: powder flash, muzzle flash and back flash.

Powder flash, or flash from the powder charge (in its true sense) is formed by the heated (White head - T) gases of this charge; it escapes from the muzzle in the wake of the projectile in the form of a weakly incandescent "bundle" (alt. bunch - T).

Muzzle flash. This forms in front of the muzzle of a piece as the result of the ignition by the powder flash of a mixture of atmospheric air and burning oxides of oxygen, hydrogen and methane which form part of the powder gas contents. A muzzle flame looks like a shining ball and can be seen from afar at night and in cloudy weather, a fact which reveals the F.P.

Back Flash. When a shot has been fired, a certain amount of powder gases remains in the bore of the barrel. The inflammable part of these gases (the same CO, H<sub>2</sub>, or C H<sub>4</sub>) mixing with air when the breech block is opened, ignite, and on meeting the counter-current of air (head wind, firing while moving etc) precipitates itself back from the breech block group of the barrel. This back flash is highly dangerous as it can burn the gun crew, ignite ammunition near the gun, powder charges etc. It is obvious that both muzzle and back flashes are highly undesirable phenomena.

The most practical means against the formation of strong flashes when a shot is fired are the so called flash extinguishers<sup>\*\*</sup> - additions introduced into the contents of propelling charges in order to impede the ignition of the gas cloud. Salts of alkali metals are used as flash extinguishers, generally one uses potassium<sup>\*\*\*</sup> (eg., K C 1, K<sub>2</sub> SO<sub>4</sub>, K H C<sub>2</sub>O<sub>4</sub> etc). It must, however, be pointed out that these substances lower the ballistic qualities of smokeless powder and increase smoke when a shot is fired.

Barrel Bore Erosion. Bore erosion and its wear is mainly the result of the high temperature developed by the combustion of the powder charge.

<sup>\*\*</sup> T - or flash eliminators

<sup>\*\*\*</sup> T - words used is "k a l y a" - 'k a l i' = potash.

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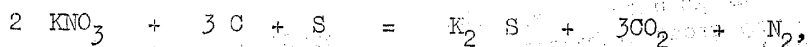
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77 The higher this temperature, the greater the erosion of the bore and the less in duration the serviceability of the artillery piece. The highest temperatures are developed by charges of nitro-glycerine powders, specially by cordite powder types, hence the duration of the serviceability of guns in which such powder charges are used is shortest. Bore erosion is most noticeable in large calibre pieces as such erosion is influenced, apart from temperature, by powder gas pressure and the latter increases with the increase of the powder charge.<sup>1</sup>

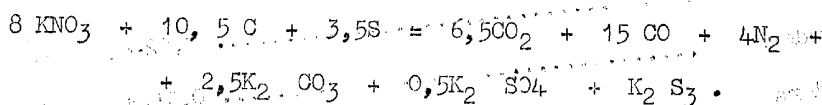
#### 34. SMOKY POWDER

Composition: The theoretically most practical composition of saltpetre - sulphur - carbon, or of smoky (black), powder should guarantee the full combustion of carbon (T - lit. coal) (if one accepts it as pure carbon) into carbonic acid gas (CO<sub>2</sub>) according to the equation.



which corresponds to the following correlation (alt. ratio - T) of weight between saltpetre, sulphur and coal: 74, 82% KNO<sub>3</sub> + 13,32% C + 11, 86% S.

In reality the combustion of smoky powders does not follow such a simple equation and the composition of the products of their combustion vary considerably. Thus, for instance, the reaction of the combustion of smoky powder composed of 72, 2% KNO<sub>3</sub> + 12, 1% C + 10, 7% S can be expressed, in accordance with experimental data, by the following equation:



78 The most practical average composition of smoky powders is the following:

75% KNO<sub>3</sub> + 10% S + 15% C.

Depending on the purpose of the powder, the ratio between saltpetre, sulphur and coal alters within fairly broad limits.

Table 20 gives information on the compositions of smoky powders which are generally used in practice.

TABLE 20.

Name of Powder	Saltpetre in %	Sulphur in %	Coal in %
Military Powders	75	10	15
Shot Gun Powders	74-78	8-10	14-16
Mine Powders	75-84	8-10	8-15
Fuze Powders	60-75	17-37	4-7
Cord Powders	78	12	10
Non-sulphurous powders	80	-	20

<sup>1</sup> This problem is examined in greater detail in book 7 of the artillery course.

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Basic Materials: The following are the basic materials in the making of smoky powders:

1. Potassium (T - ? potash, the adj. is k a l i e v a) saltpetre as an oxygen carrier which is essential for the burning of coal. In some kinds of smoky powders potassium saltpetre (T - ? potash saltpetre - Kalievaya selitra - ) is substituted by natrium (? sodium - T) or ammonium saltpetre.
2. Wood coal (? charcoal - T) - as a basic burning element of smoky powder. The best charcoal is provided by soft woods: alder, willow - thorn, lime, hazel tree, willow, poplar etc.

The following are the types of coal depending on the degree of burning and carbon contents:

1. Black (80 - 85% C);
2. Brown (70 - 75% C);
3. Chocolate coloured (52 - 54% C).

78 Sulphur is used for the mechanical binding of saltpetre and carbon and for giving great stability and firmness to the powder grains; apart from this, sulphur possesses combustive qualities and at the same time serves as a fuel element in the composition of smoky powder.

79 Qualities and Use. Smoky powder consists of polyhedral and irregularly shaped powder grains. They are slate coloured and have a dull lustre. Large grained powder has very often different colourings from blue - black to grey - black. When examining smoky powder through a magnifying glass it should be homogeneous.

Powder grains have the following sizes:

Shot gun powders .....	0,12-0,70 mm
rifle powders .....	0,75-1,25 ""
mine powders .....	1,50-8,50 ""

The specific gravity of smoky powder fluctuates, depending on its type, between 1,5 - 1,9. Its grainmetrical stability is 0,9 - 1,0. Powder grains when rubbed between the fingers should not turn to powder and leave no dust when scattered over paper.

Smoky powder which has been ignited in small quantities on a piece of paper should produce a quick flash without setting fire to the paper.

The flash temperature of smoky powders is approximately 300°, i.e. considerably higher than the flash temperature of smokeless powders and of many other explosive substances, but owing to its porous nature and irregular shape, powder grains of smoky powder very easily ignite from a flame and spark.

The ballistic qualities of smoky powders are very poor which is to be mainly explained through the slight amount of gases which form during their combustion (altogether about 43% of the total amount of weight of the products of combustion). The ballistic qualities of smoky powders can be regulated by changing their contents (the ratio between saltpetre, sulphur and coal and the degree of burning of the coal), compactness, sizes of grains and the polish of the outer surface.

Smoky powders are not used to-day as propelling means for fire weapons. An exception are shot gun smoky powders, but even these are gradually being ousted by smokeless powders.

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In blasting, mine powders which produce fairly good bursting effects, are also nearly everywhere replaced by other and more effective explosives.

An auxiliary role, but one which is very important in blasting, is played by powder compositions which are used in the manufacture of fuze cords (cord powders), whose speed of burning is reduced by increasing the sulphur and coal contents at the expense of saltpetre. Artillery uses the following kinds of smoky powders:

- (1) musketry powders - in the ignitors of powder charges of smokeless powders and in ignition (alt. bursters - U.S. expression - T) charges of some time shells (shrapnel, illuminating, incendiary and leaflet shells).
- 80 (2) Fuze Powders in powder compositions of time fuzes (T - ? time strains), powder columns (lit. T) for flash transmission from the time fuze to the burst charge and in retarders of detonators in artillery projectiles, air bombs etc. Fuze powders contain a large quantity of sulphur which increases their stability and thus lowers the speed of their combustion and guarantees better ignition.

Table 21 sets out the composition of some fuze powders and the combustion rates corresponding to them.

TABLE 21.

Saltpetre in%	Sulphur in%	Brown coal	Rate of Combustion in mm / sec
59	37	4	3
67	27	6	3,8
76	17	7	3,4

### 35. MARKING OF POWDERS

Conventional signs are stamped on the packing in which the powder is kept and transported. These show the mark of the powder, the date of its manufacture and some other data on it. These conventional signs which have been entered on the packing are known as markings.

The mark of a powder expresses its shape, dimensions of grains and type.

Plate shaped powders are designated by letters  $\Pi$  J with two figures, the first expressing the thickness of the disc (alt. plate - T) in portions (alt. lots - T) of hundredths of a millimetre and the second - its width in fractions of tenths of a millimetre. For instance, the inscription  $\Pi$  J 10-10 (T - the first figure does not appear clearly in the text and looks like l e or l c) signified that the packing contains disc (alt. plate - T) shaped powder with a thickness of 0,1 mm and a width of 1 mm.

Cylinder shaped powders are expressed in a fraction whose numerator indicates the thickness of the burning substance (word used is 'Goryashchi Svod' - T) in tenths of a millimetre, while the denominator indicates the number of grooves (alt. perforations - T). For instance, the inscription 9 7 signifies a seven grooved powder with a thickness of the burning substance of 0,9 mm; marking 4 1 means a powder with one groove (? perforation) and a thickness of the burning substance of 0,4 mm.

Tube (macaroni) shaped powder is designated in the same way as cylindrical single trooved powder, but the letters T p are added on the right.

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81 Data relating to the type of powder are expressed as follows:

- C B - powder prepared from fresh pyroxyline;
- E P - powder prepared from old powders;
- C T - powder renovated through the addition of a stabilizer;
- H and H<sup>+</sup> - nitro-glycerine powder.

Army Rifle powders are expressed by letters B<sub>L</sub> (powder for a light bullet) or by B<sub>T</sub> (powder for heavy bullets).

Powder for blank charges is expressed by letter X.

Data relating to the type of powder are written together with the data relating to the shape and size of the powder grains.

Data relating to the place and date of manufacture of the powder, include the number of the powder lot, the date of its manufacture, the cipher of the factory which made it. -

For instance, the inscription  $\frac{4}{46}$  K means: 4th lot of powder, manufactured in 1946 in the factory whose cipher is "K".

## CHAPTER FIVE

MEANS OF IGNITION AND EXPLOSION

82 All means of ignition and explosion can be summarized into the following three groups:

- (a) means of transmitting the flame - fire (alt. flash - T) conductors;
- (b) means of arousing the flame - ignitor caps and pullout fuzes (T - vytyazhnaya trubka);
- (c) means of arousing and transmitting detonation - detonator caps and detonating cords.

36. FLAME (LIT.) TRANSMITTERS.

The simplest type of flame transmitter is a quick match. This is a cotton - paper thread saturated with smoky powder. The velocity of its combustion reaches 60-70 mm / sec. Quick matches are used in some artillery projectiles (for instance, in incendiaries) for transmitting flame from the time fuze to the burst charge.

The so called Bickford fuze (alt. safety fuze - T) is widely used in blasting as a flame conductor. The kernel of this fuze consists of cord powder (alt. ribbon powder - T). The cord powder is covered on its outer surface by a jute thread plaiting. In order to produce an explosion in damp places this plaiting is made water proof. The speed of combustion of a Bickford fuze in the open air, depending on the composition of the ribbon (alt. cord - T) powder and the quality of the plaiting, fluctuates from 5 to 15 mm/sec.

MEANS OF GENERATING FLAME.

Compositions for Ignitor Caps. Compositions for ignitor caps, or percussion compositions, ignite from being pricked by a fuze striker or

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detonator (fuze cap ignitors) or from the percussion by the breech block striker, and in this case they serve for the ignition of powder charges (cartridge ignitor caps).

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Percussion compositions must possess a high degree of sensitivity to mechanical reactions and produce a strong flame. Apart from this, the duration of their combustion must be sufficient to guarantee the reaction of the explosive transformation.

The basic component of percussion compositions which ignite on percussion, is fulminating mercury with an admixture of substances lowering the velocity of its explosive transformation and at the same time increasing and strengthening the flame (potassium chlorate powder ( ? - here the page is perforated and only the letter l and the soft sign are legible - p y ' ? - T) and three - sulphureous antimony (lit. translation), known in technology as antimony).

To increase the sensitivity of the percussion compositions to mechanical reactions powdered glass or powdered quartz is added to some of them, and shellac gum-arabic, gelatine etc - for binding. This is no longer done.

The composition of the ignitor cap in the 7,6 mm rifle cartridge may be selected as an example of percussion cap compositions for cartridge ignitor caps: - 16,7% fulminating mercury, 55,5% potassium chlorate 27,8% antimony (lit. three-sulphureous antimony - T), also the percussion composition of a gun primer cap: 25% fulminating mercury, 37,5% potassium chlorate, 37,5% three-sulphureous - antimony (lit.).

These percussion compositions have one very important defect - they cause rust in the bore of the barrel, which is explained by the presence of potassium chlorate in their composition. Hence at the beginning of the XXth century the so called non-corroding (from the word corrosion) percussion compositions entered into wide circulation. These contain neither Berthollet salt nor fulminating mercury. Generally stannite of lead is used to replace the latter (T H P C), blended with tetrazene, while potassium chlorate is replaced by nitric acid barium.

The composition of the cap in time fuzes can be taken as an example of the percussion composition for fuze ignitor caps: - 28% fulminating mercury, 36% potassium chlorate and 36% antimony (lit. Three-sulphureous-antimony - T).

Compositions for Pull Out Fuzes. In separate loading without a cartridge case, a powder charge ignites with the aid of a so-called pull out fuze. This is a metal tube with two open ends, containing a grater (terka - T) and a friction composition (60% potassium chlorate, 20% antimony and 20% sulphur).

On quick withdrawal of the grater the friction composition ignites and the flame is transmitted to the powder charge through the ignition vent.

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#### MEANS OF ORIGINATING AND TRANSMITTING

##### DETONATION.

Compositions for Caps. As the purpose of detonating caps is to arouse a detonation, they must possess strong explosive qualities. That is why the principal place in the composition of caps is occupied by initiating explosive substances, of which azide of lead is the basic component.

Depending on the purpose, detonating caps are usually divided into the following two groups: blasting detonator caps and artillery detonator caps. Caps to Artillery projectile detonators belong to the category of artillery caps, detonator caps for hand and rifle grenades, air bombs etc. The cap is activated either by a flash (in blasting operations or in detonators with

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84 ignition caps) or by striking.

The contents of a cap are determined by the method of its initiation. Thus where a cap is activated by flash (alt. jet of flame - T), its contents must in the first instance guarantee satisfactory ignition. As an example of contents of this kind may be taken a detonating cap for blasting operations, consisting of 74% tetril, 15% azide of lead and 11% stifnate of lead; the object of the latter is satisfactory ignition.

The contents of a detonating cap which is activated by a strike (lit. by being pricked - T) is determined by satisfactory ignition by being pricked (alt. - struck - T). For instance, in the contents of the caps of some types of detonators contain 85% of fulminating mercury and 15% of potassium chloride or of pure fulminating mercury in a compressed form.

84 Detonating cords (alt. prima cords - T). Prime cords are used in blasting operations for the simultaneous detonation of charges. In their arrangements prima cords greatly resemble Bickford fuzes, but differ from these that their core is made of initiating explosive substances or of their blend with strong high explosive substances. In practice one generally used fulminating mercury, fulminating mercury-trotil and tetril detonating cords. The speed of detonation of these cords is 5000-7000 m/sec.

## CHAPTER SIX

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## PYROTECHNICAL EQUIPMENT

The word pyrotechnics (from the Greek "pyr" - fire) means in translation "fire technology."

Pyrotechnics are peaceful (anti conflagration craft\*) and warlike. In the military craft pyrotechnical compounds are used for illuminating, signalling, tracer and incendiary means (projectiles, cartridges, rockets etc).

Illuminating compositions are used in the manufacture of infantry illuminating equipment (cartridges, hand grenades, rockets), artillery star shells of various sizes, also for landing flares, flare bombs and photo-bombs (these are used for illuminating ground objectives during night aerial photographs) used in aviation.

Signalling equipment are for night use (lights) and for day use (smokes). To this category belong rockets, powerful signals, signal shells etc.

Tracer compositions are used for the manufacture of tracer, armour - piercing tracer, incendiary tracer ranging and ranging tracer bullets, also in the manufacture of artillery projectiles: tracer, fragmentation - tracer and armour piercing - tracer shells. The tracer composition in burning leaves a smoke or light trace and thus helps registration. Tracer bullets fired from a machine gun are also used for aim indication.

Incendiary compositions are used in the manufacture of incendiary bullets, grenades, bottles, incendiary artillery shells (thermit, phosphorus etc.), also for incendiary and fragmentation - incendiary air bombs. Apart from this, incendiary compositions are also used in flame throwers.

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40. FEATURES OF PYROTECHNICALCOMPOSITIONS

In their nature many pyrotechnical compositions are explosive substances and in certain conditions they are capable of detonation; These explosive characteristics are, however, more weakly expressed in their case than in the usual explosives.

\* T - the word here used is 'feieruerochnoe isknstvo,' 'feierver' is a Russian form for the GERMAN for a fire brigade, whereas 'feierverk is the Russian derivation from the GERMAN for fireworks; possibly the latter was intended and went wrong in print.

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The main feature in the transformation of pyrotechnical composition in the normal conditions of their use is their combustion. The energy which is released in this process is not spent on mechanical function but on the production of a pyrotechnical effect (illuminating, incendiary etc.).

Pyrotechnical compositions represent mixtures of fuel substances, oxidators and binders (lit. cementors - tsementarory - T).

The following are usually employed as fuel substances (alt. combustive substances - T) in pyrotechnics: alumina, magnesia, phosphorus, sulphur, sulphites of some metals, tars, oils, starch etc.

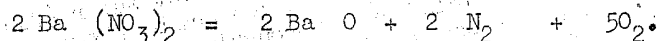
As oxidators are used mainly chlorates, perchlorates (lit), nitrates some oxides and peroxides of metals. A flame can be coloured as intended by chlorates - the produce of the combustion of chlorates. Binders (lit. cementors) or cementing substances are substances which possess good binding qualities and thus guarantee the necessary mechanical stability of the compressed pyrotechnical products. Natural and artificial tars are used as binders: shellac, iditol (sic), colophony (alt. white resin, rosin) gum-arabic etc; starch, dextrine and drying oil are also used.

#### 41. ILLUMINATING COMPOSITIONS.

A bright flame forms while the illuminating components are burning.

Metals, magnesium and aluminium, are generally used as combustive substances. Magnesium provides a better illuminating effect than aluminium but in view of the scarcity and expense of magnesium, one generally uses an alloy of both metals for illuminators. Nitrate barium (lit. azote acid barium - T) is most often used in the capacity of an acidifier [Ba (NO<sub>3</sub>)<sub>2</sub>].

The reaction of its decomposition on being heated may be expressed in the following equation:



nitrate (lit. azote acid) barium contains 30,6% of active oxygen (cooperating with the burning substance), it melts at 593° C and on burning with combustive substances colours the flame green.

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Binders (lit. cementors - T) in illuminating compositions are of organic tars (iditol, shellac, caniphole etc), or drying oil.

Binders, burning at the expense of the oxygen of the acidifier, form gaseous products, which leads to the slowing down of the reaction and to the lowering of its temperature. Hence binders lower the force of light produced by the illuminating composition.

The following illuminating compositions are used in 26-mm illuminating cartridges: nitrate (?) (lit. azole acid - T) barium - 50-62 %; aluminium alloy with magnesium (or their mixtures) - 43-27%; iditol (as a binder) - 7 - 11%. A star (lit. zvezdka - T) of the above composition gives a light of from 35 to 50 thousand candles and burns for 7 seconds. The combustive composition for these stars consists of 75-82% of potash - saltpetre, of 3-10% of magnesium and 15% of iditol.

For artillery Star Shells and aviation bombs the illuminating composition is used consisting of 72% of nitrate of barium, 18% of aluminium dust (lit. powder - T), 5% of powdered aluminium and 5% of drying oil; drying oil is sometimes replaced by other binders (e.g. caniphole); in order to increase the power of light part of the aluminium is replaced by magnesium etc. Priming powder is used as an ignitor.

With the aid of such compositions it is possible to achieve a power of light of up to 200,000 candles from the illuminating charge in a star shell and up to 700,000 candles from an illuminating charge in an aviation bomb.

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42. SIGNALLING EQUIPMENT

Night Signalling Equipment is provided with pyrotechnical compositions giving, while burning, different lights (red, yellow, green and bright blue).

Day Signalling Equipment is provided with compositions giving clouds of coloured smoke.

To obtain green flame one uses a combination of barium; - for a red flame - a combination of strontium, while for blue flame one uses salt of copper.

As acidifiers one uses chlorates of per-chlorates. The best acidifiers, for colouring flames are those containing metals. Tars which simultaneously perform the function of binders are very often used as fuel substances.

To increase the power of light (alt. light effect) one sometimes adds to the signalling compositions a small amount of aluminium or magnesium (not more than 10%).

For signalling by day one uses coloured smokes: red, yellow, black, green and blue.

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As will be appreciated, smoke represents an accumulation in the air of tiny particles of hard substances; the dimensions of these particles are measured in millionth parts of a centimetre. It is possible to obtain a coloured smoke cloud as the result of an explosion in which the previously particled colouring substance undergoes yet another process of being particled: ultra marine (blue colour), cinnabar (red colour), red lead, soot etc. However this process results in fairly large particles of the colouring substance which leads to the smoke cloud having a poor stability. Hence another method of producing coloured smokes is more widely used. This is based on the fact that some organic colouring agents when they are heated to a temperature of from 350° - 500° produced coloured steams which do not decompose in this process or at least only very slightly. Colouring agents of this kind may be used for making coloured smokes. The necessary temperature forms by the rapid combustion of the thermic mixture from the acidifier and the fuel which is mixed with the colouring agents. The most appropriate for this purpose is a mixture of chlorate of kali (? potassium - word used in genitive tense is "kaliya"; kali = kali or potash while kalii = potassium - T). (the acidifier) with lacteons (lit. molochnyi sakhar) or beet sugar (fuels); small quantities of smokeless powder are also used as a thermic mixture. Thus the smoke composition contains a particled and thoroughly mixed acidifier, fuel and a colouring agent. In some cases a binder (lit. cementer) is added. A smoke composition is computed in such a way that the temperature of combustion should not be too high as otherwise the colouring agent will decompose and will not give the required effect. For the proper formation of smoke one controls the access of air to the composition while the thermic mixture is in the process of combustion. Where the air gains free access, the fuel which has been computed for incomplete combustion, will burn up in it entirely, and will increase the temperature of the reaction thus leading to the decomposition of the colouring agent; where the air has insufficient access, smoke formation will be too slow. That is why smoke compositions are burned in containers impeding access of air and possessing an accurately computed vent for the escape of the steams of the colouring agent.

Table 22<sup>1</sup> sets out the most typical chlorate smoke compositions used for signalling equipment.

<sup>1</sup> From N.A. SHILLING's Book on "Explosives and ammunition charging" State Defence Publishers, 1946, MOSCOW.

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TABLE 22.

Components	Day Signalling Compositions			
	Colour of Smoke and Composition( % )			
	Red	Yellow	Green	Blue
Chlorate of kali .....	35	41,3	39,5	41,2
Rodamin (sic) .....	20	-	-	-
Auramin (sic) .....	-	15	26	-
Dark Orange (?) (lit. zhirooranzh) .....	20	-	-	-
89 Chryzoidin (sic) .....	-	-	14	-
Methyl blue .....	-	22,5	-	37,5
Beet sugar .....	17	15	-	15,1
Iditol .....	-	6,2	6	6,2
Starch .....	8	-	14,5	-

#### 43. TRACER COMPOSITIONS

In order to facilitate ranging on moving targets bullets and shells are used which leave a clearly visible trace along their trajectories. Bullets and shells of this kind are called tracers<sup>1</sup>; to obtain a clear visible trace on the trajectory one uses a tracer composition which is placed in a special chamber in the base part of the shell or inside the bullet.

Tracer compositions, according to the character of their combustion, are igneous, smoky and universal.

Igneous compositions while burning give a white or coloured flame, smoky compositions give a large amount of black, white and coloured smoke. Universal compositions give at the same time both flame and a sufficient amount of clearly visible smoke.

In their features tracer compositions resemble illuminating and signalling compositions.

Powdered magnesium and aluminium are the fuels used in tracer compositions. These provide a very powerful light while they burn, peroxyde of barium, nitrate of kali etc are used as acidifiers. To bind the compositions one uses tars, linseed oil, drying oil etc. For tracer compositions with coloured flames in combustion, one uses the same colouring admixtures as are used for signalling lights. Sometimes one uses retarders (phlegmatizers - lit. T) (for retarding combustion), also substances increasing the intensity of the light and the brightness of the flame.

Let us mention here as an example recipes for some tracer compositions. A good red trace is provided by a mixture of 50% of azote acid (lit (possibly nitrate - T) stronium, 30-40% of burning metal and 10% of resinate (sic) of calcium as binding substance.

The ignition of the tracing composition is caused either by the flame of the powder charge in the bore of the gun, or with the aid of a special mechanism equipped with an ignition cap. The first method is considerably simpler and cheaper and has therefore received a wider distribution.

<sup>1</sup> See book 1 Artillery Course, ed. 3, 1948, pp 212-213

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For guaranteeing the ignition of the tracer composition, one often uses the ignition composition, for instance: 48% azote-acid ( ? nitrate - T) barium, 30% peroxyde of barium, 13% magnesium, 9% iditol.

#### 44. INCENDIARY COMPOSITIONS

Two types of incendiary compositions are used:

- (1) Those containing acidifiers;
- (2) Those not containing acidifiers.

The first group includes:

- thermic incendiary compositions, in which metal oxides are used as acidifiers (for instance  $F e_2 O_3 + A l$ );
- compositions in which some kind of salt is used as acidifier (for instance  $K C l O_4 + A l$ ).

The second type includes:

- Electron;
- organic substances; - self igniting substances.

Incendiary compositions of the second type differ from the first in that they are only able to burn on access of oxygen of air.

The foundation of thermic incendiary compositions is a thermic mixture consisting of fuel (metal) and an acidifier (metal oxide). These compositions diffuse while they burn at a temperature of up to 2500-3000° and produce red hot slag able to ignite fuel materials (e.g. wood) and even to melt metals (iron, steel).

Thermic compositions have the defect of igniting with considerable difficulty and therefore are used in incendiary projectiles and air bombs not in their pure state, but with additions facilitating ignition and increasing the incendiary effect (nitrate of barium, magnesium). The incendiary elements (segments) of ammunition generally contain apart from the basic thermic contents also transitional and igniting compositions; only a system of this kind can guarantee the ignition of the main thermic composition.

For instance, for equipping incendiary projectiles, one often uses a composition consisting of 80% of thermic mixture and 20% of illuminating mixture, the first contains thermit, aluminium powder, nitrate of barium and a binder (generally bakelite laquer), the second consists of nitrate of barium, aluminium powder, magnesium and iditol. In order to facilitate the ignition of this basic composition one uses an igniting composition of three mixtures: 25% of thermit, 25% of illuminating and 50% igniting mixture. The latter consists of 82% nitrate of kali (sic), of 3% magnesia and 15% iditol.

Incendiary compositions with salt as acidifier. These ignite comparatively easily and like thermits, give a high temperature of burning; but the duration of their combustion is insignificant and is reckoned in fractions of seconds. These compositions are used for equipping bullets and small bore projectiles mainly intended for setting alight liquid fuels. To this category, for instance, belongs the composition for equipping armour-piercing incendiary bullets: - metal oxides - 50%, red phosphorus - 30%, aluminium powder - 20%, or the composition for equipping armour piercing-incendiary-tracer bullets: perchlorate of kali - 55%, alloy AM - 45%.

Electron is an alloy of magnesium and aluminium with a ratio of 92: 8.

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91. It melts at a temperature of 630-635°. The electron bomb (alt. magnesium type incendiary bomb - T) has the advantage of not carrying dead weight as its body made of electron and its charge (thermit) are both incendiary substances. When burning the electron bomb generates a temperature of from 2000 to 3000 degrees. This bomb cannot be extinguished with water because its incendiary qualities are increased through water; it must be put out with sand.

Incendiary Compositions on a basis of organic substances (crude oil, paraffin, petrol etc) possess a comparatively low temperature of burning (600-800°), but their flame has a considerably larger radius of effect than is the case with thermic incendiary compositions. Liquid organic fuels were mainly used for flame throwers.

A further stage in the perfection of compositions of this kind was the use of consolidated or condensed fuels: stearine acid was dissolved by heating in crude oil, this mixture was then processed (while still hot) by a spirits solution of acid natrium. The liquid mixture was then poured into the body of the bomb where it cooled down assuming a wax like aspect. It was used together with thermit thus obtaining a powerful incendiary giving a bright flame having a height of several metres. Incendiary bombs of this kind were used in the first world war.

Selfigniting Substances (white phosphorus, phosphorous and silicious hydrogen and some metallo-organic combinations) have such a low temperature of ignition that they ignite in normal conditions from contact with air. Some alkaline (alt. lixivial, lixivious) metals easily ignite in the air on contact with moisture.

Selfigniting substances came into wide use in the Great Patriotic War in the struggle against German tanks.

91. For equipping incendiary grenades and mines (possibly - incendiary mortar bombs - T) it is convenient to use a solution of phosphorus in sulphur - carbon ( ? sulphuric carbon - T). On the evaporation of the solvent the phosphorus remains behind as a fine powder which very easily ignites on contact with air and immediately ignites the steams of the sulphuric carbon ( ? sulphur - carbon - "serouglorod;" - T). Crude oil, oil etc are added for the prolonged duration of the combustion.

92. In the Great Patriotic War our troops widely used incendiary mixture KC representing an incendiary mixture with an admixture giving the liquid viscocity. This liquid smells of rotten eggs; it is self igniting in the air and burns with a bright flame at a temperature of 800-1000°, forming a large amount of white smoke. When hitting a tank or an AFV, this liquid firmly stuck to the metal surfaces, and stopped up vision slits; while burning it heated intensively those parts of a tank which it had struck thus causing conflagration in the tank. The liquid was poured into ordinary beer bottles. An upper layer of water and paraffin was added to protect the KC mixture from contact with air. The bottle was then closed with a rubber cork, fastened by a wire or by insulating tape. A soldier under cover in a trench or slit threw this bottle at a tank when it had come into throwing range.

Apart from KC mixtures, other mixtures were also used for whose ignition ignitors were needed.

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## CHAPTER SEVEN

## STORING AND TRANSPORTATION OF EXPLOSIVES

4.5. STORING OF EXPLOSIVES

When storing explosive substances, one eliminates causes which could produce an explosion of the explosive substances stored or lower their stability or alter their ballistic qualities.

Dumps of Explosives. Dumps of explosive substances, depending on their purpose, fall into supply base dumps and dumps for ready use. Base supply dumps receive explosives from the works and pass them on to dumps for immediate needs. No other operations are permitted to base supply dumps.

A base supply dump consists of several stone built stores (magazines), surrounded by protective ramparts. They are equipped with shelves for placing the explosives on them, and are provided with good ventilation and fire protection equipment. In a single magazine of a base supply dump are usually placed only one type of an explosive substance, a fact which permits the creation of the most advantageous conditions for the storage of each type of explosive. The capacity of magazines alters depending on the danger (sensitivity) of one kind of explosive substance or other.

A laboratory is usually attached to a base supply dump for explosives.

93 Dump for ready use are arranged by organizations and undertakings who are the immediate users of explosives (ammunition works, mines, military formations etc) and are grouped into permanent and temporary dumps.

A permanent army immediate supply dump consists of a stone dugout\* (cellar) consisting of two rooms: the front room or "tambura" (T, - 'tambar' = an air lock or gas proof shelter) for weighing and issuing of explosives and the store room itself.

94 The floor of the dugout is of flawless wood without chinks; it is covered with matting (T. - two other words are added all of which are translated as mats, they are 'rogozha' and 'mata'). For better ventilation of this dugout the floor is slightly raised above the earth and air vents (alt. draught eyes, air holes, vent-holes, ventilators - T) and built into the basement (lit. span below the floor - T) which are closed by shutters. The dugout has double doors: the first (outer door) is compact, bound with iron or felt and the other is shuttered for ventilating the interior. Only exterior lighting is permitted, reaching the interior through a window of the 'tambara' (the first room where the explosives are weighed and issued - T) (there are no windows in the explosives store); iron grills are placed into the windows from the interior and the glass is painted over with white-wash (lit. chalk solution - T).

The dugout is equipped with shelves for placing the explosives on them; a special niche is arranged in the dugout for storing ignition and explosion equipment (possibly for storing ignitors and detonators - T).

The dugout is provided with fire fighting equipment; apart from this, two or three lighting conductors are installed on it.

For the timely and immediate call of the fire fighting team, means for alerting this should be installed either in the dugout or near it. (telephone, electric signals, bells etc.).

The dugout is sited not less than 200 metres from living quarters, heated buildings and not less than 500 metres from a railway line, factories and works.

(\* alt. translation is earth hut - T).

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94 The capacity of one dugout is not above 4000 kgs of explosives.

Temporary dumps for immediate use (e.g. camp dumps) are generally installed as ordinary dugouts; where sufficient materials and time are available these dugouts should be equipped in the same way as permanent dumps for immediate use. Single buildings not used as living quarters may be used as temporary dumps for immediate use provided they are at the right distance from living quarters, communication routes etc.

#### STORAGE REGULATIONS FOR EXPLOSIVES

Regulations for storing explosives are determined by the nature of the explosives in question and above all by their sensitivity to various external reactions.

Depending on this reaction of explosive to be used for military purposes, the groups for storing purposes are the following:

1. Smoky Powders;
2. Smokeless Powders;
3. Nitrocombinations (trotil, melinite, tetril etc.), ammonites and pyroxylines;
4. Dynamites;
5. Ignition and Explosion agents.

Each of these groups must be stored separately and special regulations apply for the storing of each group. Where enough space is available, nitro-combinations, ammonites and pyroxylines should be kept separate.

Where not enough storage space is available in military formations different explosive groups may be stored together, but on condition that the following regulations be observed:

- (1) The amount of explosives of each group must not exceed 50 kg;
- 95 (2) Explosives of the third group may only be stored either with smoky powders or with ignition and explosion agents; smoky powders may only be stored either with explosives of the third group or with the smokeless powders, smokeless powders may only be stored with smoky powders.

As has already been repeatedly said, all explosives possess, to a larger or lesser extent, a sensitivity to various mechanical reactions (blows, shocks, friction etc.) and to flame effect.

Therefore in order to avert explosion of such substances while they are stored:

- (1) fires will not be lit and mobile kitchens etc. will not be used in the area of explosive stores and within a radius of 40 metres of such stores;
- (2) artificial light will not be used by personnel working in the stores; work will only be done in daylight hours; at night (where absolutely necessary) stores will only be entered with an electric lamp fed from dry elements or from an accumulator battery;
- (3) when working in stores, only instruments will be used which do not produce a spark (copper, wood etc);
- (4) Stores will not be entered carrying arms, wearing steel helmets, spurs and hard sold boots; before entering weapons will be removed and felt slippers or galoshes placed over boots;

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- 95 (5) no lighting materials whatever, for instance, matches will be carried while in the stores;
- (6) stores must be kept absolutely clean and this includes lofts, passages, stairs etc; special attention must be paid to no fuels or easily inflammable materials being left in or near the stores (oily rags, tow, wood shavings etc.).

Explosive substances must be kept out of contact with moisture as their quality is lowered by dampness. This specially applies to smoky powders and ammonites; superfluous moisture by dissolving the saltpetre contents disturbs the homogeneity of the composition of these explosive substances and finally makes them altogether useless.

In order to protect explosives from becoming damp, one must ventilate the stores very thoroughly during the day in dry weather and to close them in wet weather and at night. Explosives must be kept in their correct and undamaged packings, in their factory packings as a rule. In the case of explosives allergic to moisture the packing must be hermetic.

Apart from this, the following main regulations must be complied with when storing explosives in army dumps (alt. translations: corps or division depot - T):

- (1) Smokeless powders should only be stored in hermetically sealed packings so as not to allow an alteration in the moisture contents and of the volatile solvent in their composition.
- 96 (2) Pyroxyline must be kept in a moistened condition (16-22% moisture content); it must be kept from freezing as frozen pyroxyline has an increased sensitivity.
- (3) Ignition and explosion agents may only be stored in their factory packings - in tin or zinc boxes; free space in the boxes is fitted in with felt or wood shavings.

Storing dynamites in army dumps (alt. translations corps or division depots - T) is absolutely forbidden.

Explosive substances stored in base dumps are periodically tested; these tests consist of the external inspection of the explosives, of determining their physical condition, their chemical stability and their ballistic qualities.

#### 46. TRANSPORTATION OF EXPLOSIVE SUBSTANCES

Explosive substances can be transported by any kind of transport vehicles - in h.d. vehicles, motor vehicles and on the railway etc.

In transport as in operations connected with it (loading and unloading etc.) more or less the same safety rules apply as in storing, i.e. the explosives to be moved are protected as much as possible from shocks, vibrations, ignition etc.

Explosives which are intended for carriage must be in their proper factory packing and each case should be either sealed with lead or sealing wax.

Safety rules for the carriage of explosives by different kinds of transport mainly consist of the following:

##### Regulations for the carriage of explosives in M.Vs.

1. The body of the M.V. must be in good condition and dry.

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2. where loading boxes and barrels with explosives these should be put down with care and not thrown.

Boxes and barrels must be placed in such a way so that during movement they will not knock against anything nor rub against each other or the sides of the vehicle body. Boxes (alt. cases - T) must not be loaded more than in three tiers. The load must be finally tied with string and covered with a tarpaulin.

3. Explosives which should be kept separately must not be carried on the same motor vehicle.
4. Liquid fuel containers or barrels must not be carried with explosives.
5. Each motor vehicle carrying explosives must carry a small red flag showing an emblem of an exploding bomb.

- 97 6. The speed limit for a motor vehicle carrying explosives must not exceed 15 km.p.h.

7. The spacing between trucks proceeding in column must not be less than 50 metres when moving over a level road, and not less than 100 metres in descents and ascents.

8. When moving explosives by road, a road should where possible be selected for the convoy which has no ruts (alt. pit holes - T), pot holes or other irregular features, with undamaged bridges and with no sharp descents and ascents.

9. Inhabited localities should be avoided or by-passed; where this is not possible streets with heavy traffic must be avoided.

10. Where an open fire is found in the vicinity of the road (e.g. a camp fire) steps must be taken to put it out or to by-pass it; conflagrations should also be by-passed or else their full extinction should be awaited where it is found impossible to by-pass them.

11. During thunder storms halting in woods is not allowed, or near high trees nor in the vicinity of lone tall buildings.

12. When passing over level crossings the convoy\* must be brought to halt at a distance of not nearer than 200 metres from the level crossing, and only cross the railway when it has been established that no train is being presently expected.

13. During prolonged halts the convoy\* must move off the road; the halting place must not be nearer than 100 metres off the road.

14. A convoy with explosives is accompanied by an escort. The convoy\* leader and the escort are placed in such a way, that the former can observe the whole convoy, and each escort the load for which he is responsible.

The convoy\* may not smoke or have in their possession lighting utensils (lighters, matches etc.)

\* (Translator's note: the Russian word which has been translated as convoy is "transport" which could also mean a single truck, although "transporter" is the word more generally used).

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Carriage of Explosives by Land

1. Vehicles intended for transporting explosives must be clean and dry, in full repair, steady and where possible sprung.
2. Cases and barrels containing explosives must be loaded with care, avoiding throwing, and in such a way as to avoid mutual knocking or rubbing either against each other or the sides of the vehicle while they are being moved.
3. Not more than 300 kgs of explosives should be loaded on one vehicle, while those explosives which are stored separately must be carried in separate vehicles.
4. Each vehicle should be covered with a tarpaulin placed over the load.
5. In the movement of several vehicles carrying explosives they are spaced at 20 metres over a level road surface. This spacing is extended to not less than 100 metres in the case of sharp descents and ascents.

The leading and the rear trucks must carry red flags showing an emblem with a bursting bomb.

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6. Trucks loaded with explosives can only proceed at walking pace along cobbled surfaces.
7. In a thunderstorm the whole convoy must be halted and spaced at 50 metres between each truck.
8. One escort leader should not be made responsible for more than five trucks.

Apart from the above, the regulations for the carriage of explosives in h.d. vehicles are identical with those for m.v.s.

Carriage on Railways

1. For transporting explosive, special goods trucks are chosen, but without brakes.
2. Cases and barrels containing explosives are loaded in such a way that they will be prevented from altering their position as the result of knocks during movement, and that they will not knock either against each other or against the sides of the trucks.
3. Easily inflammable materials, acids and heavy loads may not be loaded in the same truck with explosives.
4. Explosives may be transported in whole trains or in single trucks forming part of a goods train, military train and other trains.

In the latter case trucks carrying explosives are placed in the centre of the train and are separated from passenger coaches and from trucks and flats carrying easily inflammable materials, by not less than four goods trucks with ordinary loads.

5. A poster representing a bursting bomb is posted on each truck with explosives. The locomotive carries at the base of its funnel a red flag by day and a red lamp by night.

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PART TWOINFORMATION FROM INNER BALLISTICSCHAPTER EIGHTGENERAL INFORMATION47. THE SUBJECT OF INNER BALLISTICS

The word "ballistics" derives from the Greek word βαλλω "I throw."

Ballistics is the science of the throwing of an artillery projectile. In throwing an artillery projectile, one distinguishes between two stages in its movement:

- (a) propulsion through the influence of gases forming as the result of the combustion of the powder charge, when the artillery projectile is moving inside the bore of the barrel of a gun;
- (b) after the exit of the projectile from the muzzle when the projectile continues its movement through the air through inertia and in this movement is subject to the law of gravity and to atmospheric resistance.

According to these two phases, ballistics are divided into inner and outer ballistics.

Inner ballistics studies the movement of a projectile through the agency of gases which form as the result of the combustion of the powder charge and all other phenomena connected with the process of combustion and the expansion of powder gases; outer ballistics studies the movement of a projectile when the powder gases have ceased to effect it.<sup>1</sup>

100 In order to study such a complex problem as is presented by the movement of a projectile under the influence of powder gases within the bore of a gun barrel, one must first of all study the phenomena directly linked with the combustion of powder and the effect from the gases during the process of this combustion.

Inner ballistics are therefore divided into pyro-statics examining the combustion of powder in an altering volume, i.e. in the bore of the gun barrel after the commencement of the movement of the projectile.

Knowledge of pyro-statics facilitates the solution of the main practical problem of inner ballistics; pyro-statics studies the laws of the combustion of powder in simplified conditions independently of the movement of powder gases, i.e. a phenomenon depending on the chemical and physical features of powder and on the ratio between the quantity of powder in the charge and the volume in which this charge is placed.

<sup>1</sup>. Let us give a more precise definition. "Inner ballistics" studies the phenomenon occurring within the bore of a gun during a shot and in particular the movement of a projectile along the bore of the barrel, the character of the increase in its velocity not only in the bore of the barrel but also in the period of the effect from the gases.

(Prof. M.E. SEREBRYAKOV, K.K. GREYEN,

Prof. G.V. OPOKOV. Inner Ballistics, OBORONGIZ, 1939).

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100 Pyrodynamics should provide the correct solution of the main practical problem of inner ballistics, and this is: how to provide a projectile of a given weight and size with the required muzzle velocity when it leaves the bore of the barrel, on condition that the maximum gas pressure will not exceed the magnitude required depending on the strength of the casing of the projectile.

For a correct solution of this problem, one should learn how to spend the powder gas energy more rationally during the course of a shot, or in other words, how to manage the phenomenon of the shot.

This is only possible if one sufficiently masters a thorough knowledge of the processes occurring in the bore of the barrel during the course of the shot.

The difficulty of mastering the basic problem of inner ballistics is connected with the conditions in which the phenomenon of the shot occurs:

- (a) The insignificant duration of the shot, measured in fractions of thousandths or hundredths of a second (usually from 0,002 to 0,06 seconds);
- (b) the exceptionally high temperature in barrel bore (2400-3500°);
- (c) the huge pressure (2000-3000 at. and more);
- (d) the constant change in the dimension of the volume in which the combustion of the gas takes place during the shot.

These peculiarities have led to special methods being worked out for the study of the phenomenon of shots and to the creation of special instruments for this purpose.

Engineering constructors come up against the solution of the chief problem of inner ballistics in its fullest extent when designing guns, gun carriages, time fuzes and detonators, also engineers engaged on the perfection of powders.

An artillery officer must be thoroughly familiar with the problems of inner ballistics in order to be able to use pieces, projectiles and powder charges in their correct technological aspects and to an advantage, and to know which methods for their use will guarantee their best effect and which of them lower their qualities and may damage or burst the piece, thus endangering the lives of those who service it.

#### 48. THE SHOT

The phenomenon of the shot occurs in a very short interval of time, measured in thousandths or hundredths fractions of a second, all the same the processes which in their conjunction make up the shot, pursue their course in strict sequence.

In the process of the combustion of the powder charge three phases are distinguished: ignition, inflammation and combustion in the true sense of the word.

Ignition is the process which gives the powder a certain impulse, under whose influence there begins the reaction of the explosive transformation in a part of the powder charge.

This impulse consists of arousing a flame in some part of the powder charge from its rapid heating to a definite temperature at which the powder catches fire. This temperature is called ignition temperature. It varies for different types of powder, alters in dependence on the composition of the powder, type, degree of moisture of the powder, character of its surface etc.

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Most often it fluctuates within the limits of 160-300.°C.

Thus, for instance, in order to ignite smokeless pyroxyline powder, some part of it must be heated to approximately 200°, and for igniting ballistics (one of the kinds of nitro-glycerine powders) - up 180°.

Smoky (black powder) ignites as the result of rapid heating of some part of it at approximately 300°. The speed of heating has in this connection a very real significance, as in slow heating, powder may decompose without explosion; it is sulphur in particular, which in smoky powder is first to melt, followed by saltpetre.

In spite of the lower temperature of ignition, a smokeless powder charge ignites with a considerable greater difficulty in the bore of a gun barrel than is the case with a smoky powder charge.

This, of course, has its reasons. Ignition occurs with greater difficulty:

- (a) the smoother the surface of the powder grains, which causes the flame to slide unobstructed over them and prevents the heating of the powder particles to the required temperature,
- (b) the greater the size of the powder grains (let. us remember an analogy with wood fuel - in order to heat a stove, fine cut wood chips are needed)
- (c) the firmer the grain construction, the fewer are the pores contained by them, which when penetrated by the flame would quickly heat other particles enveloped by it from several sides;
- (d) the greater the moisture of the powder absorbing a considerable amount of the heat of the igniting jet for evaporation.

On the contrary, ignition is facilitated if the flame meets on its path rough surfaces, pores i.e. obstacles obstructing the flame or forcing it to alter the direction of its movement: when meeting on its path resistance of this kind, the flame is halted and the powder particles obstructing the forward sliding movement of the fire become quickly heated to ignition temperature.

Smokeless powder is denser in comparison with smoky powder, possesses a smoother surface and a firmer (alt. more compact - T) grain structure. That is why it is harder to ignite than smoky powder notwithstanding its lower ignition temperature.

This leads to adding to the main part of a smokeless powder charge a small amount of fine grained smoky powder - the so-called ignitor - for facilitating ignition.

The igniter consisting of more easily combustible smoky powder, plays the same part in the ignition of a powder charge, as small cut chips when lighting a stove.

The source for the impulse for igniting a powder charge are generally the heated (lit. white hot - T) gases of the initiating explosive substances inserted in the primer cup (percussion composition) or the pull out fuze (friction composition).

The flame provided by the cup or pull out fuze, is sufficient for igniting the igniter. But in order to ignite smokeless powder this flame may be found insufficient; having slid along the smooth surface of the grains of the smokeless powder, the flame may fail in igniting the powder charge and there will be no shot. When, after the striker has been lowered no shot results, a phenomenon of this kind is known as a misfire.<sup>1</sup>

<sup>1</sup> Misfires may, of course, be caused by other causes: for instance the blow of the striker may not be sufficiently strong (over oiling, weakening of the striker spring); in such cases the percussion unit in the cup may not act at all and give no jet of flame.

Thus, an igniter is essential for avoiding misfires.

The igniter is placed in a special small flat bag ("powder bag") which is sewn onto the main package of the powder charge of smokeless powder.<sup>2</sup> It is important to pay attention that nobody of the gun crew alters the position of the packages and bundles of the powder charges in the cartridges and that the igniter should always remain at its place immediately over the primer cup.

Powder ignition is the distribution of the flame over the surface of the powder charge grains. The speed at which the flame spreads over the surface of a powder grain or charge is called ignition velocity.

103 In the case of smoky powder the flame spreads very quickly over the surface of the grains and is very rapidly passed on by one grain to the other - up to 2,5 metres / second at an atmospheric pressure of and several times quicker at an increased pressure (in a closed chute three times faster, and ten times faster in the bore of a gun).

Smokeless powder ignites slowly under atmospheric pressure; its grain when lit from one side, burns like a candle from one end to the other, and the flame does not spread at once like a flash over the whole surface of the grain as in the case of smoky powder. The burning up of smokeless powder occurs in transversal layers. Smokeless powder ribbon or tube which has been lit on one side can be held in the hand till the flame nearly reaches the end (diag. 21).

The speed of ignition of smokeless powder under atmospheric pressure is altogether only two or three times greater than the speed of its burning (apx. 1 mm / sec).

The ignition of smokeless powder follows an entirely different course on an increase in pressure. The speed of ignition of smokeless powder increases sharply when pressure increases.

Diag. 21. A ribbon of smokeless powder in the open air (under atmospheric pressure) burns at an angle (ignition is from 2-3 times faster than combustion)

Already at a pressure of 10-15 at. (in an enclosed space), the ignition of smokeless powder charges used in practice can be considered as almost instantaneous.

Strongly heated gases penetrated intensively when under high pressure into the intervals between the grains of the charge, and thus almost immediately enter into contact with its entire surface.

It is very important for the uniform function of the grains, that all the grains of a powder charge will start burning simultaneously and that they finish the process of combustion at one and the same moment.

Should this not happen and the powder grains ignite at different times from each other, then part of them will be late in igniting, the pressure in the bore which is needed for shifting the projectile will be belated, the duration of the shot will be protracted thus leading to the phenomenon called a delayed shot.

2. In some cases the powder bag together with the igniter are stuck on with asphalt laquer to cartridge nipple; imiters of pressed black powder blocks are also used.



Moreover, grains which have ignited later than the others, may not succeed in finishing their combustion process before the projectile has left the bore; part of the powder will have been ejected from the muzzle without having burnt itself out (the so-called non-combustion of powder).

104 The part of the powder charge which has not succeeded in burning itself out before the projectile has left the muzzle and has thus not been turned into gas, takes no part in giving the projectile the energy needed for its flight. The energy acquired by the projectile will be less than was needed and its muzzle velocity will be below normal for the charge concerned. As the result of a projectile of the kind will drop shorter than was anticipated by the person who fired it.

This phenomenon is known as a short "projection (T. Russian: "nedonos") of the projectile."

Short projections often lead to casualties among friendly infantry where the latter is fairly near the target at which the artillery is directing its fire.

On the other hand short projection cannot be reckoned with when ranging on a target as the range of such a projectile cannot be considered normal. The person conducting the shoot must be aware of the fact that a short projection is possible from the shot in question. Hence each case of a delayed shot must be reported to the officer in charge of the shoot or where the powder fails to complete its combustion which generally lead to short projection.

Signs of delayed shots: on the release of the striker the shot does not follow instantaneously but only after some time (interval up to several seconds); after the striker has been released a characteristic sharp hissing sound is heard in the bore.

Signs of the non-combustion of powder: part of the grains of the powder charge are ejected from the muzzle. These finish their combustion late when dropping to the ground near the gun, or the grains which have not finished combustion are found in the cartridge on its ejection after the shot has been fired.<sup>1</sup>

104 All this points to the fact how important it is for all grain of a powder charge to ignite at the same time. To produce this result it is necessary to bring about such a pressure in the powder chamber already at the moment of ignition at which the surface of all the powder grains of the charge will ignite simultaneously.

This problem is solved with the aid of smoky powder discs (lit. small flat cakes of smoky powder - T) which are placed into the primer cup for strengthening the jet of flame, also with the aid of the igniter which has already been mentioned. A small amount of smoky powder in the primer cup and which forms part of the igniter composition, is sufficient for creating in the powder chamber a pressure of 30-50 at., and at such a pressure, one may almost be allowed to assume instantaneous ignition of a smokeless powder charge as guaranteed.

Thus an igniter not only eliminates misfires but also delayed shots. Powder combustion follows immediately on ignition.

Powder combustion consists of the flame penetrating to the depth of each grain along the perpendicular to its surface.

1. Fire which sometimes flares up in the cartridge when the latter is ejected, where the cartridge does not contain unburnt powder grains, is explained not by the failure of the powder grains to burn but by burning on contact with oxygen of those products of the decomposition of the powder as for instance oxide of carbon (CO).

CHAPTER NINE

POWDER COMBUSTION IN A CONSTANT SPACE.

49. COMBUSTION VELOCITY OF POWDER.

The speed at which powder burns is measured by the thickness of its layer burning in a time unit; in other words, speed of combustion means the linear velocity of the flame distribution of the powder grain in depth along the perpendicular to its surface (diag. 22). (lit. translation - T).

Diag. 22. Powder Combustion in concentric layers:

- a - powder layer burning up in the first unit of time;
- b - powder layer burning up in the second unit of time; the thickness of such a layer determines the velocity of powder combustion.

Experiments with powders have allowed one to establish that the velocity of powder combustion mainly depends on the following five factors:

- (a) On the composition of the powder itself;
- (b) On the degree of the moisture of the powder;
- (c) On the compactness of the powder substance;
- (d) On the temperature of the powder;
- (e) On the outer pressure in which combustion occurs, this pressure being closely linked with the compactness of charging.

106 Influence of the Powder Composition. It is already known that smokeless pyroxyline powder is prepared from a mixture of soluble and non-soluble pyroxyline, while nitro-glycerine powder is made of pyroxyline and nitro-glycerine. The greater the percentage of non-soluble pyroxyline or of nitro-glycerine in the powder composition, the faster does the powder burn and vice versa. For instance, in order to obtain a fast burning pyroxyline powder, one takes 85% of non-soluble pyroxyline and 15% of soluble pyroxyline, while in order to obtain slow burning powder, one takes 60% of non-soluble pyroxyline and 40% of soluble pyroxyline.

Another way for influencing the speed of combustion of powder is to introduce to its contents various inert admixtures which will slow down its combustion (the so-called phlegmatizers). The greater the percentage of the phlegmatizing contents, the slower will be the combustion of the powder. Camphor, vaseline etc are used in this capacity (see p.36).

Volatile solvents which have not been removed during drying also react on the speed of combustion.

It is reckoned that a 1% increase in a volatile solvent decrease the combustion velocity of powders by 10-12%.

Influence of Moisture in Powder. Water is also one of the phlegmatizers which considerably slows up combustion as part of the heat which is produced

in the process of the reaction is spent on the evaporation of the water in the powder contents.

Consequently; the greater the moisture of the powder, the less will be the speed of its combustion. Powder which has become very damp may even fail to complete the combustion process in time before the projectile leaves the bore and part of it will be ejected after the projectile has left the bore. The muzzle velocity will consequently be considerably below the normal velocity which may lead to short projection. The harmful consequences of short projection have already been mentioned. From this one may draw this practical conclusion: one must pay careful attention to that the packing of the powder or powder charges both in the stores and in the troop will be hermetical and in no case to disturb this hermetic sealing unnecessarily, to keep charges in dry places and not to use old charges without dire need to do so.

Influence of the compactness of powder grains. The greater the true compactness of the powder grain, the fewer pores it possesses, and the more difficult it will be in consequence for the flames to penetrate to the interior of the grain, and the slower will be the process of the powder combustion.

Influence of the temperature of the powder (temperatures of the charge). An increase in the temperature of powder raises the speed of its combustion. This depends on two causes.

1. The more one or the other powder particle is heated, the less thermal energy will have to be spent on heating it to a temperature at which it will ignite. Consequently, at a definite temperature created by the combustion of neighbouring powder particles, and the heat currents aroused by this combustion,

107 each powder particle will ignite the quicker, the more it has been heated prior to the ignition of the charge.

2. With the increase in temperature, the reaction of the decomposition of the powder proceeds, as in fact any chemical reaction, easier and quicker.

Influence of outer pressure. The greater the pressure from the medium surrounding the powder, the more energetically do the heated (white hot-lit) gases which have formed in the course of combustion, penetrate to the depth of a powder grain and consequently the greater will be the speed of powder combustion.

However, with the lowering of pressure the speed of combustion drops and may become insignificantly small in a sufficiently rarified space. Experiments in powder combustion in a hermetically sealed strong vessel (manometric bomb) prove the dependence between the speed of powder combustion and the outer pressure.

These experiments have made it possible to draw up the following empirical formula:

$$u = A.p,$$

u = velocity of powder combustion;

p = outer pressure;

A = proportionality coefficient.

In order to determine this coefficient, let us assume that combustion occurs at a pressure of  $p = 1$ . Then

$$u = A$$

or

$$A = u_1$$

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(by  $u_1$  one expresses the speed of combustion of powder on  $p = 1$ ).

This means that the coefficient of proportionality  $A$  numerically equates the speed of powder combustion if the pressure is  $p = 1$ .

The above formula show that the speed of combustion of the powder is in direct proportion to the outer pressure.

The magnitude of the speed of powder combustion.

The size of the magnitude (lit. dimensionality; razmernost' - T)  $u_1$  can be seen from this equation

$$u = \frac{u}{p}$$

When "u" is expressed in  $\text{DM} / \text{cek}$ ;  $p$  - in  $\text{kg} / \text{DM}^2$ .

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For pyroxyline powders quantity  $u_1$  alters from 0,0000060 to 0,0000090

$\text{DM} / \text{cek}$

$\text{kg} / \text{DM}^2$

Influence of the Density of Charging. Density of charging is measured by the relation of the weight of a charge in kilogrammes to the volume (space ?) of the powder chamber in  $\text{DM}^3$  (the weight to one unit of space):

$$= \frac{w \text{ kg}}{V \text{ DM}^3}$$

Should the powder chamber be completely filled with the charge, the compactness of charging will in such a case equate the grainmetrical compactness of the powder.

108 With an increase in the compactness of charging, powder gas pressure increases and leads in consequence to the increase in the combustion velocity of the powder.

This problem will be examined in greater detail below.

#### 50. INFLUENCE OF THE SHAPE OF POWDER GRAINS ON THE FORMATION OF GASES.

##### Duration of Burning of the Powder Charge.

##### Law of Gas Formation

It was established already in the first half of the XIXth. Century that the combustion speed of powder does not depend on the extent of the burning surface and that powder grains burn in concentric layers in the open air (diag. 22 and 23).

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It was then thought that powder grains also burn in concentric layers in the bore of a barrel.

Recent experiments have, however, shown that smoky powder grains only burn in concentric layers at pressures close on atmospheric pressure.

At the huge pressures, however, which develop in bores of gun barrels, the flame quickly penetrates into the pores of each smokeless powder grain, creating a strong pressure inside the grain.

This pressure from inside breaks and bursts a grain into small particles which in their turn break up into yet smaller parts in the next moment, and thus smoky powder cannot burn in a barrel bore in concentric layers.

Diag. 23. Combustion of a Tubular Powder grain up to half of its thickness leads to the combustion of the whole charge.

a) tube before beginning of the combustion;

b) the same tube after it has been burning for some time; c) the tube at the last moment of combustion; 1, the tube has burnt to this thickness from inside;

2, the tube has burnt to this thickness from the outside; 3, radius of the tube at the last moment of combustion.

Contrary to this however, smokeless powders consisting not of a porous but of a compact colloid mass, burn in concentric layers at any pressure (law of powder combustion).

As evidence of smokeless powders burning in concentric layers is the proportionality established by experiments between the minimum size of the grains (their thickness) and the duration of their combustion in a closed vessel.

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In this connection one ought to bear in mind that in the case of powders with inner grooves, the minimum thickness between these grooves, the so-called thickness of the circumference (lit. vault, arch, curvature)\* (diag. 24, size 2e), is considered as the thickness of the grain.

The second proof of the correctness of this law:

It sometimes happens in the course of fire (in retarded fire, in cases where charges have become damp etc) that a part of the powder grains fail to complete their combustion before the projectile leaves the bore; these grains, which have not succeeded in burning up, are ejected from the bore of the gun barrel; they always resemble geometrically the original shape of the grain and only differ in size from it. This could not have been the case had the grains of smokeless powder burned not by concentric layers but in some other way.

#### Conclusions from the Law of Powder Combustion

1. The duration of the Combustion of a Powder Grain. After ignition a powder grain burns simultaneously over

\* Russian = 's v o d' - T.

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109 its whole surface and from all sides. The burning surfaces move towards the depth of the grain from its opposite sides and meet in the centre of the circumference of the grain. From this one can deduce that:- the combustion of the grain will cease, the grain will be burnt completely when it will have burnt to one half of its minimum size, i.e. to the middle of circumference of its bulk (diag. 25).

Diag. 24. Thickness of the circumference of a seven grooved Powder grain.

In other words: the duration of the combustion of a grain at a constant velocity of combustion equates the quotient from the division of the half of the minimum dimension of the grain by the velocity of its combustion:

$$t = \frac{e_1}{u},$$

$t$  = time of duration of the combustion;

$e_1$  = half of the thickness of the powder grain;

$u$  = velocity of its combustion.

Diag. 25. Shape of Powder Grains:

- 110 a - cylindrically shaped grain (the height of the cylinder is greater than diameter of its base);  
 b - cylinder shaped grain (height of cylinder less than the diameter of its base); c - ball shaped grain; d - ribbon shaped grain; e - tube shaped grain;  
 e - irregularly shaped grain.

On any alteration (in connection with changing pressure) of the speed of burning the duration of the combustion of the grain depends on the speed of combustion and on the smallest dimension of the grain and is determined by the time required for the grain to burn down to one half of its thickness.

## 2. Duration of Combustion of a Powder Charge.

The inflammation of all powder grains of a charge in a closed vessel (pressure gage bomb, in the bore of a gun barrel) can, as has already been said above, be assumed as being practically instantaneous, i.e. it can be reckoned that all grains of the charge start burning simultaneously. Being identical in size and burning in identical conditions, they should also burn up simultaneously (alt. finish their combustion at the same time - T). We have already said that a grain will finish burning at the moment when it will have burned down to one half of its thickness. At that moment, however, all the other grains of a homogeneous charge will have burned themselves out.

From this one may conclude: the duration of the combustion of a powder charge composed of homogeneous grains, is determined by the duration of the combustion in the given conditions, of one grain to half its thickness.

As the duration of the combustion of a charge depends on the minimum extent (thickness) of its grains, it is obvious that, all other conditions being equal, a grain which is bulkier than the other will burn longer.

In other words, if the intention is to secure longer combustion for a charge, then, on all other conditions being equal, it is enough to select for the charge a type of powder with bulkier grains.

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### 3. Dependence of the amount of gases on the burning surface.

As has already been said, the speed at which powder of a given composition burns depends neither on the size nor the shape of grains. Whether the grain is large or small, ball shaped, cubic or of any other form, a layer of equal size will burn down simultaneously in combustion by concentric layers, provided all other conditions are identical.

Meanwhile, the amount of the gases which form depends on the quantity (volume) of the powder which has been burned, i.e. not only on the speed of combustion, but on the size of the burning surface also.

This means that the amount of gases forming in a time unit during the burning of powder grains, is in proportion to their burning surface.

### 4. Dependence of the amount of gases forming in a time unit on the size of the grains of a powder charge.

Were one to take two powder charges of identical weight and with identically (similar) shaped grains, the duration of the combustion will be longer in the case of the charge containing the finer grains. Let us imagine two charges with the same weight consisting of cube shaped grains: one consists of cubes with edge<sup>#</sup>  $b$  and the other consisting of cubes with edge  $- 2 b$ .

The bulk of the small grain will be  $b^3$ ; the bulk of the large grain  $(2b)^3 = 8b^3$ , or eight times larger. Therefore the weight of the large grain will also be eight times greater than the weight of the small grain. Where both charges weigh the same, the one which has the fine grains will contain a number of grains which will be eight times more: Where in the charge with the larger grains their number will be  $n$ , there will be  $8n$  grains in the charge with the smaller grains.

The surface of the smaller grain equates  $6b^2$ , and of all  $8n$  grains of this charge  $6b^2 \cdot 8n = 48b^2n$ .

The surface of the large grain will equate  $6(2b)^2 = 24b^2$ , and the surface of all the grains of this charge will equate  $24b^2n$ .

Thus, in the case of a charge the linear dimensions of whose grains are smaller by two, the surface of combustion will be twice greater and consequently the amount of gases forming in a time unit will be twice more on all other conditions being equal.

But at the same time this charge will burn up quicker as it disposes over small size grains. Moreover a large proportion of gases secreted at the beginning of the combustion will lead to a considerable increase in pressure which in its turn results in a greater speed of combustion of the grains of this charge.

From this the following deduction can be made: the speed of the combustion of a charge consisting of finer grains of the given composition is greater while the duration of the combustion of this charge will be less than is the case with a charge consisting of larger grains, or, in other words, where the powder contents are identical, a charge of smaller grains will burn quicker than one consisting of larger grains.

A charge of finer grains will not only burn and burn itself out quicker, but will develop a greater pressure to start with than a charge with larger grains.

### 51. Progressivity of Combustion of a Powder.

As has already been said, the amount of gases forming in a time unit during the combustion of a powder charge is proportioned to the burning surface.

<sup>#</sup> alt. translation- rib; the Russian word is 'r e b r o'.

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The extent of the burning surface, however, is closely linked to the sizes and shapes of the powder grains.

In fact, (see the example on page 110) at the first instance the surface of combustion of all the grains of the first charge equated  $48 b^2 n$ .

At the moment when each grain will have burned on each side by  $1/4$  of its original dimension, each of its edges will equate:

$$b - \frac{1}{4} \quad b - \frac{1}{4} \quad b = \frac{1}{2} b,$$

The surface of each grain will equate:

$$6 \cdot \left(\frac{1}{2} b\right)^2 = \frac{3}{2} b^2$$

and the surface of all  $8 n$  grains of this charge will form;

$$8 n \cdot \frac{3}{2} b^2 = 12 b^2 n,$$

112 i.e. it will be less by one quarter than the original surface of combustion.

This decrease in the burning surface will continue during the whole time of combustion until each of the grains will have burned itself out.

The same state of affairs applies not only to cube shaped but also to ball shaped, prismatic and cylindrical etc., grains, in short, to grains of any shape, whether of a regular or irregular pattern - representing one compact body without inner grooves.

Consequently also the amount of gases which form in each successive time unit will similarly constantly decrease in the case of such charges and under the given constant pressure.

This is very unprofitable in fire: at the beginning of the combustion when the projectile is still immobile or has just started moving, but still comparatively slowly, the current of gases is at its maximum; a high pressure forms against the sides of the gun in the small initial air space<sup>1</sup>. This high pressure reacts destructively on the sides. With its progress along the bore of the barrel, the projectile gathers growing speed, the initial air space goes on increasing while the amount of newly forming gases constantly decreases; consequently pressure in the bore rapidly drops and the accretion of speed constantly grows less.

It would have been incomparably more satisfactory, if on the contrary the flow of gases would have been at its minimum at the beginning of the combustion when the initial air space increases still slowly, and subsequently when the initial air space starts increasing at an even faster rate, there would be a greater quantity of gases forming in each successive time unit.

A powder with which at a given rate of combustion the gas flow increases in a time unit according to the degree of combustion of the grains, is known as a powder of progressive combustion.

A powder of progressive combustion does not result in sharp jumps of pressure at the commencement of the combustive process of a charge, and in view of the constantly increasing gas flow, according to the rate of the combustion of powder grains, it allows this flow to maintain a high pressure for a comparatively longer duration not permitting it to drop rapidly.

1. An initial air space is a space in the bore of a gun to the rear of the charge between its base and the base of the bore (breach block).



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Such a more even distribution of pressure creates a lesser stress in the sides of the gun and at the same time it permits the projectile to acquire a comparatively great muzzle velocity.

As the amount of gases forming in a time unit at the given rate of combustion depends on the size of the burning surface, it is essential in order to obtain progressive combustion to select a shape of grains with which the surface of each grain will increase according to the degree with which it burns.

113 This condition, as we have already seen, is not fulfilled by any shapes of grains which consist of a compact mass without interior grooves.

Only where there are inner grooves in the grain (the diameter, and consequently also the surface of each of them increases according to the degree of burning of the grain) can one achieve an increase in the surface of a grain according to the degree of its combustion.

Influence of the shape of grains on progressive combustion.<sup>1</sup> Let us take an irregularly shaped grain (diag. 25, e). Let us mark by S the changeable dimension of its burning surface and its changeable bulk-by letter  $\Delta$ .

After some interval of time a layer will have burned whose thickness will be expressed by letter e. The surface of the grain is an alternating quantity changing in dependence on the thickness of the burned up layer; it can be said that S is a function from e:

$$S = f(e).$$

As we have not the expression of the function of S in its general aspect, one will have to solve the problem for some individual cases.

Let us examine grains with the following shapes:

- (a) Ball;
- (b) Cylinder;
- (c) Ribbon;
- (d) tube (macaroni);
- (e) many grooved;
- (f) square beamed with right angled grooves (KISNEMSKI's powder).

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(a) Ball shaped grain (diag. 25, a). the ball shaped form is one of the least advantageous: according to the ratio of combustion of the layers of the grain, the burning surface will rapidly decrease and with it - the flow of gases will also decrease progressively.

Example: Let us take a ball shaped grain with a radius of 4 mm and let us assume that in a unit of time a 1 mm thick layer has burned down.

<sup>1</sup> Accepted nomenclature ("Artillery terminology", I edition):

- initial thickness of powder grain ..... 2 e<sub>1</sub>
- thickness of burnt layer of powder grain
- (mutable size) ( ? quantity T) ..... e.

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initial surface of powder grain .....  $S_1$

surface of powder grain (mutable size) .....  $S$

initial bulk of powder grain .....  $\Lambda_1$

bulk of powder grain (mutable size) .....  $\Lambda$

relative thickness of a burnt layer of

a powder grain .....  $z = \frac{e}{e_1}$

relative surface of a powder grain

(mutable size) .....  $\phi = \frac{S}{S_1}$

relative bulk of a powder grain

(mutable size) .....  $\psi = \frac{\Lambda_1 - \Lambda}{\Lambda_1}$

114 Initial bulk of the powder grain

$$\Lambda_1 = \frac{4}{3} \pi r^3 = \frac{4}{3} \pi (4)^3 = \frac{4}{3} \pi \cdot 64 \text{ mm}^3$$

After a 1 mm thick layer has burned,  $r = 3$  mm and the bulk of the remaining part of the grain

$$\Lambda' = \frac{4}{3} \pi (3)^3 = \frac{4}{3} \pi \cdot 27 \text{ mm}^3$$

Bulk of the burnt layer

$$\Lambda_1 - \Lambda' = \frac{4}{3} \pi (64 - 27) = \frac{4}{3} \pi \cdot 37 \text{ mm}^3$$

In the following interval of time when the second 1 mm thick layer will have burned,  $r = 2$  mm, the bulk of the remaining part of the grain will be:

$$\Lambda'' = \frac{4}{3} \pi (2)^3 = \frac{4}{3} \pi \cdot 8 \text{ mm}^3$$

The bulk of the part of the grain which has burned in the second time interval will be:

$$\Lambda' - \Lambda'' = \frac{4}{3} \pi (27 - 8) = \frac{4}{3} \pi \cdot 19 \text{ mm}^3$$

The proportion of the bulk of the second burnt layer to the bulk of the first

$$\frac{\Lambda' - \Lambda''}{\Lambda_1 - \Lambda'} = \frac{19}{37} = 0,51$$

This proportion shows that in the second time interval the flow of gases has decreases by nearly one half in comparison with their flow in the first time interval.

A combustion, in the course of which the flow of gases at a given rate of burning decreases according to the degree of burning of the powder grain, is known as degressive.

Consequently, a ball shaped powder grain burns very degressively.

(b) Cylinder shaped grain. This can be of two kinds.

1. a small cylinder whose height is greater than its diameter, and, therefore, its diameter is its smallest dimention. (diag. 25, a);

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2. A small cylinder whose height is smaller than its diameter and its height is therefore its least dimension (a cylinder of this kind looks like a biscuit, diag. 25 b).

In both cases, the combustive surface decreases in proportion to the burning of the grain, and the combustion of a cylinder shaped grain will be degressive.

Example 1. Let us take a grain shaped like a cylinder having a height of 12 mm and a diameter of 6 mm. Let us assume, as we did in the preceding example, that a 1 mm thick layer burns down in a unit of time.

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The initial bulk of the grain

$$V_1 = \pi r^2 h = \pi \cdot 3^2 \cdot 12 = 108\pi \text{ M.M.}^3.$$

After the 1 mm thick layer has been burned  $r = 2 \text{ mm}$ ,  $h = 10 \text{ mm}$ , and the bulk of the burnt part

$$V' = 10 \cdot 2^2 \cdot \pi = 40\pi \text{ M.M.}^3.$$

After the second identical layer has been burned  $r = 1 \text{ mm}$ ,  $h = 8 \text{ mm}$  and the volume of the remaining grain

$$V'' = 8 \cdot 1^2 \cdot \pi = 8\pi \text{ M.M.}^3.$$

The volume of the layer which burned in the first unit of time equates

$$V_1 - V' = 108\pi - 40\pi = 68\pi \text{ M.M.}^3.$$

The volume of the layer which burned in the second unit of time equates

$$V' - V'' = 40\pi - 8\pi = 32\pi \text{ M.M.}^3.$$

The proportion of the volume of the second burnt layer to the volume of the first

$$\frac{V' - V''}{V_1 - V'} = \frac{32}{68} = 0,47.$$

Consequently a cylindrically shaped grain burns very degressively.

Example 2. Let us take a cylindrically shaped grain with a height of 4 mm and a 12 mm diameter.

Let us solve the problem in the same way as we solved the preceding problem.

$$V_1 = \pi r^2 h = \pi \cdot 6^2 \cdot 4 = 144\pi \text{ M.M.}^3.$$

After the burning of the first 1 mm thick layer  $h = 2 \text{ mm}$   
 $r = 5 \text{ mm}$ ,

$$V' = \pi \cdot 5^2 \cdot 2 = 50\pi \text{ M.M.}^3.$$

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After the second layer of the same thickness has burned  $l = 4$  mm, while  $h = 0$ , consequently  $\Lambda'' = 0$ , i.e. the grain has burned

$$\Lambda_1 - \Lambda' = 144 - 509\pi = 949\pi \text{ M.M.}^3.$$

$$\Lambda' - \Lambda'' = 509\pi - 0 = 509\pi \text{ M.M.}^3.$$

The proportion of the volume of the second burnt layer to the volume of the first is:

$$\frac{\Lambda' - \Lambda''}{\Lambda_1 - \Lambda'} = \frac{509}{949} = 0.53$$

The combustion is degressive.

- (c) Ribbon shaped grain (diag. 25g). Ribbon shaped grains belong to the class which result in degressive combustion; but as the thickness of the grain is insignificant in comparison with its length and breadth, degressive combustion will be very much less than is the case with ball shaped grains.

Example. Let us take a grain with the following dimensions: length of ribbon 200 mm, breadth 20 mm, thickness 5 mm. Allowing the same assumptions as in the preceding examples, and expressing the length of the ribbon by 2 c, its width - by 2 b and its thickness - by 2 e, we find

$$2c_1 = 200 \text{ M.M.}, 2c' = 198 \text{ M.M.}, 2c'' = 196 \text{ M.M.};$$

$$2b_1 = 20 \text{ M.M.}, 2b' = 18 \text{ M.M.}, 2b'' = 16 \text{ M.M.};$$

$$2e_1 = 5 \text{ M.M.}, 2e' = 3 \text{ M.M.}, 2e'' = 1 \text{ M.M.};$$

$$\Lambda_1 = 200 \cdot 20 \cdot 5 = 20000 \text{ M.M.}^3;$$

$$\Lambda' = 198 \cdot 18 \cdot 3 = 10692 \text{ M.M.}^3;$$

$$\Lambda'' = 196 \cdot 16 \cdot 1 = 3136 \text{ M.M.}^3;$$

$$\Lambda_1 - \Lambda' = 20000 - 10692 = 9308 \text{ M.M.}^3;$$

$$\Lambda' - \Lambda'' = 10692 - 3136 = 7556 \text{ M.M.}^3;$$

$$\frac{\Lambda' - \Lambda''}{\Lambda_1 - \Lambda'} = \frac{7556}{9308} = 0.81.$$

$$\Lambda_1 - \Lambda' = 9308$$

Degressive combustion is considerably in comparison with ball or cylinder shaped grains.

- 116 (d) Tubular (macaroni) grains (dia. 25, .)

Let us take a tube shaped grain  $h = 20$  mm with a diameter of a cylinder shaped base  $D = 6$  mm and a diameter of the groove  $d = 2$  mm and let us assume that in one unit of time a layer burns having a thickness of 0,5 mm.

In this case the initial volume of the grain will equate

$$\begin{aligned} \Lambda_1 &= \pi R^2 h - \pi r^2 h + \pi R (R^2 - r^2) = \pi \cdot 30 (3^2 - 1^2) = \\ &= \pi \cdot 20 \cdot 8 = 160\pi \text{ M.M.}^3. \end{aligned}$$

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After the first layer has burnt

$$h' = 19 \text{ M.M.}; D' = 5 \text{ M.M.}; d' = 3 \text{ M.M.}$$

(the diameter of the inner groove will increase).

The volume of the remaining part

$$V' = \pi \cdot 19 \left[ \left(\frac{5}{2}\right)^2 - \left(\frac{3}{2}\right)^2 \right] = 789\pi \text{ M.M.}^3$$

After the second layer has burnt

$$h'' = 18 \text{ M.M.}, D'' = 4 \text{ M.M.}, d'' = 4 \text{ M.M.}$$

Volume of the remaining part

$$V'' = \pi \cdot 18 (2^2 - 2^2) = 0$$

i.e. the grain has burnt

$$V_1 - V' = 1609\pi - 789\pi = 829\pi \text{ M.M.}^3;$$

$$V' - V'' = 789\pi - 0 = 789\pi \text{ M.M.}^3;$$

$$\frac{V' - V''}{V_1 - V'} = \frac{789\pi}{829\pi} = 0.95$$

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Although the combustion is degressive, it is so to an insignificant degree as the gas flow proceeds almost uniformly. Thus, the tubular form is the most convenient of all the forms hitherto received.

- (e) Multi grooved grain (diag. 26). Let us take a grain shaped like a cylinder with a height of  $h = 20 \text{ mm}$ , of base diameter of  $D = 6 \text{ mm}$  and with seven grooves having a diameter of  $d = 0.5 \text{ mm}$  each, and let us assume that in each time unit a layer of powder burns having a thickness of  $0.25 \text{ mm}$ .

We find when solving the problem in the same as before, that

$$V_1 = \pi R^2 h - 7\pi r^2 h = \pi h (R^2 - 7r^2) = \pi \cdot 20 \left[ 3^2 - 7\left(\frac{1}{4}\right)^2 \right] = 171,25\pi \text{ M.M.}^3$$

After the first layer has burnt

$$D' = 5,5 \text{ M.M.}; R' = \frac{11}{4} \text{ M.M.}; d' = 1 \text{ M.M.}; r' = 0,5 \text{ M.M.}; h' = 19,5 \text{ M.M.};$$

$$V' = \pi \cdot 19,5 \left[ \left(\frac{11}{4}\right)^2 - 7\left(\frac{1}{2}\right)^2 \right] = 113,39\pi \text{ M.M.}^3$$

After the second layer has burnt

$$D'' = 5 \text{ M.M.}; R'' = 2,5 \text{ M.M.}; d'' = 1,5 \text{ M.M.}; r'' = 0,75 \text{ M.M.}; h'' = 19 \text{ M.M.}; V'' = \pi \cdot 19 \left[ \left(\frac{5}{2}\right)^2 - 7\left(\frac{3}{4}\right)^2 \right] = 143,99\pi \text{ M.M.}^3;$$

$$V_1 - V' = 171,25\pi - 113,39\pi = 57,95\pi \text{ M.M.}^3;$$

$$V' - V'' = 113,39\pi - 143,99\pi = 69,49\pi \text{ M.M.}^3;$$

$$\frac{V' - V''}{V_1 - V'} = \frac{69,49\pi}{57,95\pi} = 1,2$$

$$V_1 - V' = 57,95\pi$$

Diag. 26 A powder grain of a multi-grooved form (cylinder with seven grooves).

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This proportion shows that the volume of the part of the grain which has been consumed in each successive time interval, has not only not decreased but has even increased.

Consequently powder with seven grooves burns progressively.

118 This progressively burning powder has, however, one serious defect. At the moment when the inner grooves have become consumed to such an extent that they interjoin, the grain will not cease burning; the grain will crumble into several pieces (disintegrate - alt. T), each of which, being a compact prismatic body, will complete its combustion very progressively. (diag. 27).

Multi grooved powder can be improved somewhat, if it is given a shape shown in diag. 28. In this case both inner and outer prisms must become absolutely identical and complete combustion simultaneously.

Diag. 27.  
Multi-grooved grain at the moment of disintegration (The non-consumed particles are shaded)

Diag. 28.  
Improved shape of a multi-grooved grain.

Diag. 29.  
Powder grain with trapezoidal grooves

(f) Powder with Trapezoidal Grooves and with Square Cut Grooves.

In order to avoid degressive combustion of a many grooved powder grain after its disintegration, it was proposed to replace circular grooves by trapeze shaped grooves as shown in diagram 29. In theory grains of this shape ought not to disintegrate.

The Russian engineer KISNEMSKI proposed a prism shaped powder with square cut grooves (diag. 30). Theoretically the grains of such powders should also not disintegrate. But the proposal of inventors were not in this case confirmed by experiments; the combustion occurs from the corners along the radii with identical velocity in all directions, and according to the way the grains burn, the transversal section of the square or trapeze shaped groove constantly takes on the corresponding shape with rounded corners. (diag. 31).

Diag. 30 KISNEMSKI'S Powder grain

Diag. 31. Disintegration of KISNEMSKI'S powder grain.

- Fig. 1 - grain up to time of combustion;  
Fig. 2 - grain in the process of combustion (apertures have already lost their square shapes).  
Fig. 3 - grain at the moment of disintegration.

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It has not yet been possible to avoid the disintegration of a grain into degressively burning particles.

The manufacture of a powder with trapezoidal or square section is very complicated.

This is why the suggestions which we have described have in no way been widely adopted.

(g) Reinforced (lit. armoured - T) powder (diag. 32).

The most rational solution of the problem of degressive combustion of powder seems to be found in the so-called reinforced powder. The gist of this proposition consists of the following:

The exterior surface of the grain with its tubular or macaroni like form, is covered with a firm layer of a neutral substance, as though it were protected against burning. The grain only burns from the inside, as the result of which the surface constantly and sharply increases.

Diag. 32. Reinforced Powder grain.

But it is very hard to find for the upper layer a sufficiently firm and non-heat conducting substance, a thin layer of which would serve as "armour", which could resist the immense temperature developed during the combustion of the charge without passing this temperature to the powder below it; secondly, this neutral substance which is ejected on a shot from the bore of a barrel, must form a smoke cloud and this will deprive a powder from being smokeless; thirdly, the neutral admixture will lower the force of the powder and will thus deprive it of a part of its advantages made up of its progressive combustion to the end of this process.

In view of all these difficulties the task of creating a reinforced powder has not yet been solved satisfactorily for practical purposes. Reinforced powder have not yet left the stage of laboratory experiments. Thus the problem of finding a powder which will burn to the end progressively and could be used for mass production.

Fig. 1.

Diag. 32. Smoky Prism shaped Powder:

Fig. 1. Prism with one groove;

Fig. 2. Prism with seven grooves.

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Contemporary artillery mainly uses powders whose grains have a cylindrical shape and are equipped with seven small grooves, or else tubular (macaroni) shaped grains. In the course of the First World War mainly ribbon shaped powder grains were in use. This type predominated at the beginning of the XXth. Century.

(h) Prismatic Smoky Powder. Theoretically the problem of the progressivity of multi-grooved powder combustion had already been worked out at the end of the XIXth century. Even before the introduction of smokeless powder (in 1868) the well known Russian generals GADOLIN and MAIEVSKI had worked out a smoky powder grain which was exceptionally satisfactory from the ballistic point of view. This was a six sided prism with one and with seven grooves (diag. 33.)

Prismatic smoky powder was in fact the prototype of contemporary single and seven grooved smokeless powders.

Professor VISHNEGRADSKI designed a special mechanical press for the manufacture of prism shaped grooved grains of smoky powder. Prism shaped smoky powders was mainly used for large calibre coastal guns.

Experiments, however, made it clear that these prisms burn in concentric layers at low pressures (in the open air), but the moment pressure develops to certain circuits within the bore, prisms of smoky powder start crumbling into small irregularly shaped particles which burn degressively.

In the XXth century, however, the invention of Russian artillery scientists was used for the betterment of the shape of smokeless powder grains.

#### 52. Powder Gas Pressure in an Unaltering Space

Gases forming in the course of the combustion of smokeless powder at a temperature of  $0^{\circ}$ , would occupy a space approximately 1000 times greater than occupied by the powder before the combustion. But heated to a temperature of from  $2400 - 2500^{\circ}$ , gases, as the result of expansion through temperature, tend to occupy a space which is 8-10 times greater than the volume of gases at  $0^{\circ}$ , i.e. 8000-10,000 times greater than the volume of the powder charge prior to the time when it starts its combustion (prior to combustion - T). The tendency of gases towards expansion leads to an enormous pressure in a closed vessel.

This pressure depends on the volume of the vessel containing the gases.

The first part of this book contains the lase of the interdependence between the pressure, volume and temperature of gases (Law of BOYLE - MARIOTT - HEY - LUESSAC).

There one will find set out (pp 41-42) the deduction from equation

$$p \omega = RT, \quad (2)$$

p = pressure;

$\omega$  = volume;

R = gas constant, equating  $\frac{P_1 \omega_1}{273}$

Equation (2) has been deduced (? drawn - T) on the basis of the Law of BOYLE - MARIOTT - HEY - LUESSAC.

This law is true only for ideal gases, i.e. for such gases which can be compressed to a limitless extent (to a volume equating zero); for imperfect



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gases, this law becomes less accurate the more the gas is compressed.

121 Powder gases, however, are not perfect, "ideal" gases when subjected to great pressures. Under great pressure, the molecules of the gas approach each other to an extent resulting in the appearance of molecular attractions (similar to those existing in liquids) and the gas increasingly loses its individual qualities, and, in this connection, starts resembling the qualities of liquid. Moreover, during a great compression of gas, one cannot disregard the sum of the volumes of the molecules themselves, which are assumed to be non-compressible, because, although the volume of each molecule is very inconsiderable, it yet represents a finite dimension, and the amount of molecules in the volume of gas is vast.

Hence, under great pressures, as for instance in a pressure gauge "bomb" and in the bore of a barrel, the gas is enclosed not in the whole space at its disposal -  $W$ , but in a lesser space and of the total of the volumes of the molecules themselves which are compressed to the point of near contact, i.e. in a space of  $W - a$ .

Where the pressure is slight, the volume of the molecules will be insignificant in comparison with the volume of the gases. But in great pressures where the space dividing the molecules is greatly reduced, the volume of the molecules is of significance.

Quantity  $\alpha$  - the minimum volume to which powder gases obtained from 1 kg of powder can be compressed - is known as covolume.

In other words, covolume is the quantity accounting for the volume of gas molecules or gas pressure

Covolume is expressed by letter  $\alpha$ . Its magnitude is constant for each explosive substance and different for different explosives, it is determined by experiment.

For perfect gases  $\alpha = 0$ ; for smokeless pyroxyline gas  $\alpha = 1 \frac{0.003}{\text{kg}}$ \*

As powders burn in practice in very limited spaces (pressure gauges, bores of gun barrels) and at great pressures one cannot disregard the covolume in practical artillery computations; the application of equation (2) to powder gases, which would be correct for "ideal" gases, would lead to serious inaccuracies. That is why in artillery practice a correction for covolume is introduced to equation (2).

The volume of all gases resulting from the combustion of 1 kg of powder will, as has already been said, be not  $W$  but  $W - \alpha$ , because from the whole volume  $W$ , which is possible in the case of "ideal gases", one will have to subtract volume  $\alpha$ , beyond the limits of which the powder gases can no longer be compressed († - the translation of this part of the sentence cannot be guaranteed correct as the page is perforated in the margin).

Equation (2) will take on another aspect:

$$p (W - \alpha) = RT \quad (3)$$

122 We know from physics that real gases are not subject to the Law of BOYLE - MARIOTT - HEY - LUESSAC.

\* Fluctuates between  $0,94 \frac{0.003}{\text{kg}}$  to  $0,98 \frac{0.003}{\text{kg}}$

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The equation of the condition of the true gases has this aspect

$$\left( p + \frac{a}{v^2} \right) (v - \alpha) = RT \quad (4)$$

$p$  stands for pressure;

$v$  = volume;

$\alpha$  = covolume;

$a$  = the characteristics of the force of the cohesion of gas molecules;

$R$  = gas constant;

$T$  = gas temperature.

Equation (3) which we have obtained represents equation (4) for an individual case where one can disregard the force of the cohesion of gas molecules in view of the high temperature in the bore of the barrel during the shot.

In order to determine the pressure developed by the powder gases in the given conditions, let us solve this equation with regard to  $p$  :

$$p = \frac{RT}{v - \alpha} \quad (5)$$

The quantity of covolume  $\alpha$  has been taken into the equation for 1 kg of powder. Consequently  $v$  should also express the volume of gases obtained from 1 kg of powder. The gases, expanding during the combustion of the powder, will occupy the whole volume of the vessel (powder chamber, pressure gauge) in  $W_0$ .

Should the charge weigh  $w$  kg, only a part of the general volume of the chamber, equating  $\frac{W_0}{w}$  will fall to the lot of the gases which form as the result of the combustion of 1 kg. of powder.

As  $W$  in equation (1) expresses the volume which will be occupied by the gases from 1 kg of powder, one may write the following:

$$w = \frac{W_0}{W}$$

This expression may be rewritten thus:

$$w = \left( \frac{W_0}{W} \right)$$

Relation  $\frac{W_0}{W}$  expresses the compactness of the charging, symbolized by letter  $\Delta$ . Hence

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Let us substitute to equation (5)

the value of  $W$  instead of  $W_0$  (lit. let us substitute to equation (5) instead of  $W$  this its value -  $T$ )

$$p = \frac{RT}{\frac{1}{\Delta} - \alpha} = \frac{RT}{1 - \alpha \Delta} = \frac{RT}{1 - \alpha \Delta}$$

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Replacing the gas constant  $R$  by its value  $\frac{P_1 \omega_1}{273}$ , we finally get

$$p = \frac{P_1 \omega_1 T \Delta}{273 (1 - \alpha \Delta)} \quad (6)$$

In this form equation (6) is used in artillery. This formula expresses the dependence of the magnitude of the pressure:

- (1) on the nature of the gas ( $R = \frac{P_1 \omega_1}{273}$  and  $\alpha$ );
- (2) on the condition of charging ( $\Delta$ );
- (3) on the temperature of the combustion of the powder ( $T$ ).

Quantity  $\frac{P \omega_1 T}{273}$  is known in ballistics as the

force of powder and is expressed by letter  $f$ . This force is expressed in functional units (lit. units of work -  $T$ ). By substituting to equation (6)  $f$  instead of

$\frac{P_1 \omega_1 T}{273}$ , we get

$$p = \frac{f \Delta}{1 - \alpha \Delta} \quad (7)$$

This equation was originally obtained in this form by way of experiment independently of theoretical considerations.

53. Solution of Various Problems connected with Powder Combustion.

In solving these problems, let us make use of table 20 which shows the characteristic features of powders. Part of the data of this table has been obtained by means of experiment, the other, by computation:

TABLE 20.

Basic Features of Powders

<u>Features of Powders</u>	<u>Name of Powders</u>			
	<u>Smoky</u>	<u>Pyroxyline</u>	<u>Ballistite</u>	<u>Cordite</u>
Specific volume of powder gases (at an atmospheric pressure and a temperature of 0°) from 1 kg of burned up powder $\omega_1$ , $\frac{1}{3} M^3$ .....	280	910 - 970	810	880
Gas temperature at the moment of the explosion $t^\circ C$ .....	2200-2500	2300 - 2850	2850	2800
Head of explosive transformation (quantity of heat generated by 1 kg of powder when burning in a constant space) .....	685-720	905	1310	1250
Covolume $\frac{1}{3}/kg$ .....	0,488	0,94 - 0,98	0,82	0,88
Potential Energy of 1 kg of powder $\times 0,6 \pi = 427 QK \text{ all}$ apx .....	290,000	380,000	560,000	530,000

The potential energy of 1 kg of a charge (potential of charge), computed in the last line of the table, was obtained from formula

$$E_{\pi} = Q_{\omega} \cdot 427 \text{ kg m / kg,}$$

$Q_{\omega}$  stands for the amount of calories of heat secreted by the explosion of 1 kg of powder;

427 stands for the mechanical equivalent showing how much mechanical energy (kgm of work) is obtained from 1 K of heat.

For instance, for a pyroxyline powder charge, for a 76 - mm gun, weighing 0,879 kg, we have  $\omega = 0,879 \text{ Kg}$ ; according to table 20  $Q_{\omega} = 905 \text{ K}$ ;

Whence

$$E = 905 \cdot 0,879 \cdot 427 = 340,000 \text{ kgm.}$$

Problem 1. Determine the gas pressure in a constant (lit. unaltering - T) space  $W_0$ , equating 1  $\text{dm}^3$ , during the combustion of a pyroxyline powder charge weighing  $\omega = 0,5 \text{ kg}$ .

Solution: Let us use equation (6)

$$p = \frac{p_1 \omega_1 T_{\Delta}}{273 (1 - \alpha_{\Delta})}$$

$p_1$  = an atmospheric pressure amounting to 1,033 kg.

to 1  $\text{cm}^2$ , or 103,3 kg to 1  $\text{dm}^2$ ;  $\omega_1 = 920 \text{ dm}^3$ .

Let us determine the density of charging  $\Delta$ :

$$\Delta = \frac{\omega}{W_0} = \frac{0,5 \text{ kg}}{1 \text{ dm}^3} = 0,5 \text{ kg / dm}^3.$$

Let us find the absolute temperature of the explosion, having attained from table 20 a gas temperature which at the moment of the explosion amounts to 2300°.

$$T = 273^{\circ} + 2300^{\circ} = 2573^{\circ}$$

We find covolume  $\alpha = 0,94$  from the same table. By substituting these quantities to equation (6) we get:

$$p = \frac{1,033 \cdot 920 \cdot 0,5 \cdot 2573}{273 (1 - 0,5 \cdot 0,94)} \approx 8450 \text{ kg/cm}^2,$$

i.e. apx. 8450 technical atmosphere.

Problem 2. Which pressure should a pressure gauge with a volume of 8  $\text{dm}^3$  withstand if it is intended to explode in it 2 kg of cordite ?

Solving this problem in the same way as in the preceding case, we take from table 20

$$\omega_1 = 880 \text{ dm}^3;$$

$$T = 273^{\circ} + 2800^{\circ} = 3073^{\circ};$$

$$\alpha = 0,88 \text{ dm}^3/\text{kg.}$$

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Let us determine the density of charging:

$$\Delta = \frac{w}{w_0} = \frac{2 \text{ kg}}{8 \text{ dm}^3} = 0,85^* \text{ kg/dm}^3,$$

125 By substituting these qualities to equation (6), we find:

$$p = \frac{1,033 \cdot 800 \cdot 0,25 \cdot 3073}{273 (1 - 0,25 \cdot 0,88)} = 3280 \text{ kg/cm}^2,$$

or about 3280 technical atmosphere.

Problem 3. Experimental determination of the covolume and force of powder f.

Let us place a charge of the kind of powder to be tested in a pressure gauge so as to obtain a density of charging of 0,3, let us explode this charge and determine the pressure during this explosion<sup>1</sup>

Let us assume, we found from this experiment:

$$p_{0,3} = 3000 \text{ kg/cm}^2, \text{ or } 300,000 \text{ kg/dm}^3.$$

Now let us make another similar experiment but at density of charging of 0,2. Let us assume that the pressure obtained from this experiment

$$p_{0,2} = 1800 \text{ kg/cm}^2, \text{ or } 1800 \text{ kg/dm}^3.$$

Let us equation (7)

$$p = \frac{k \Delta}{1 - \alpha \Delta}$$

Let us substitute instead of p and their values which we found from the experiment:

$$300,000 = \frac{k \cdot 0,3}{1 - 0,3 \alpha};$$

$$180,000 = \frac{k \cdot 0,2}{1 - 0,2 \alpha}.$$

By solving this system of equations with two unknown quantities with regard to f and  $\alpha$ , we determine quantities f and  $\alpha$  for the powder charge in question.

Let us divide the first equation by the second

$$\frac{300000}{180000} = \frac{0,3 (1 - 0,2 \alpha)}{0,2 (1 - 0,3 \alpha)};$$

$$\frac{5}{3} = \frac{0,3 (1 - 0,2 \alpha)}{0,2 (1 - 0,3 \alpha)}; \quad 10 - 3 \alpha = 9 - 1,8 \alpha;$$

\* This figure has been partly obliterated in the photostat, figure 8 might be 2 or 3<sup>1</sup> - T.

<sup>1</sup> Ways of determining pressure in a pressure gauge are described later.

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Hence

$$1,2 = 1; \alpha = \frac{1}{1,2} \approx 0,83 \text{ } \mathcal{M}^3 / \text{kg.}$$

Having substituted value  $\alpha$  to the second equation, we obtain quantity  $f$

$$180000 = \frac{f \cdot 0,2}{1 - 0,83 \cdot 0,2} = \frac{2f}{8,34}$$

$$\text{Whence } f = \frac{180000 \cdot 8,34}{2} = 750600 \text{ kg } \mathcal{M} = 75060 \text{ kg } \mathcal{M} / \text{kg.}$$

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Inter dependence between the Density of Loading and Pressure in a Constant Space.

Density of loading has a considerable influence on the nature of the action of an explosive substance and on the development of pressure as the density of the gases forming on an explosion depends on it.

Where the density of loading is slight, i.e. where the charge burns in a large space, gases spread in the vessel according to the degree in which they form, pressure develops slower and more gradually and is slight.

Where on the contrary the density of loading is considerable, gases developing at the beginning of the powder combustion quickly form a considerable pressure in the vessel,

Pressure  
at:

S  
M  
O  
K  
E  
L  
E  
S  
S

S  
M  
O  
K  
E  
Y

P  
O  
W  
D  
E  
R

P  
O  
W  
D  
E  
R

Density of Loading.

Diag. 34. Dependence of Pressure of Powder gases on Density of Loading.

which noticeably accelerates the subsequent combustion of the charge. As the result of the fact that pressure grows quickly, the speed of the powder combustion also increases rapidly.

The dependence of the pressure on the density of loading is studied by experiment. Various quantities of different explosive substances are exploded in a very strong and hermetically closed vessel (pressure gauge). The pressures forming in the course of this are measured.

A graph is then constructed on the foundation of these experiments. The densities of loading  $\Delta$  are laid off along the axis of the abscissae, and pressure  $p$  - along the axis of the ordinates. The curves of the dependence between pressure and the densities of loading are that constructed (diag. 34).

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The curve for smoky powder has been constructed in full on the basis of experimental data; the curve of the smokeless powder has been drawn on the foundation of experiments for a pressure of only up to 4500 at. and beyond this - on the basis of theoretical calculations (part of the curve shown by a dotted line).

A similar curve can be drawn on the foundation of purely theoretical calculations, making use of equation (7):

$$p = \frac{f \Delta}{1 - \chi \Delta}$$

Equation (7) determines the dependence between the density of loading and the magnitude of pressure for every powder, the force and covolume of which are known.

It will be seen from the equation that with the increase in density of loading pressure will grow quicker than the growth of  $\Delta$ , as the numerator of the right part of the equation increases during this, while its denominator decreases (T - one word missing through perforation text. The accuracy of this last part of the sentence is doubtful).

Knowing already  $f$  and  $\chi$  for the given powder, one can draw a curve expressing the dependence of  $p$  on  $\Delta$  (diag. 34, the right sketch).

As the result of the examination of the curved dependencies of the pressure on the density, one can reach the following conclusion.

With the increase in the density of loading pressure does not develop regularly in the case of smoky and smokeless powders; Smoky powder is less sensitive to an increase in density of loading than smokeless powder; Its curve rises less sharply and pressure (ordinated) grow less quickly.

At an identical density of loading, the pressure developed by smokeless powder, is approximately three times greater than is the pressure obtained from smoky powder. On the other hand, identical pressures are obtained when the density of loading in the case of smokeless powder is approximately three times less than is the case with smoky powder.

Where the density of loading of smoky powder is brought up to  $1 \text{ kg}/\text{dm}^3$  (the smoky powder filling the whole space of the vessel), a pressure of approximately 7000 at. is obtained.

Smokeless powder, already at a density of loading of  $0,6 \text{ kg}/\text{dm}^3$ , gives a pressure of up to 9000 at. in a constant space, and at a density of loading of  $0,7 \text{ kg}/\text{dm}^3$ , the pressure developed by the gases from smokeless powder, increases at a very considerable rate.

Examining the curve for smokeless powder shown in diag. 34, one can make two important deductions.

First deduction: Smokeless powder produces a huge pressure at a density of loading of  $0,7 \text{ kg/cm}^3$  only when exploded in a constant space. In a gun, however, where the volume of the powder chamber (the initial air space) begins increasing, the projectile scarcely moving from its place, an accretion of this kind will not be observed. In modern guns, so as to exploit their technical possibilities to the full, density of loading is sometimes brought to  $0,75 \text{ kg/cm}^3$ .

Should the shell at such a density of loading, fail to move timely from its place, such conditions will be created as in an explosion in a constant space: pressure will rise very sharply and the gun will burst.

128 This can happen in the following cases:

- (a) Where the bore is dirty (through fouling, sand etc) and the projectile as a result meets with strong braking. To avoid this one must constantly see to it that the bore should be faultlessly clean, and when firing in dry sandy ground where the bore is specially apt to be fouled by dust, one must rub the bore through in the intervals with the rammer.
- (b) Where as a result of careless loading the guide ring of the shell is not sent home to the beginning of the rifling (diag. 35). To avoid this, the gun crew must be taught in separating loading to force the shell carefully home in the bore, until the copper guide ring has properly settle itself where the rifling begins, and in order

a

b

Diag. 35. A carelessly inserted shell leads to an increase in the density of loading:

- (a) a shell forced home;  
(b) a shell not forced home.

to achieve this, it is necessary to make use of a rammer, in the case of guns equipped with one and to ram the shell strongly home.

- (c) Where the shell is badly caliberated and the diameter of its centring bulge exceeds to a certain extent the calibre of the gun.

Shells are caliberated in the factories and their calibration is tested in artillery stores till they are forwarded to military formations. The test is done by means of ball-calibres (instrument for measuring circumference - T), or (in the case of fixed rounds) in testing chambers. As the centring bulge settles already during loading in the rifled portion of the bore, a badly calibrated projectile more often than not gets wedged (alt. ? gets stuck - T) before it reaches its place in the chamber and obstructs the insertion of the cartridge. In this case the obstruction is noticed before firing the shot.

Second Conclusion. In view of the great sensitivity of smokeless powder to the alterations in the density of loading one must not alter it arbitrarily and, especially one must not increase it. One must not add extra powder



bags to the charge over and above those provided for by the regulations; one must not fire long range shells with charges which are only permissible for old (unlengthened) shells, as, for instance, No. 1 charge for the 122 mm howitzer M.1910/30. One must not fire elongated shells from pieces whose powder chambers are not designed for elongated projectiles (old guns which have not been modernized,) etc. Any on these steps may lead to the situation that the density of loading will go beyond the critical limits; moreover the sharp increase in pressure in the bore caused by the rise in the density of loading, may lead to the damage of the gun: to the swelling of the barrel, where the pressure goes beyond the elastic resistance of the sides of the barrel, or to the bursting of the barrel.

Blank (Russian word = kholostoi) smokeless powder is particularly sensitive to an increase in the density of loading. Therefore one must not force home a wad of a blank charge further than was done in the laboratory, insert an additional wad, increase the amount of powder in a blank charge, force rags etc. into the bore in addition to the wad, which is sometimes attempted by gun crews for "increasing the sound" from a blank charge. Any of these measures either leads to an increase in the density of loading or brakes the course of the wad on its way out of the barrel and may thus lead to a sharp increase in pressure and to the bursting of the gun. Not a few cases are known where guns have burst and men have been injured through the keenness of numbers on the gun who sought to "strengthen the sound" of a blank charge.

It is not permissible to use blank powder for operational charges.

In order to avoid accidents, the gunner officer must be perfectly conversant which charges and shells may be used and when, for fire from his gun (this he must learn from the Firing Tables). He must blindly fulfil the rules for their use which are set out in the FIRING TABLES for type of gun, and he must pay the greatest attention to the fulfilment of the regulations for charging.

#### 55. Experimental Determination of Pressure in a Constant Space.

Experimental determination of the dependencies of pressure on density of charging is, as has already been said, done by exploding of different quantities of explosive substances in pressure gauges (diag. 36).

When powder explodes in a pressure gauge, the piston is subjected to the action of the pressure from the gases. The piston starts compressing the crusher gauge (alt. interior pressure gauge). A material of a kind is chosen for the interior pressure gauge which will cause the pressures to be tested to exceed the limits of its resilience and that these pressures will bring about residual deformation (lit. translation - T) (generally chemically pure copper).

The residual deformation will naturally be the greater, the greater the pressure which is exerted on the interior pressure gauge. An altered compression of the small cylinder to a certain and slight extent, can, with an accuracy sufficient for practical purposes be considered as proportional to the alteration in pressure.

The gist of measuring pressure with the aid of an interior pressure gauge consists of the following:

If, let us assume, it is expected that there will be a pressure in the gauge of from 1900 - 2000 at., the interior pressure gauge is, as a preliminary step, subjected to a pressure which is less than that expected by 200 at (1700 at). The next step consists of carefully measuring the height of the interior pressure gauge. Let us say it is found to measure 10 mm (generally one uses as interior pressure gauges small cylinders with a height of

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13 mm and a diameter of

130 8 mm). The interior pressure gauge is again subjected to a pressure of 100 at. more than before, i.e. to a pressure of 1800 at.

It is known that where the metal has undergone residual deformation through the action of a weight or pressure, than the subsequent action of an identical or a lesser weight (pressure) will not give any deformative results. On increasing weight (pressure) deformation increases and will reach the extent which it would reach if this weight had been added to a new metal of the same dimensions and qualities.

Let us assume that the height of the interior pressure gauge is 9,7 mm after the secondary action upon it (by a weight corresponding to a pressure of 1800 at).

Consequently where pressure is increased to 100 at., (from 1700 to 1800) the interior pressure gauge will have been compressed by 0,3 mm (from 10 to 9,7 mm).

Thereon the interior pressure gauge is inserted into the instrument housing which is screwed into the pressure gauge. .... cont. p. 119.

Diag. 36.

Layout of the Mechanism of a Pressure Gauge.

1. Body; 2. Ignition screw plug with a transversal groove; 3. Interior pressure gauge plug; 4. Piston conducting electric current (insulated from plug 2 with fish bladder); 5. Head of screw, screwed on to the end of the piston 4. (serves for attaching the electric wire); 6. Pressed copper pins for the passage of current; a nickel wire ignitor, not shown in the diagram, is inserted between these pins; this wire runs through a small cigarette paper cartridge which is filled with black powder or dry pyroxyline; 7. piston of the interior pressure gauge; 8. interior pressure gauge; 9. stop plug; 10. rubber washer mounted on the interior pressure gauge; 11. shell pen recording the course of the piston in its time relation, on carbon paper (lit. blackened paper - T) pasted on a recording cylinder. This cylinder is not shown in the diagram; 12. Salted leather washer (lit. small disk, aide - T) preventing a gas escape; 13. Refractory mastic of a mixture of wax and gun lubricant (for obturation); 14. Copper obturator rings.

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Under the influence of a higher pressure from the powder gases in the gauge, the interior pressure gauge will become compressed still slightly more.

After removing the interior pressure gauge from the instrument, one again measures its height. Let us assume it is 9,3 mm.

When the interior pressure gauge was inserted in the instrument it measured 9,7 mm in height, therefore it became compressed by 0,4 mm during the test.

During the previous reaction on the interior pressure gauge, the additional 100 at. caused it to become compressed by 0,3 mm. Thus, the pressure

131 in the course of the experiment came to more than the pressure to which the interior pressure gauge was exposed during the preparation for the test, - i.e. the pressure was greater by  $\frac{100 \cdot 0,4}{0,3} = \frac{100 \cdot 4}{3} = 133$  at.

Consequently the pressure during the test was

$$1800 + 133 = 1933 \text{ at.}$$

The interior pressure gauge becomes deformed in all directions after it has been subjected to pressure, as has already been said, but the diameters of the base, on the contrary, increase and the interior pressure gauge takes on a barrel like shape (see diag 38).

In practice the method for determining pressure, which we have described, by means of two (?) preliminary pressures on the interior pressure gauge, is used only for determining pressure in guns; for experiments with pressure gauges, however, one uses so called t a r a z h tables which have been previously prepared on the basis of the principle, we described.

To draw up such tables for the given set of crushers, one takes from 5 to 10 crushers from the set and exposes them to pressure on a press, successively increasing the load and each crusher is then carefully measured after each pressing. The mean result which has been obtained after each pressing is then entered on the table.

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Chapter Ten.

Powder Combustion in an Alternating Space

56. Powder gas Pressure in a Gun

Barrel.

To someone standing near a gun a shot sounds instantaneous. In fact, however, the phenomenon of a shot takes some time, though this is very slight.

If we were to allow, for a very rough reckoning, that, let us say, the projectile of a 76 - mm gun, or having the barrel with a muzzle speed of 680 m/sec, had taken on this speed evenly in the bore, then the mean speed of its movement along the bore will approximately equate.

$$\frac{0 + 680}{2} = 340 \text{ m/sec}$$

When the rifled part of this gun has 42 calibres, i.e. 76,2 mm x 42 = 3,2 m, the shell will pass through the bore, moving at an average speed of 340 m/sec, in the course of 3,2 : 340 = 0,0094 sec.

\* t a r a z h n y e t a b l i t s y - first word unknown - T

In spite of the speed of its occurrence, the phenomena of a shot falls into several phases. The shot occurs in the following sequence.

The jet of flame from the cap or the pull out fuze ignites the igniter which burns up quickly. The gases from the burned up igniter create a pressure of 30-50 at. in the powder chamber as the result of which the smokeless powder charge ignites almost at once. The charge begins burning. While all this is happening the shell has not yet started moving. This is the so called preliminary phase of the shot phenomenon. The projectile can only move from its place at the moment when the gases which have accumulated as the result of the combustion of the charge create a sufficient pressure which will not only surpass the inertia of the projectile itself but also the resistance from the copper guide ring which has inserted itself into the steel of the rifling. This is the so-called pressure to overcome the inertia of the projectile (Russian = pressure of forcing - T).

133 Depending on the weight of the shell, the arrangement of the rifling and guide ring, the pressure to overcome the inertia of the projectile alternates from 300 to 500 at.

The first (main) phase of the shot begins at the moment when the pressure of overcoming the inertia of the projectile has been reached and the projectile has started moving. As the projectile constantly experiences pressure from the powder gases, its movement appears accelerated.

At the beginning of the movement when the pressure of overcoming the inertia of the projectile is, comparatively speaking, slight and acceleration is also slight, it follows that the speed of the projectile is also slight. Accordingly, the initial air space occupant by the gases will also increase slowly. As the volume of the initial air space increases slowly, the gases which accumulate in the space which has altered only a little, create a rapidly growing pressure.

After several thousandths parts of a second when the shell has passed a distance of 2-7 calibres (differing with different guns and charges), pressure ceases to grow and a kind of equilibrium is reached between the flow of gases on the one hand and the growth of the initial air space - on the other. This is the moment of the greatest pressure against the base of the shell -  $p_{max}$ , reaching 2000 - 3000 at. with modern guns.

Subsequently the flow of gases continues; but at the same time the initial air space becomes enlarged at such a rapid rate that pressure begins falling.

At the same time part of the heat of the gases has been already spent on work done. Consequently the compactness of the gases diminishes, pressure is falling. Shortly before the shell leaves the muzzle the charge ends its combustion. With this the first phase ends and the second begins.

The second period has no gas flow and the projectile draws its growth in speed from the still existing pressure. The magnitude of acceleration constantly lessens but it retains its positive value, so that the shell constantly gains in speed.

It is clear that the fall in pressure in the bore during phase two, when there is no flow of new gases, passes fairly quickly. None the less, when the shell leaves the bore pressure in the bore still reaches 200-600 at (muzzle pressure).

Phase two ends with the projectile leaving the bore.

Tests show that after the projectile has left the bore, gases do not at once conclude their action with regard to the projectile.

The heated gases which rapidly escape from the bore, create a gas jet (diag. 37), pushing the projectile on and giving it acceleration over a section of its path

134 in the air for several meters until the falling gas pressure becomes unequal to the opposition offered by the air. This is the moment of the maximum speed of the projectile as subsequently this speed will constantly fall in view of the air opposition.

Diag. 37. Sequel from the gases (gas jet):

1. Shell leaving the gun;
2. Gases escaping from the bore in the wake of the shell, continuing to push it on

The period of time from the moment when the projectile leaves the bore to the time when the gases cease their function with regard to the projectile is known as the phase of gas consequence (lit. T).

Although the speed of a projectile is greatest at the end of this phase, it differs only slightly from the speed at the moment when the projectile left the bore of the gun. In connection with this, it may be added that the study of the phase of the gas sequence is very difficult indeed.

Therefore it is generally reckoned when making practical computations, that a projectile has its greatest speed at the moment it leaves the bore and the movement of the shell in the first and second phase of a shot is studied in detail.

#### 57. Determination of Bore Pressure by Experiment.

Experimental determination of bore pressure is by way of crush gauge instruments (alt. interior pressure gauges).

To determine maximum pressure in bores, one uses insertable crusher gauges which are easily insertable in the powder chamber (diag 38, a) or else into the cartridge with the charge.

A properly placed insertable instrument either remains in the bore after the shot or else drops to the ground not far from the piece.

To determine pressure against the base of a bore (against the breech block) one uses a screw crusher gauge instrument which is screwed into a housing specially arranged for it in the breech block (diag 38, b). In order to study the law of the pressure distribution along the bore, one uses crusher gauge instruments screwed in at various points of the barrel (diag. 38 c and d). For this the shell of the bore is drilled through at places intended for the test. Work of this kind is very difficult and consequently one resorts to it only in extreme cases: in the cases of experimental checking of newly constructed guns, for the introduction of new powders, etc.; usually however one limits oneself to measuring pressure against the base of a bore, considering this pressure as at its maximum.

We must point out that crusher gauges which have been screwed into the shell of a bore at points which are near the point of maximum pressure, do not show the pressure which existed when the base of the projectile passed the point where the instrument has been placed, but the maximum pressure to which this point on the shell of the bore had been exposed in general.

On the other hand, crusher gauges which have been screwed into the bore of a gun barrel further away from the point of maximum pressure, show the pressure which existed at the point in question when the base of the projectile passed it; it is this which is the maximum pressure for the point in question.

The crusher gauge instrument (diag. 38) is arranged as follows:

A steel piston 2 is placed inside a steel case 1. The piston has been rammed well into the bore of the case and rests with its head 4 against the small red copper cylinder 4 (the crusher gauge). So as to take the instrument to pieces and to change crusher gauges, cases are closed by a screw plug 3.

So that the piston head will always rest against the crusher gauge, independently from its height, steel spring 5 is mounted below the piston head. To prevent the crusher gauge from slanting sideways (poss. - altering its position, being moved from its position, word is "perekositsya" - T) or from collapsing (alt, fall over, down - T), it is held in position by a centring rubber ring 6 mounted on it.

Powder gases must not penetrate to the interior of the instrument case; the section of its piston which is exposed to the action of the gases is lubricated with for this reason with a mastic of a mixture of crude oil grease and wax.

The case of a screw crusher gauge instrument has an outside threading for screwing it into the side of the gun barrel (diag. 38, 6).

Pressure is determined by the method described on paragraph 54.

58. Curve of the Pressure against the base of the Projectile.

The law of the growth and the drop in pressure in a bore of a gun in connection with the movement of the projectile, can be depicted very clearly by way of a graph by the so called pressure curve (diag. 39). This curve is drawn as follows:

Crusher Gauges

Crusher Gauges

Diag. 38. Crusher Gauge:

- a. Insertable gauge (into the powder chamber).
- b. Threaded gauge (for insertion into a pressure gauge bomb or into the side of a gun barrel);
- c. Breech block pressure gauge;
- d. cross section of a barrel of the gun to be tested with threaded crusher gauges; 1 - steel case 2 - steel piston; 3 - plug; 4 - red copper cylinder (crusher gauge); 5 - steel spring; 6 - rubber centring ring; 7 - obturating ring; 8 - cartridge; 9 - aperture in the cartridge; 10 - Breech block body; 11 - Crusher gauge before pressing; 12 - Crusher gauge after pressing; 13 - A conical crusher gauge is used for a more accurate determination of pressure.

A point is accepted for the starting of the coordinates which marks the site of the centre of the base of the projectile which has been rammed into the piece. The linear displacements of the centre of the base of the projectile along the bore of the barrel are laid off along the axis of the abscissae, and the pressure magnitudes, experienced by the base of the projectile along the corresponding points of its path (in atmospheres), are laid off along the axis of the ordinates. Up to the shot the pressure exerted on the base of the projectile equates zero, hence the curve passes through the beginning of the coordinates. As has already been said the projectile does not begin moving from the very moment of the start of the combustion of the charge, but only when the pressure reaches a definite extent.

Pressure

$$p = 2200 \text{ at.}$$

$$P_{\text{max}} = 2400 \text{ at.}$$

$$p = 1000 \text{ at.}$$

Diag. 39. Pressure curve of Powder Gases

against the base of a projectile:

OX = axis of the bore of the barrel.

Pressure grows, yet the projectile is still immobile: at some extent the curve merges with the axis of the ordinates. When the pressure has reached the point of overcoming the inertia of the projectile, the projectile begins moving and the curve separates from the axis of the ordinates and rises steeply; after the projectile has passed the point of maximum pressure the curve drops, but less steeply than it rose over the preceding sector.

At the moment, the projectile leaves the barrel, the curve suddenly ceases (the gas sequence phase is generally not reckoned with).

Study of the nature of a pressure curve shows that the section of the curve over the sector from point O to point A (pressure of overcoming the inertia of the projectile), where the curve coincides with the axis of the ordinates, represents a straight line; the section from point A (the starting point of the movement of the projectile) to point B<sup>1</sup> (maximum pressure) resembles a parabola and beyond point B<sup>1</sup>, where the pressure starts dropping, the curve has a more complex shape, which is determined in the highest ballistics course.

If one compares the pressure curves of various powders - of the fast and slow burning powders - we will see that among the first, pressure rises sharply in the initial phase and then falls nearly as sharply.

In the case of a slowly burning powder pressure grows more gradually, but pressure drops also more gradually.

The point at which the pressure reaches its greatest extent in the case of slowly burning powder, is situated somewhat nearer the muzzle than is the case with quick burning powder.

Slowly burning powder gives a more marked pressure near the muzzle than fast burning powder (diag. 40).

Diag. 40. Pressure Curves of Quick and Slow Burning Powders:

I - pressure curve of a quick burning powder. II - pressure curve of a slow burning powder:  $p'_{max}$  - maximum pressure on a quick burning powder charge;  $l'_m$  - path of projectile to the maximum pressure point with this charge;  $p''_{max}$  - maximum pressure with a slow burning charge;  $l''_m$  - path of projectile to the maximum pressure point with this charge.

59. Pressure against the Base and sides of a Barrel.

At the moment when the base of the projectile has reached, let us assume, point B (diag. 41) and the whole initial air space is filled with gases possessing both great compactness and resilience, any point of the base of the projectile, of the sides of the barrel and base of the bore must experience an identical gas pressure, measured by ordinate  $BB_1$ ; at the moment when the shell has reached point M there should, it would seem, be an equal distribution of pressure behind it, measured by the ordinate of curve (here the page has been perforated and the designation of the ordinate is missing, only figure 1 appears like in the case of  $BB_1 - T$ ).

In other words, the distribution of pressure against the sides of the bore in the various oblique sections should be represented by a straight line running parallel to the axis of the bore and passing through the corresponding point of the pressure curve ( $B_1, M_1$  etc).

Where the gases, the projectile and barrel are static this would have been true.

138 In fact, however, a very violent process occurs in the bore of the gun among the influx of the white hot gases, part of whose heat is spent on the spot on propelling the projectile, on expanding and heating the walls of the barrel etc; gas particles constantly alter position, collide, experience a wave-like motion, causing concentration at some spots and rarification at others. To add to this, the projectile too, is moving as though escaping from the gas waves pushing it and this somewhat weakens their blows; the base of the bore is also in motion through the recoil action of the barrel, the sides of the barrel are moving with it.

Experiments in the determination of pressures in various sections of a bore show that the base of the projectile, the base of the bore and various points of the sides of the barrel experience for this reason a dissimilar pressure.



Diag. 41. Pressure curves against the sides of a Barrel.

Curve NT'B<sub>1</sub> shows the maximum pressure against various points of the side of the barrel at the moment when the base of the projectile finds itself at point B; Curve N'B<sub>2</sub>M<sub>1</sub> shows the pressure against various points of the sides of the barrel at the moment when the base of the shell is at point M.

1. Pressure against the base (lit. bottom) of the bore is always greater than the pressure against the base of the projectile.

Between these two pressures there exists a definite relationship, expressed in semi empirical formulae.††

The most generally used in the approximate formula by SARRO (sic):

$$P_{\Delta H} = p \left( 1 + 0 \frac{w}{q} \right),$$

$P_{\Delta H}$  - pressure against the base of the bore in at;

$p$  - pressure against the base of the projectile in at;

$w$  - weight of charge in kg;

$q$  - weight of projectile in kg;

$O$  - coefficient determined by experiment is generally used for smokeless powder for  $\frac{1}{2}$  (generally speaking, its quantity fluctuates from  $\frac{1}{3}$  to  $\frac{2}{3}$ ).

2. Pressures against the sides of the bore differ in different sections, but pressure is always greatest against the bottom of the bore.

Thus, the law of the distribution of pressure along the bore of a piece cannot be expressed by straight lines A<sub>1</sub> B<sub>1</sub> and A<sub>2</sub> M<sub>1</sub> running parallel to the axis of the bore, but must be expressed by curves I (NB<sub>1</sub>) and II (N'M<sub>1</sub>).

Curve OB<sub>1</sub> M<sub>1</sub> M<sub>2</sub> - here, as before, the pressure curve is against the base of the shell, curves I and II, however, show successive distribution of pressure against the sides of the bore in different sections of it to the rear of the projectile.

†† deduced on the ground of experiments.

† Initial letters of Russian for base - T)

Curve I shows that at the moment when the base of the projectile finds itself at point B and undergoes a pressure measured by ordinate  $BB_1$ , the base of the bore undergoes a pressure of  $AN > BB_1$ , while the sides of the bore undergo different pressures in different sections of it, expressed by ordinates of curve I, thus, for instance, point T experiences a pressure measured by ordinate  $TT'$ .

Curve II shows in a similar way the law of the distribution of pressures against the sides of the base of the bore at the moment when the base of the projectile finds itself at point M.

Problems solved with the help of SARRO's formula.

Problem 1. Using an insertable crusher gauge, we have measured the maximum pressure against the base of the bore of a 152 mm gun; this pressure has been found to be 1920 at. Determine the maximum pressure against the base of a projectile if its weight is  $q = 41$  kg, the weight of the charge  $\omega = 3$  kg.

This problem is solved with the aid of SARRO's formula by substituting to it certain quantities, and by solving the equation in relation to the unknown p:

$$P_{\Delta H} = P \left( 1 + 0 \frac{\omega}{q} \right);$$

Whence

$$P = \frac{P_{\Delta H}}{1 + 0 \frac{\omega}{q}} = \frac{1920}{1 + 0 \cdot \frac{3}{41}} = \frac{1920}{1 + \frac{3}{82}} = \frac{82 \cdot 1920}{85} = 1852 \text{ at.}$$

Problem 2. Maximum pressure against the base of a projectile amount to 1657 at. Determine the maximum pressure against the base of the bore where the shell weighs  $q = 41$  kg, and the charge  $\omega = 2,14$  kg.

The problem is solved by SARRO's formula.

By substituting certain quantities we determine the unknown:

$$P_{\Delta H} = 1657 \left( 1 + \frac{2,14}{41} \right) \approx 1700 \text{ at.}$$

## 60. Function of Powder Gases. Coefficient of the Useful

### Action of the Charge

The immediate (lit. direct) object of powder gases consists of giving a projectile a great initial speed - and at the same time to make it revolve.

140 Therefore the useful function of powder gases is measured by the kinetic energy of the projectile at the moment when it leaves the muzzle (muzzle energy).

From physics it is known that

$$E_K = \frac{mv^2}{2} = \frac{qv^2}{2g};$$

$m = \frac{q}{g}$  - the mass of the body;

$v$  - its velocity

$q$  - its weight

$E_K$  = the kinetic energy of the body.

As in the examination of the energy acquired by the projectile, we take the speed of the projectile into consideration which in ballistics is expressed by  $v$ , this equation will look as follows in ballistics:

$$E_k = \frac{m \cdot v^2}{2} = \frac{q \cdot v^2}{2g}$$

But apart from this primary function which we will call  $A_1$  the energy from the gases is spent on a whole series of secondary functions, namely

- on imparting to the projectile its revolving motion (function  $A_2$ );
- or overcoming friction between the guide ring and the inner surface of the barrel, also on overcoming the friction of the central bulge of the projectile and the lands of the riflings (function  $A_3$ );
- 141 - on the displacement of the gas like products of combustion as well as the particles of powder which have not yet completed the process of combustion (function  $A_4$ );
- on moving the recoil parts of the gun and the recuperator mechanism as well as on the vibration of the body of the gun (function  $A_5$ );
- on setting the guide ring into the rifling during the displacement of the projectile (function  $A_6$ );
- on heating the sides of the barrel, cartridge and shell (function  $A_7$ );
- on overcoming air resistance and on expelling the air column in the bore, in the path of the projectile (function  $A_8$ );
- on the expansion of the sides of the barrel (function  $A_9$ ).

Moreover, part of the energy from the gases is lost with them. They escape through the gaps of the guide ring and the sides of the barrel (this part of the energy might have fulfilled function  $A_{10}$ ); the other part of the gas energy is lost as the result of the fact that the gases escape from the bore after the shot has been fired in a white hot condition without having transformed their potential energy into function  $A_{11}$ .

Of all these functions, the first five may be determined directly with some approximations, function  $A_6$  may be accounted for either directly or indirectly; function  $A_8$  is insignificant in comparison with the others and therefore is not generally reckoned with, while the rest of the energy expenditure has not yet been successfully accounted for by the direct method.

Experiments show that functions  $A_2, A_3, A_4, A_5$  are in proportion to the main aspect of the work done by the powder gases, i.e. function  $A_1 = \frac{m \cdot v^2}{2}$ ,

This gives us the right to represent each of the enumerated functions in the following form:

$$A_i = K_i \frac{m \cdot v^2}{2}$$

$K_i$  - is the coefficient of proportionality.

The general expenditure of the energy directly accounted for can then be expressed as follows:

$$\sum_1^5 A_i = \sum_1^5 K_i \frac{m \cdot v^2}{2} = \frac{m \cdot v^2}{2} (1 + K_2 + K_3 + K_4 + K_5),$$

\* This formula does not account for the energy of the revolving motion of the projectile. This will be considered later.

$$1 = k_1.$$

Having designated the sum of coefficient by  $\psi$ .

$$\psi = 1 + K_2 + K_3 + K_4 + K_5;$$

Where

We get

$$\sum_{i=1}^5 A_i = \psi \frac{m v^2}{2}$$

Calculations and experiments show that the quantities of coefficient  $\psi$  for various guns, projectiles and charges fluctuate from 1,05 to 1,20.

Were we to relate this coefficient  $\psi$  not to the whole live force of the projectile  $\frac{m v^2}{2}$  but only to the mass, and having rewritten the formula thus:

$$\sum_{i=1}^5 A_i = \psi \frac{m v^2}{2} = \psi m \cdot \frac{v^2}{2},$$

we may then reckon conventionally that the function of the gases has been spent on conferring successive movement at speed  $v$  on the projectile which is heavier than the real projectile, i.e. on a projectile possessing not mass

$m$  but  $\psi m$ .

142 This gives us the opportunity of replacing the consideration of the successive motion of the true shell, taking the secondary functions into account, by the consideration of the successive motion of a shell with a fictitious mass of  $\psi m$ ; in this process the energy expenditure remains the same while calculation is easier.

Coefficient  $\psi$  is known as the coefficient of the fictivity of the mass (lit. -  $\Psi$ ).

The full function of the gases, corresponding to the potential energy of the charge (potential of the charge) is, of course, much greater than the main function fulfilled by them: in this respect a gun does not principally differ from other engines.

The potential energy of a charge (potential of the charge) is, as has already been said (para. 15), determined by formula

$$E = 4.27 \omega Q_w \text{ kg m.}$$

$\omega$  - stands for weight of charge;

$Q_w$  - number of heat calories secreted on an explosion of 1 kg of powder.

Obviously,  $4.27 \omega Q_w = \sum_{i=1}^n A_i$ .

Already knowing the kinetic energy of the shell and the potential of the charge, it is not hard to determine the coefficient of the useful function (K. П. Д.)<sup>\*</sup> of the charge which characterizes a gun as well as an engine:

$$K. П. Д. = \frac{A_{\text{useful}}}{A_{\text{total}}} = \frac{\frac{m v^2}{2}}{4.27 \omega Q_w} = \frac{q v^2}{8.54 q \omega Q_w} = \frac{q v^2}{8.54 q \omega Q_w}$$

\* These are the initial letters of the Russian words for "coefficient of useful function" i.e. efficiency -  $\eta$

$A_{\text{ПОВЕЗН}}$  = efficiency

$A_{\text{ПОЛН}}$  = full function

The other expressions are those already used.

Calculations made for various guns, projectiles and charges show that the efficiency is close on  $\frac{1}{3}$ .

Thus an artillery piece, in so far as the efficiency of its charge is concerned, is among the most perfect of modern machines and surpasses most of them (the coefficient of useful function of modern locomotive is 18-20%, of a diesel engine - about 35%).

Example 1. For a 76 mm gun M. 1942,  $q = 6,2$  kg;

$U_0 = 680$  met/sec;  $\omega = 1,080$  kg; for pyroxyline powder  $Q_{\omega} = 905$  cal.

Hence,

$$K. П. П. \text{ (efficiency)} = \frac{q \cdot U_0^2}{854 \cdot \omega \cdot Q_{\omega} \cdot g} = \frac{6,2 \cdot 680^2}{854 \cdot 1,080 \cdot 905} \approx 35\%$$

Example 2. For a 122 mm how. M. 1938, on a full charge,

$q = 21,8$  kg,  $U_0 = 515$  met/sec;  
 $\omega = 2,075$  kg.

Consequently

$$K. П. П. \text{ (efficiency)} = \frac{21,8 \cdot 515^2}{854 \cdot 2,075 \cdot 905} \approx 36,7\%$$

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61. Extent of the Force of Recoil (lit. blow back - T)

The pressure formed against the base of the bore causes the recoil of the barrel.

This force, being variable (alt. alternating, changeable, fluctuating - T), reaches a considerable extent. For determining its maximum extent one must multiply the maximum pressure against the base of the bore by the area of this base. Assuming for an approximate computation the diameter of the base of the bore as equating the calibre of the gun (the diameter of the base of the bore is in fact a little larger than the diameter of the bore of the gun), we get:

$$P_{\text{кг}} = P_{\text{П.Н.}} \cdot \frac{\pi d^2}{4}$$

$P_{\text{кг}}$  - the force of recoil;

$P_{\text{П.Н.}}$  - maximum pressure against the base;

$d$  - calibre of gun.

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Example I. The maximum pressure against the base of the shell of a 76 - mm gun M.1942 attains 2320 kg/cm<sup>2</sup>. The weight of its shell is  $q = 6,2$  kg; the weight of the charge is  $\omega = 1,08$  kg. According to SARRO's formula the maximum pressure against the base of the bore will be:

$$P_{\text{ДН}} = 2320 \left( 1 + 0,5 \cdot \frac{1,08}{6,2} \right) = 2320 \cdot 1,087 = 2522 \text{ кг/см}^2$$

Having multiplied this quantity by the area of the base of the bore, we will get the maximum force of the recoil.

$$P_{\text{КЗ}} = P_{\text{ДН}} \times \frac{\pi d^2}{4} = 2522 \frac{3,14 \cdot (7,6)^2}{4} = 114351 \text{ кг},$$

or more than 114т.

Example II: The maximum pressure against the base of a shell of a 122 mm howitzer M.1939 is 2350 kg/cm<sup>2</sup>, the weight of its shell is about 21,8 kg; the weight of the full charge is 2,075 kg. The maximum pressure against the base of the bore with a full charge will be

$$P_{\text{ДН}} = 2350 \cdot \left( 1 + 0,5 \cdot \frac{2,075}{21,8} \right) = 2350 \cdot 1,0475 = 2462 \text{ кг/см}^2$$

Assuming the area of the base of the bore of a 122 - mm howitzer to be

$$\frac{\pi d^2}{4} = \frac{3,14 (12,2)^2}{4} = 116,8 \text{ см}^2,$$

we find that the maximum recoil force of a 122 mm howitzer comes to

$$P_{\text{КЗ}} = 2462 \cdot 116,8 = 287,562 \text{ Т.}$$

As similar computation for a 152 mm gun howitzer provides us with a maximum recoil force of approximately 450 т, for a 120 mm mortar - above 110 т, etc.

This computation is not absolutely accurate, all the same it gives a clear picture of the huge force of recoil. Recuperator mechanisms and the gun carriage, absorbing such a considerable recoil force, must possess great stability.

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In some cases, part of the recoil force can be directed to useful work. Thus where gun breech locks are partly automatic, the recoil force is used for opening the breech lock after the shot has been fired, for ejecting cartridges and for locking the block after charging, and where the lock is automatic, the force can be turned to reloading the gun after a shot.

This function carried out by the recoil force allows one to increase to a considerable degree the quick firing propensity of a gun.

## 62. Propelling Force of Powder Gases and its Graphic Expression.

Hitherto we have discussed only the pressure which is experienced by the base of a projectile (in atmospheres, in kilograms to a square centimetre). Let us now consider the problem of what is the force acting on the projectile at each point of its path - of the propelling force of the powder gases. In order to determine this force the magnitude of the pressure, exerted on 1 cm<sup>2</sup> of the area of the base of a projectile, must be multiplied by the area of the cross section of the projectile<sup>1</sup>, expressed in square centimetres.

<sup>1</sup> The rifles being taken into account.

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For instance, if in accordance with the pressure curve the projectile experiences at point B (see diag. 39) a pressure of 2400 at. and the radius of the cross section of the projectile equates 4 cm, then the force acting against the projectile at point B equates:

$$F_B = 1,033 \cdot p \cdot R^2 = 1,033 \cdot 2400 \cdot 3,14 \cdot 4^2 = 124600 \text{ kg.}$$

At point M where the pressure against the base of the projectile amounts to 1000 at, the propelling force of the powder gases will come to:

$$1,033 \cdot 1000 \cdot 3,14 \cdot 4^2 = 51900 \text{ kg. etc.}$$

144 The pressure against the base of the projectile is a variable force, hence the propelling force of powder gases is also variable.

As in every case the extent of the force propelling the projectile is obtained from a multiplication which is constant for the projectile in question of quantities  $r^2$  (alt. magnitudes - T) by the extent of the pressure experienced by the base of the projectile at the given point along its path, then it follows that the propelling force of the powder gases is in proportion to the pressure against the base of the projectile along the whole of its path.

The pressure curve against the base of the projectile can therefore be used simultaneously as a curve indicating the alteration in the propelling force of the powder gases, but only on another scale: the ordinate expressing pressure in 'p' atmospheres will in this case express the motive power whose extent equates  $p \cdot 1,033 \cdot r^2$  kg.

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Therefore, the pressure curve against the base of the projectile is at the same time also the curve of the variable moving force of the powder gases (only on another scale).

### 63. Graphic Expression of the Efficiency of Powder Gases

Let us determine the efficiency of the powder gases at some sector of the path, for instance, between points M and N (see diag. 39). Let us designate the force pushing the projectile - by F, and the distance M N - by l.

We know from mechanics that the function of force equates the work done by the force on the path covered by a body as the result of the action of this force.

The propelling force of powder gases is a variable force. Let us designate the values of this force at points M and N correspondingly by F' and F'',  $F' = MM'$  and  $F'' = NN'$ .

In the case where the sector of the path of the projectile is sufficiently short, we can without erring too far assume sector M'' N' of the pressure curve to be a straight line, in that case square MM' NN' will be trapeze shaped.

On sector l of the path of the projectile the mean value of the propelling force

$$F = \frac{MM' + NN'}{2};$$

consequently the function of the force

$$F \cdot l = \frac{MM' + NN'}{2} \cdot MN.$$

We know from geometry that this expression designates the extent of the area of trapeze MM' N'N.

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Therefore, the work of the gases on sector MN is numerically expressed by the area, bounded by the pressure curve against the base of the projectile, by the ordinates of this curve at points M' and N' and by the axis of the abscissae.

The whole efficiency of the powder gases along the extent of the path of the projectile along the bore of the barrel will express itself as the sum of the areas of similar trapezes for all sectors of the path of the projectile in the bore of the barrel.

In order, however, to compute the whole efficiency of the powder gases we would have to break down the whole path of the projectile in relation to the bore of the barrel ( ) into a great number of elementary sectors similar to sector MN in diag. 39; to determine the efficiency of the gases on each of these sectors we would have to compute the area of the trapeze in the same way in which we computed the area of trapeze MM'N'N' ; to determine the extent of the efficiency on the whole of path ( ) we would have to add the areas of all these trapezes, which would give us, when added together, the area limited by the pressure curve, its final ordinates and axis of the abscissae (diag. 42).

For rough computations with the required degree of accuracy, the path of the projectile with regard to the bore of the barrel, will have to be broken down into a sufficiently large amount of sectors. On each of these one will have to construct a trapeze of a kind such as trapeze MM' N' N in diag 39.

The more there are trapezes of this kind the more accurately obviously, will be the approximate computation of the efficiency of the powder gases.

On the other hand, however, as we have already pointed out, the work done by powder gases is measured by the kinetic energy of the projectile at the moment when it leaves the muzzle; - secondary functions being taken into account:

Diag. 42. Method of computing the work of the motive power of powder gases; the area limited by a curve is broken up into trapezes.

$$A = \frac{F m v^2}{2}$$

In other words, the work of the gas pressure against the base of a projectile can be measured in the same way as the kinetic energy of the projectile at the muzzle, i.e. the gas efficiency, by the extent of the area limited by the pressure curve, the limit of the

ordinate and the axis of the abscissae.

This means that the amount of units of the kinetic energy of the projectile at the muzzle and units of function (kg. ms), spent by the gases on providing the projectile with motion, numerically equates the amount of square units contained by the area which is limited by the pressure curve, its ordinate at the muzzle and the axis of the abscissae (provided that the curve has been drawn up in the corresponding scale).

In short, the function of the powder gases is measured by the kinetic energy of the projectile at the muzzle and the axis of the abscissae.

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64. Computation of Velocities along the Pressure Curve against the Base of the Projectile.

Velocities Curve.

To study the law of the accretion in the speed of a projectile in the process of its movement along the bore of a barrel we can use the same trapezes into which we broke down the area limited by the pressure curve (see diag. 42)

The gas efficiency on the path of the projectile - OB - is measured by the area of trapeze OAB<sub>1</sub>B. It equates the kinetic energy of the projectile at point B. Let us designate the speed of the projectile at point B by v<sub>1</sub> and the extent of the efficiency of the gases at sector OB - by R<sub>1</sub>.

Then,

$$\frac{\varphi m v_1^2}{2} = \frac{OB(CA + BB_1)}{2} \cdot R_1$$

It is not hard to determine from this equation the extent of the speed of the projectile at point B:

$$v_1 = \sqrt{\frac{2 R_1}{\varphi m}} = \sqrt{\frac{OB(CA + BB_1)}{\varphi m}}$$

and expressing the mass in technical units and by abbreviation,

$$v_1 = \sqrt{\frac{2 R_1 g}{\varphi \cdot g}} = \sqrt{\frac{OB(CA + BB_1) g}{\varphi \cdot g}}$$

Hence we have to express the quantities of ordinates OA and BB<sub>1</sub> finally, not in pressure units but in power units, i.e. make a preliminary multiplication of the pressure extent by the area of the cross section of the projectile (taking the rifling into account).

In order to determine velocity of the projectile at point C - in the same way, one will first have to compute the efficiency at sector OC.

The function of the gases at the sector of path OC will equate the sum of the functions at sector OB (we expressed it by R<sub>1</sub>) and at sector BC (we expressed it by R<sub>2</sub>):

$$\frac{\varphi m v_2^2}{2} = R_1 + R_2$$

The sum R<sub>1</sub> + R<sub>2</sub> equates the sum of the areas of trapezes AOBB<sub>1</sub> and BCC<sub>1</sub>B<sub>1</sub>:

$$R_1 + R_2 = \frac{OB(AO + BB_1)}{2} + \frac{BC(BB_1 + CC_1)}{2}$$

thence

$$v_2 = \sqrt{\frac{[OB(CA + BB_1) + BC(BB_1 + CC_1)] g}{\varphi \cdot g}}$$

In a similar way one can find the velocity of the projectile at any point of its course along the bore of the barrel. Thus,

$$\frac{\varphi m v_3^2}{2} = R_1 + R_2 + R_3$$

Whence

$$v_3 = \sqrt{\frac{2(R_1 + R_2 + R_3)g}{\varphi \cdot g}}$$

etc.

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Finally, the sum of all 'n' trapezes will equate the area limited by the curve; the efficiency of the gases and the kinetic energy of the projectile at the muzzle is measured by the extent of this area:

$$W = \sum_{i=1}^n R_i$$

Whence

$$W = \sqrt{2} \sum_{i=1}^n R_i g$$

$R_i$  is the work on the elementary sector of the path expressed by the size of the trapeze area.

When the speed of the projectile has already been determined at some point of the bore of the barrel, for instance at point  $B_1$  one can determine its speed at each following point by the formula familiar from mechanics:

$$v_2^2 - v_1^2 = \frac{m v_2^2}{2} - \frac{m v_1^2}{2} = \frac{q v_2^2}{2g} - \frac{q v_1^2}{2g} = \frac{q}{2g} (v_2^2 - v_1^2)$$

after the introduction to it of the coefficient of fictivity  $\varphi$ .

The extent of force  $F^1$  is obtained, as has already been said, from the multiplication of the pressure against the base of the projectile at the given point by the area of the cross section of the projectile taking the rifling into account; we can consider the extent of sector  $l$  of the path at will depending on the required degree of accuracy;  $v_1$  has been determined earlier and is, therefore, already known. Thus one thing is not known in the equation and this is  $v_2$ . When solving the equation with regard to this unknown quantity we get, designating  $l'' - l'$  by 'a' (extent of the sector of the path of the projectile) \*

$$2 F a g = \varphi q (v_2^2 - v_1^2)$$

Whence

$$v_2 = \sqrt{\frac{2 F a g}{\varphi q} + v_1^2}$$

Having found  $v_2$  one can then in a similar way determine  $v_3$  etc.

For a more approximate determination of velocities one can use squares (diag. 43) instead of trapezes for calculating gas efficiency. The sequence of the calculation will be identical, but the calculation itself will be a little simpler, but at the cost of its accuracy.

When entering the curve on graph paper, the area limited by the curve, can be computed by calculation of the small squares which it contains.

Finally the area can be determined with the greatest amount of accuracy with the help of a special instrument for measuring areas - The planimeter (alt. plane measurer - T), for which all that is required is outlining the borders of the plane by special points which are fixed on a movable lever of the instrument. Thus one will be able to have a mechanical reading of the area of the plane on the drum of the instrument.

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\* An average extent of force F is taken for the given sector of the path.

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After calculating the velocities of the projectiles at points B, C, D, etc. up to  $v_{11}$  (at the muzzle) inclusive, one lays off on a definite scale (already considered) the magnitudes of these velocities opposite the corresponding points as the ordinates of the future curve.

After linking up the points of this curve we obtain the curve of the speed of the projectile in the bore, clearly illustrating the law of the accretion of the velocity of a projectile (diag. 44).

The ordinates of this curve express in the accepted scale the magnitude of the speed of the shell at each given point of the bore. The muzzle velocity of the projectile at the given scale equates the final ordinate of the curve velocities.

Diag. 43. Simplified method of the rough computation of the motive power of powder gases: area limited by the curve is broken down into rectangles.

Study of the curve of the velocities of a projectile in the bore shows the following:

1. The acceleration of the movement of the projectile in the bore rapidly increases from zero to the maximum extent reached at the moment of the development of the maximum pressure; thereon according to the degree of approach to the muzzle, the acceleration of the movement constantly drops, remaining, however, positive.

2. The speed of the movement of the projectile along the bore is fast to begin with and then progressively loses speed.

CURVE OF VELOCITIES  
CURVE OF PRESSURE

Diag. 44. Pressure and velocities curves: RIGHT - scale of velocities; LEFT - scale of pressures.

Example of the construction of a velocities curve (diag. 45)

Let us assume: the pressure of forcing OA is 500 at; pressure at point B (ordinate  $BB_1$  has been measured) is 950 at, at point C (ordinate  $CC_1$ ) pressure is 1500 at; at point D (ordinate  $DD_1$ ) pressure is 1500 at; sectors of path  $OB = BC = CD = 0,1$  m; the plane of the cross section of the shell is  $50$  cm<sup>2</sup>; weight of the shell  $q = 7$  kg;  $\gamma = 1,1$ . The speed of the shell at point O (up to the beginning of its movement) obviously equates zero.

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We determine from trapeze  $OBB_1A$  the speed of the shell at point B which we designate by  $v_1$ :

$$v_1 = \sqrt{\frac{2 R_1 q}{\gamma q}} = \sqrt{\frac{0,1(500 + 950) \cdot 9,81 \cdot 50}{7,1 \cdot 1}} = \sqrt{9236,6} \approx 96 \text{ m/sec.}$$

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Curve of Velocities

Curve of Pressures

Diag. 45. Example of the construction of a  
Curve of Velocities with the aid of Trapezes.

Knowing the velocity of the shell at point B, let us determine its speed  
at point C from equation

$$F (v_2^2 - v_1^2) = \frac{\rho (g v_2^2 - g v_1^2)}{2g}$$

Let us determine the extent of force F at sector BC of the path of the shell.

On this sector on an average

$$F = \frac{BB_1 + CC_1}{2} \cdot S,$$

S - stands for the area of the base of the shell.

As

$$BB_1 = 950 \quad \text{and} \quad CC_1 = 1300,$$

We get

$$F = \frac{950 + 1300}{2} \cdot 50 = 56250 \text{ kg},$$

By substituting the known quantities to the equation,

We find

$$56250 \cdot 0,1 = \frac{7 \cdot v_2^2 - 7 \cdot 96^2}{2 \cdot 9,81} - 1,1,$$

151 Solving the equation with regard to  $v_2$  we get

$$\sqrt{\frac{56250 \cdot 0,1 \cdot 2 \cdot 9,81 + 7 \cdot 96^2}{7 \cdot 1,1}} = 153 \text{ M/sec.}$$

etc.

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65. Computation of Pressures and Velocities

from Tables.

Often it becomes necessary to construct pressure curves and velocities curves for guns to be tested or even for those to be designed without possessing the experimental data on how pressure is distributed over various points of the bore.

This problem is solved with the help of special tables drawn up on the basis of computations checked by many experiments.

To use these tables, it is sufficient to know the extent of the initial velocity, maximum pressure in the bore and the constructional data for the gun.	S C A L E	$p_m = 2400 \text{ at.}$  m/sec	S C A L E
---	-----------------------	---------------------------------------	-----------------------

Initial velocity is determined practically.

Maximum pressure is not hard to determine by means of an insertable crusher gauge. The constructional data of the gun are known.	O F		O F
--	--------	--	--------

Using data computed from the tables, one draws up the pressures and velocities curves for the gun to be tested. An example of the curves drawn up with the aid of such tables is shown in diag. 46.	P R E S S U R E S		V E L O C I T I E S
---	---	--	--

Diag. 46. Example of the Construction of Pressure and Velocities curves with the aid of Tables.

Efforts to draw up tables of the kind were made long ago. However, the empirical tables worked out by various scientists did not provide a sufficiently accurate solution of the main practical problem of inner ballistics; they only made it possible to construct pressures and velocities curves approximately, and even so with fairly serious inaccuracies; for instance, the extent of the muzzle pressure of the energy of the translation of a projectile is considerably less according to KRANZ's tables than in fact:

Only the Russian artillery scientist N.F. DROZDOV succeeded in 1902 in working out an analytical method of solving the basic formula of inner ballistics and on the ground of this solution to construct his tables for the quick determination of  $p_{max}$  and  $v_1$ , and during this process incidentally, the point was also determined at which the powder ends its combustion depending on the thickness of its grains. This was not provided by the other tables, and which is very important in the choice of powder grains.

The original short tables by Prof. DROZDOV were perfected in 1933 and became the foundation of the modern tables which allow one to construct all pressures and velocities of a gun.

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66. Velocities and Pressures Curves with Quick and slow

Burning Powders.

An experiment carried out with charges of identical weight but consisting of grains of different thickness, leads to the following conclusions.

All other conditions being equal (the gun is identical, shells weight the same, temperature, moisture and the chemical composition of the powder of the charge are all identical); a charge consisting of slighter (lit. thinner) grains, i.e. of grains which burn up quicker, develops a higher pressure in the bore than a charge consisting of bulkier grains which burn more slowly, but as against this pressure drops faster.

Diag. 47 Pressures and Velocities Curves for Charges of Quick and Slow Burning Powders:

I. Curves for quick burning powder: II - Curves for slow burning powder.

Thus the pressure curve of a fast burning charge rises higher than the curve of a slow burning charge, at some point both curves will intersect after which the curve of the slow burning charge will rise above the curve of the fast burning charge. In the case of a slow burning charge the point of the maximum pressure is to be found slightly (insignificantly) nearer the muzzle, than is the case with a fast burning charge.

153 A charge of thinner grains gives the projectile a greater initial velocity than do bulkier grains; this has its reason in a higher maximum pressure in the bore (diag. 47).

To obtain identical initial speeds from both powders, one must increase the weight of the charge made up of the bulkier grains.

If one choses two charges with different weights consisting of grains of varying thickness in such a way that they will develop an identical maximum pressure for which the gun barrel has been assigned, the charge of the thicker grains, with which pressure drops more gradually, will perform more work than a charge made up of thinner grains, consequently the former will give a great initial velocity (diag. 48).

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Diag. 48. Pressures and Velocities Curves for two charges providing an identical maximum pressure:

I. - for a fast burning powder: II - for a slow burning powder.

However a charge of this kind will burn longer and for this a longer barrel is needed. Hence a fast burning charge is more advantageous for short barrelled pieces, while for those with longer barrels - slow burning charges are best.

For howitzers one generally selects charges made up of thinner grains than for guns of the same calibre.

67. Mean Pressure. Estimation of the Quantity of the Powder.

While studying the action of various powder charges, we have approached the answer to the question: after which kind of nature of combustion should one strive, as representing the most satisfactory kind?

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Apparently it is most advantageous that the efficiency of which the charge is capable should be obtained at the least maximum pressure. This could have happened in the case where the pressure against the bottom of the shell, and therefore on the base of the bore as well, would remain equal (alt. constant) over the whole path of the shell along the bore, i.e. the curve of pressure now rising to 2000 - 3000 at, now falling to 500 - 600 at, were to be replaced by a straight line running parallel to the axis of the bore (diag. 49).

Such a constant pressure could be considerably less than the pressure which is reckoned with when designing gun barrels.

Diag. 49. Conception of Mean Pressure:

- fictitious pressure: AB mean pressure: the shaded area

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As an example let us examine the gun whose pressure curve is shown above (see diag. 46). The variable motive force of the powder gases has worked efficiently in this gun at 152 640 kg over a 2 metres path traversed by the projectile.

Work of this kind could have been done by a constant force

$$F' = \frac{152\ 640}{L_{HP}} = \frac{152\ 640}{2} = \frac{76\ 320}{1} \text{ kg.}$$

This force would have been exerted over the whole area of the cross section of the projectile which we will assume to equate, let us say, 50 cm<sup>2</sup>. On each square centimetre of the area of the cross section of the projectile there would have been a pressure of

$$p' = \frac{F'}{S} = \frac{76320}{50} = 1526,4 \text{ kg / cm}^2 = 1477,6 \text{ at.}$$

Which is considerably less than  $p_{max} = 2400 \text{ at.}$

The imagined constant pressure which would have fulfilled an identical function as is done by a real variable pressure against the base of a projectile, is known as mean pressure  $p_{cp}$ .

$$p_{cp} = \frac{\varphi q v_{II}^2}{2 g s l_{II}}$$

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- $\varphi$  - is the coefficient of fictivity ( ? imaginary factor ? - T) which accounts for the secondary function of the powder gases (see above);
  - $q$  - weight of the shell in kgs.
  - $v_{II}$  - muzzle velocity of the shell, i.e. the speed of the shell in relation to the barrel at the moment when it leaves it;
  - $g$  - acceleration of the force of gravity;
  - $s$  - cross section of the bore in cm<sup>2</sup>;
  - $l_{II}$  - full path in relation to the bore traversed by the shell at the moment, it leaves the bore.

In the example quoted  $p_{cp} = 1477,6 \text{ at} = 1526,4 \text{ kg/cm}^2$ .

The relation  $\frac{p_{cp}}{p_m}$  or the difference  $p_m - p_{cp}$  is the character of the

quality of the powder: the nearer to a unit is the ratio of  $\frac{p_{cp}}{p_m}$  or the

nearer to zero - the difference between  $p_m - p_{cp}$ , the better is the quality of the kind of powder in question.

A powder would be considered as "ideal" with which the ratio of  $\frac{p_{cp}}{p_m} =$

1 and the difference of  $p_m - p_{cp} = 0$ .

Practical experience, however, forces one to introduce two amendments to this conception of a "perfect" powder.

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1. If with the beginning of the process of combustion a pressure developed of 1000 - 1500 at., then the percussion from a force of this kind would not be borne by the guide ring of a projectile and each projectile would then tear itself loose from the rifling. Therefore it is important that pressure should grow gradually.

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2. As in practice even charges belonging to one lot do not burn identically, one cannot compute the duration of the combustion of a charge, as though it were to end its combustion simultaneously at the moment when the projectile leaves the gun. In such a case powder which has not succeeded in finishing its combustion would often be ejected from the gun. This would lead to a considerable variation in the action of charges, and consequently to a considerable range dispersion of shells. One must choose one's charge in such a way that the powder will finish burning a little before the shell leaves the gun. Then, of course, the pressure will begin dropping at the end of the path of the shell along the bore in the absence of the flow of new gases.

Thus an ideal pressure curve will not merge with the straight line of the mean pressure, but will only be close to it. (diag. 50).

A powder giving a curve of this kind, as well as a powder burning progressively to the end, has not yet been invented.

Diag. 50. An ideal pressure curve:

- OA L - actual pressure; OK Mean pressure;
- OABEF - practically possible optimum pressure curve.

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68. Peculiarities of the Inner Ballistics of Mortars

The inner ballistics of mortars have a number of features brought about by differences in the construction of their rifling which contrast from rifled artillery types, by the peculiar mechanisms of mortar bombs and the charges for these.

The modern mortar is a smooth bored weapon, projecting a drop shaped bomb which does not rotate during its flight. It is equipped with a stabilizer (guide ribs? - T) to steady it in the air. see p. 142.

Because a mortar is a smooth bored weapon, it lacks the energy of translating the projectile (lit. it lacks the phenomenon of forcing - T), i.e. the overcoming of the resistance from rifling to a copper guide ring. The mortar bomb starts its movement in the bore as soon as the powder gas pressure is sufficient for overcoming its weight and friction from the guide rings of its centre bulge against the sides of the mortar barrel. No energy of the

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powder charge is spent on providing the mortar bomb with its rotating motion.

The initial velocity of a mortar bomb is not great and even on a full charge does not generally exceed 300 m (table 23).

TABLE 23.

Initial Velocity of a Mortar Bomb with  
Various Charges.

Charge	Initial Velocity in m/sec	
	82 - mm bombs <sup>2</sup>	120 mm bombs
Basic .....	70	-
First .....	105	119
Second .....	132	156
Third .....	155	191
Fourth .....	175	221
Fifth .....	193	247
Sixth .....	211	272

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In order to provide the mortar bomb with a comparatively low velocity there is no need for great pressure in the bore; in modern mortars this pressure does not generally exceed 1200 kg/cm<sup>2</sup> on a full charge and often it is considerably lower (about 500 kg/cm<sup>2</sup>).

Thus the maximum pressure in the bore of a 122 - mm barrel of a regimental mortar equates on a full charge, according to experimental data, 1160 kg/cm<sup>2</sup>, while the maximum pressure in the bore of an 82 mm mortar = 499 kg/cm<sup>2</sup>.

In order to reach such a comparatively low pressure, a slight density of loading is sufficient in the main powder chamber (i.e. in the space between the base of the bore, its sides and the tail wing of the stabilizer of the mortar bomb); This pressure does not generally exceed (?) 14 kg/cm<sup>2</sup> on a full charge (Translator's note: the page has been holed just in front of figure 14). In order to guarantee the proper burning of the subsidiary charges at so low a rate of density, it is necessary to select a powerful and quick burning powder. For this the shape of the powder must guarantee a rapid accretion in the pressure from the powder gases in the main chamber. With this end in view one uses disc shaped nitro-glycerine powders; in addition, a powerful igniter is required to make sure that the burning process will develop in the right sequence.

The main charge fulfils the function of such an igniter. This igniter which is housed in a cardboard cartridge, is inserted into the guide rib (stabilizer - lit) tube.

1 The general aspect of a mortar bomb is shown in book 1 of the Artillery Course (see 3rd edition, diags 47 and 231 or pp 49 and 214).

2 Ring charges (lit) have only three charges, apart from the non charge, - (first, second and third) corresponding to the second, fourth and sixth charges when there are additional (subsidiary) boat shaped charges.

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The density of charging must be sufficiently great inside this inner chamber for the main charge to burn up quickly, generally it is close on the gravimetric density of the powder.

Owing to the presence of two chambers - the inner (in the stabilizer tail) and the main chamber - the phenomenon of the shot in a mortar is accompanied by some special features when compared with rifled types of artillery, and in the following sequence:

1. When the striker hits the cap mounted at the base of the main charge the percussion composition which is pressed into the cap explodes. The powder of the main charge begins burning in the permanent (fixed, constant - alt. translation) space. The process of burning in the permanent space continues until such time when the powder gas pressure reaches an extent which is enough for knocking an opening through the sides of the cartridge opposite the corresponding openings in the guide ribs tube. This pressure is known as pressure for forcing openings and is expressed by  $P_{\phi}^*$ . The extent of this pressure of forcing opening reaches, according to experimental data, 600 - 750 kg/cm<sup>2</sup>.

158 This considerable magnitude of pressure for forcing openings is explained by the fact that the process of forcing open a passage with powder gases is not instantaneous; while in the course of the time interval needed for ending of this process, the pressure in the inner chamber succeeds in reaching the required extent. This phase in the phenomenon of the shot is known as the pyrostatic or preliminary phase. Its duration is measured in a few 10,000ths parts of a second.

2. After openings have been knocked through the cartridge case sides of the primary charge (basic charge, main charge - alt. translation), the powder gases begin escaping into the main chamber containing the subsidiary (alt. secondary - T) charges (rings or boats (lit)) and ignite them.

Meanwhile two contradictory processes occur in the stabilizer tube. On the one hand the main charge continues burning resulting in the continued growth of the current of fresh powder gases and the pressure in the stabilizer tube tends to grow. On the other hand powder gases flow from this tube through the openings in its sides, which ought to lead to a drop in powder gas pressure. At the beginning of this phase the first process predominates, and pressure in the stabilizer tube grows and then the second phase begins predominating and the powder gas pressure having reached its height begins dropping. Maximum pressure in the tube of the stabilizer reached in this phase an extent of about 1500 kg/cm<sup>2</sup>.

A mortar bomb stabilizer tube must be made strong enough to be able to take such a pressure which considerably exceeds the pressure in the main chamber.

The phase of the shot from the moment of the forcing of openings till the end of the burning process of the main charge is known as the first phase (for the stabilizer tube). Its duration is measured in several 10,000ths fractions of a second (it is computed to about 0,0005 sec.)<sup>1</sup>

158 3. The first phase for the stabilizer tube is followed by the second phase, whose beginning is determined by the moment when the main charge finishes burning, and whose end is marked by the moment when the mortar bomb leaves the mortar barrel. During this phase the gas escape from the stabilizer tube into the main chamber ends at the moment when the gas pressure in the stabilizer tube decreases and draws level with the pressure in the main chamber when the subsidiary charges are burning simultaneously.

<sup>#</sup> Here and also later we have used terminology suggested by professor, doctor of technical sciences OPEKOV, G.V. in his work: "Ballistics of Smooth Bored Artillery types", ed. Artillery Academy, 1943.

<sup>1</sup> Professor OPEKOV, G.V. Ballistics of Smooth Bored Systems, p. 39.

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Thus three phases in the phenomenon of a mortar shot are distinguished with regard to a stabilizer tube. The pyrostatic (preliminary), the first and the second.

Three phases of a shot must also be distinguished in the main chamber.

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1. The Preliminary Phase (for the main chamber) begins from the moment when openings have been forced and ends at the moment when the main charge has finished burning in the tube of the stabilizer, i.e. in time it coincides with the first phase for the stabilizer tube. The following processes occur in the course of this time in the main chamber: first, the subsidiary charges start burning mainly following the geometric law of combustion; secondly, there occurs a flow of gases from the stabilizer tube. Both these processes contribute to the increase of pressure in the main chamber. Simultaneously part of the powder gases flow forward from the main chamber through the gaps between the sides of the bore and the rings of the mortar bomb centring bulge. At this very moment the bomb begins moving in the bore of the mortar barrel, a situation which leads to the growth in the initial air space.

As the beginning of the path of a mortar bomb along the bore of a mortar barrel is considered the point through which the plane of the rear rim of the centring waist of the mortar bomb passes at the moment, the latter starts moving.

These two processes - the gas escape and the increase in the initial air space - contribute towards the drop in the powder gas pressure in the main chamber. Meanwhile the leakage of gas from the main chamber through the gaps is insignificant in view of the small area of these gaps and has not the least practical significance.

At the end of the preliminary phase the speed of the mortar bomb and the path covered by it is very slight. Thus in the case of an 82 mm mortar, the speed of the mortar bomb at the end of this preliminary stage is only 4 m / sec in all, while the path covered by it is 0,05 cm. The tiny extent of these elements of the shot allows one to ignore the preliminary phase and to reckon that in fact all powder gases from the stabilizer tube at once enter the main chamber at the beginning of the first phase.

2. The next phase in the phenomenon of a shot for the main chamber, called the first or the main, begins at the moment when the powder has ended burning in the tube of the stabilizer and ends at the moment when the powder finishes burning in the main chamber.

Where the secondary charges have been placed sufficiently far from the gaps in the sides of the stabilizer tube then, in contrast to the general case which we have already considered, the secondary charges start burning at the beginning of this very period; in such a case the phenomenon of the flow of gases from the burning of the secondary charges is lacking in the preliminary phase for the main chamber.

Pressure in the main chamber grows rapidly during this phase, reaches its maximum and begins dropping; the mortar bomb gathers speed quickly and the initial air spaces rapidly increases.

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3. The last (third) phase in the phenomenon of a shot starts, in the case of the main chamber, at the moment when the secondary charges have finished burning and ends, if one disregards powder gases sequences, with the moment when the mortar bomb leaves the bore of the mortar. At this moment occurs the expansion of the powder gases in the initial air space and the bomb constantly gathers speed in its movement.

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Thus one must also distinguish three phases in the shot for the main chamber: preliminary, first (main) and second.

Where one main charge is used for firing (fire of this kind is only allowed in the case of an 82 mm mortar) and no secondary charges are used, one distinguishes between only two phases for the main chamber. They are separated from each other by the moment ending the burning of the powder in the stabilizer tube.

Consequently the chief peculiarity of a mortar, in so far as inner ballistics are concerned, is the presence of two chambers: the chamber inside the stabilizer and the main chamber.

The phases in the occurrence of the shot may be graphically shown in this table (table 24).

TABLE 24.Phases in the occurrence of a Shot from a mortar

For a Stabilizer Tube	For the Main Chamber.
Preliminary	-
First	{ First
Second	{ Second

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Chapter ElevenPractical Measurement of Muzzle Velocities.

The muzzle velocities of projectiles are measured by firing through frame targets (lit. translation), a chronograph-type LE-BOULANGER. This apparatus is accurate but cumbersome and inconvenient to transport; hence it is put up in a stationary state in the establishments of the ballistic laboratories of testing and research ranges.

In field conditions one also uses type LE-BOULANGER Chronographs, but these are more portable and are mounted on lorries. Latterly general use is being made of solenoid chronographs.

Before the Great Patriotic War experiments were made for field ballistic laboratories with the aid of the more portable but less accurate instrument known as the SHIRSKI milli-second-meter-chronoscope.

Muzzle velocity can also be determined by means of photography, visually by accelerated kino-photography (time omphalopter) also by the sound ballistic method (with the aid of sound ranging instruments).

69. LE-BOULANGER's Chronograph

The method of determining muzzle velocities of fire through flame targets with the aid of a chronograph consists of the following:

The frame-target is put up near the gun, whose barrel is laid horizontally, and at a safe range from the gases escaping from the barrel (generally at 15-50 m, depending on the calibre of the piece).

This apparatus consists of a wooden frame with thin doubly tinned (?) copper wire stretched vertically over it. This wire is switched into the circuit passing through the electro-magnet of the apparatus. The frame target is so arranged that a projectile will not be able to pass through two wires without having torn one of them, - These wires being usually spaced at intervals of  $1/4$  -  $1/2$  of the calibre of the gun to be tested (diag. 51).

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After passing through the frame target, the projectile tears the wire and opens the electric current.

The powerful electromagnet 1 of the chronograph, which attracts towards its iron core a long hollow rod with an iron point 2, known as chronometer. At this moment becomes un-magnetized and the rod starts dropping (diag. 52).

Another exactly identical frame-target is mounted to the rear of the first frame at an exactly spaced distance from it. The wire of the second frame is on the same circuit with electro-magnet 3 of the chronograph. A shorter rod 4 is freely suspended from the iron core of this electro-magnet. This rod is called a recorder because it records the moment when the projectile reaches the second frame.

#### Diag. 51.

The moment the projectile tears one of the wires of the second frame, the current in the second circuit to which electro-magnet 3 holding recorder 4 has been switched, will be closed (lit. will cease - T).

#### Diag. 52.

Lay out of the function of LE-BOULANGER's CHRONOGRAPH.

- K. - base on which the apparatus is mounted: P<sub>1</sub> and P<sub>2</sub> - frame-targets;
- battery; B-wires; 1 and 3 - electro-magnets, 2 - chronometer;
- 4 - recorder; 5 - yoke (alt. sear - T) platform; 6 - yoke (sear - T); 7 - lowering rack; 8 - knife (lit. - T - ? cutter ? - T);
- 9 - knife spring; 10 - measuring disc ( ? marker - T); 0-zero mark; A B = 3 - distance between frames.

The recorder starts dropping and knocks against platform 5 of sear 6; the platform is lowered; lowering rack 7 releases steel cutter 8 which jumps forward through the action of spring 9. In this process the cutter (lit. knife) knocks against the dropping chronometer and marks figure 10 on it.

163 In order that the marks on the chronometer will be clear, a soft zink tube is mounted before hand on the chronometer rod.

Before firing the gun to be tested and when the chronometer has already been suspended from electro-magnet 1, one presses the lowering mechanism base with the hand in order to release knife 8 and to mark which point of the chronometer came opposite the knife before the chronometer began dropping. There will be the lower, the so-called zero marking. Thereon the knife is returned to its old position and is reconnected to the lowering rack.

Thus the zero (lower) mark designates the position of the chronometer at the moment when the projectile has passed through the first frame-target.

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In accordance with the law of the free drop of bodies (Galileo's Law) the path covered by a freely dropping body

$$h = \frac{gt^2}{2};$$

from this the time for the drop of the body

$$t = \sqrt{\frac{2h}{g}}$$

The distance between the frames has been accurately measured.

Let us express it by  $s$ .

Knowing the time taken by the projectile in its flight from one frame to the other and knowing the distance between them, the velocity of the projectile over the sector of the path between the frames can be easily determined by the formulae of mechanics.

Let us assume that:

$$s = vt,$$

then

$$v = \frac{s}{t}$$

164 However some time ( $t'$ ) is also spent on the drop of the recorder, on lowering the knife (lit) and on receiving the upper mark, and this upper mark is in fact not obtained at that point of the chronometer which was opposite the knife at the moment when the projectile passed through the second frame but a little further away from the zero mark (further up). This time  $t'$  must be subtracted from the time found from the formula quoted above so as to be able to solve the problem of the determination of the velocity of the projectile correctly. Time  $t'$  could have been determined by placing both frames at one and the same point after firing a preliminary shot. Then the time taken by the passage of the projectile between the frames would equate zero and the retardation of the recorder (alt. marker - T) would have been as before. The chronometer would have started dropping at the same time as the recorder (alt. marker - T) and would have already succeeded in passing some distance before the knife would have made the second mark on its tube. This second mark corresponds to the path of the chronometer during the time of the retardation of the marker - time  $t'$ . Were we to designate the distance between the marks by  $h'$ , then time  $t'$  will be determined from the formula, which we have cited above:

$$t' = \sqrt{\frac{2h'}{g}}$$

The actual time taken by the projectile in its passage between the frames is:

$$t = t'' - t'$$

$t''$  is the time of the drop of the chronometer determined by the path covered by it between the zero and the upper marks during the time of the shot at the frames and  $t'$  represents the correction (alt. adjustment - T) of the instrument for the retardation of the marker.

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The actual velocity of the projectile will be obtained from expression:

$$v = \frac{s}{t} = \frac{s}{t'' - t'} = \frac{s}{\sqrt{\frac{2h}{g}} - \sqrt{\frac{2h'}{g}}}$$

In fact, however, the frames are not placed together but a special instrument known as an insulator is used. This insulator makes it possible to interrupt the current simultaneously in both circuits and to receive the time of the retardation of the marker without firing a shot. For this one of the insulator discs is inserted into each circuit and then the current is switched off simultaneously in both circuits by pressing the insulator spring.

So as not to subtract each time the retardation of the marker -  $t'$ , the instrument is regulated in such a way that the retardation will constantly have one and the same extent.

An increase or decrease in the retardation of the marker is achieved by altering the distance between the marker and the seat platform and consequently between the time of drop of the marker and the time of retardation.

In order to regulate the instrument, one is concerned with a definite (lit, determined -  $T$ ) time of retardation of the marker which is generally 0,15 seconds.

One calculates the distance which should occur in this process between the marks:

$$h = \frac{gt^2}{2} = \frac{9,81 \cdot 0,15^2}{2} = 0,110363 \text{ m} = 110,36 \text{ mm.}$$

165 Using an accurate measuring rule one makes a mark on the chronometer cover at a distance of 110,4 mm. from the zero mark. Next one suspends the marker and chronometer from the electro-magnet, presses the spring of the insulator and obtains the mark on the chronometer. Should this mark fail to coincide with the line which has been traced, one lifts (where the mark has come lower) or lowers (where the mark has come higher) the electro-magnet of the marker, and renews the test until the mark coincides with the mark which has been traced on the chronometer cover.

Having regulated the instrument one once again suspends the chronometer and marker and fires a shot.

The velocity of the projectile is determined from formula:

$$v = \frac{s}{\sqrt{\frac{2h}{g}} - 0,15}$$

The distance between the frames should be such that the time of flight of the projectile from one frame to the other will be within the limits of 0,10-0,15 seconds.

Then, taking the retardation of the marker into account, the chronometer succeeds in passing a distance of about 45 cm (where it has an overall length of 52 cm).

Example: The chronograph is regulated thus that the retardation of the marker equates 0,15 seconds. The distance between the frames

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is 80 m; the path of the chronometer is 45 cm. Let us determine the velocity of the projectile:

$$v = \frac{80}{\sqrt{\frac{2 \cdot 0,45}{9,81} - 0,15}} = \frac{80}{0,3028 - 0,1500} = \frac{80}{0,1528} = 522,9 \text{ m/sec.}$$

If the distance between the frames were to be excessively magnified, the top of the chronometer will be able to avoid the blade of the knife and there will be no marks whatever; if, however, the frames were to be moved too close to each other, the time of the flight of the projectile would be shortened, the upper mark on the chronometer will move close to the mark of retardation and each insignificant inaccuracy in the measurement of distance will lead to a noticeable error in the determination of the velocity of the projectile.

In order to achieve greater accuracy one fires not one but from 7-10 shots and accepts as the velocity to be determined the arithmetic mean from the results of the separate measurements.

The velocity thus determined is not in fact the velocity of the projectile neither at point A, where the first frame has been set up (see diag. 51), nor at point B, the site of the second frame; this velocity relates to some point C which is approximately in the middle between points A and B.

By using the formulae set out in the higher ballistics course, one passes from the velocity of the projectile at point C to its muzzle velocity

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#### 70. The Solenoid Chronograph.

The gist of the function of the solenoid chronograph reduces itself to the following:

Solenoids coils (reels alt. translation) are attached to the frame; the diameter of the coils and the dimensions of the frame are set up in dependence on the calibre of the projectile and the distance of the solenoid from ..... cont. p. 150.

Electric trigger

(Russian: electrospusk - T) Recording Instrument

Diag. 53. Layout of the Solenoid Chronograph.

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the gun. A solenoid coil may consist of one or two windings whose terminals are joined to the recording instrument.

The layout of the installation of the solenoid chronograph is shown in diagram 53.

The function of a solenoid chronograph consists in this that at the moment when the projectile passes through the solenoid the magnetic flow passing through the solenoid alters.

#### Time Scale

Diag. 54. Recording received with the aid of a solenoid chronograph.

The recording of the fluctuations of a tuning fork is received on a light reacting paper for obtaining a time scale and the recording of the alteration in the magnetic current. When the projectile passes the centre of the solenoid the maximum of the magnetic current can be observed in the latter; this moment is by the interruption of the recording (lit. tearing assunder, bursting of the recording - T) on the oscillogram, by the so-called "Splash" (diag. 54).

167 From two solenoids sited at a definite distance from each other two 'bursts' of the recording are obtained on the oscillogram. One can easily determine from the recording of the oscillations of the tuning fork on this oscillogram the time in the course of which the projectile has passed the space between the centres of the solenoids.

The distance between the solenoids is accurately measured when carrying out experiment; the number of oscillations of the tuning fork in one second is known; having calculated from the number of these oscillations the time of the movement of the projectile between the centres of the solenoids, one determines the average speed of the projectile on this sector of its path from formula

$$V = \frac{s}{t}$$

The solenoid chronograph is thoroughly checked before starting work on it by the Le-Boulanger chronograph as the latter gives more accurate findings.

#### 71. Work with the SHIRSKI Milli-second meter Chronoscope.

In determining initial velocity of a projectile with SHIRSKI's milli-second-meter-chronoscope, the frames are put up in the same way as they were when working with Le-Boulanger's chronograph.

The chronoscope has like the chronograph two electro-magnets of which the first causes the hand of the instrument to move while the second stops it. Each of the electro-magnets is switched into the circuit with the corresponding frame in the same way as was done when using Le-Boulanger's chronograph. After the projectile has torn the wire on the first frame the hand starts moving; after the projectile has passed through the second frame the hand stops. The time reading is recorded directly on the scale of the instrument. The instrument is adjusted exactly in the same way as in the case of the chronograph - by the simultaneous switching off of both circuits. The

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frames are placed at such a distance from each other (the same as when working with the chronograph) that the projectile will pass this distance in the course of 0,1-0,15 sec.

The first shot is not reckoned with. The arithmetic mean is determined from the chronoscope readings of the rest of the shots. The velocity of the projectile is then calculated. It is accepted that this velocity is reached by the projectile in the middle of the distance between the frames. One then determines the velocity of the projectile at the muzzle with the aid of a simplified formula

$$v_{*} = v_1 + (v_0 - v_2) \frac{n}{d}$$

$v_{*}$  - is the sought velocity at the muzzle;

$n$  - the distance from the gun to the centre of the space between the frames;

$v_1$  - mean velocity of the projectile in 'n' metres in front of the muzzle as determined from the chronoscope recordings;

$v_0$  - the table initial velocity;

$d$  - first range as shown in the column for 'range' in the Firing Table of the artillery type in question;

$v_2$  - the final velocity of the projectile from the tables corresponding to this range.

The adjustment for the temperature deviation of the charge from that marked in the table (+ 15°) is then introduced to the velocity established by this formula.

Example: During fire the following chronoscope readings have been recorded:

(1) 0,1050;           (2) 0,1035;           (3) 0,1060;  
 (4) 0,1045;           (5) 0,1030;           (6) 0,1020;  
 (7) 0,1040.

The charge temperature measured by the troop thermometer is + 20°. The first frame is a 15 m from the piece, the distance between the frames is 60 m.

168 Let us determine the mean time of the flight of the projectile between the frames:

$$t = \frac{0,1050 + 0,1035 + 0,1060 + 0,1045 + 0,1030 + 0,1020 + 0,1040}{7} = 0,1040 \text{ sec.}$$

The distance of the centre of the space between the frames from the muzzle of the piece.

$$n = 15 + \frac{60}{2} = 45 \text{ m.}$$

Speed of the projectile at 45 m from the piece

$$v_1 = 60 : 0,1040 = 576,9 \text{ m/sec.}$$

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From the Firing Table we find the difference between the table muzzle velocity:

$$v_0 = 588 \text{ m/sec and table velocity } v_2 \text{ at a distance of 200 m from the muzzle} - 561 \text{ m/sec.}$$

$$v_0 - v_2 = 588 - 561 = 27 \text{ m/sec.}$$

Let us determine the initial velocity at the muzzle:

$$v_x = 576,9 + 27 \frac{45}{200} = 576,9 + 6 = 585,9 \text{ m/sec.}$$

The adjustment for the charge temperature which exceeds the table temperature by  $5^\circ$  is then introduced to the established muzzle velocity.

The alteration in the charge temperature by  $1^\circ$  alters the muzzle velocity by 0,11% or by 0,0011 of the extent of this velocity. The rise in temperature of the charge leads to an increase in the muzzle velocity of the projectile. Consequently the adjustment for the charge temperature comes to:

$$\Delta v = 0,0011 \cdot 5 \cdot 585,9 = 3,2 \text{ m/sec.}$$

While the speed of the shell at the muzzle would at the table temperature of the charge have amounted to:

$$585,9 - 3,2 = 582,7 \text{ m/sec.}$$

As the result of the insufficient accuracy of this method field ballistic stations with Le-Boulangier chronographs have been accepted on establishment.

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## Chapter Twelve.

### Influence of Various Factors on the Alteration in Muzzle Velocity and on Maximum Pressure.<sup>1</sup>

#### 72. Influence of an Alteration in the Density of Loading.

The influence of density of loading on the speed at which powder burns and on the pressure resulting from this, expresses itself through the fact that on an alteration in the density of loading the pressure inside the bore drops and thus the muzzle velocity (lit. initial velocity -  $T$ ) of the projectile decreases; an increased density of loading leads to a heightening in pressure and to an increase in muzzle velocity. Considerable alterations in the density of loading are not permissible, as has already been said. Slight alterations in the density of loading are, however, sometimes made in the modernization of artillery systems for a fuller exploitation of their possibilities.

Decrease in the density of loading can be attained by increasing the area of the initial air space (i.e. by extending the powder chamber), while a decrease in the density of loading may be brought about by altering the shape of the projectile, i.e. by elongating its base (thus the area of the chamber is decreased).

When the density of loading is increased, muzzle velocity develops four times slower than the maximum pressure. For instance where at a given increase in density of loading muzzle velocity has grown by 2%, maximum

<sup>1</sup> All formulae quoted in this chapter were drawn up empirically and are correct only for slight alterations of the various factors.

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pressure will simultaneously increase by 8%. The following formulae are used for computations:

$$\Delta v_0 = \frac{1}{3} v_0 \cdot \frac{\Delta W_0}{W_0}$$

$$\Delta P_{\max} = - \frac{4}{3} P_{\max} \cdot \frac{\Delta W_0}{W_0}$$

170  $\Delta v_0$  - is the alteration in muzzle velocity;

$\Delta P_{\max}$  - is the alteration in maximum pressure;

$\Delta W_0$  - is the alteration in chamber space;

$W_0$  - is the chamber space.

Example 1.  $v_0 = 600$  m/sec ;  $P_{\max} = 2200$  at;

$$W_0 = 1000 \text{ cm}^3$$

Let us determine how muzzle velocity and maximum pressure alter in fire with an elongated projectile, where as a result of the elongation of the base of the projectile the area of the chamber is decreased by  $100 \text{ cm}^3$ , i.e. Where the chamber space will equate  $1000 - 100 = 900 \text{ cm}^3$ . in this case

$$\Delta v_0 = - \frac{1}{3} \cdot 600 \cdot \frac{100}{1000} = + 20 \text{ m/sec.}$$

Therefore,  $v_0 = 620$  m/sec;

$$\Delta P_{\max} = \frac{4}{3} \cdot 2200 \cdot \frac{100}{1000} = + 293 \text{ at,}$$

i.e. maximum pressure will grow to  $2200 + 293 = 2493$  at.

Where on the introduction of a new shape projectile the maximum pressure exceeds the permissible limit, it can be decreased without serious loss of muzzle velocity by increasing (Russian word *rastochyat'* or *rastochit - T*) the powder chamber (modernization of the system).

Example 2: When experimenting with a new shell a maximum pressure of  $P_{\max} = 2800$  at. resulted and this pressure was found dangerous for the piece; the muzzle velocity reached  $v_0 = 650$  m/sec. For the given piece a maximum pressure should not exceed 2500 at. Let us now determine to what extent the powder chamber must be extended in order to lower the maximum pressure to 2500 at. and how the muzzle velocity will change as a result.

The space of the powder chamber before enlargement was  $1000 \text{ cm}^3$ . It is necessary to alter the maximum pressure by extent:

$$\Delta P_{\max} = 2500 - 2800 = - 300 \text{ at.}$$

By substituting this value  $\Delta P_{\max}$  to the formula,

we get

$$- 300 = - \frac{4}{3} \cdot 2800 \cdot \frac{\Delta W_0}{1000}$$

or

$$- 300 = - \frac{4 \cdot 2800 \cdot \Delta W_0}{3 \cdot 1000}$$

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Whence

$$\Delta W_0 = + \frac{9000}{112} \approx + 80 \text{ cm}^3$$

i.e. the space of the powder chamber must be increased by about  $80 \text{ cm}^3$

Here the muzzle velocity will alter to the extent of

$$\Delta v_0 = - \frac{1}{3} v_0 \frac{\Delta W_0}{W_0} = - \frac{1}{3} \cdot 650 \cdot \frac{80}{1000} = - 17 \text{ m/sec.}$$

i.e. it will equate  $650 - 17 = 633 \text{ m/sec.}$

Example 3. For firing with a piece, the space of whose powder chamber equates  $8000 \text{ cm}^3$  whose muzzle velocity is  $800 \text{ m/sec.}$  and the maximum pressure inside the bore is  $2300 \text{ at.}$  we will use a modern shaped shell having a base elongation with an extent which is by  $1000 \text{ cm}^3$  greater than that of the base elongation of an old type shell. The maximum permissible pressure is  $2500 \text{ at.}$  How are we to cope with this situation?

171 Solution:  $\Delta W_0 = - 1000 \text{ cm}^3$  and

$$\Delta P_{\text{max}} = - \frac{4}{3} 2300 \cdot \frac{-1000}{8000} = + \frac{4 \cdot 2300}{3 \cdot 8} = + 383,3 \text{ at.}$$

i.e. maximum pressure reaches

$$2300 + 383,3 = 2683,3 \text{ at.}$$

In order to lower the maximum pressure of  $2683 \text{ at.}$ , to the permissible extent of  $2500 \text{ at.}$ , one will have to expand the chamber, whose space has now become  $7000 \text{ cm}^3$ , by so much that  $\Delta P_{\text{max}} = 2500 - 2683 = - 183 \text{ at.}$

To compute  $\Delta W_0$  we will use the formula which we quoted above and will introduce to it the known quantities.

$$- 183 = - \frac{4}{3} \cdot 2683 \cdot \frac{\Delta W_0}{7000}$$

$$\text{or } 183 = \frac{4 \cdot 2683 \cdot \Delta W_0}{3 \cdot 7000}$$

$$\text{Whence } \Delta W_0 = \frac{183 \cdot 3 \cdot 7000}{4 \cdot 2683} = 358 \text{ cm}^3.$$

Consequently the powder chamber will have to be expanded by  $358 \text{ cm}^3$ .

What will happen to the muzzle velocity in this process? Where we to use an elongated shell without a chamber expansion, we would in this way have increased the muzzle velocity by

$$\Delta v_0 = - \frac{1}{3} \cdot 800 \cdot \frac{-1000}{8000} = + \frac{800 \cdot 000}{3 \cdot 8000} = + 33 \text{ m/sec.}$$

In this way the muzzle velocity would have to equate

$$800 + 33 = 833 \text{ m/sec.}$$

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By expanding the powder chamber the new muzzle velocity (833 m/sec) will decrease by the following extent as the result of the decrease in the density of loading:

$$\Delta v_0 = - \frac{1}{3} \cdot 833 \cdot \frac{358}{7000} = - \frac{833 \cdot 358}{3 \cdot 7000} = - 14 \text{ m/sec.}$$

i.e. the muzzle velocity will equate  $833 - 14 = 819 \text{ m/sec.}$

Example 4. As the result of the wearing down (lit. by pointing out - T) of the rifling lands the projectile is rammed home further than it should be, and this has led to the increase of the space of the chamber by 1000 cm<sup>3</sup>. How will this wearing down affect  $v_0$  and  $P_{max}$ , if the normal space of the chamber of the gun is 8000 cm<sup>3</sup>;  $P_{max} = 2300 \text{ at.}$ ,

$$v_0 = 650 \text{ m/sec.}$$

For the computation we will avail ourselves of the formulae set out for  $\Delta v_0$  and  $\Delta P_{max}$ .

$$\Delta v_0 = - \frac{1}{3} \cdot 650 \cdot \frac{1000}{8000} = - 27 \text{ m/sec.}$$

$$\Delta P_{max} = - \frac{4}{3} \cdot 2300 \cdot \frac{1000}{8000} = - 383 \text{ at.}$$

Consequently the muzzle velocity will decrease by 27 m/sec. and will equate 623 m/sec while maximum pressure will decrease by 383 at., and will equate 1917 at.

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## 72. Influence of a Change of the Weight of the Charge.

There are two ways of altering the weight of a charge.

1. One can either increase or decrease the weight of the powder in the propelling charge without altering the space of the chamber; this will lead to a change in the density of charging as we will place either more or less powder into the old chamber.
2. One may alter the weight of the powder in the gun simultaneously changing the space of the chamber (either enlarging or decreasing it) in such a way that the density of loading will not change (this is usually done in modernizing guns).

In the first case maximum pressure will increase almost three times faster (more accurately put by  $\frac{8}{3}$  times) than the muzzle velocity of the shell.

The following formulae are used for calculations:

$$\Delta v_0 = \frac{3}{4} v_0 \frac{\Delta w}{w};$$

$$\Delta P_{max} = 2 P_{max} \frac{\Delta w}{w},$$

$w$  = weight of the charge;

$\Delta w$  = change in the weight of the charge.

The other expressions are the same as those in the preceding formulae.

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Example: Let us add 50 grammes of powder to the propelling charge of the gun which had the following data for it:  $w = 1 \text{ kg}$ ;  $p_{\max} = 2200 \text{ at}$ ;

$$v_0 = 600 \text{ m/sec.}$$

As the result of the change in the weight of the charge

$$\Delta v_0 = \frac{3}{4} \cdot 600 \cdot \frac{50}{1000} = + 22,5 \text{ m}$$

and the muzzle velocity will reach an extent of:

$$600 + 22,5 = 622,5 \text{ m,}$$

while maximum pressure will alter by

$$\Delta p_{\max} = 2 \cdot 2200 \cdot \frac{50}{1000} = + 220 \text{ at.}$$

and will reach an extent of

$$2200 + 220 = 2420 \text{ at.}$$

Clearly such a considerable increase in pressure from powder gases is not always admissible. Hence more often than not when increasing a propelling charge in modernizing guns one simultaneously increases the space of the chamber by advancing the beginning of the rifling towards the muzzle (alt. by pushing the beginning of the rifling nearer the muzzle - T).

Experiments show that a measure of this kind is more advantageous than simply increasing the charge with which the increase in the density of loading is connected.

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When increasing a charge without an alteration in the density of loading, muzzle velocity increases as well as maximum pressure, but the latter increases only twice faster than the velocity. Were we to increase the powder charge (with a parallel increase in the chamber space in order to leave the density of loading unaltered) so that the muzzle velocity will grow by 2%, then maximum pressure will grow in this process by 4% and not by 8% as would have been the case when only the density had been increased, and not by 5 1/3% as could have been the case when only the charge had been increased.

One uses the following formulae for calculations

$$\Delta v_0 = \frac{1}{2} v_0 \frac{\Delta w}{w};$$

$$\Delta p_{\max} = p_{\max} \frac{\Delta w}{w}.$$

Example. In the piece in question, on the introduction of a new type of powder of a charge weighing  $w = 3 \text{ kg}$ ,  $p_{\max}$  has come to 2200 at;  $v_0 = 350 \text{ m/sec}$ . A maximum pressure of 2400 at is permissible for this piece. By how much can the charge be increased and what will be the gain in muzzle velocity we will obtain as a result?

$$\Delta p_{\max} = 2400 - 2200 = 200 \text{ at.}$$

Hence

$$\Delta w = \frac{w \Delta p_{\max}}{p_{\max}} = \frac{3 \cdot 200}{2200} = \frac{600}{2200} = 0,273 \text{ kg} = 273 \text{ g.}$$

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On such an increase of the charge the gain in muzzle velocity will be as follows:

$$\Delta v_0 = \frac{1}{2} \cdot 350 \frac{0,273}{3} = 15,9 \text{ m/sec.}$$

74. Influence of the Alteration in the Weight of the Projectile.

- 173 A shell weighing above the norm is harder to move as its mass is greater. Consequently a shell of this kind will start moving at a higher pressure than a normal weight shell. Hence all subsequent burning of the charge will occur at an increased pressure and faster than in a normal case. In order to provide a heavy projectile with a normal initial velocity (alt. muzzle velocity - T) a great amount of effort would be required from the powder gases. But as the usual charges are incapable of an effort of this kind, the initial velocity of the shell will be below normal. The maximum pressure will be abnormal (lit. above the norm + T); the point at which pressure will have reached its height will draw near to the base of the bore while pressure is in the muzzle part of the gun will be below normal.

For identical reasons a lighter shell will have a greater muzzle velocity.

- 174 Maximum deviations in the weight of a shell from the standard (up to 3%) are reckoned with when introducing range adjustments from the Firing Tables (see Book 3 of the Artillery Course).

When introducing new types of shells on establishments, whose weight differ from the old types by more than 3%, one must select the appropriate powder lots for their charges. For instance, in order to prevent maximum powder gas pressure from increasing and the muzzle velocity from dropping on the introduction of a heavier shell, one will have to select a charge from a powder which burns more slowly, and increase the weight of the charge.

The following formulae are used for calculations:

$$\Delta v_0 = - 0,4 v_0 \frac{\Delta q}{q};$$

$$\Delta p_{\max} = \frac{3}{4} p_{\max} \frac{\Delta q}{q},$$

$q$  = weight of shell, and  $\Delta q$  = alteration in the weight of the shell.

Let us assume that it is intended to replace a shell weighing 40 kg by one weighing 43 kg. In this gun  $p_{\max} = 2200$  at.  $v_0 = 350$  m/sec. By introducing the new shell weighing:

$$\Delta q = 43 - 40 = 3 \text{ kg.}$$

Here

$$\Delta v_0 = - 0,4 \cdot 350 \cdot \frac{3}{40} = - 10,5 \text{ m/sec,}$$

i.e. muzzle velocity will equate 339,5 m/sec;

$$\Delta p_{\max} = \frac{3}{4} \cdot 2200 \cdot \frac{3}{40} = 124 \text{ at.}$$

i.e. maximum pressure equates 2324 at.

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75. Influence of the Alteration in the Moisture of Powder.

The increase of moisture in powder above the standard exerts a great influence on its effect. By raising the moisture by 1% the muzzle velocity of a shell decreases by about 4%, and maximum gas pressure by 15%. Thus when using damp charges there will always be considerable shorts. In ordinary storage conditions at fire positions charges are affected by dampness unevenly which, apart from short, results in a very serious range dispersion of projectiles.

In the contrary case, drying of powder leads to the increase of both muzzle velocity and maximum pressure and in such case the latter grows very quickly and may easily reach a dangerous proportion for the piece.

Therefore one must pay great care that the packing of charges both in stores as well as in formations should be hermetical.

175 One uses the following formulae for computations:

$$\Delta v_0 = - 0,04 v_0 \Delta H ;$$

$$\Delta P_{max} = - 0,15 P_{max} \Delta H ;$$

$\Delta H$  = change of dampness of the powder in percentages.

Example. In the charges of a gun with a muzzle velocity of 600 m/sec. and a maximum pressure of 2200 at, the dampness of the powder has increased by 1%.

In this case

$$\Delta v_0 = - 0,04 \cdot 600 \cdot (+ 1) = - 24 \text{ m/sec};$$

$$\Delta P_{max} = - 0,15 \cdot 2200 \cdot (+ 1) = - 330 \text{ at.}$$

76. Influence of a Change in Temperature of a Charge.

An increase in the temperature of a charge results in an increase in the speed at which a charge burns. Maximum pressure and muzzle velocity become abnormal as a result.

A lowering in the temperature of the charge leads to a decrease in the speed at which a charge burns and consequently also to a lowering of the maximum pressure and of muzzle velocity. One may reckon approximately that a change in the temperature of a charge by 10° alters muzzle velocity by 1% (more precisely by 1,1%), and maximum pressure by 4% (more precisely by 3,6%). Normal (Table) temperature for a charge is considered to be + 15 ° C.

The following formulae are used for calculations:

$$\Delta v_0 = 0,0011 v_0 \Delta t_3 ;$$

$$\Delta P_{max} = 0,0036 P_{max} \Delta t_3 ,$$

$\Delta t_3$  - alteration in charge temperature.

Example 1. Charge temperature in a test shoot for determining muzzle velocity is + 25°. Muzzle velocity has been found to be 590 m/sec. One will have to determine the muzzle velocity of this piece at a normal charge temperature.

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$$\Delta t_3 = 25^\circ - 15^\circ = + 10^\circ ;$$

$$\Delta v_0 = 0,0011 \cdot 590 \cdot 10 = 6,49 \approx 6,5 \text{ m/sec.}$$

Consequently in normal conditions

$$v_0 = 590 - 6,5 = 583,5 \text{ m/sec.}$$

Example 2. A gun has in normal conditions a muzzle velocity of 800 m/sec and a maximum pressure in the bore of 2800 at. How will firing on a hot day affect  $p_{max}$  and  $v_0$  if the charge temperature is  $+ 45^\circ \text{C}$  ?

$$\Delta t_3 = 45^\circ - 15^\circ = + 30^\circ ,$$

hence

$$\Delta p_{max} = 0,0036 \cdot 2800 \cdot 30 = + 302 \text{ at,}$$

i.e. maximum pressure will reach extent

$$2800 + 302 = 3102 \text{ at.}$$

$$\Delta v_0 = 0,0011 \cdot 800 \cdot 30 = 26,4 \text{ m/sec.}$$

Consequently

$$v_0 = 826,4 \text{ m/sec.}$$

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### 77. Influence of a change in the Thickness of Powder grains.

The smaller the powder grains, the more there will be of them in the charge at its given weight. The sum of their surface will be greater, there will be more gas produced in a time unit (for instance in a thousandth part of a second), pressure will be greater and the whole charge will burn up faster. Both pressure and muzzle velocity will increase, but maximum pressure will grow four times more than muzzle velocity (the same as in the case of an increase in the density of charging).

An increase in the bulk of grains will decrease both pressure and muzzle velocity and in the same proportion.<sup>1</sup> see p. 160

The following formulae are used for calculation:

$$\Delta v_0 = - \frac{1}{3} v_0 \frac{\Delta e}{e_1} ;$$

$$\Delta p_{max} = - \frac{4}{3} p_{max} \frac{\Delta e}{e_1} ,$$

$2 e_1$  - is the initial thickness of a grain and  $\Delta e$  is the change in its thickness.

Example. As the result of the burning up of a powder charge consisting of grains with a thickness of 1,5 mm, the muzzle velocity of a shell is 800 m/sec. while the maximum pressure in the bore amounts to 2800 at. What will happen if one were to increase the thickness of the grain by 0,1 mm, i.e. if the thickness of the grain will be 1,6 mm ?

$$\Delta v_0 = - \frac{1}{3} \cdot 800 \cdot \frac{0,1}{1,5} = - 17,8 \text{ m;}$$

$$\Delta p_{max} = - \frac{4}{3} \cdot 2800 \cdot \frac{0,1}{1,5} = - 249 \text{ at.}$$

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i.e.

$$v_0 = 800 - 17,8 = 782,2 \text{ m/sec}$$

$$P_{\text{max}} = 2800 - 249 = 2551 \text{ at.}$$

### 78. Influence of an Alteration in the Length of the Bore of a Barrel.

Were one to increase the length of the bore of a barrel, the path of a shell under the influence of the gases will be stretched to the extent of CD, to which the barrel has been lengthened (diag. 55). The plane which is limited by the pressure curve, will become larger; this means that the efficiency of the gases will be increased. Consequently, the muzzle velocity will also be raised. As will be seen from the diagram the maximum gas pressure will undergo no change.<sup>2</sup>

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One may reckon approximately that an elongation of the bore of a barrel by 4% will increase the muzzle velocity by 1%.

One uses the following formulae for computations.

$$\Delta v_0 = \frac{1}{4} v_0 \frac{\Delta L_{KH}}{L_{KH}};$$

$$\Delta P_{\text{max}} = 0$$

$L_{KH}$  - is the length of the bore of the barrel;  $\Delta L_{KH}$  - its alteration.

Diag. 55. Pressure Curve against the base of the bore where the barrel has been lengthened;

AB - maximum pressure; CD - lengthening of the barrel.

Example: Length piece - 40 calibres;  
muzzle velocity - 600 m/sec. Let us lengthen the piece by 2 calibres.

In this case

$$\Delta v_0 = \frac{1}{4} \cdot 600 \cdot \frac{2}{40} = + 7,5 \text{ m/sec,}$$

hence

$$v_0 = 607,5 \text{ m/sec.}$$

<sup>1</sup> The thickness of the arch ( ? Russian 'svod') is taken as the thickness of grains with many grooves.

<sup>2</sup> More precisely put, it will increase only slightly, as a greater air layer will have to be expelled.

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79. Influence of Calibre (Similarity of guns).

Let us take two guns of various calibres; the calibre of one of them being twice that of the other. In order to provide the heavier shell with the same muzzle velocity as for the lighter shell, one will have to take a bigger charge for the heavier piece. By increasing the calibre by two, the cross section of the bore will increase by  $2^2 = 4$  times, and the weight of the shell by  $2^3 = 8$  times.

So as to give this heavier shell the same muzzle velocity, one will have to increase the weight of the charge 8 times. Thus, in the case of a gun with a calibre which is twice bigger, the weight of the shell and the charge has increased by 8 while their relative weight has not altered.

178 or

$$\frac{w_2}{w_1} = \frac{4}{1}$$

$$\frac{c_2}{c_1} = \frac{8}{1}$$

In other words, in order to obtain identical muzzle velocities in guns of different calibres, one must use identical relative ( ? corresponding - T) weights of charges (if the shells and types of powder are identical). But with such an increase of a charge the muzzle velocity would have sharply increased. To avoid this from happening one will have to leave the density of loading unaltered, i.e. increase the space of the chamber in proportion to the increase in the weight of the charge - in our case 8 times. None the less the need to displace a very heavy shell will lead to the situation that the charge will burn up faster and thus maximum pressure will grow considerably faster (the area subjected to the gas pressure has increased by four and the weight of the shell - by eight). To avoid this growth in the maximum pressure, one will have to select a powder, whose burning process will be slower. But when adopting powder of this kind, the pressure curve will no longer give the same area at the previous length of the bore, as the curve of a fast burning powder; consequently the shell will not have the required muzzle velocity. Moreover a slow burning powder will not succeed in finishing its burning process before the shell has left the barrel. To prevent this one will have to lengthen the barrel. Experiments have shown that the bore of a large calibre barrel must be brought to such a relative length (in calibres) as the bore of a barrel of a lesser calibre.

Where mean pressure is identical in both guns, the correlation of the mean motive forces will be as follows for the first and second piece:

$$\frac{F_2}{F_1} = \frac{P_{cp} \pi r_2^2 l_2}{P_{cp} \pi r_1^2 l_1}$$

but as we are concerned with  $r_2 = 2r_1$  (increase of calibre by two) then:

$$\frac{F_2}{F_1} = \frac{P_{cp} \pi (2r_1)^2 l_2}{P_{cp} \pi r_1^2 l_1} = 4$$

i.e. the mean propelling force in a gun of a twice larger calibre will be four times as great (it will grow proportionally to the square of the calibre).

Powder gas efficiency  $F_1 l_1$  at  $l_1 = 22'$  (i.e. at an identical relative barrel length of both pieces) will equate in the case of the lighter calibre piece  $F_1 l_1$ , while in the case of the heavier calibre piece it will be  $F_2 l_2 = 4 F_1 \cdot 22' = 8 F_1 l_1$ , i.e. it will grow 8 times in proportion to the cube of the calibre. There will, obviously, be enough efficiency at hand for giving the heavier shell the same muzzle velocity as was given to the lighter shell.

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Thus in order to be able to give a shell double the same velocity when the barrel has been lengthened, the length of the barrel will also have to be doubled (i.e. leave its relative length unaltered), to retain the same relative weight of the charge, the same relative chamber space and then we will achieve the same muzzle velocity for both pieces.

Guns of this kind are called 'similar guns'. A large calibre gun, similar to a small calibre gun, needs, as has already been said, a slower burning powder charge. From this it follows that it is necessary to manufacture a powder of various types not only in dependence on the relative length of the barrel at the calibre in question but also depending on the calibre of the gun; powder intended for larger calibre guns has a great thickness of grains.

#### 80. Measures in the Modernization of Artillery.

Before the beginning of the Great Patriotic War the Soviet Army had on its establishment a considerable number of guns constructed before the first Imperialist World War and modernized after this War<sup>1</sup>. The purpose and gist of artillery modernization are set out in book 1 of the Artillery Course.

The following measures which are taken for the modernization of guns with the object of giving them greater muzzle velocity and greater range are connected with inner ballistics.

1. Density of charging has been increased to a slight and permissible extent.
2. The weight of the charge was increased, also the chamber was calculated to prevent the density of charging from increasing too much.
3. A more progressively burning powder was selected. Ribbon powder was the most generally used type during the First World Imperialist War of 1914-1918, thereafter many-grooved and tubular (macaroni) powders were in general use.
4. Length of barrels was increased and a slower burning powder was selected. Thus, the 76 - mm gun M. 1902 had a barrel measuring 30 calibres in length, but after modernization the length of M 1902/20 was increased to 40 calibres. Generally all these measures were adopted for the modernization of guns.

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Resulting from the use of all these measures and from the betterment of the shape of the shell (more streamlined) the range of shells has increased with modernized guns by 30-50%, and sometimes more.

Resulting from the lengthening of barrels these have become heavier and through the weight increase of charges the recoil force has also increased. Hence when modernizing guns, one had to introduce some alterations in the construction of the gun carriage.

<sup>1</sup> 76 - mm gun M 1902/30, 122 - mm howitzer M 1910/30 and M 1909/37,  
152 - mm howitzer M 1909/30, 107 - mm gun M 1910/30 etc.

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