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A treatise on gun-powder, a treatise on fire-arms, and a treatise on the service of artillery in time of war

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First part.

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TREATISE
ON
GUN-POWDER.

FIRST PART.

OF THE PROPERTIES OF GUN-POWDER.

The properties and effects of Gun-powder can only be ascertained by the means of Fire: let us, therefore, in the first place, examine the nature of Fire itself; according to the doctrine of those philosophers, who, by the closest investigation of its effects, have endeavoured to explore its principles and causes.

CHAP. I.

OF FIRE.

THE celebrated HERMAN BOERHAAVE, whose opinions have been adopted by the most eminent chemists, could only, after a long series of experiments, discover a few of the properties from which fire has derived its several denominations; according to the various modifications under which it presents itself to our senses.

I. Pure fire is called *fire, solar matter, light and heat*: under this idea it is conceived to be a substance essentially fluid, composed of particles very subtle, and continually agitated,

tated, though not always in the same degree. The learned BECCARI has proved that it exists in all places, and in almost all bodies, without being able to decide whether it be a constituent and essential principle. A gentle friction of a globe of glass in the electric machine, shews that every thing partakes of it; and two hard bodies rubbed violently together gradually grow warm, and at length emit sparks and flame according to their several qualities.

2. Fire, which seems to pass from a fluid to a solid state, and become a part of the body, as the inflammation of some bodies evidently shews, is called *combustible matter, sulphur, the food of fire, and phlogiston.*

3. One of the distinct characters of fire, considered as solar matter, light, &c. (1.) is to easily penetrate bodies, by insinuating itself into them equally, and expanding them so as to cause a disjunction of the component parts when introduced in quantity. But the facility with which fire effects this is different, according to the qualities of the bodies it enters: there are even some which, far from being dilated by the action of fire, are contracted; as wood, animal bodies, &c.

4. Another character of fire is, to render substances luminous, either by means of the flame which breaks from them, or by their becoming red.

5. Fire, considered as combustible matter, sulphur, phlogiston, &c. (2.) causes no change in the body in which it resides, nor does it communicate to it either light or heat, unless it pass from a quiescent state to ignited motion, or inflammation.

6. The different effects of the first species of fire may be considered under three heads.

1. In a determined space.

2. As actually existing in a body.

3. With regard to the manner and law in which it enters and expands bodies of different natures.

7. Considering fire in a determined space, we find that, as its quantity and velocity may vary, so also in the same proportion will its activity and efficacy be different; as may be observed in burning glasses, reflecting telescopes, &c. The activity and efficacy of fire can only be ascertained by the expansion of bodies, and the disjunction of their parts; but hitherto the method of measuring exactly not only the quantity

quantity and velocity of fire separately, but even its absolute effects on bodies, are unknown. The point to which a body entirely deprived of fire can be condensed is equally undetermined with the first instant of its expansion. The condensation of mercury, produced by a certain quantity of sal ammoniac and snow mixed together, is, in the construction of thermometers, the lowest point that we know; while that, from experiments made in more northern climates, it is clear that mercury can be much more condensed. In the construction of pyrometers, the point of the greatest condensation depends on the variable temperature of the atmosphere. Thus these two instruments serve only to shew, by their graduation, the difference of expansion, according to the degree of fire that they contain or are penetrated with.

8. The activity of fire considered as actually existing in a body, (6. N^o 2.) depends not only on the quantity and velocity of the ignited matter, but also on the mass of the body in which it exists. On attempting to reduce two fluids of unequal density to the same temperature, the most dense requires the greatest degree of heat: thus, when the activity and degree of fire which the two bodies contain are proportional to their respective masses, they are equally hot. On touching two bodies of unequal density, reduced to the same temperature, the most dense appears the hottest; because the hand being in contact with a greater number of particles in the denser body, the sensation excited is proportionally stronger.

9. The manner and law (6. N^o 3.) under which fire penetrates bodies, is modified by the degree of its activity, the time of application, and the superficies, quality, and mass, of the surrounding bodies; for should any one of these circumstances vary, a different modification will result. Put into the same fire two pieces of iron of the same quality, but of different sizes, the smaller piece will become hot much sooner than the larger one; and if the surface of the larger piece be increased by flattening it with a hammer, it will become hot in less time. This diversity of effects may be equally remarked on comparing a piece of iron with a stone, or any other body, put into the same fire.

These observations on the facility with which fire insinuates itself into bodies, are equally applicable to the facility

with which it quits them, and diverges from its focus: for when the quantity of fire in any body is greater than in the atmosphere or other surrounding bodies, it quits that body, and removes from it, spreading itself equally on all sides; its activity diminishes in proportion to its distance from the body which it quitted, and its extension depends on its excess over the external fire, on the time of application, the superficies, quality, and mass, of the surrounding bodies.

10. Having thus examined the various circumstances that tend to modify the effects of fire, let us now consider these modifications with respect to the ignition and destruction of combustible bodies. Whether the ignited motion excited in a combustible body appears under the form of flame, or burning coal, it is always produced in two manners; *either by applying to the combustible body a quantity of external fire, or by increasing the motion of the fire that exists in it.*

11. From the facility with which combustible bodies take fire, they may be ranged in two classes. In the first may be placed spirits of wine rectified, sulphur, &c. in which, by applying fire to any one part, it is communicated to the whole mass, so as to produce a total destruction. In the second class may be ranked coal, the greater part of vegetables, &c. in which fire can be propagated only by a continued application; by increasing the motion in the ignited parts; or by placing the bodies in such a manner, that the fire, in escaping from the burning particles, may meet almost instantaneously those not yet ignited.

12. The degree of ignition varies according to the different qualities of the bodies themselves; for a greater degree of fire is requisite in proportion to the rarefaction of the surrounding air, or to the difficulty of removing from the ignited body smoke or other substances which do not serve as food to fire. In both these cases, it is necessary either continually to apply fresh fire, or to increase the motion of that which already exists in the body.

13. From these premises, it may be inferred, that fire admits of infinite diversity in its effects, arising not only from the time of application, the superficies, quality, and mass, of the bodies to which it is applied, and which surround it, but even from the modifications that ensue from the quantity and velocity of the ignited matter.

14. Where-

14. Wherefore, the force of gun-powder fired in muskets, cannon, mortars, mines, &c. being in proportion to its inflammation, its effects must inevitably be modified by the quantity and the proportion of the ingredients, the temperature of the atmosphere, and other circumstances that will be hereafter pointed out. And since it is not in our power to determine every point that affects its inflammation and total consumption, we cannot be always certain of producing the same effects with the same quantity of powder fired from the same piece of ordnance.

C H A P. II.

OF SULPHUR, SALTPETRE, AND CHARCOAL.

15. **S**ULPHUR is a substance composed of *vitriolic acid and a combustible matter*. It is ranked in the class of minerals, because it is extracted from the bowels of the earth. When exposed to a moderate degree of heat, it liquefies, and sublimes in little tufts called *flowers of sulphur*: thus it is purified from heterogeneous substances by sublimation.

16. The property of sulphur is to take fire, inflame, and be entirely consumed, when exposed in the open air to a stronger fire than that which will liquefy it. It is made use of in the composition of gun-powder, because the ignited motion is easily propagated in it.

17. The facility with which sulphur takes fire and burns depends on the rarefaction of the surrounding air. To burn it in an exhausted receiver, it requires a continued application of a much greater degree of heat than would inflame it in the open air: the receiver should also be of a size proportioned to the quantity of sulphur, lest the condensation of the smoke prevent its total consumption. (12.) The only method of decomposing sulphur is by burning; which destroys the combustible matter, and the vitriolic acid exhales in vapour.

18. Charcoal, used in the composition of gun-powder, is defined to be a body composed of *a combustible matter, and*

of the dense earthy particles contained in vegetables. In making charcoal, the vegetables are burned in such a manner, that they do not inflame; and then the combustible matter unites itself intimately with the most dense earthy particles. Charcoal can only be decomposed by fire; which, at the beginning of the ignition, separates the combustible matter from the earthy particles; which are then termed *cinders*.

19. When charcoal is exposed in the open air to a sufficient degree of fire, its property is to burn and be consumed. It sometimes emits a little blue flame; but more frequently sparkles, and becomes red, without emitting any flame. If, in this state, it be agitated by the wind, it appears of a more lively and brilliant red in proportion to the force of the wind, and is sooner reduced to cinders. From this property it enters into the composition of gunpowder.

20. Generally speaking, charcoal appears red only when a greater degree of fire is applied to it than will burn sulphur: the propagation of the ignited motion, and its total consumption, are effected more slowly than in sulphur. These effects differ according to the quality of the charcoal: that which is the lightest, or which contains least of the dense earthy particles, takes fire and is consumed the quickest.

21. The more the air is rarefied, (12.) the more difficultly charcoal burns, and the greater degree of fire is requisite to keep it red-hot.

22. Saltpetre is formed from a combination of *the nitrous acid with a fixed alkali*. It is extracted principally from animal and vegetable substances, found in a putrescent state, mixed with stones, earths, and plaisters; and is separated from them by boiling them in a water impregnated with a fixed alkali. The salt chrysalizes in long filaments, lying the one upon the other. This is the only method of purifying it; and must be repeated two or three times, according to the quantity of the heterogeneous matters. When, by this process, the saltpetre has been well purified, it has always the same properties, from whatsoever substances it may have been extracted.

23. Its properties are, to dissolve in water, more fully in boiling than in cold water; and to liquefy, by a greater degree of heat than is required to liquefy sulphur. If the heat be increased while the saltpetre is in fusion, it sublimes

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in visible particles; which, collecting together on the upper part of the vessel, are called *flowers of nitre*. To separate the acid from the alkali, without putting the saltpetre in contact with a combustible body, it is necessary to expose it a long time to a very strong fire; and even then the decomposition is brought about very slowly.

24. If a combustible body, containing a sufficient degree of heat, touch saltpetre, a very fierce flame is excited at the point of contact, accompanied with detonation and a wind, which increases the activity of the fire. In this operation the acid is separated from the alkali, and dissipated. The combustible body is instantly consumed, and the alkaline residuum is termed decomposed or fixed nitre.

25. This decomposition of saltpetre takes place equally in the open air and in vacuo; provided that, in vacuo, the action of the fire be sufficient to keep the combustible body (12.) in a state of ignition.

26. Saltpetre may be decomposed by fire in two ways.

1. By coming in contact with an ignited combustible body when in a solid state.

2. Or by communicating, when in fusion, the ignited motion to a combustible body in contact with it.

27. In the first case, by applying burning charcoal, the decomposition begins and continues till the saltpetre or the charcoal be entirely consumed. To effect the destruction of both at the same time, the quantity of charcoal must be proportioned to the quantity of saltpetre. The better the substances are mixed together, the more immediate will be the contact between the several parts, and the sooner will both be consumed.

28. Burning sulphur not being able of itself to decompose saltpetre, charcoal is added to it. Now charcoal of every kind burns when exposed a sufficient time to the action of burning sulphur; yet this takes place sooner or later in proportion to the density of the charcoal, or to the quantity of dense earthy particles; wherefore, that the fire produced from the sulphur may be sufficient to burn all the charcoal, the quantity of each must be exactly proportioned, and attention paid, at the same time, to the quality of the charcoal.

When this proportion is determined, a quantity of saltpetre added, and the three substances well ground together, in order to render the inflammation more instantaneous, even then the effects vary; for if the saltpetre be

in too great a quantity, the combustible particles being too far separated, the fire applied to one part will not be able to spread to the others; or the combustible particles, being in too small a quantity, will be consumed long before the saltpetre. If, on the contrary, the saltpetre be in too small a quantity, it will be consumed before the other two ingredients: wherefore, that the destruction of the three may begin and end at the same time, they must be mixed in a just proportion. As soon as the saltpetre begins to be decomposed, the wind (24.) generated from it, renders the heat of the charcoal more intense, increases the activity of the fire, and accelerates the total destruction of the whole. (7.)

29. This decomposition of saltpetre, by the application of charcoal and sulphur, is similar to the process that takes place when powder is burned in the open air, or in fire-arms.

30. It requires a greater degree of heat to decompose saltpetre in the second manner (26. N° 2.) than in the first.

FIG. I. To the plate AB of the pneumatic machine, fix a thin thimble C, of beaten brass, with the convexity downward; put into it a mixture of saltpetre, sulphur, and charcoal; and apply a red-hot iron concave in D, so that it may exactly admit the convexity of the thimble: in a short time the mixture will explode, and be entirely consumed. Put again into the thimble an equal quantity of the same mixture, and place above the plate a glass receiver, from which pump out some of the air, then the red-hot iron being applied as before, the explosion will not so soon take place. If the air be entirely exhausted, the decomposition of the saltpetre will not begin till both it and the sulphur are liquefied, and fall into ebullition,

31. To burn powder in vacuo, the second method must be used; for it will not explode before it be reduced to a state of liquefaction, and an ebullition ensues.

32. On decomposing saltpetre in either of these methods, if the vessel be suffered to cool, and a small aperture be opened, an air will be instantly perceived to rush out, with a force proportioned to the quantity of saltpetre used in the experiment.

experiment. This air proceeds from an elastic fluid generated at the decomposition of the nitre, and is essentially different from the smoke which, after a little time, fixes upon the inside of the vessel, and produces no effect. On the contrary, the elastic fluid proves its force and effects after a considerable interval of time; whence may be inferred, that it is a *permanent fluid*, and in it consists almost the whole force of gunpowder. It may be further observed, that this force is always increased by heat.

33. When the experiment is made in the first method, (26. N^o 1.) in a close vessel, with a quantity of sulphur and charcoal sufficient to decompose the nitre, if the vessel be too small, or a considerable time be requisite to effect the decomposition, on account of the want of sufficient proximity in the nitrous and combustible particles, the redundancy of the smoke inclosed in the vessel will retard the operation, the combustible body will lose its heat, and recourse must be had to the second method of continually applying fresh fire.

34. The following experiment proves that the *permanent elastic fluid* proceeds from the saltpetre alone. Let a quantity of sulphur and charcoal be burned in a close vessel, the vessel be suffered to cool, and a hole be opened, no wind will be perceived to issue: from this and other experiments, it is clear that no permanent fluid is produced by burning together these two combustible bodies. The smoke, nevertheless, is elastic when hot; but so soon as it is deprived of heat, it not only entirely loses its elasticity, but even absorbs a portion of the common air, and a part of the permanent elastic fluid generated from the nitre, whenever this fluid mixes with the smoke; as will be shewn hereafter.

35. From these experiments, and others that might be made on the same subject, the following properties may be deduced—

1. A certain degree of heat is requisite to set fire to the combustible bodies, and decompose the nitre.

2. The degree of heat must be increased in proportion to the rarefaction of the surrounding air, or to the density of the smoke.

3. The decomposition of the nitre being always progressive, the more intimate the mixture, and the juster the proportion of the combustible ingredients, the sooner will it be effected.

4. In

4. In the decomposition of saltpetre, an elastic fluid is generated, which is permanent for a considerable space of time.

C H A P. III.

O F G U N - P O W D E R .

36. **GUN-POWDER** is composed of very light charcoal, sulphur, and well-refined saltpetre. These materials are put into a wooden trough, where they are ground together, to render the contact of the nitrous and combustible particles intimate and equal throughout the whole mass. The mixture is occasionally sprinkled with water, to form an amalgam, which is afterwards granulated, and prevent the finer particles of the sulphur and charcoal from flying off, which would necessarily alter the proportion of the composition. The powder-makers employ more or less time in the operation of grinding, in proportion to the quantity of saltpetre. When they conceive that the ingredients are properly mixed together, they form from the paste those little grains which, being dried, obtain the name of gunpowder.

37. There seems to be nothing in the fabric of gunpowder that can alter any of the properties of the constituent parts, taken either individually or collectively. (35.) The necessity of having a combustible body capable of producing the total and instantaneous decomposition of the nitre, makes sulphur and charcoal requisite ingredients: sulphur, because it easily takes fire, and propagates the inflammation, though the heat it produces is not sufficient to decompose the nitre: charcoal, because its inflammation, as well as the propagation of fire into all its parts, being slower, it acquires, when it becomes red-hot, a stronger degree of heat than the sulphur, and is therefore more capable of producing the entire decomposition of the nitre. Therefore, from their combination with a proper proportion of nitre, the most instantaneous explosion may be expected; but if the quantity of nitre be too great, the fire communicating to the combustible particles with so much the more difficulty as the excess is the greater, may produce no effects.

If to a composition of 14 parts of saltpetre, 1 of sulphur, and 1 of charcoal, a burning coal be applied, those parts
only

only of the mixture in contact with the coal will burn, the flame not being able to communicate itself to the other parts. If, on the contrary, the nitre be in too small a quantity, on applying fire to one part, the flame which breaks out at its decomposition is too weak to spread itself to the others, owing to the great distance of the nitrous particles: the destruction of the whole, therefore, requires a much longer time; and the quantity of permanent elastic fluid, on which depends the greatest force of the powder, is less; as may be proved by burning a mixture of equal parts of sulphur, charcoal, and saltpetre.

38. That proportion which will most readily produce the destruction of all the composition, and yield the greatest possible quantity of the permanent elastic fluid in a given time, ought to be found out, and will constitute powder of the best quality: it evidently appears, from the above experiments, to lie between the quantities there made use of.

39. In the first years that succeeded to the discovery of gun-powder in EUROPE, the proportion of the constituent parts, and the size of the grains, varied very much; which gave rise to the several denominations it has obtained. At the beginning of this century, these proportions and sizes were almost every where reduced to three; and at present, throughout all Europe, only one kind is used for military purposes.

As it will be shewn in this treatise that the properties of powder are modified by the qualities of the ingredients and the size of the grains, to save repeated descriptions of the different kinds of powder that may come under our investigation, we will subjoin a general account of them, according to the various denominations that they are commonly known by; with this observation, that whatever may be advanced concerning the modifications of one kind of powder is applicable to all others.

40. Powder composed of 5 parts of saltpetre, 1 of charcoal, and 1 of sulphur, and granulated so as to enter with ease into the vents of new musquets, is called *musquet powder*; when the grains are three or four times larger, it is called *cannon powder*. Powder composed of 6 parts of saltpetre, 1 of charcoal, and 1 of sulphur, the grains of which are of the same size as musquet powder, is called *common war powder*; and obtains the name of *fine war powder* when the grains are about half that size. Powder made with the same proportion,

proportion, and with grains of the same size, as the fine war powder, but with a less dense charcoal, is used by sportsmen in shooting game. When composed of 7 parts of saltpetre, 1 of charcoal, and 1 of sulphur, and granulated as the fine war powder, it is called *fire-work*, or *rejoicing powder*.

41. We will now proceed to prove, that fired powder preserves constantly the properties remarked in the combination of its ingredients; (35.) modified, nevertheless, by the exactness of the mixture, the size of the grains, and other circumstances that will be pointed out.

42. All degrees of heat are not sufficient to fire powder for if it be only sufficient to inflame sulphur, the effects before mentioned (28, 35. N° 1.) will result, as may be proved by throwing several grains of powder near hot coals. The burning of the grains contiguous to the coals will be so instantaneous, as not to be distinguishable from the inflammation of the sulphur; but the grains at a little distance from the coals will emit, after some time, a small, blue, lambent flame, which at length becomes brighter; the intenseness of the fire increases, and the gradual destruction of the saltpetre is clearly discernible; some of the grains are consumed, while in others the blue flame disappears without producing their destruction: at length the more distant grains become warm, without emitting any flame, or being consumed. This may be exemplified by putting some large grains of powder on an iron plate, which may be put near to, or drawn back from the fire, in order to give it different degrees of heat; or by directing upon them the solar rays, united by means of a convex glass, as different degrees of heat may be produced by augmenting or diminishing the circle formed by the re-union of the rays.

43. These experiments prove that powder, like other combustible bodies, may become hot or inflamed, without being in the same instant consumed. It is necessary, therefore, to distinguish between the inflammation and the final destruction of each grain: for fire, when applied to two grains of different sizes, does not always cause any sensible difference in their destruction; yet there is a great difference in the force of two equal quantities of powder, made with the same proportion of ingredients, of the same quality, but differently granulated, as is seen on comparing cannon and musquet powder.

44. The

44. The following experiment will prove that the degree of heat to fire powder should be greater in proportion to the rarefaction of the surrounding air, or to the density of the smoke. (35. N^o 2.)

PLATE I. FIG. II. To the plate A B of the pneumatic machine, let a thin thimble C of beaten brass, be joined, with the convexity upwards. Let the iron M exactly fill the concavity D; and a moveable ring, F G, be fitted round the thimble, so that on covering the convexity C with powder, part may fall on it. Then if M, made red-hot, be introduced into D, when F C G is covered with powder, in the open air, the powder will instantly explode; but if a glass receiver be placed upon the plate A B, and in part exhausted, and the hot iron be applied, the explosion of the powder on C will not be so sudden as before, and part of that on F G will remain unaffected by the heat, in proportion to the quantity of air left in the receiver. When the air is quite exhausted, the powder upon the convexity C will liquefy before it takes fire, after having emitted several ebullitions; then explode at once, and cover with its flame the powder upon F G: this will, nevertheless, not liquefy; and a part of it will remain upon the ring and plate, where it has been pushed by the blast.

45. This proves that the powder upon the ring, being in a very rarefied medium, does not burn, though surrounded by the flame of the fired powder. In this case, the fired powder spreading itself on all sides in the receiver, which is much larger than the space occupied by the powder, the grains that remain unfired are only surrounded by a part of the flame. If the receiver were filled with powder, the fire inclosed in a smaller space would be more intense, but the quantity of fired powder would be proportioned to the rarefaction of the atmospheric air contained between the grains. (FIG. III.) A B C is a funnel of bronze or iron, of which the part C C is made to screw on to V V of a receiver of beaten copper V X Z, containing about 70 cubic inches. The part D F of the funnel, which is to contain the powder for the experiment, may be diminished at pleasure, by means of the rings G, of exact calibre, and of different lengths, to be applied to the part F of the space D F. A H I is a canal conical from A to H, and cylindrical from H to

H to I; shorter than the funnel A B C by half a diameter D D. The part K L of the iron rod K L M, fits the conical part A H so exactly, that no air can pass: the cylindrical part is a little longer than H I. The capital N N O of brass, of which the aperture O O is less than D D, can be fastened by the spirals N N to B B.

Let the space D F be so diminished by the ring G, that the remaining part D P be entirely filled with the powder used in the experiment; and let the powder be retained by a hog's bladder tied fast to the thread of the screw B B. The funnel, thus charged, is screwed into V V of the receiver, placed upon the base X Z, which keeps the funnel perpendicular. Then if the iron rod be made red-hot, and pressed forcibly into the funnel, the point M coming below the bottom of the funnel I, without touching the bladder, will nevertheless set fire to the powder, and the bladder will burst. If this experiment be made with 24 grains of cannon powder, when the receiver is placed so that the lower aperture X Z fits a large tub or other vessel, no unfired grains of powder will be found; but if the receiver be placed upon the plate of the pneumatic machine, and the air be half exhausted, $\frac{1}{3}$ or $\frac{1}{2}$ of the grains will be found unfired upon the plate after the explosion; and if the receiver be exhausted, $\frac{4}{5}$ or $\frac{5}{6}$ of the grains will be found untouched by the fire.

In these three modifications of the air in the receiver, the funnel is always charged in the same manner, and with the same quantity of powder; and the bladder tied fast in B B entirely prevents any communication between the receiver and the part D P of the funnel; so that when the receiver is exhausted, no change takes place in the part of the funnel that communicates with the external air by means of the little canal A H I; and consequently, when the rod is introduced into the canal, the powder inclosed in the funnel, and the air contained between the grains, remain in the same state, whatever alteration be made in the air of the receiver; wherefore, the bladder bursting at the beginning of the inflammation of the powder, the air which is between the grains in D P, spreads itself into the receiver; and in proportion as it becomes more rarefied, less powder is fired. In each of these three different states of the air in the receiver, it may be observed, that the insides D P of the funnel

nel are bronzed by the flame of the powder. As the powder first takes fire in R, that which is placed above in P cannot fall upon the plate without passing across the flame of the burning powder in R; so that, in this experiment, the fire being inclosed in a smaller space, is more active than in the former one; (44.) yet all the powder is not fired, because the air, on the bladder's bursting, is too rarefied.

46. But to destroy all doubt of this property of gun-powder, let the funnel be charged as before, the capital N O screwed on to B B, and a wad put at the aperture O to retain the powder: then, if the bladder be tied fast in q q, and the receiver be exhausted, the quantity of fired powder will always be greater in proportion as the hole O is narrower; and if it be nearly of the same size as the hole I of the little canal A H I, all the powder in D P will be consumed. In the preceding experiment, (45.) it was found, that when the air had been entirely exhausted from the receiver, only $\frac{1}{5}$ or $\frac{1}{6}$ of the powder took fire, and that a great part of the flame spread itself into the receiver when the bladder burst; while that the remaining part expanded itself in D P, which it bronzed. On the contrary, in this experiment, where the aperture O O is narrower than D D, as neither the air contained between the grains, nor the flame, is able to pass with the same facility into the receiver, they remain in much greater quantity in D P; the fire is therefore more intense, and consequently a greater quantity of powder is consumed; indeed all the powder will be fired when O O is reduced to the size of I. The same effects take place with all kinds of powder, (40.) the only difference being in the quantity that remains unfired.

47. It is then ascertained (44, 45, 46.) that, in order to fire powder, the heat should be in proportion to the rarefaction of the surrounding air, and that it is increased by preventing the expansion of the flame. It remains now to be proved, that the degree of heat must be likewise greater in proportion to the density of the smoke.

It has fallen within the observation of every artillerist, that when shells sink into stiff earth with the fuses downward, the smoke finding no passage, the fire is extinguished, and the shell does not burst; but if they fall into water, the smoke mixing with the water, the fire continues till the powder in the shell explodes. Fuses are generally filled with a
mixture

mixture of mealed powder, sulphur, and saltpetre. Let two or three fuses, of the same size, be filled with composition of different degrees of strength; after being set on fire, let them be buried in earth equally stiff, or covered in any other manner, so as to prevent the escape of the smoke; it will be found, on taking them out after some minutes, that the quantity of composition which is consumed is in proportion to its strength; since the density of the smoke was the same, as the ground was equally solid. Hence, it is evident, that the greater the force of the fire, the greater is the consumption of the composition. Care should be taken not to make it so strong as to burst the fuses.

48. Having ascertained those two properties, it remains to demonstrate, that when fire is applied to grains of powder, the inflammation of the contiguous grains, and the destruction of each individual grain, takes place progressively; (35. N^o 3.) and that the velocity with which fire spreads itself on all sides to inflame the contiguous grains, is greater than that with which it penetrates into the substance of each grain. It is too obvious to need insisting on, that all motion, however rapid or short it may be, takes up a certain time; though to us, from the shortness of its duration, it appears instantaneous: consequently, the inflammation and entire destruction of powder produced by the action of fire, communicating itself to every thing around, like rays from a centre, must necessarily take place in a determined space of time; which varies according to the strength of the fire, the proportion of the ingredients, the nicety of the mixture, and the size of the grains.

When a sufficient degree of fire is applied to one grain of powder, it first acts upon the surface, and then penetrates towards the centre. (43.) As the surface burns, a flame is excited which catches the nearest grains; if the degree of heat be sufficient, and the surrounding air not too much rarefied. In the mean time, the fire which attacked the first grain, continues its action towards the centre till it be totally consumed. There are then two distinct actions in the inflammation and the total consumption of powder: the first is the expansion of the inflamed fluid; which, spreading itself from the surface of the burning grains, surrounds the contiguous ones: the second is the penetration of the fire from the surface of each grain towards its centre. But the flame always spreads with more rapidity between the intervals of the other

other grains, than it penetrates towards the centre of each grain.

49. The following observation will prove that a determined time is requisite for the consumption of each grain. Make, of the common mixture, some grains of powder as large as pistol bullets; dry, and set fire to them: it will then be seen that the fire penetrates from the surface to the centre, in a longer or a shorter space of time according to the size of the grains; so that if there be no difference between these large grains and common ones than in size, it may be inferred, from analogy, that the smallest must require a certain space of time, however short. It is likewise clear, that the flame, in spreading itself from the burning grains to the contiguous ones, takes up a certain space of time; as may be exemplified by setting fire to a train of powder.

50. An experiment will prove, that the action of fire is also progressive when applied to powder confined in a vessel; where the burning fluid being more dense, is also more active than when powder is burned in the open air. (FIG. III.) To the funnel charged as before, (45.) let the capital N O be fastened, with the aperture O of such a size, that the receiver being exhausted, only $\frac{1}{2}$ or $\frac{1}{3}$ of the powder contained in the funnel may take fire. Introduce the red-hot rod, and leave it to cool; then admit by degrees the air into the receiver, and loosen carefully the capital from the funnel. If proper attention has been paid in this process, it will be seen—

1. That nothing touches the point M of the rod; as the powder being burnt all around, leaves a cavity nearly spherical.

2. That each of the grains which form the sides of the cavity are burnt a little towards the concave side; as may be distinguished by the fixed nitre, and the smooth surface of each grain.

3. That the grains which are between the interior surface of the funnel and those which form the sides of the cavity, are whitened by the flame of the sulphur, and that the sides of the funnel are bronzed.

It is then proved, that the fire both spreads itself between the intervals of the other grains, and penetrates from the surface to the centre of each grain progressively.

51. But it is not sufficient to have proved that the burning of each grain, and the inflammation of the contiguous ones, are progressive; it is necessary further to shew, that the

activity with which fire spreads itself between the interstices of the grains, is greater than that with which it penetrates from the surface toward the centre of each grain. If we consider that the inflamed fluid, in passing between the grains, meets no other resistance than the common air, which is easily penetrated, by reason of its rarefaction; and that the fire, in insinuating itself from the surface toward the centre of the grain, must pass through a substance much more dense; it is evident, that the resistance in the second case being greater than in the first, the fire must consequently be slower in its progress.

The following experiment will serve in proof of this assertion. Let a pistol barrel, with the vent closed up, be filled with powder to the muzzle: on applying fire to it, the barrel will instantly empty itself, with an explosion. Let it be again filled with powder well compressed, so that the interstices between the grains may be as small as possible, and form, as it were, a solid body; the time that the barrel will take to empty itself will be sensibly longer than before.

The great velocity with which the inflamed fluid passes from the muzzle to the breech of the pistol barrel, between the interstices of the grains, is observable in the first experiment; and, in the second, it is seen how much this velocity, from the necessity of penetrating the powder itself, is retarded.

52. From the three preceding paragraphs, the following principles are deducible.

1. That in burning two equal quantities of powder, made of the same composition, but differently granulated, as cannon and musquet powder, the latter will be consumed in less time than the former; because the grains being smaller, (40.) present to the fire a greater superficies, and produce, at the first instant, the inflammation of a greater quantity of matter; which is consumed so much the sooner, as the fire has less space to pass through from the surface to the centre of each grain.

2. That this depends not only upon the size of the grains, but also upon the facility with which the fire passes between them. On the other hand, the grains should not be too small; for then the interstices will be so diminished, as to admit the flame to pass with difficulty; and they will be so compact, as to form, as it were, a solid body.

53. The grains of powder are generally of a very irregular form and uneven surface; whence arise many varieties in the quickness of its inflammation and explosion. To remedy these inconveniencies, some manufacturers put the powder into a barrel suspended by two pivots; and having turned it for some time, separate, by means of a screen, the dust from the grains; which are, by this operation, sufficiently smoothed and rounded. On comparing powder made in this manner with powder of an irregular form and uneven surface, the latter is found to take fire more quickly, though the proportion of ingredients be precisely the same in both. Nevertheless, as the interstices between the round grains are larger than between grains of an irregular figure, and as upon them the quickness of the inflammation greatly depends, the round grains may be so small, that the interstices being equal in both, the fire may be able to spread itself equally, and consume the powder with the same rapidity; and as powder of an irregular grain takes fire more easily than smooth-grained powder, a proportional size might be fixed on which would cause the latter to inflame with greater, or at least equal promptitude.

54. As these properties are common to all kinds of powder (40.) that are well made, of proper materials, and equally dried, varieties in their effects can only result from the different proportion of the ingredients, the size of the grains, their figure, and smooth or uneven surface. If the ingredients, however good in quality, are not well mixed together, the powder will not so readily burn, and the difference of the effects will be very sensible.

55. The following experiment will prove, that from fired powder a permanent elastic fluid (35. N^o 4.) is produced in great quantity, upon which depends its principal force. (Fig. IV.) ABCZ is a hollow cylinder of bronze, with a screw at BC to receive DEF. GG is a key to open or shut the communication between the parts of the funnel HH. To the spiral FF, fix the air-gun MM, to receive the elastic fluid generated in the cavity BP; and screw DE into BC. Put the powder into the cavity; and screw IKL, made of bronze, into AP. Lm is the vent; *no* a small moveable plate of iron, to which is fastened a fuse *op*, and joined to the pin K, &c. *qr* is a smooth bar of iron, made to slide in a groove by the spring V_y, which keeps it in the position *ts*, when not forcibly held back; and closing the vent, totally prevents the passage of the air; so that, when

the several parts are properly adjusted, and the bar of iron qr is in the position ts , the elastic fluid inclosed in the cavity BP , though very much condensed, cannot escape. QQ are pivots, or trunnions, to support the machine.

In this experiment the machine must be placed vertically, that the powder contained in the space BP may rest on BX ; the little funnel Hh having been previously filled with hog's lard, that the powder, when fired, may not act immediately on the key GG , and prevent it from being drawn out. By means of a thread of silk, fastened with two little nails at the hole m , the iron qr is held back, the fuse is charged with powder, and the vent Lm primed. Then IK is screwed into AP , and fire applied at L ; which, communicating by m , sets fire to the fuse in o ; and burning, at the same time, the thread of silk, sets at liberty the iron qr ; which, pressed by the spring Vy , slides into st , and closes the hole m . The fuse burns from o to p , and sets fire to the powder in BX : the vent being closed in m ; and, for greater certainty, a little screw introduced into L .

(FIG. V.) When it is judged that the powder in BX is fired, which can only be known by the heat of the cylinder $ABCZ$, as no motion can be perceived, let a bullet be put into the air-gun, and the machine be pointed against a plank, by means of the semicircle of iron BB , which can be stopped by C in any direction; then giving a half turn to the key GG , that the cavity BP may communicate with the bore of the air-gun, on touching the trigger A the bullet is discharged with velocity, and impinges on the plank with the same force as would have been produced by a very great condensation of air.

The cavity BP will contain ten ounces of powder, but with one ounce only, sixteen or eighteen bullets may be discharged successively, and at the distance of forty paces, each bullet will pass through a fir plank half of an inch thick. After these discharges, if the key GG be turned as it was at first, the air-gun be unscrewed, a large bladder fastened in its place, and the key again turned, the bladder will be filled with an invisible fluid; which, being close tied up for several days, will not sensibly diminish in bulk. In the coldest weather it is equally elastic; so that, considered relatively to its elasticity, it may be compared to the atmospheric air. Unscrewing KI , the inside BPX will be found covered with saline particles; which, collected and examined, form a fixed alkali

alkali that easily attracts moisture, and falls in *deliquium* when exposed to an air abounding in vapour.

56. Since the fluid generated at the burning of powder preserves its elasticity for a long time, it follows, that at the instant of explosion its elastic force must be the greatest. In proof of this, let a barometer be fixed to the pneumatic machine; and, having exhausted the receiver, apply fire to the thimble. (FIG. I.) At the instant of explosion, the mercurial gage descends rapidly, then rises; and, after some undulations, seems to fix, for a time, below the point where it was before the explosion. This apparent fixation shews that the elastic fluid is reduced to the temperature of the air; and the sinking of the mercury, in the beginning of the experiment, proves that the force of this fluid is much greater at the instant of the explosion than afterwards. If, instead of burning the powder in vacuo, it be fired in the open air, the elasticity of the fluid will be greater during the application of fire than when its effects totally cease.

57. From these premises (32, 34.) it may be inferred, that the quantity of the permanent fluid is always in proportion to the quantity of nitre contained in the powder, since it alone produces the fluid; as sulphur and charcoal, when burned, produce none. Other experiments might be made to confirm this, by burning different quantities of powder, of the same or different qualities, under the receiver of the pneumatic machine; exhausting the air to the same degree in each experiment, and observing the apparent fixed point of the mercurial gage: it would then be seen that it sensibly falls or rises in proportion to the saltpetre contained in the different quantities of powder.

58. Though the penetration of the bullet into the plank, and the apparent fixed point of the mercurial gage, (55, 56, 57.) be the effects of the permanent fluid generated from the saltpetre, yet they ought not to be attributed solely to that; as the smoke and the common air contained in and between the grains of powder, are also rarefied by the action of the fire.

59. From all experiments hitherto made upon smoke, it is found to be elastic while hot; wherefore it is reasonable to conclude, that the smoke produced at the explosion is one of the causes that concur to give it force: but when cold, it not only ceases to be elastic, but even absorbs a portion of the permanent fluid. It is impossible, at the explosion, by separating

rating the smoke from the elastic fluid, to determine the absolute force of each; yet it may be safely inferred, that the greater part of it depends upon the permanent fluid.

60. The common air that is within and between the grains contributes likewise, by its expansion, to the force of the powder when fired. Its absolute force might be easily determined; but is very small, in comparison of the elasticity of the permanent fluid generated from powder.

61. Thus, the diminution of the ranges of fire-arms, when heated by frequent discharges, or when the air of the atmosphere is more rarefied, ought not to be attributed to less elasticity in the air, but rather to the second property of powder; where, being fired in a rarer medium, less takes fire, though the same quantity be used; and hence the range is shortened, as will hereafter be more clearly proved.

62. For the same reason, the increase of force obtained by triturating powder for a long time, and the force which damaged powder resumes after having undergone a fresh process, proceed not, as some think, from the greater quantity of air compressed into the substance of the powder, but simply from a more exact mixture of the ingredients, whence they more easily and generally take fire.

63. In illustration of this remark, it is sufficient to observe, that the best manufactured powder is liable to be damaged by excessive heat or moisture. The powder-makers, in drying powder, take care to stir it frequently, and suffer it to cool before they put it into the barrels; as they pretend that it ferments when very hot: and in fact, if, when much heated, it be closed up in a barrel for some hours, and afterwards poured gently upon a cloth, a great part of the grains, especially those towards the middle of the barrel, will be caked together; on examining them carefully, it will be found to be owing to the great heat, which having liquefied the sulphur, it glues the grains together when cold: but this never happens if the powder be allowed to cool before it is put into the barrel. A partial or total liquefaction of the sulphur is always prejudicial to the inflammation and quick destruction of the powder, (27, 28.) as it destroys the exact mixture of the ingredients, which can be only recovered by subjecting it to a fresh process. If the heat be not sufficient to liquefy the sulphur, a large quantity of dust, consisting principally of sulphur and charcoal, will be found in barrels of powder that have been long manufactured and exposed to damp. The powder from which this dust is detached will
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be altered in quality; and while the interior of the grains, from which the sulphur and charcoal are fallen off, continue in the same state they were in when made, the exterior will have lost the greater part of the substances necessary to facilitate the inflammation. Thus, on applying fire to these grains, the surface burns slowly till the fire penetrates the interior, and meets a sufficient quantity of sulphur and charcoal; the powder must therefore have become weaker. Now, if the powder, thus reduced in strength, be manufactured again, the grains will become homogeneous both internally and externally; but, owing to the diminution of the quantity of sulphur and charcoal, they will be altered in quality, since the saltpetre will be in greater proportion than either of the other two ingredients; so that if, before the powder became damp, it was not very strong, it will now have become much stronger; but, on the contrary, if it was as strong as possible before, and the ingredients (38.) well-proportioned and intimately mixed together, it will in this new operation have lost part of its strength. Hence it may be inferred, that grinding serves only to mix the ingredients together; and that when there is a perfect contact between the nitrous and combustible particles, it is useless any longer to continue the operation.

64. Powder, however well dried and fabricated it may have been, loses its strength when allowed to become damp. If daily observations on powder, put into damp magazines, and carefully preserved in barrels, are not sufficient to establish this fact, the following experiment will render it incontrovertible.

Let a quantity of well-dried powder be nicely weighed, and put into a close room, where the air is temperate, and seemingly dry, and be left for three or four hours; on weighing it again, its weight will be increased. This same powder, exposed to an air loaded with vapour, acquires much additional weight in a short time. Now the increase of the weight being proportional to the quantity of vapour contained in the atmosphere, and to the length of time that the powder is exposed to it; it follows, that powder easily attracts moisture.

65. Wherefore, if a degree of heat, sufficient only to fire dry powder be applied to powder that is damp, the moisture will oppose the action of the fire, and the grains either will not take fire at all, or their inflammation will be slower: thus, as the fire will spread more slowly, fewer grains will

burn; and the penetration of the fire from the surface to the centre of each grain, and consequently their consumption, will require more time. Whence it may be concluded, that all degrees of moisture diminish the force of powder. Saltpetre, not sufficiently refined, attracts moisture very readily; and as the substances that render it impure lessen the quantity of fluid, and prevent its detonation, it should be refined as much as possible before it is employed in the fabrication of gun-powder.

66. In drying damp powder, the degree of heat should be moderate. (63.) When any of the saltpetre has been dissolved, it should be ground afresh, to establish a just mixture of the several ingredients; and if part of it be absolutely lost, which may be known by passing a certain quantity of the powder, well dried and weighed, through a sieve, it will be necessary, before it is ground, to add the quantity of saltpetre that is deficient.

67. Having thus shewn that the force of powder is owing to an elastic fluid generated at the explosion, the suddenness of which depends upon the proportion of the ingredients, the contact between the nitrous and combustible particles, and the size of the grains, &c. it may be concluded, that when several powders, equally well dried, and fired under the same state of the atmosphere, are compared together, that which produces the greatest quantity of the elastic fluid, in a given space of time, is the strongest.

C H A P. IV.

THE PROPERTIES OF POWDER ARE THE SAME
IN FIRE-ARMS OF ALL CALIBRES.

68. **H**AVING proved that every degree of heat is not capable of firing powder, and that its force depends on the elastic fluid generated at the explosion, it is needless to adduce any more arguments in support of this fact; but with regard to the second and third properties (44, 48, 49.) of powder, which are undoubtedly of greater consequence, and have often, for want of due investigation, occasioned a difference of opinion among artillerists, in treating of the proper charge and length of guns, it is necessary to be more particular,

particular. These two properties, as well as the first and fourth, hold good in all fire-arms, and in every other cavity where powder is burned; they are also modified by the same causes, (41.) and by others that will be hereafter mentioned.

69. The second property is observable in all fire-arms, when, on applying fire to different quantities of the same powder, either the whole or a part only of the grains take fire, in proportion to the strength of the fire, and the density of the medium. For example, if a quantity of cannon powder be all burned in a gun of large calibre, the same quantity, in a piece of smaller calibre, will not be all burned. In the same piece, charged with different quantities of powder, the smaller charge will entirely explode, while a part only of the larger will be consumed. If, in the largest charge, the resistance to the explosion be increased by a high wad, shot, &c. a greater quantity of powder will burn than when the piece is fired with a common wad, and without shot. These varieties constitute the second property of powder. (44, 45, 46, 47.)

70. The third property of powder is equally observable in all fire-arms. The inflammation of each grain, and of the contiguous ones, being progressive in all kinds of powder, the varieties that occur arise not only from the size of the grains, and the proportion of the ingredients, but also from the size of the vessel in which the powder is fired. For example: if in two vessels, of unequal sizes, two equal quantities of powder be burned, the fire in the smallest vessel, being most intense, accelerates the destruction of each grain, and all the powder is consumed in less time than in the larger vessel. The same circumstance occurs, when two equal quantities of powder are burned in vessels of equal size; one of which resists the action of the powder, and the other bursts at the beginning of the explosion: the heat being more intense in the vessel that resists than in the other, the destruction of each grain is accelerated.

71. To prove that the inflammation of powder in fire-arms of all calibres depends on the density of the air contained between the grains, and the degree of fire that surrounds them, (69.) let a musquet or pistol barrel be filled with powder to four or five diameters; let a small wad, made of a substance not easily combustible, be lightly compressed upon the powder; and let the piece be fired into a vessel made

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on purpose to receive the discharge: a certain number of grains will be found unfired; let these be collected and weighed. If this experiment be repeated several times, with the same piece, and with the same quantity of powder of the same quality, and the piece be suffered to cool after each discharge, the number of unfired grains will be always nearly the same. Instead of repeating the experiments with the same piece, let two or three, of the same calibre, but the lengths of which are in the ratio of 1, 2, 4, be charged with the same quantity and quality of powder, and fired as above, the same number of unfired grains will be found in the vessel; which proves that the additional length does not contribute to the inflammation of a greater number of grains, provided that the experiments be made with dry powder, and in a very dry day. These effects equally take place in musquets or cannon: for if a thirty-two-pounder be charged with 8lb. 5oz. of powder, carefully collected together in the chamber, and lightly compressed with a wad, and the gun be fired horizontally upon hard snow or ice, a great quantity of dirt will be found before the muzzle of the gun, but hardly any unfired grains of powder; but if the gun be fired with 25lb. of the same powder, a number of unfired grains will be found: again, with 50lb. of powder, the number of unfired grains scattered upon the snow will be greater. It evidently results, from these experiments, that in all fire-arms the quantity of powder that burns is limited. It now only remains to be proved, that this proceeds from the intensity of the fire, and the density of the air contained between the grains; and that when these causes vary, the quantity of powder that is burned in the same piece varies also, though the charges be equal.

72. When one of the barrels is charged with the same quantity of powder, of the same quality, if a very high wad be rammed on it, or the resistance to the explosion considerably increased by any other method, after the discharge, fewer unfired grains will be collected. This not only corresponds with the result of former experiments, (46.) since the degree of fire is increased by the resistance, but serves to confirm the progressive inflammation of the grains. But it should be remarked, that the increase in the quantity of powder that takes fire is not always proportional to the increase of the resistance; for, under some circumstances, a slight
resistance

resistance causes a more intense fire than a much greater one does in others.

The experiments made with the machine described in the third figure, prove that a difference in the density of the air between the grains produces varieties in the quantity of powder that takes fire; the following simple experiment will further confirm it. Let a musquet be charged with a full quantity of powder, with a single wad, and fired into a large vessel, when the air of the atmosphere is very dense and dry; let it be again charged precisely in the same manner, and fired when the air is rarefied, as it is sometimes in summer, at two or three o'clock in the afternoon; and, to render the effects more striking, let the barrel be heated by exposure to the sun. If the powder, after each discharge, be collected and weighed, a much greater number of unfired grains will be found after the second than after the first: now the only difference between them being in the density of the air contained between the grains, it is evident that this must be the sole cause of the varieties that take place. The decrease in ranges, observed in very hot weather, or when the guns are much heated by preceding discharges, ought not to be attributed to the less elasticity of the air, since its action, compared to that of the elastic fluid generated from powder, is hardly sensible; the true cause is the rarefaction of the air, whence less powder takes fire.

73. The size and position of the vent render this property of powder subject to other varieties. On firing two pistols, of the same calibre, but the vent of the one larger than that of the other, fewer unfired grains will be found in the vessel from the former than from the latter. The same circumstance occurs when the vent of the one is situated at a greater distance from the bottom of the bore than the vent of the other, though they be equal in size.

74. The charges that at each elevation produce the longest ranges, depend also upon this property of powder. It is necessary to vary the charges according as the density of the air contained between the grains differs, as the elevation is altered, or as the atmosphere is more or less loaded with vapour. Thus it constantly happens, that on firing at the same time two pieces of the same calibre, but of unequal lengths, the vents of which are of the same size and in the same position; the charge which in the longest piece gives the longest range, gives it equally in the shortest piece; provided

vided that the two longest ranges of the two pieces, when compared together, be unequal.

75. In seeking the charge that gives the longest range, it will be found that by using small charges at first, and increasing the quantity of powder by degrees, the ranges will increase to a certain point; after which, if the charge be augmented, they will progressively diminish; though the recoil will still continue in the ratio of the increase of the charge. This is a consequence deducible from the foregoing experiments, and agreeable to the principles of mechanics; since the recoil and the range ought to be in the reciprocal ratio of the gun and the shot, making allowance for the resistance which these bodies meet with. Thus, when all the powder explodes, the recoil and the range ought to be in the above ratio; but when a part only takes fire, the burning powder must not only impel the wad and the shot, but also the unfired grains. Now the substances impelled towards the muzzle of the gun being in greater quantity, the weight approaches nearer to the weight of the gun, which always remains the same, and the range is consequently diminished.

76. The following experiments will prove the third property of powder in fire-arms of all calibres. (70.) Let a gun of any nature be taken, and, to simplify the experiment, be charged with such a quantity of powder as will all explode: on examining the ranges from two equal charges of powder, of the same quality, but of differently sized grains, as cannon and musquet powder, it will be constantly found, *ceteris paribus*, that the range produced from the musquet powder is much longer than that from the cannon powder. Now as the action of fired powder depends on the elastic fluid, the shot, in the longest range, must necessarily have been impelled by a greater quantity of this fluid: but it has been demonstrated, (57.) that from equal charges of cannon and musquet powder, equal quantities of the elastic fluid are generated when they are totally consumed; wherefore, in this case, all the fluid is not generated in the time that the shot is moving along the bore of the gun, and consequently we may conclude that its generation is progressive. A comparative trial of all other kinds of powder that have the same proportion in their ingredients, and differ only in the size of the grains, gives a similar result: whence it is clear, that each grain is consumed progressively in pieces of all calibres; and

and that the only variation consists in the length of time from the first instant of its inflammation till its final consumption.

77. Some artillerists, from the intense heat excited in a piece of ordnance at the instant of explosion, particularly with large charges, conceived that all the powder must be consumed before the shot begins to be in motion; but it having been already proved (71, 72.) that the quantity of powder that burns is limited, it will suffice to shew, by a conclusive experiment, that the inflammation and destruction of each grain is progressive. It is well known that fine war powder is much stronger than musquet powder; and that, on firing equal quantities of these powders from the same piece, the former will give the longest range: but if of the same paste from which the former powder be made, grains four or five times larger than those of the musquet powder be formed, and the difference of the ranges between this large grained powder and musquet powder, fired in equal quantities from the same gun, be remarked, the ranges from the latter will be found much longer than from the former; consequently the shot must have been impelled by a greater quantity of the elastic fluid. But the large grained powder, if totally consumed, should produce the same quantity of fluid as the fine war powder, which was found to produce more of it than an equal quantity of musquet powder. In this experiment, therefore, all the fluid is not disengaged from the large grained powder, and the destruction of each grain is progressive, as the charge is so proportioned, that the whole should take fire in the gun.

78. This progressive destruction of each grain is never totally effected within the bore of the gun, in the charges at present in use; for, independent of the above observations, fire is always seen to issue in great abundance from the muzzle of the gun, which could never happen if all the powder were consumed before the shot began to move.

79. Upon this third property of powder in some measure depends the difference of ranges in two guns of unequal length, but of the same calibre, charged with equal quantities of powder of the same quality. The reason why the shot from the longest piece ranges farthest, is not only because it is impelled for a longer time by the fluid, but also because a greater quantity is generated during that time. But shot from long pieces only range farther when at quit-

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ting the gun they are still impelled by the elastic fluid; or, in other words, when arrived at the mouth of the piece, their velocity is less than that of the fluid itself.

80. The action of the elastic fluid on the shot in moving along the bore of the gun is so powerful at the beginning of the movement, that the range from a small charge sometimes equals, and even exceeds, that from a larger charge, though they both take fire before the shot begins to move. This is owing to the small charge occupying a less space of the bore; whence the shot is longer impelled by the fluid, as it has a longer space to move through in the gun. To elucidate this, let an experiment be made with a gun a diameter and half of its shot in length; the ranges, or the penetrations of the shot into soft earth, will be greater when the charge occupies half, than when it occupies a whole diameter. Thus the decrease of range in a piece of ordnance that is overcharged arises not only from the greater weight of matter to be impelled by the fired powder, but also from the less space that the shot has to pass through in the piece, and the less impulsion of the elastic fluid.

81. From these premises, it will be easy to explain, why, in fire-arms loaded in the common manner, only a certain quantity of powder can take fire.

There are two actions to be distinguished in the fluid generated at the burning of powder; of fire, and elasticity. As the fluid separates, and disengages itself from the burning grains, it carries off with it different inflamed combustible particles; the degree of fire is then weakened, as much from its expansion, as from the extinction of the flame, owing to the destruction of these combustible particles: wherefore the fluid, at a certain distance from the burning grains, does not contain heat sufficient to inflame other grains; but its elasticity, though weakened by the decrease of heat, does not cease to act against the sides of the containing vessel. Now as the inflammation of powder in fire-arms commences at the vent situated at the bottom of the bore, there is generated from the first grains an elastic fluid, which insinuates itself into the interstices of the other grains; but the more this fluid expands, and the combustible particles mixed with it are destroyed, the heat becomes less intense, and unable to fire the grains more distant from the vent: but a fresh fluid is successively generating, and inflaming those which the first produced fluid had not power to inflame; the quantity of the
fluid,

fluid, and the intensity of the heat, increase by degrees, till the wad and shot begin to move. From this instant of movement the space containing the fire, the fluid, and the unfired grains, enlarges; and though fresh fluid is continually generating, yet, as the fire does not increase in proportion as the space which contains it is enlarged by the removal of the wad and shot towards the mouth of the gun, the unfired grains will not be inflamed; as, from the rarefaction of the air, the fire is not sufficiently intense. Hence we may conceive why, in moderate charges, properly wadded, the fluid has sufficient elasticity to force out the wad and shot, and, at the same time, heat enough to fire all the grains; and why, in charges that are too large, and wadded in the same manner, the heat is not intense enough to inflame the grains that are distant from the vent, while that its elasticity is sufficient to overcome the resistance of the shot and wad, and put them both in motion.

82. It may be concluded from the preceding observations, that the form of the vessel in which powder is burned has no influence on the force of the elastic fluid. Indeed, as the powder may be more compact in one form of chamber than in another, the fire, in spreading itself from the vent with more rapidity, may inflame more grains; thus a greater quantity of the fluid may be produced in equal times, but the absolute force of an equal portion of it will not be increased. Mortars with spherical chambers give the longest ranges; because, of all the different forms, of equal contents, in which chambers can be made, the spherical has least superficies, as may be demonstrated geometrically; all the powder, therefore, is nearer to the vent in this chamber than in any other.

83. As the properties of fired powder are the same in fire-arms of all calibres, in proportion to the compactness of the charge around the vent, the resistance opposed to its explosion, and the variation in the density or moisture of the atmosphere; it is evident that, in firing equal quantities of powder of the same quality, at different times and places, different effects will result. If the state of the air be altered, both with respect to density and moisture, the ranges will be sensibly shorter, as the successive inflammation of the grains will be slower: this frequently occurs when cannon are fired over the sea, lakes, or marshy grounds, from which there is a strong exhalation.

It will be shewn, in the second part of this treatise, that the initial velocity of a musquet bullet, in a very moist day, is to its velocity, with an equal charge, in a dry day, as six to seven.

84. It might be supposed, that experiments made at different times and places, with mortars constructed with the same proportions, and from the same model, might be conclusive in proving the comparative goodness and force of different powders; but the contrary is the case: for, independant of the varieties ensuing from alterations in the state of the atmosphere, there will inevitably be a difference in the construction of the mortars, in spite of the utmost precaution of the founder. These differences, or inequalities, though scarcely discernible, will nevertheless greatly affect the range; even if the mortars are fired from the same spot, in the same position, and with all other circumstances as nearly corresponding as possible.

85. To ascertain the goodness and force of powder, by proving it with a mortar—

1. Fire some rounds with a particular powder, made with the greatest exactness, called *proof powder*; then fire the same number of rounds, from the same mortar, charged with an equal quantity of the powder to be proved, which should be of the same kind as the *proof powder*: if the ranges be equal, the force and goodness of the powder is ascertained. It signifies little whether the *proof powder*, provided that it be in good preservation, has at other times given longer or shorter ranges; since this comparative trial proves that the two powders are of equal force.

2. Before the proof, the two powders should be exposed to the sun for some time; (63, 66.) and the proof made on a day when the air is clear and serene.

3. To lessen the varieties that any alteration in the rarefaction of the air might occasion in the inflammation of the powder, or the resistance of the shot, the two powders should be fired as nearly at the same time as possible, and in small quantities, that the whole charge may take fire: wherefore, if the chamber be cylindrical, as it commonly is in *proof mortars*, and the vent situated at the bottom, the charge ought not to exceed one diameter of the chamber; though a larger quantity might take fire, if the powder be of sufficient strength.

4. The

4. The mortar should be firmly fixed in a heavy bed, that the machine may not be deranged by the explosion, and laid at 45° ; the shot should be of equal weights and diameters, with the centre of the figure corresponding with the centre of gravity: without these precautions, the result of the experiments cannot be depended upon.

In this manner the goodness and force of powder may be with more accuracy ascertained, than by any other method yet invented: for complicated machinery is subject to numerous accidents; many of which are avoided by fixing the mortars so solidly and firmly in their beds, as to form as it were but one simple machine.

CHAP. V.

OF THE CHARGES THAT GIVE THE LONGEST RANGES.

86. **T**O ascertain the charges that give the longest ranges, has ever been one of the chief objects of research among artificers; it is to be deduced from the second property of powder, and can only be known by experiments made in particular cases. Having proved, in the preceding chapter, that the second property of powder has effect in all fire-arms (47, 71), and that the quantity which takes fire is in proportion to the resistance to the explosion, the density of the air contained between the grains (72, 74), the size and position of the vent, the form of the chamber, and the state of the atmosphere (82), it is impossible to fix invariably the charges for giving the longest ranges; the utmost that can be done, is to establish rules adapted to certain determined circumstances: and, in order to render them useful and conclusive, they should be deduced from experiments made with guns of the same calibre with those of which the proper charge is sought, and the common mode of firing should be observed.

87. In these experiments two objects are principally to be had in view:

1. To find the charge which, of all others under similar circumstances, will with powder of the same quality produce the longest range,

C

2. To

2. To ascertain the greatest quantity of the same powder that takes fire in the piece, fired precisely in the same circumstances. This distinction must be carefully observed.

It has been demonstrated, in speaking of short guns (80), that when the greatest number of grains take fire, the range is not always the longest: Now it is easy to extend this demonstration to pieces of all lengths. To suppose that the charge is entirely converted into elastic fluid before the shot begins sensibly to move from its place, and that the fluid preserves constantly the same degree of heat, is to consider it as liable to no other modification than expansion as it passes along the bore of the gun, which is proved to be false in the experiments related in the Philosophical Institutions. It is there shewn, that the longest range is obtained from a charge that occupies about $\frac{1}{27}$ of the length of the bore, and that all other charges give shorter or longer ranges according to their deviation from this proportion. Thus the experiments made with the powders described (40), far from invalidating the former conclusion, on the contrary confirm it; by proving, that in fire-arms overcharged with powder, and the shots and wads rammed as usual, all the grains do not take fire, and that all the elastic fluid is not generated before the shot issues from the mouth of the piece. Whence on comparing two unequal charges of cannon powder, the smallest of which is entirely consumed in the piece, while the larger is only consumed in part; it will be seen, that though the longest range might be expected from the largest charge, as more of it may take fire; yet conclusions entirely opposite may be drawn from practice: whether it is, that the unfired powder increases the weight of the substances to be impelled; or whether from the quantity of the charge, the space through which the shot should pass is too much diminished. Since, then, in spite of the inflammation of a greater number of grains, these large charges do not always give the longest ranges, and they uselessly increase the consumption of powder, and shatter the carriages; our principal object should be to determine precisely the charge which, of all others under similar circumstances, will give the longest range in pieces of all calibres.

88. There are three methods of determining experimentally the charge that impels the shot with the greatest force, and of course gives the longest range.

1. By

1. By finding the initial velocity of the shot near the mouth of the piece.

2. By firing against a butt penetrable and homogeneous, in which may be measured the penetrations of the shot.

3. By measuring the length of the ranges.

The last method is the most complex, and gives approximations least exact; as several circumstances may concur to impede the motion of the shot, and alter its direction; but, as it is most common in practice, we will first examine it. The investigation of the others will lead us to the solution of several very important problems.

To find the charge that gives the longest range—

1. Fire several rounds from the same piece, under circumstances as nearly similar as possible, with shot of the same kind, and with wads rammed with the same force as is generally employed; in a word, with no other difference than in the quantity of powder.

2. Continue firing till a charge be found, any increase or decrease of which gives shorter, or at least equal ranges.

3. Alter the elevation of the guns, and fire several rounds in each position, till the proper charge be found.

Impressed with a necessity of adhering to these principles, and anxious, at the same time, to avoid a prolixity that could add nothing to the exactness of the conclusions, the officers of artillery at TURIN, in making the following experiments, laid the gun, at first, horizontally, and afterwards, at the highest elevation the carriages would admit of.

89. The experiments began the 7th of February, and terminated the 30th of March, 1746. They were generally carried on in moderate weather, and in the afternoon. Several rounds were fired from each piece, with equal charges. The guns were mounted on a part of the fortifications of the city, where the axis of the piece was thirty feet higher than the level of the country where the shot fell. In the direction of the range a line was traced, and pickets fixed in the ground at every hundred feet; and, to prevent all possibility of mistake, each picket was numbered. To the right and left of the ranges, men were posted to mark exactly the spot where the shot first grazed; while the officers made the necessary observations upon the guns, which moved freely upon a solid horizontal platform, twenty feet in length, and ten in breadth. The guns were four, eight, sixteen, and thirty-two-pounders; and those

which had the bore cylindrical, and the vent situated at the bottom, were constructed according to the proportions laid down in the First Book of Artillery.

| Nature of Guns. | | Length of Bore. | | Weight. | | |
|-----------------|-----------|-----------------|---|---------|----|-----|
| Pounders. | Calibres. | | | Cwt. | q. | lb. |
| 4 | — | 27 | — | 9 | 1 | 9 |
| 8 | — | 27 | — | 18 | 2 | 10 |
| 16 | — | 23 | — | 31 | 3 | 26 |
| 32 | — | 20 | — | 57 | 2 | 17 |

They were fired on their carriages, and loaded with the ladle: the powder was the common-grained cannon powder; four strokes of the rammer were given to the wad over the powder, and three to that over the shot, by the same gunner, and as nearly as possible with the same force. The wads were of twisted hay, properly gauged; the shot were weighed, to see that they were exactly equal in weight; and the windage was in the ratio of twenty to twenty-one.

The guns being loaded, and pointed along the range, were fired with the axis always horizontal; which was ascertained by the pendulum and water-level. After each discharge, the length of the recoil was measured; the wheels were placed in the same position, between lines, to prevent the slightest difference. The coins placed under the breech were marked before the discharge; and if moved by the shock, the experiment was not considered as exact.

These precautions being taken, the smallest charges were used at first, and increased gradually till the ranges began to diminish: three rounds, at least, were fired with each charge. The charge that gave the longest range having been ascertained by repeated firings, the principal object was, during the last five days, to remark what alteration might arise from any change in the state of the atmosphere; with this view, the same gun was fired each afternoon, with the charges marked in the following table. For example, from the four-pounder three rounds were fired, with each of the charges of 1 lb. 4 oz. 1 lb. 10 oz. 2 lb. 1 oz. of powder: the following day, from the eight-pounder three rounds were fired, with the charges of 2 lb. 7 oz. 3 lb. 5 oz. and 4 lb. 2 oz. of powder. In like manner the sixteen-pounder was fired on the third, and the thirty-two-pounder on the fourth day. At length, to form a comparison of the ranges of the different guns, on the fifth day the four and eight-pounders were fired, with charges equal

equal to half the weight of their shot: the charges of the sixteen and thirty-two pounders were equal to $\frac{1}{3}$ of the weight of their shot. The following table will shew the result of the experiments during the five days.

| Nature of Guns. Pounders. | Weight of Powder. lb. oz. | Length of Range. Yards. | Recoil. Inches. |
|---------------------------------|---------------------------------|-------------------------------|--------------------|
| 4 | 1 4 | 478 | 43 |
| | 1 10 | 489 | 62 |
| | 2 1 | 472 | 72 |
| 8 | 2 7 | 512 | 45 |
| | 3 5 | 532 | 64 |
| | 4 2 | 532 | 82 |
| 16 | 3 5 | 505 | 42 |
| | 4 6 | 526 | 55 |
| | 4 15 | 522 | 78 |
| 32 | 6 9 | 485 | 54 |
| | 8 12 | 492 | 71 |
| | 9 13 | 489 | 82 |

90. These experiments having been made with the greatest accuracy, we may conclude, that in cannon fired under similar circumstances, the charge of powder which will give the longest range, is equal to half of the weight of the shot in four and eight pounders, and to $\frac{1}{3}$ of its weight in sixteen and thirty-two pounders; and moreover draw the following inferences with respect to two important effects which constantly appear.

1. The recoil always increases in proportion to the augmentation of the charge, that the length of the range increases to a certain point, and afterwards decreases in a much less ratio than the recoil increases.

2. That the charge which gives the longest range in pieces of small calibre, is proportionally larger than in pieces of large calibre.

91. The following experiment will explain the cause of the first effect (90, No. 1.): Charge any piece of ordnance with the greatest quantity of powder that will all take fire without a wad; after the discharge mark the recoil: use again the same quantity of powder, with a wad strongly rammed on it; the length of the recoil will be greater than at the first discharge: fire a third round with the same charge

well wadded, with the addition of a shot and wad over it; the length of the recoil will be again increased. At length, with similar charges and wads, and, instead of one, putting two or three shot into the gun, the recoil will increase in proportion to the number of shot, and the range will diminish.

92. We may easily apply this fact to the experiments of 1746.

It has been proved (71 75), that only a limited quantity of cannon powder takes fire: thus, till the charge be so proportioned as to be all fired in the piece, a greater quantity of elastic fluid is generated in proportion to the largeness of the charge. Now considering the gun and its carriage taken together as a constant quantity termed C, and the substances impelled towards the mouth of the gun, viz. the two wads and the shot, as P; the length of the range ought to be to the length of the recoil as C : P, without making allowance for friction and the resistance of the air to the motion of the shot. But as the space that the shot should move through in the piece is diminished in proportion as the charge is increased, and the *vis motrix* consequently acts upon it for a shorter time; the decrease of impulsion must be deducted from the action of the elastic fluid generated in greater quantity as the charge is larger: Hence it results, that the ranges are proportionally shorter than the recoil, though they both increase as the charge is augmented.

But if the charge be so augmented, that a part I arrives at the mouth of the piece without taking fire, then the substances to be impelled being in greater quantity, the same circumstance that occurs when several shot are put into the piece will in part occur here. As no more grains will be fired, than if the charge were smaller and all ignited, the shot will acquire less velocity; but the reaction against C increasing at the same time, the recoil will be greater than before. The substances P + I forced towards the mouth of the piece, presenting to the explosion of the elastic fluid a greater resistance than P alone, and the number of ignited grains and the quantity of fluid generated during the time that the shot is moving along the bore being more considerable, the absolute increase of fire acting against the gun and carriage must also augment the recoil; while the range may be shorter, equal, or longer, than that produced by a charge that is entirely consumed in the gun, in the ratio that the increase of fluid bears to the substances P + I, and to the space that the shot has

has to move through in the piece. This shews clearly, that *the ranges or the initial velocities of shot impelled from guns are proportionally less than the recoils*, and that if the charge be augmented to a certain point, the ranges will diminish, while the recoils will increase.

93. Thus, very large charges should never be used in the service of artillery, as the ranges from them are shorter, or at most but equal; and beside the uselefs expenditure of powder, the carriages are soon rendered unserviceable, and the greater part of the shot are of no effect.

94. The causes of the recoil merit a more particular examination. There are two motions in the breech of a gun, at the instant of discharge; one up and down, by which it sinks into the coils, and sometimes throws them upon the ground, if too obtuse or improperly placed: this reflected movement of the breech takes place when the center of gravity of the gun is too near to the axis of the trunnions, or when the coils are made of too elastic a substance. The other is an attempt to retire with all the machine in a direction opposite to that of the movement of the shot, which is termed the recoil.

95. The better to understand the cause of this double motion; let a resisting vessel, in which powder takes fire, be supposed to have the vent stopped at the beginning of the inflammation, no motion will in this case be perceived, because the elastic fluid, pressing equally upon the sides of the containing vessel, and all the parts having a mutual attraction, its powers are in equilibrio: the balloon inflated with air is a very simple demonstration of this.

96. But if the elastic fluid can escape through an aperture made on purpose, or through a cleft caused by its action on the sides of the vessel, it will be impelled in a direction opposite to the aperture, with a force proportionate to the density and velocity of the fluid. For the elastic fluid in escaping meets resistance from the external air, and impels it and the vessel in opposite directions; and if the vessel itself be not equal in weight to the action of the fluid, it will be put in motion: since the column of air which resists this motion, and tends to preserve the vessel in a state of rest, will not be able to prevent it; (its resistance being proportional to the velocity of bodies moving in it:) the greater the velocity with which the fluid rushes out, the greater will be the resistance, and the longer the recoil: a number of experiments

might be adduced in support of this, but the common sky-rocket fully exemplifies it.

97. When fire is introduced into the vent of a gun, the action of the breech against the coins is in proportion to the density of the elastic fluid in the charging cylinder: now as the wad and shot cannot move before there be a sufficient quantity of the fluid generated to overcome their resistance, and force out the column of air from the bore of the gun; if the wad be too strongly rammed, or a part only of the powder take fire, or more than one shot be put into the gun, or it be more elevated at one discharge than another, the resistance to the fluid being increased by one or more of these causes, a greater quantity must be generated before the shot and wad will be moved. Before this motion commences, there can be no recoil (95), for the shot and wad form, as it were, a part of the gun itself: wherefore, if so large a quantity of substances be put into a gun, as totally to prevent, by their resistance, the escape of the elastic fluid, there will be no other movement in the piece than that of the breech up and down against the coins; which might, if necessary, be more fully demonstrated. Moreover, since a part of the elastic fluid escapes through the vent during the time of its generation in the charging cylinder, it is clear, that the action of the breech against the coins in the opposite direction, must commence as soon as the powder takes fire, but the recoil will begin sooner or later according to the resistance opposed to the explosion.

98. Hence, if the movement of the breech up and down has not totally ceased before the shot quits the gun, it may be thrown above or below the point aimed at. When the wheels are of unequal diameters, or not placed in the intervals of the corresponding lines and nails, or the platform on which the gun moves while the shot is passing along the bore, is not even and solid; in all these cases, the gun will not recoil in the proper direction, and the shot will be thrown wide of the mark.

99. The length of the recoil during the time that the shot is passing along the bore varies according to circumstances. If the charge, for instance, be rammed in the common method, and the gun placed on an even horizontal platform, the elastic fluid must exert more force to move the charge than to move the gun; as is the case in using the wad-hook to draw out the charge, the gun being drawn forward before

before the wad is displaced. If, on the contrary, part of the platform be raised, the same force that will draw out the wad will not be sufficient to draw the gun up the inclined plane. Similar varieties occur in the recoil, when the elevation of the gun is altered, or the wheels turn more freely on the axle-tree.

To give to this question a practical solution, with respect to charges that all take fire in the gun; let the gun and carriage be considered as one body = C, the wads and shot = P, the length of the bore from the shot to the muzzle = D, the

recoil will be = $\frac{PD}{C}$. Let one round be fired with a wad

over the powder, and the recoil = A. Let a second be fired with the addition of a shot, the recoil = B will be greater

than A; and $A : B :: \frac{PD}{C} : \frac{BPD}{AC}$ = the length of the recoil

in the time that the shot is passing along the gun. This experiment having been made with a thirty-two pounder, charged with common powder, and fired horizontally on a

horizontal platform $\frac{BPD}{AC} = \frac{1}{2}$ an inch. So that if the plat-

form be very solid and even for $\frac{1}{2}$ an inch, at the spot on which the wheels and trail of the carriage rest, the remainder of the platform is only useful in facilitating the operations

of the artillery-men: indeed, as the value $\frac{BPD}{AC}$ may from

circumstances vary a little, allowance should be made for it.

100. Let the second effect (90. N^o 2.), viz. that *the charge which gives the longest range in pieces of small calibre, is proportionally greater than the charge which gives the longest ranges in pieces of large calibre*, be now considered.

This effect, which constantly appeared in the foregoing experiments, could only proceed from the size of the vent being equal in the four guns, and from the wads being rammed with the same force. From the former circumstance, a relatively greater degree of fire is produced in the small guns;

and from the force with which the wads are rammed, the powder is more compact, and the charge adhering closer to the

the

the sides of the gun, the resistance is increased, and more grains are fired.

101. In the spring of 1750, the officers of artillery being directed to investigate some professional points under the orders of the Chevalier FERRERO DI PONSIGLIONE, made several experiments to find the charge that gives the longest range, when the piece is fired at the highest elevation the carriage will admit of. The guns were of the same calibre and proportions as in 1746, only the shot being rather larger, the windage was less. They were loaded with the ladle with different charges of common grained cannon powder: three rounds were fired from each gun with the same charge; the same artillery-men gave five strokes of the rammer to the wad over the powder, and three to that over the shot; the guns on their carriages, moving freely upon a horizontal platform were always laid at the same elevation, and every precaution was taken to load them equally; and measure exactly the length of the ranges, upon a flat piece of ground nearly on the same level with the battery.

Result of Experiments made in the Spring of 1750.

| Nature of Guns. | | Weight of Powder. | Length of Range. | Recoil. |
|-----------------|------------|-------------------|------------------|---------|
| Pounds. | Elevation. | lb. oz. | Yards. | Inches. |
| 4 | 14° | 2 1 | 2375 | 52 |
| | | 2 8 | 2219 | 60 |
| | | 2 14 | 2422 | 70 |
| | | 3 5 | 2526 | 76 |
| | | 3 5 | 2321 | 46 |
| 8 | 11° | 4 2 | 2463 | 65 |
| | | 4 15 | 2486 | 85 |
| | | 5 12 | 2375 | 102 |
| | | 6 9 | 2675 | 119 |
| | | 5 12 | 2659 | 71 |
| 16 | 12° | 6 9 | 2860 | 76 |
| | | 7 3 | 2663 | 90 |
| | | 8 3 | 2810 | 97 |
| | | 9 0 | 2764 | 108 |
| | | 9 13 | 2892 | 113 |
| 32 | 11½° | 11 8 | 3172 | 117 |
| | | 13 2 | 3032 | 120 |
| | | 14 6 | 2995 | 124 |
| | | 16 6 | 3220 | 146 |
| | | 18 0 | 3084 | 168 |

102. It

102. It results from these experiments, that the charges that give the longest ranges when cannon are fired at the highest elevation their carriages will admit of, are greater than those which produce the same effect when fired horizontally (89). But the ranges do not increase in the regular progression that might be expected. For instance, in the sixteen pounder, the charges of 5 lb. 12 oz. and 7 lb. 3 oz. gave ranges nearly equal, while 6 lb. 9 oz. gave one much longer. These irregularities proceed from the different charges not having been fired on the same day; the 5 lb. 12 oz. were fired the 23d of March, the 6 lb. 9 oz. the day following, and the 7 lb. 3 oz. on the 1st of April; if they had been fired on the same morning, the modifications in the explosion of the powder, and the air's resistance to the shot, resulting from the alterations in the state of the atmosphere, would have been avoided: in the 4th and 5th chapters of the second part, this matter will be more fully discussed.

On repeating these experiments with such precautions as to avoid the modifications arising from changes in the state of the atmosphere, the charges (101) that give the longest ranges will be found to be almost double of those used in 1746; but the increase of range is of little importance compared to the increase of the recoil, and the greater shock sustained by the carriage; these large charges should never be used for common service.

103. In experiments of this kind, a remarkable inequality between two ranges from equal charges of powder will occasionally occur, though every precaution be taken to fire them under circumstances as nearly similar as possible. These inequalities were neither so frequent nor considerable in 1746 as in 1750; but it is impossible totally to avoid them, for supposing the direction of the guns to remain unaltered at the explosion, yet there are two causes which separately or conjointly may render the ranges from equal charges of powder unequal.

1. The shot in passing through the plane of the gun, may not exactly follow the direction of the bore; or on quitting the gun, it may take a different direction.
104. 2. The powder may not be equally well collected in the piece, so that charges though equal in quantity, have not the same figure: large charges are more liable to this accident than smaller ones, particularly when rammed

rammed with the same force. In this case the quantity of powder fired in the larger charge, varies in proportion to the disposition of the grains to inflammation; for instance, in guns laid above the horizon, more powder ought to take fire, as the resistance to the explosion is greater. The larger the charges, the more frequent are the inequalities in the ranges independent of the violent concussion of the carriages.

105. Wherefore, the two extremes of very large or very small charges should be equally avoided; for the first does not compensate for the uncertainty of their ranges, or the great increase of recoil, by the additional velocity and force given to the shot: and with very small charges, the least difference in the size of the wads or ramming, causes a great alteration in the impulsion of the shot and ultimately in the range; as is often seen in ricochet-firing, and in mortars loaded with small quantities of powder.

106. This object of ascertaining the charges that give the longest ranges, has engaged the attention of the French, as well as the Piedmontese artilleryists; and the result of their experiments appears to be, that in cannon of large calibre, the charge ought to be about $\frac{2}{3}$ of the weight of the shot.

The knights of Malta, on seeing the report of the French experiments, were induced to direct Sig. MARANDONE, engineer of the order, in the month of August, 1747, to repeat them. He sent to the regiment of artillery at Turin a detail of his practice, and asked the opinion of the officers on the conclusions to be drawn from it. Having observed, that on using larger charges than $\frac{2}{3}$ of the weight of the shot, the ranges still increased proportionally; he did not think it necessary to pursue his experiments for finding the charge that would give the longest range; and judging that the French powder was weaker than his, he concluded that when cannon of a large calibre are charged with a stronger powder than the French use, the charge which ought to produce the longest range, must exceed $\frac{2}{3}$ of the weight of the shot: this conclusion is conformable to our theory, and the results of our practice.

It is clear then, that the artilleryists in former days, consumed a superfluous quantity of powder, in making the charge equal to the weight of the shot: it even sometimes exceeded it, as their powder was much weaker than that now in use,

107. The charges we have laid down as giving the longest ranges (89, 102) are under similar circumstances, the same in all guns of the same calibre, whatever be their length; since the increase of length does not generally cause the inflammation of a greater number of grains (71) the charge which in one gun will give the longest range will give it equally in a shorter one of the same calibre: very short guns are indeed an exception to this rule; for in them the action of the elastic fluid upon the shot in two unequal charges that all take fire, is at least equal, or even greater, in the smallest charge; as the shot having a greater length of the bore to pass through (80) is longer impelled by the elastic fluid.

108. It only then remains to ascertain the best charges for service; we should previously recollect, that the great utility of fire-arms consists in two points: the first and principal one is, to strike the object aimed at; the second is, to strike it with a due degree of force. The first is ever indispensable; the second admits of certain modifications: for the greatest force that fire-arms can produce is not always requisite; and even when it is (Philos. Infit.) it is better to diminish the charge, and lessen the effect of the shot, than run the hazard of missing the object, from the uncertainty of using very large charges; this needs no illustration. Beside, brass guns fired frequently with large charges are in a few days rendered unserviceable; wherefore the advantages and disadvantages attending the use of them should be fully weighed, as upon the preservation of the guns may entirely depend the success of an enterprise.

109. To apply these considerations to practice, and combine the justness of the range with the necessary force, and with the preservation of the gun and carriage; the charges of powder for sixteen and thirty-two pounders, ought never in the attack and defence of places to exceed half of the weight of the shot, if the gun be properly proportioned (89) and fired at the distances set down in the second and third book of Military Architecture, and the Treatise of Artillery; this we will call the largest service charge, and should only be used in cases of necessity: the smallest service-charge should not be less than $\frac{1}{4}$ of the weight of the shot, and the medium charge $\frac{1}{2}$ or $\frac{3}{8}$ of its weight.

The charge for eight and four pounders should vary according to circumstances, from $\frac{1}{2}$ to $\frac{3}{4}$ of the weight of the shot; the wads in these pieces and in thirty-two and sixteen pounders,

pounders, should be rammed in proportion to the weight of the charge, in order to produce the proper effect; perhaps too much force cannot be used, provided that the grains of powder are not crushed and beat so close as to prevent the fire from penetrating. The charge for ricochet and red-hot firing, is very small in proportion to the calibre; it depends in sieges on the situation of the gun, as the distance from the enemies batteries is the only point to be considered. The charges for field artillery in general actions, in affairs of posts, in attack and defence of intrenchments, &c. should be between $\frac{1}{4}$ and $\frac{3}{8}$ of the weight of the shot, according to the calibre and weight of the gun.

110. Though our observations have been hitherto confined to the proper charges for guns; yet those for mortars may be easily ascertained by knowing the quality of the powder, and the form of the chamber. All the mortars now in use, in which the communication between the chamber and the chase is narrower than the greatest diameter of the chamber, as the spherical, elliptical, parabolic, and those in form of a pear, always range the farthest, when the chambers are filled with the common cannon powder, and the shell closely confined by well sifted earth rammed upon it; it is clear in this case that the charge cannot be augmented. Beside the concussion is more violent, and the ranges are less exact, when the chambers are not filled; therefore, to throw a shell to a certain point, the chamber should be filled, and the range regulated by the degree of elevation.

111. We will conclude this chapter by shewing experimentally how much the difference in the size of the vent affects the force of the shot. A musquet was taken $\frac{5}{16}$ of an inch in diameter, and 33 inches in length of barrel. The axis of the large screw which closes the breech, was perforated with a hole $\frac{5}{16}$ of an inch in diameter, with spiral sides to receive a smaller screw; one end of the smaller screw was armed with a little piece of red hot iron, to set fire to the powder in the barrel; to the other end a winch was fixed to screw it up; at the part where the vent is generally placed, a circular hole with spiral sides was drilled $\frac{5}{16}$ of an inch in diameter, to which three screws were successively applied; the first exactly closed the opening, and consequently forced all the fired powder to pass through the muzzle. The second had in its axis a hole or vent $\frac{1}{16}$ of an inch in diameter, through which a part of the fluid might escape; and the third had a vent of $\frac{2}{16}$ of

of an inch in diameter. The musquet thus prepared was loaded each time with 10 drachms of fine powder put into cartridges, and with an iron ball $1\frac{1}{2}$ oz. in weight; the wads were rammed down with equal force by the same man.

The experiments began by firing the musquet with the screw that entirely closed the vent; it was then fired with the screw $\frac{1}{10}$ inch in diameter; afterwards with that of $\frac{2}{10}$, and at length without any screw. The charges were fired by the hot iron screwed into the breech: the object was a plank placed at 5 feet from the muzzle of the musquet.

The medium of the penetration of the balls in 24 rounds is as follows:

| | | <i>Inches.</i> | |
|------------------------|---|---|----------------|
| In the dif- charges | { | with the vent entirely closed - - - | 6 |
| | | with the vent $\frac{1}{10}$ of an inch in diameter - | 8 |
| | | with the vent $\frac{2}{10}$ of an inch in diameter - | $6\frac{1}{2}$ |
| | | with the vent $\frac{5}{10}$ of an inch in diameter - | 4 |

It results from this experiment, that when there is no vent less powder is fired, and that which does take fire burns more slowly. If the large vent be left open, and a sheet of paper stretched at 2 feet from it, the paper will be pierced full of holes by the powder forced through the vent at the explosion. Soldiers firing in line are often pricked in the face by grains of powder driven with force from the musquets on their left; the common opinion that these grains are a part of the priming is erroneous.

SECOND PART.

OF THE FORCE OF FIRED GUN-POWDER.

112. **I**T was shewn in the former part of this work that the principal properties of powder are subject to many modifications, even in experiments conducted with the utmost care. How much more important and frequent then must they be when powder is employed in military operations; where, from the nature of things, there can neither be so much attention paid to prevent irregularities, nor so much accuracy