



PHILOSOPHICAL
TRANSACTIONS.

XV. *New Experiments upon Gun-powder, with occasional Observations and practical Inferences; to which are added, an Account of a new Method of determining the Velocities of all Kinds of Military Projectiles, and the Description of a very accurate Eprouvette for Gun-powder.* By Benjamin Thompson, Esq, F. R. S.

Read March 29, 1781.

THESE experiments were undertaken principally with a view to determine the most advantageous situation for the vent in fire-arms, and to measure the velocities of bullets, and the recoil under various circumstances. I had hopes also of being able to find out the velocity of the inflammation of gun-powder, and to measure its force more accurately than had hitherto been done. They were begun in the month of July in the year

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1778,

1778, at Stoneland Lodge, a country seat of Lord GEORGE GERMAIN's, and I was assisted by the reverend Mr. BALE, rector of Withyham, who lives in the neighbourhood.

The weather proved remarkably favourable for our experiments, being settled and serene, so that the course of them was never interrupted for a whole day by rain or by any accident. The mercury in the barometer stood in general pretty high, and the temperature of the atmosphere was very equal, and moderately warm for the season. In order that each experiment might, as nearly as possible, be under similar circumstances, they were all made between the hours of ten in the morning and five in the afternoon: and after each discharge the piece was wiped out with tow till all the inside of the bore was perfectly clean, and as bright as if it had just come out of the hands of the maker; and great care was taken to allow such a space of time to elapse between the firings, as might render the heat of the piece nearly the same in every experiment.

A description of the apparatus.

The barrel principally used in these experiments was made by WOODON, one of the most famous gunsmiths in London; and nothing can exceed the accuracy with which it is bored, or the fineness of the polish on the inside. It is made of the very best iron, and, agreeably to Mr. ROBINS's advice, I took care to have it well fortified in every part, that there might be no danger of its bursting. Its weight and dimensions may be seen in the table of the weight and dimensions of the apparatus, p. 242.

Fig. 1. Represents a longitudinal section of a part of the barrel, with the apparatus first made use of for shifting the vent from one part of the chamber to another, or rather for moving
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the bottom of the chamber further from, or bringing it nearer to, the vent, in order that the fire might be communicated to the powder in different parts of the charge.

a, b, represent the lower part of the barrel.

c, is the breech-pin, which is perforated with a hole four-tenths of an inch in diameter, the axis of which coincides with the axis of the bore.

Into this hole the screw *b, n*, about four inches in length, is fitted; to the end of which, *n*, that passes up into the bore, is fixed a piston *o, p*, which, by means of collars of oiled leather, is made to fit the bore of the piece very exactly. The end of the piston *p*, nearest the muzzle, is of brass, and forms a moveable bottom to the bore, which by turning the screw *b, n*, by means of the handle *m*, is brought nearer to, or removed further from, the fixed vent *v*, by which means the powder is lighted at any assignable distance from the bottom of the charge.

But the length of the bore being altered by moving the piston, which occasioned a small inaccuracy, and some inconvenience attending the apparatus, it was laid aside, and another represented by fig. 2. was substituted in the room of it.

a, b, is a section of part of the barrel as before, and *c* is the breech-pin, which being perforated with a small hole through its center receives the screw *f, g*, which is about two-tenths of an inch in diameter, and four inches long. This screw being perforated with a very small hole, serves to convey the fire into the chamber of the piece, and by screwing it further up into the bore, or drawing it backwards, the fire is communicated to different parts of the charge.

But this method being found to be not intirely free from inaccuracies and inconveniencies, a third was substituted in the

room of it, which was found to answer much better than either of the preceding.

The end of the bore was now firmly closed by a solid breech-pin *p*, fig. 3. and three vent holes *m*, *n*, and *o*, were made in the barrel; one of them, *m*, even with the bottom of the bore, and the other two at different distances from it. Any two of these vent holes, as *n* and *o* for instance, being closed up by solid screws, a perforated screw, or vent tube *v*, was screwed into the third, which served to contain the priming, and to convey the fire to the powder lodged in the bore of the piece.

Sometimes a longer vent-tube, represented by fig. 4. was made use of; which, passing through the powder in the chamber of the piece, communicated the fire immediately to that part of the charge that lay in the axis of the bore.

Another vent-tube also was used occasionally, which differs in many respects from both those that have been described. It is so constructed as to convey the fire to the charge; but, as soon as the powder in the chamber of the piece begins to kindle, and the elastic fluid to be generated, the vent is firmly closed by a valve, and no part of the generated fluid is permitted to escape. This I shall call the *valve-vent*, and it is represented by fig. 5. upon an enlarged scale, that the parts of it may appear more distinct.

a, b, is a longitudinal section of a small portion of the solid side of the barrel.

c, d, is the vent-tube, which is in all respects like the short vent-tube commonly made use of, except only that in this the end of the vent-hole (*c*) which goes into the chamber is enlarged in the form of the wide end of a trumpet or funnel.

To this enlarged aperture the valve, *v*, is accurately fitted, and by means of the small stem or tail, *t*, which is fixed to the valve,

valve, and which passes up through the vent-hole, and is connected with the spring S, the valve is pressed, or rather drawn into its place, and the vent is closed. The stem of the valve was at first made cylindrical; but, in order to make way for the priming to pass down to the valve, one-half of its substance was taken away, as is represented in the figure.

When this vent is primed, the space between the vent hole and the stem of the valve is filled with fine-grained powder, and the valve is gently opened by pressing upon the end of the stem till one or more grains of powder lodge themselves between the valve and the aperture; which preventing the valve from closing again, a small opening is left for the passage of the flame into the chamber of the piece: therefore, when the priming is lighted, the fire passing down the vent, and entering the chamber, inflames the charge, and the small grains of powder that were lodged between the valve and the aperture being destroyed by the flame in its passage through the vent, the valve immediately closes, and prevents the escape of any part of the elastic fluid generated by the inflammation of the powder in the chamber of the piece. The pressure of this fluid upon the valve assists the action of the spring, by which means the valve is more expeditiously and more effectually closed.

The valve was very accurately fitted to the aperture by grinding them together with powdered emery, and afterwards polishing them one upon the other. And it is very certain, that no part of the elastic fluid made its escape by this vent; for, upon firing the piece, there was only a simple flash from the explosion of the priming, and no stream of fire was to be seen issuing from the vent, as is always to be observed when a common vent is made use of, and in all other cases where this fluid finds a passage.

In order that every part of the apparatus employed in these experiments might be as perfect as possible, all the more delicate parts of it were executed by Mr. FRASER, mathematical instrument-maker in Duke's Court, St. Martin's Lane, and, among the rest, all the contrivances just described relative to the vent.

The velocities of the bullets were determined by means of a pendulum, according to the method invented by Mr. ROBINS.

The pendulum I made use of (fig. 6.) is composed of a circular plate of hammered iron (*a*), 13 inches in diameter, and 0,65 of an inch thick, to which is firmly fastened a bar of iron (*b, c*) 56,5 inches in length, 2,6 inches broad, and half an inch in thickness, by which it is suspended by means of two pivots (*d, e*) at the end of the bar (*c*), and at right angles to its length. These pivots being very accurately finished, and moving on polished grooves, which were kept constantly oiled to lessen the friction, the vibration of the pendulum was very free, as appeared by the great length of time its vibrations continued after it had been put in motion, and was left to itself. To the circular plate of the pendulum, targets of circular pieces of wood of different thicknesses were fixed, which in the course of the experiments were often spoiled and replaced: and, in order to mark the weight and dimensions of the pendulum in each experiment, the pendulums are numbered according to the different targets that were made use of; and the weight and dimensions of each pendulum are set down in a table at the end of the description of the apparatus.

The target of the pendulum N^o 1. was made of a circular piece of elm-plank, $3\frac{1}{2}$ inches thick, and equal in diameter to the iron plate of the pendulum to which it was fixed; but this target being too thin was very soon ruined.

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The pendulum N° 2. was furnished with two targets, which were circular pieces of very tough oak-plank, near five inches thick, placed on opposite sides of the plate of the pendulum, and firmly fixed to it by screws, and to each other by iron straps. When one of these targets was ruined, the pendulum was turned about, and the other was made use of. This pendulum lasted from experiment N° 9. to experiment N° 39. when it was so much shattered as to be rendered unfit for further service.

The pendulum N° 3. was like the pendulum N° 2. ; only, instead of oak, elm-plank near seven inches in thickness was made use of for the targets. This pendulum served from experiment N° 40. to experiment N° 101. inclusively.

But finding that targets made of planks of the toughest wood were very soon shattered to pieces by the bullets, I composed the pendulum N° 4. in a different manner. Instead of circular pieces of plank, solid cylinders of elm-timber were made use of for the targets, so that the bullets now entered the wood in the direction of its fibres. These cylinders are 13 inches in diameter, and about $5\frac{1}{2}$ inches in length, hooped with iron at both their ends to prevent their splitting, and firmly fastened to the plate of the pendulum, and to each other by four iron straps. This pendulum lasted till the experiments were finished. It is still in being, and appears to be very little the worse for the service it has undergone.

Fig. 7. shews the two ends of the pendulum upon a large scale, together with the hooks or grooves by which it was suspended.

a, b, is the bar of the pendulum, which is seen broken off, as there is not room to shew the whole of its length.

c, d, are the pivots by which it was suspended.

e, is the circular plate of the pendulum, to which
f, *g*, two circular targets, are fastened by screws, and by means of the iron straps, 1, 2, 3, 4, which are nailed to the edges of the targets.

b, *k*, are the hooks which served instead of grooves to receive the pivots, *c*, *d*, of the pendulum.

The hooks were firmly fixed to the horizontal beam R. S. which supported the whole apparatus by means of three screws *m*, *n*, *o*, which passed through three holes in the plate that connects the two hooks. When the hooks were fastened to the beam, the middle screw, *n*, was first put into its place, and the pendulum was allowed to settle itself in a position truly perpendicular, after which the grooves were immoveably fixed by means of the screws *m*, *o*.

The chord of the arc, through which the pendulum ascended in each experiment, was measured by a ribbon, according to the method invented and described by Mr. ROBINS.

The recoil was measured in the following manner. The barrel was suspended in an horizontal position (and nearly in a line with the center of the target) by two small pendulous rods, 64 inches in length, and 25,6 inches asunder; which being parallel to each other, and moving freely upon polished pivots about the axes of their suspension, and upon two pair of trunnions that were fixed to the barrel, formed, together with the barrel, a compound pendulum; and from the lengths of the vibrations of this pendulum, the velocity with which the barrel began to recoil, or rather its greatest velocity, was determined.

But in order that the velocity of the recoil might not be too great, so as to endanger the apparatus when large charges were made

made use of, it was found necessary to load the barrel with an additional weight of more than 40 lbs. of iron.

This additional weight of iron, which I shall call the *gun carriage*, as it was so constructed as to serve as a carriage to the barrel, is composed of a bar of hammered iron 28 inches in length, 2,6 inches broad, and half an inch in thickness, which is bent in the middle of its length in such a manner, that its two flat sides or ends are parallel to each other, and distant asunder two inches. In the middle of this bar where it is bent is a hole in the form of an oblong square, which, receiving the end of the breech-pin, supports the lower end or breech of the barrel. The other end of the barrel is supported and confined in the following manner. A ring or hoop of iron, near half an inch thick, and two inches in diameter, is placed in a vertical position between the parallel sides of the bar, and near its two ends, and firmly fixed to them by screws. The barrel passing through the middle of this ring is supported upon the ends of three screws, which passing through the ring in different parts of its circumference all point towards its center.

The carriage, together with the barrel, was suspended by the pendulous rods by means of two pair of polished trunnions that are fixed to the outside of the carriage. They are placed in an horizontal line perpendicular to, and passing through, the axis of the bore.

Fig. 8. represents the barrel fixed to the carriage.

a, b, c, is the bar of iron which forms the carriage seen edge-ways.

2, 2, 4, 4, are the trunnions by which it was suspended.

d, e, is the barrel in its proper place.

p, is the breech-pin, which passing through a hole in the middle of the bar, *a, b, c,* supports the end, *e,* of the barrel; and

n, is the ring that supports the end, *d,* of the barrel.

Fig. 9. represents a perpendicular section through the line 2, 2, fig. 8. and in a line perpendicular to the length of the barrel.

This figure is designed to shew the manner in which the muzzle of the piece was supported and confined in the ring *n*, fig. 8.

a, c, are the two ends of the bar that are seen cut off.

n, is the ring, and

o, p, are the screws by which it is fastened to the two parallel sides of the bar, the ends of which form the trunnions 2, 2, fig. 8.

d, is a transverse section of the barrel, and

r, s, t, are the three screws by which the barrel is supported and confined in the center of the ring.

Fig. 10. is the same as fig. 9. but upon a larger scale.

Fig. 11. represents the two ends of one of the pendulous rods by which the barrel was suspended; and fig. 13. shews the same seen sideways.

a, b, is the rod which is seen broken off.

c, d, are the pivots by which it was suspended by a pair of hooks or grooves that were fastened to an horizontal beam, in the same manner as the pendulum for measuring the velocities of the bullets was suspended.

e, f, are the hooks which receive the trunnions that are fixed to the carriage.

The dimensions of every part of this apparatus may be seen in the table, p. 242.

The chord of the arc through which the barrel ascended in its recoil was measured by a ribbon, and the lengths of those chords, expressed in inches and decimal parts of an inch, are set down in the tables. The method of computing the velocity

city of the recoil from the chord of the arc through which the barrel ascended, is too well known to require an explanation: and it is also well known, that the velocities are to each other as the chords of those arcs. The lengths of those chords, therefore, as they are set down in the tables, are, in all cases, as the velocities of the recoil.

The powder made use of in these experiments was of the best kind, such as is used in proving great guns at Woolwich. A cartridge, containing 12 lbs. of this powder, was given to me by the late General DESAGULIERS of the Royal Artillery, and Inspector of Brass and Iron Ordnance; who also, in the politest manner, offered me every other assistance in his power towards completing the experiments I had projected, or in making any others I should propose that might be useful in the prosecution of my inquiries.

This powder was immediately taken out of the cartridge, and put into glass bottles, which were previously made very clean and dry; and in these it was kept carefully sealed up till it was opened for use. When it was wanted for the experiments, it was weighed out in a very exact balance, with so much attention, that there could not possibly be an error in any instance greater than one quarter part of a grain. The bottles were never opened but in fine weather, and in a room that was free from damp, and no more charges of powder than were necessary for the experiments of the day were weighed out at a time. Each charge was carefully put up in a cartridge of very fine paper, and these filled cartridges were kept in a turned wooden box, that was varnished on the inside as well as the outside, to prevent its imbibing moisture from the air.

The paper of which these cartridges were made was so fine and thin, that 1280 sheets of it made no more than an inch in

thickness, and a cartridge capable of containing half an ounce of powder weighed but three quarters of a grain.

The cartridges were formed upon a wooden cylinder, and accurately fitted to the bore of the piece, and the edges of the paper were fastened together with paste made of flour and water.

When a cartridge was filled, the powder was gently shaken together, and its mouth was tied up and secured with a piece of fine thread; and when it was made use of it was put intire into the piece, and gently pushed down into its place with the ram-rod, and afterwards it was pricked with a priming-wire thrust through the vent, and the piece was primed; so that no part of the powder of the charge was lost in the act of loading, as is always the case when the powder is put loose into the barrel; nor was any part of it expended in priming; but the whole quantity was safely lodged in the bottom of the bore or chamber of the piece, and the bullet was put down immediately upon it, without any wadding either between the cartridge and the bullet, or over the bullet.

The bullets were all cast in the same mould, and consequently could not vary in their weights above two or three grains at most, especially as I took care to bring the mould to a proper temperature as to heat before I began casting; and when leather was put about them, or other bullets than those of lead were made use of, the weight was determined very exactly before they were put into the piece.

The diameter of the bullet was determined by measurement and also by computation from its weight, and the specific gravity of the metal of which it was formed; and both these methods gave the same dimensions very nearly.

The apparatus was put up for making the experiments in a coach-house, which was found very convenient for the purpose,

as the joists upon which the floor over head was laid afforded a firm and commodious support for suspending the pendulum and the barrel, and the walls and roofs of the building served to screen the apparatus, which otherwise might have been discomposed by the wind, and injured by the rain and dews. A pair of very large doors, which formed the whole of one end of the room, were kept constantly open during the time the experiments were making, in order to preserve the purity of the air within the house, which otherwise would have been much injured by the smoke of the gun-powder; and that, in all probability, would have had a considerable effect in lessening the force of the powder, and vitiating the experiments. In order still further to guard against this evil, the barrel was placed as near as possible to the door, and the pendulum was hung up at the bottom of the room.

Fig. 12. represents the apparatus as it was put up for making the experiments.

a, b, is the barrel with its carriage, suspended by the pendulous rods *c, d*, and

R, is the ribbon which served to measure the ascending arc of its recoil.

P, is the pendulum, and

r, the ribbon that measured the arc of its vibration.

The distance from the mouth of the piece to the pendulum was just 12 feet.

A table shewing the weights and dimensions of all the principal parts of the apparatus.

Of the barrel.

	Inches.
Length	44,7
Length of the bore from the muzzle to the breech-pin	43,45
Diameter of the bore	0,78
Thickness of metal at the lower vent	0,36
Thickness of metal at the muzzle	0,1
Weight of the barrel, together with the solid breech-pin, and the vent-screws and vent-tube, 6 lbs. 6 oz.	

Of the gun carriage.

Length	28,4
Distance between the two pair of trunnions	25,6
Diameter of each trunnion	0,25
Weight 40 lbs. 14 oz.	

Of the rods by which the carriage was suspended.

Length from the axis of suspension, or center of the pivots, to the center of the trunnions of the gun carriage, 64 inches.

Weight of each rod, 1 lb. 4 oz.

Total weight of the barrel and its carriage, together with the allowance that was made for the weight of the rods by which it was suspended, 48 lbs.

N. B. This was its weight from experiment N° 3. to experiment N° 123. inclusive.

Of

Of the bullet.

Diameter 0,75 of an inch.

Weight in lead 580 grains.

Of the pendulum.

	Inches.
Total length of the pendulum from the axis of suspension to the bottom of the circular plate	69,5
Diameter of the circular plate to which the targets were fastened	13,~
Distance between the shoulders of the pivots	3,8
Diameter of the pivots	,27
Weight of the iron part of the pendulum	47 lb. 4 oz.

Of the pendulum with the targets fixed to it, as it was prepared for making the experiments, and numbered.

	Total length to the ribbon.	Distance from the axis of suspension.		Total weight of iron and wood.
		To the center of gravity.	To the center of oscillation.	
	Inches.	Inches.	Inches.	lbs. oz.
Pendulum N ^o 1	69,25	50,25	58,45	57 0
— N ^o 2	69,5	54,4	59,15	82 4
— N ^o 3	—	55,62	60,23	100 12
— N ^o 4	—	54,6	59,18	88 4

N. B. The measure is English feet and inches, and the weight is avoirdupois.

Having

Having now gone through the description of all the principal parts of the apparatus, I shall proceed to give an account of the experiments. And as it may be satisfactory to the Society to see the method of conducting these enquiries, as well as the result of them, I shall first give a table of the experiments in the exact order in which they were made, together with my original remarks; I shall then make such general observations as may occur: and afterwards I shall select, combine, and compare them, in the manner which best answers the different purposes to which I shall apply them.

General table of the experiments.

In the two first experiments the barrel was fixed to a carriage (that has not been described) which, together with the barrel and rods by which it was suspended, weighed only 23½.

Length of the bore of the piece 43,5 inches.

Weight of the bullet 580 grains.

The pendulum, N° 1.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	The bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	Grs.	In.	In.	Inches.	Inches.	In.	Ft.in Sec.	
N° 1	208	1,8	0,	13,2	64,5	33,5	1267	First day.
2	..	..	,5	14,5	..	36,5	1399	

This gun carriage being found to be too light, the other, described, and represented fig. 8. was substituted in the room of it.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	The bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in sec.	
N ^o 2	208	1,8	0	12,6	65,	17,8	1213	Second day.
4	..	..	,5	—	—	18,5	—	The pendulum gave way.
5	..	..	0	—	—	38,68	—	4 bullets were fired at once.
6	..	..	,5	—	—	38,48	—	Ditto.
7	..	..	0	—	—	6,1	—	Without any bullet.
8	416	3,6	..	—	—	16,5	—	Ditto.
9	208	1,8	0	8,5	65,	17,69	1281	Pen. N ^o 2; very fair; 3d day.
10	104	,9	..	5,2	65,25	10,18	782	
11	310	2,7	0	9,6	64,6	24,69	1459	
12	..	..	1,22	10,1	65,	24,95	1527	The powder was lighted by the long vent-tube (fig. 4.).
13	..	..	2,65	11,85	64,75	24,9	1801	
14	..	..	..	10,9	65,25	..	1646	
15	330	2,9	2,65	10,9	61,5	26,2	1748	
16	..	..	..	13,25	63,5	..	2060	The barrel very much heated.
17	330	2,7	2,65	..	..	12,7	..	
18	..	2,9	0	10,4	63,5	26,3	1619	
19	..	..	..	..	63,	26,4	1633	
20	165	1,45	0	6,8	62,2	14,73	1084	
21	..	..	..	6,85	..	14,2	1093	
22	..	..	1,32	6,7	..	14,8	1071	
23	..	..	..	6,3	60,6	14,58	1035	The short vent-tube (v, fig. 3.) was made use of.
24	..	..	..	7,5	61,5	14,68	1142	

In order to determine how much of the force of the powder was lost by windage and by the vent, oiled leather was fastened round the bullet, so that it now accurately fitted the bore of the piece; and in the five experiments, from N^o 35. to N^o 39. inclusive, the valve-vent was made use of.

Weight of the bullet, together with the leather in which it was enveloped, 603 grains.

Order

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	The bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N ^o	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in fec.	
25	165	1,45	0	6,8	65,	14,95	1004	Fourth day.
26	..	..	..	7,8	..	15,6	1153
27	..	..	..	8,05	..	16,15	1192
28	330	2,9	..	10,2	63,	26,	1559	
29	..	..	2,6	..	64,	28,1	1536
30	165	3,2	..	5,9	62,4	13,2	914	
31	..	1,45	1,3	6,65	62,6	15,15	1027	

Finding that the blast of the powder always reached as far as the pendulum, when large charges were made use of, and suspecting that this circumstance, together with the impulse of the unfired grains, might in a great measure occasion the apparent irregularity in the velocities of the bullets; to remedy these inconveniences, a large sheet of paper of a moderate thickness was stretched upon a square frame of wood, and interposed as a screen before the pendulum at the distance of two feet from the surface of the target.

Two reasons conspired to induce me to prefer this method of preventing the impulse of the flame upon the pendulum to the obvious one of removing the pendulum further from the mouth of the piece; the first was, that I was unwilling to increase the distance between the barrel and the pendulum, lest the resistance of the air might affect the velocities of the bullets; and the second, which I confess did not operate less strongly than the first, was, that the length of the house did not admit of a greater distance,

distance, and I was unwilling to expose any part of the apparatus in the open air.

But the screen was found to answer perfectly well the purpose for which it was designed, and it was continued during the remainder of the experiments, the paper being replaced every third or fourth experiment.

The experiments continued.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	Bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N ^o	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft.in sec.	
32	165	1,45	0	5,45	63,	15,45	839	Not leathered; weight of the bullet and was 603 grs. In exp. N ^o 32. no less than 40 large grs. of unfired powder were driven through the screen.
33	..	..	..	...	...	12,65	839
34	7,9	...	15,45	1217	In these 6 experiments the bullets were leathered, and the powder was lighted by the valve-vent.
35	..	..	..	7,	60,25	15,25	1129
36	..	..	..	7,4	62,	16,3	1161
37	..	..	1,3	8,	61,	17,9	1277
38	290	2,6	2,6	9,	58,6	23,5	1497	
39	..	..	..	...	...	24,8	..
								The pend. N ^o 2. ruined.

The bullets were now put naked into the piece, and the powder was lighted by the short vent-tube (v, fig. 3) and some little improvement was made in the steel edges between which the ribbons passed that served to measure the ascending arcs of the pendulum and of the recoil, by which means the friction was lessened, and the ribbon was prevented from twisting or entangling itself as it was drawn out.

Apparatus.

The barrel with its carriage as before.

The pendulum, N° 3. and

Lead bullets, weighing 580 grains each.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	Bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N°	Grains.	In.	In.	Inches.	Inches.	Inches.	Ft. in sec.	
40	218	1,9	0	6,45	64,6	18,	1236	{ 5th day; medium velocity in these experiments and N° 47. 1225.
41	6,31	65,3	17,71	1197	
42	6,45	65,	17,91	1230	
43	1,3	6,5	64,6	18,3	1248	
44	6,75	64,5	18,35	1299	{ Medium velocity 1276
45	6,6	64,9	..	1265	
46	6,4	61,6	..	1293	
47	0	6,3	62,	18,1	1266	
48	290	2,6	0	7,2	63,5	22,58	1414	{ Medium velocity 1427.
49	7,4	..	22,92	1455	
50	7,3	64,6	22,38	1412	
51	290	2,6	1,3	7,4	63,	23,21	1476	
52	7,6	64,	23,76	1520	{ Medium velocity 1493.
53	7,25	61,	23,6	1483	
54	2,6	7,5	62,3	..	1502	
55	7,4	64,	23,26	1450	
56	7,1	62,2	..	1433	{ Medium velocity 1460.
57	7,4	64,	23,56	1454	
58	1,31	..	11,12	—	
59	1,2	..	11,62	—	
60	0	1,16	..	9,62	—	{ In these 4 experiments the piece was fired with powder alone, and the screen was taken away from before the pendulum.
61	1,3	0,6	..	11,33	—	

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	Bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N ^o	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in fec.	
62	330	2,9	1,3	8,	63,	26,4	1599	} 6th day; medium velocity 1625.
63	8,5	65,	..	1652	
64	2,6	7,2	59,5	25,3	1562	} Medium velocity 1528.
65	7,7	65,	..	1495	
66	0	8,4	..	26,35	1633	} Medium velocity 1594.
67	8,	..	25,8	1556	
68	218	1,9	0	6,82	64,	19,56	1349	} The powder was rammed very hard.
69	6,6	64,6	18,2	1294	
70	6,85	..	19,12	1345	} Ditto as hard as in N ^o 68.
71	1,3	5,5	..	16,33	1080	
72	0	—	—	8,72	—	} Government powder, no bullet.
73	—	—	8,44	—	
74	1,3	—	—	8,47	—	} Government powder.
75	—	—	9,3	—	

The following experiments N^o 78, 79, 80, and 81. were made in hopes of being able to discover a method of adding to the force of gun-powder. Twenty grains of the substances mentioned in the remarks upon each experiment were intimately mixed with the powder of the charge. In the experiment N^o 82. a large wad of tow, well soaked in ethereal spirit of turpentine, was put into the piece immediately upon the bullet: and in the experiment N^o 83. a wad, soaked in alkohol, was put into the piece in like manner.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	Bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in fec.	
N ^o								
76	145	1,3	0	5,3	65,	13,25	1037	7th day; medium velocity 1040.
77	..	..	..	..	64,6	13,25	1044	
78	..	..	..	3,2	..	8,92		20 grs. best alkaline salt of tartar.
79	..	..	..	4,35	..	11,68		20 grs. æthiops mineral.
80	..	..	..	3,3	63,6	9,83		20 grs. fal ammon.
81	..	..	..	4,2	63,4	11,45		20 grs. fine brads dust.
82	..	..	..	—	—	15,25	—	The screws which held the hooks by which the pendulum was suspended gave way, and the pendulum came down.
83	..	..	..	—	—	14,35	—	

In the nine following experiments, *viz.* from N^o 84. to N^o 92. inclusive, the valve-vent was made use of, and the bullets were made to fit the bore of the piece very exactly by means of oiled leather, which was so firmly fastened about them that in each experiment it entered the target with the bullet.

The bullet made use of in experiment N^o 85. was of wood.

Those used in the experiments N^o 86. and N^o 87. were formed in the following manner; a small bullet was cast of plaister of Paris, which being thoroughly dried, and well heated at the fire, was fixed in the center of the mould that served for casting all the leaden bullets made use of in these experiments; and melted lead being poured into this mould, the cavity that surrounded the small plaister bullet was intirely filled up, and a bullet was produced, which to the eye had every appearance of solidity, but was as much lighter than a solid leaden bullet of the

the same diameter as the plaister bullet was lighter than a leaden bullet of the same size.

In the experiments N^o 88. and N^o 89. solid leaden bullets were made use of. In the experiment N^o 90. two bullets were discharged at once; in the experiment N^o 91. three; and in the experiment N^o 92. four were used.

In each of these experiments a fresh sheet of paper was made use of as a screen to the pendulum, in order that the velocities of the bullets might be measured more accurately; and also, that the quantity of unfired powder might be estimated with greater precision.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Weight of the bullet.	Chord of the ascending arc of the pendulum.	Bullet struck the target below the axis of the pendulum.	Chord of the arc of recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.							
	Grs.	In.	In.	Grs.	Inches.	Inches.	Inches.	Ft.in sec.	
N ^o 84	145	1,3	0	—	—	—	4,5	—	} 8th day; in each of these 4 experiments from 50 to 70 granulae or particles of unfired powder were driven through the screen.
85	90	1,33	62,2	7,16	1763	
86	251	2,82	63,2	9,62	1317	
87	354	3,32	61,2	11,3	1136	
88	600	6,5	65,4	15,22	1229	} Very few unfired grains of powder struck the screen.
89	603	6,3	64,6	15,13	1229	
90	1184	10,12	65,	21,92	978	} There were no marks of any unfired powder having reached the screen.
91	1754	13,65	63,4	27,18	916	
92	2352	16,55	63,3	32,25	833	

In the seven following experiments the piece was fired with powder only.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	Chord of the arc of the recoil.	Remarks.
	Weight	Height.				
N ^o	Grs.	ln.	ln.	Inches.	Inches.	
93	145	1,3	0	—	4,3	
94	165	1,45	..	—	5,5	
95	..	..	..	—	5,6	
96	290	2,6	..	—	11,70	
97	437½	3,9	..	1,68	17,5	The screen was taken away.
98	..	..	..	6,7	15,88	{ The whole surface of the target was bespattered with unfired grains of powder.
99	..	..	..	—	17,9	The pendulum was not observed.

In the following experiments N^o 100. and N^o 101. the bullets were not put down into the bore, but were supported by three wires, which being fastened to the end of the barrel projected beyond it, and confined the bullet in such a situation that its center was in a line with the axis of the bore, and its hinder part was one-twentieth of an inch without or beyond the mouth of the piece.

In experiment N^o 102. the bullet was just stuck into the barrel in such a manner that near one-half of it was without the bore.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	Bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft.in sec.	
N ^o								
100	165	1,45	0	,65	60,5	4,9	138	In each of these experim. near $\frac{1}{10}$ th part of the substance of the bullet was melted and blown away by the impulse of the flame.
101	..	..	..	,43	uncertain.	4,8	92	
102	..	..	..	,80	63,	5,6	180	

All that part of the bullet which lay towards the bore of the piece appeared to be quite flat from the loss of substance it had sustained; and its surface was full of small indents, which probably were occasioned by the unfired grains of powder that impinged against it.

The following experiments were made with the pendulum N° 4. The rest of the apparatus as before.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the ascending arc of the pendulum.	Bullet struck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N°	In.	In.	In.	Inches.	Inches.	Inches.	Ft. in sec.	
103	104	,9	0	4,51	65,	10,6	732	9th day. { About 40 grains of powder were driven through the screen.
104	145	1,3	..	5,4	...	12,92	877	{ About 40 unfired grs. of powder. Medium velocity 894. 40 unfired grains.
105	..	..	..	5,6	...	13,28	910	
106	..	1,14	..	6,18	65,8	14,3	990	{ Double proof battle powder; no unfired grains.
107	218	1,8	..	8,48	65,	19,68	1380	{ Ditto, ditto.
108	290	2,6	..	9,45	65,6	23,9	1526	{ Government powder; bullet leathered; weight 602 grains.
109	..	..	..	8,73	65,2	22,8	1419	{ Bullet naked; very few unfired grains.
110	..	..	..	9,3	65,6	23,4	1460	
111	..	..	..	...	...	...	1462	{ Medium velocity 1444.
112	..	..	..	8,85	65,5	22,94	1436	
113	..	..	2,6	8,65	64,	23,7	1438	{ Medium velocity 1413.
114	..	..	..	8,5	63,6	24,1	1423	
115	..	..	..	8,4	65,	23,8	1378	{ Double proof battle powder.
116	..	2,28	..	9,15	64,	24,6	1525	
117	437½	3,9	..	10,56	64,9	33,	1738	{ Gov. pow. } { No unfired grains thro' the screen.
118	..	..	..	11,	64,5	33,3	1824	
119	..	..	..	10,5	65,	33,6	1729	{ Medium velocity 1764.
120	..	..	2,6	10,35	...	32,5	1706	
121	..	..	..	10,65	...	33,2	1757	{ Medium velocity 1751.
122	..	..	..	10,6	63,6	32,9	1789	
123	..	..	0	—	—	17,9	—	{ Without any bullet.

Of the method made use of for computing the velocities of the bullets.

As the method of computing the velocity of a bullet from the arc of the vibration of a pendulum into which it is fired is so well known, I shall not enlarge upon it in this place, but shall just give the theorems that have been proposed by different authors, and shall refer those who wish to see more on the subject to Mr. ROBINS'S *New Principles of Gunnery*; to Professor EULER'S *Observations upon Mr. ROBINS'S Book*; and, lastly, to Dr. HUTTON'S *Paper on the initial Velocities of Cannon Balls*, which is published in the *Transactions of the Society for the year 1778*.

If a denote the length from the axis of the pendulum to the ribbon which measures the chord of the arc of its vibration;

g , the distance of the center of gravity below the axis;

f , the distance of the center of oscillation;

b , the distance of the point struck by the bullet;

c , the chord of the ascending arc of the pendulum;

P , the weight of the pendulum;

b , the weight of the bullet, and

v , the original velocity of the bullet;

$v = \frac{c}{a} \times \frac{Pg}{bb} + \frac{b}{f} \times \frac{f}{\sqrt{2b}}$, is a theorem for finding the velocity

upon Mr. ROBINS'S principles.

* $v = \frac{c}{a} \times \frac{Pg}{bb} + \frac{f+b}{2f} \times \sqrt{\frac{f}{2}}$, is the theorem proposed by Professor EULER, who has corrected a small error in Mr. ROBINS'S method; and

* Put the rational part $\frac{c}{a} \times \frac{Pg}{bb} + \frac{f+b}{2f} = n$, and express f in the thousandth parts of a Rhynland foot; then the velocity with which the ball strikes the pendulum will be $= \frac{n}{4} \sqrt{\frac{f}{2}}$ Rhynland feet in a second.

$v = 5,672 \text{ eg} \sqrt{f} \times \frac{P+b}{bha}$ is Dr. HUTTON's theorem, which is sufficiently accurate, and far more simple and expeditious than either of the preceding. It is to be remembered, that g , b , and c , may be expressed in any measure; but f must be English feet; and v will be the velocity of the bullet in English feet in a second.

The velocities of the bullets in most of the foregoing experiments were first computed by EULER's method, as I had not then seen Dr. HUTTON's paper; but in going over the calculations a second time, I made use of Dr. HUTTON's theorem. Both these methods gave the same velocity very nearly, but the Doctor's method is by much the easiest in practice.

In these computations care was taken to make a proper allowance for the bullets that were lodged in the pendulum, and also for the velocity lost by the bullet in passing through the screen.

The corrections necessary on account of the bullets lodged in the pendulum were made in the following manner.

b was continually added to the value of P ,

$\frac{b-g}{P} \times b$ to the value of g , and

$\frac{f-b}{P} \times b$ to the value of f .

Of the spaces occupied by the different charges of powder.

The heights of the charges of powder, or the lengths of the spaces which they occupied in the bore, were determined by measurement; and in order that this might be done with greater accuracy, inches and tenths of inches were marked upon the ram-rod, and the charge was gently forced down till it occupied the same space in each experiment.

The following table shews the heights of the charges as they were determined by measurement, and also their heights computed.

puted from the diameter of the bore of the piece, and the specific gravity of the powder that was made use of.

N. B. By an experiment I shall give an account of hereafter, I found the specific gravity of this powder shaken well together to be to that of rain water as 0,937 is to 1,000.

Weight of the powder.	Height of the charge.	
	Measured.	Computed.
Grs.	Inches.	Inches.
104	,9	0,8957
145	1,3	1,2490
165	1,45	1,4211
208	1,8	1,7914
218	1,9	1,8775
290	2,6	2,4980
310	2,7	2,6700
330	2,9	2,8422
416	3,6	3,5828
437½	3,9	3,7680

In the experiment N° 30. the powder was put into a cartridge so much smaller than the bore of the piece, that the charge, instead of occupying 1,45 inches, extended 3,2 inches. By this disposition of the powder, its action upon the bullet appears to have been very much diminished.

Of the effect that the heat which pieces acquire in firing produces upon the force of powder.

It is very probable, that the excess of the velocity of the bullet in the second experiment over that of the first was occasioned more by the heat the barrel had acquired in the first experiment than by the position of the vent, or any other circumstance; for I have since found, upon repeated trials, that the force of any given charge of powder is considerably greater when it is fired in a piece that has been previously heated by firing, or by any other means, than when the piece has not been heated. Every body that is acquainted with artillery knows, that the recoil of great guns is much more violent after the second or third discharge than it is at first; and on ship-board, where

where it is necessary to attend to the recoil of the guns, in order to prevent very dangerous accidents that might be occasioned by it, the constant practice has been in our navy, and, I believe, on board the ships of all other nations, to lessen the quantity of powder after the first four or five rounds: our 32 pounders, for instance, are commonly fired with 14 lbs. of powder at the beginning of an action, but the charge is very soon reduced to 11 lbs. and afterwards to 9 lbs. and the filled cartridges are prepared accordingly.

By the recoil it should seem, that the powder exerted a greater force also in the fourth experiment, being the second upon the second day, than it did upon the third, or the first upon that day; but the pendulum giving way, it was not possible to compare the velocities of the bullets in the manner we did in the two experiments mentioned above.

This augmentation of the force of powder, when it is fired in a piece that is warm, may be accounted for in the following manner. There is no substance we are acquainted with that does not require to be heated before it will burn; even gun-powder is not inflammable when it is cold. Great numbers of sparks or red-hot particles from the flint and steel are frequently seen to light upon the priming of a musket, without setting fire to the powder, and grains of powder may be made to pass through the flame of a candle without taking the fire; and what is still more extraordinary, if large grains of powder are let fall from the height of two or three feet upon a red-hot plate of iron, laid at an angle of about 45° with the plane of the horizon, they will rebound intire without being burnt, or in the least altered, by the experiment. In all these cases the fire is too feeble, or the duration of its action is not sufficiently

long;

long to heat the powder to that degree which is necessary in order to its being rendered inflammable.

Now as gun-powder, as well as all other bodies, acquires heat by degrees, and as some space of time is taken up in this as well as in all other operations, it follows, that powder, which has been warmed by being put into a piece made hot by repeated firing, is much nearer that state in which it will burn, or, I may say, is more inflammable than powder which is cold; consequently, more of it will take fire in a given short space of time, and its action upon the bullet and upon the gun will of course be greater.

The heat of the piece will also serve to dry the air in the bore, and to clear the inside of the gun of the moisture that collects there when it has not been fired for some time, and these circumstances doubtless contribute something to the quickness of the inflammation of the powder, and consequently to its force.

As it takes a longer time to heat a large body than a small one, it follows, that meal-powder is more inflammable than that which is grained; and the smaller the particles are, the quicker they will take fire. The sailors bruise the priming after they have put it to their guns, as they find it very difficult, without this precaution, to fire them off with a match: and if those who are fond of sporting would make use of a similar artifice, and prime their pieces with meal-powder, they would miss fire less often, the springs of the lock might be made more tender, and its size considerably reduced without any risk, and the violence of the blow of the flint and steel in striking fire being lessened, the piece might be fired with greater precision.

Concluding from the result of the four experiments mentioned above, as well as from the reasons just cited, that the temperature of the piece has a considerable effect upon the force of the powder, I afterwards took care to bring the barrel to a proper degree of heat, by firing it once or oftener with powder each time I recommenced the experiments after the piece had been left to cool.

Of the manner in which pieces acquire heat in firing.

I was much surprised upon taking hold of the barrel immediately after the experiment N° 17. when it was fired with 330 grains of powder without any bullet, to find it so very hot that I could scarcely bear it in my hand, evidently much hotter than I had ever observed it before, notwithstanding the same charge of powder had been made use of in the two preceding experiments, and in both these experiments the piece was loaded with a bullet, which one would naturally imagine, by confining the flame, and prolonging the time of its action, would heat the barrel much more than when it was fired with powder alone.

I was convinced that I could not be mistaken in the fact, for it had been my constant practice to take hold of the piece to wipe it out as soon as an experiment was finished, and I never before had found any inconvenience from the heat in holding it. But in order to put the matter beyond all doubt, after letting the barrel cool down to the proper temperature, I repeated the experiment twice with the same charge of powder and a bullet; and in both these trials (experiments N° 18. and N° 19.) the heat of the piece was evidently much less than what it was in the experiment above mentioned (N° 17.).

I now regretted exceedingly the loss of a small pocket thermometer, which I had provided on purpose to measure the heat of the barrel, but it was accidentally broken by a fall the day before I began my experiments; and being so far from London, I had it not in my power to procure another: I was therefore obliged to content myself with determining the heat of the piece as well as I could by the touch.

Being much struck with this accidental discovery of the great degree of heat that pieces acquire when they are fired with powder without any bullet, and being desirous of finding out whether it is a circumstance that obtains universally, I was very attentive to the heat of the barrel after each of the succeeding experiments; and I constantly found the heat sensibly greater when the piece was fired with powder only, than when the same charge was made to impel one or more bullets.

Though the result of these experiments was totally unexpected, and even contrary to what I should have foretold if I had been asked an opinion upon the subject previous to making them; yet, after mature consideration, I am now convinced, that it is what ought to happen, and that it may be accounted for very well upon principles that are clearly admissible.

It is certain, that a very small part only of the heat that a piece of ordnance acquires in being fired is communicated to it by the flame of the powder; for the time of its action is so short (not being, perhaps, in general longer than about $\frac{1}{200}$ th or $\frac{1}{150}$ th part of a second) that if its heat, instead of being 4 times, as Mr. ROBINS supposes, was 400 times hotter than red-hot iron, it could not sensibly warm so large a body of metal as goes to form one of our large pieces of cannon. And besides, if the heat of the flame was sufficiently intense to produce so great an effect in so short a time, it would certainly be

sufficient to burn up all inflammable bodies that it came near, and to melt the shot that it surrounded and impelled, especially when they were small, and were composed of lead or any other soft metal; but, on the contrary, we frequently see the finest paper come out of the mouth of a piece uninflamed, after it has sustained the action of the fire through the whole length of the bore, and the smallest lead shot is discharged without being melted.

But it may be objected here, that bullets are always found to be very hot if they are taken up immediately after they come out of a gun; and that this circumstance is a proof of the intensity of the heat of the flame of powder, and of its great power of communicating heat to the densest bodies. But to this I answer, I have always observed the same thing of bullets discharged from wind-guns and cross-bows, especially when they have impinged against any hard body, and are much flattened; and bullets from muskets are always found to be hotter in proportion to the hardness of the body against which they are fired. If a musket ball is fired into any very soft body, as (for instance) into water, it will not be found to be sensibly warmed; but if it is fired against a thick plate of iron, or any other body that it cannot penetrate, the bullet will be demolished by the blow, and the pieces of it that are dispersed about will be found to be in a state very little short of fusion, as I have often found by experience. It is not by the flame therefore that bullets are heated, but by percussion. They may, indeed, receive some small degree of warmth from the flame, and still more perhaps by friction against the sides of the bore, but it is in striking against hard bodies, and from the resistance they meet with in penetrating those that are softer, that they acquire by far

the greater part of the heat we find in them as soon as they come to be at rest, after having been discharged from a gun.

There is another circumstance that may possibly be brought as an objection to this opinion, and that is the running of the metal in brass guns upon repeatedly firing them, by which means the vent is often so far enlarged as to render the piece entirely useless. But this, I think, proves nothing but that brass is very easily corroded, and destroyed by the flame of gun-powder; for it cannot be supposed, that in these cases the metal is ever fairly melted. The vent of a musket is very soon enlarged by firing, and after a long course of service it is found necessary to stop it up with a solid screw, through the center of which a new vent is made of the proper dimensions. This operation is called bushing, or rather bouching the piece; but in all the better kind of fowling-pieces the vent is lined, or bouched, with gold, and they are found to stand fire for any length of time without receiving the least injury. But every body knows that gold will run with a less heat than is required to melt iron: but gold is not corroded either by the spirit of nitre, or the acid spirit that is generated from sulphur, whereas iron is very easily destroyed by either; and that I take to be the only reason why a vent that is lined with gold is so much more durable than one that is made in iron. But it seems, that iron is more durable than brass; and perhaps steel, or some other cheap metal, may be found that will supply the place of gold, and by that means the great expence that attends bouching pieces with that precious metal may be spared, and this improvement may be introduced into common use.

This leads us to a very easy and effectual remedy for that defect so long complained of in all kinds of brass ordnance, *the running of the vent*; for if these pieces were bouched with
iron,

iron, there is no doubt but they would stand fire as well as iron guns; and if steel, or any other metal, either simple or compounded, should upon trial be found to answer for that purpose better than iron, it might be used instead of it; and even if gold was made use of for lining the vent, I imagine it might be done in such a manner as that the expence would not be very considerable, at the same time that the thickness of the gold should be sufficient to withstand the force of the flame for a very great length of time.

But to return to the heat acquired by guns in firing. It being pretty evident that it is not all communicated by the flame, there is but one other cause to which it can be attributed, and that is the motion and friction of the internal parts of the metal among themselves, occasioned by the sudden and violent effort of the powder upon the inside of the bore, and to this cause I imagine the heat is principally if not almost intirely owing. It is well known, that a very great degree of heat may be generated in any hard and dense body in a short space of time by friction, and in a still shorter time by collision. “ For if two dense hard elastic bodies be struck against
“ each other with great force and velocity, all the parts of
“ such bodies will every moment be closely compressed, and
“ being rigid will re-act with equal force. Hence a quick and
“ powerful contraction and expansion will arise in every part,
“ resembling that swift kind of vibrations observed in stretched
“ strings; how great these vibrations are may be learnt from
“ the instance of a bell, when struck with a single blow, by
“ which the whole bulk, however vast, will for a long time
“ expand, and contract itself in infinite ellipses. And when
“ the attrition above described is produced, with what force and
“ velocity are all the particles of the rubbed body compressed,
“ shaken,

“ shaken, and loofened to their very intimate fubftance*?” And in proportion to the fwiftnefs of this vibration, and the violence of the attrition and friftion, will be the heat that is produced.

A piece of iron that would fuftain the preffure of any weight, however large, without being warmed, may be made quite hot by the blow of a hammer; and even foft and un-elastic bodies may be warmed by percuffion, provided the velocity with which their parts are made to give way to the blow is fufficiently rapid. If a leaden bullet is laid upon an anvil, or any other hard body, and in that fituation it is ftruck with a fmart blow of a hammer, it will be found to be much heated; but the fame bullet in the fame fituation may be much more flattened by preffure, or by the froke of a very heavy body moving with a fmall velocity, without being fenfibly warmed.

To generate heat therefore the action of the powder upon the infide of the piece muft not only be fufficient to ftrain the metal, and produce a motion in its parts, but this effect muft be extremely rapid; and the heat will be much augmented, if the exertion of the force and the duration of its action are momentaneous; for in that cafe, the fibres of the metal (if I may ufe the expreffion) that are violently fretched, will return with their full force and velocity, and the fwift vibratory motion and attrition before defcribed will be produced.

The heat generated in a piece by firing is therefore as the force by which the particles of the metal are ftrained and compressed, the fuddennefs with which this force is exerted, and the fhortnefs of the time of its action; that is to fay, as the ftrength of the powder and the quantity of the charge, the quicknefs of its inflammation, and the velocity with which the generated fluid makes its efcape.

* Vide SHAW's tranflation of BOERHAAVE's *Chemiftry*, vol. I. p. 249.

Now the effort of any given charge of powder upon the gun is very nearly the same, whether it be fired with a bullet or without; but the velocity with which the generated elastic fluid makes its escape, is much greater when the powder is fired alone, than when it is made to impel one or more bullets; the heat ought therefore to be greater in the former case than in the latter, as I found by experiment.

But to make this matter still plainer, we will suppose any given quantity of powder to be confined in a space that is just capable of containing it, and that in this situation it is by any means set on fire. Let us suppose this space to be the chamber of a piece of ordnance of any kind, and that a bullet, or any other solid body, is so firmly fixed in the bore immediately upon the charge, that the whole effort of the powder shall not be able to remove it. As the powder goes on to be inflamed, and the elastic fluid is generated, the pressure upon the inside of the chamber will be increased, till at length all the powder being burnt, the strain upon the metal will be at its greatest height, and in this situation things will remain, the cohesion or elasticity of the particles of metal counterbalancing the pressure of the fluid.

Under these circumstances very little heat would be generated; for the continued effort of the elastic fluid would approach to the nature of the pressure of a weight; and that concussion, vibration, and friction, among the particles of the metal, which in the collision of elastic bodies is the cause of the heat that is produced, would scarcely take effect.

But instead of being firmly fixed in its place, let the bullet now be moveable, but let it give way with great difficulty, and by slow degrees. In this case, the elastic fluid will be generated as before, and will exert its whole force upon the chamber

of the piece; but as the bullet gives way to the pressure, and moves on in the bore, the fluid will expand itself and grow weaker, and the particles of the metal will gradually return to their former situations; but the velocity with which the metal restores itself being but small, the vibration that remains in the metal, after the elastic fluid has made its escape, will be very languid, as will be the heat that is generated by it.

But if, instead of giving way with so much difficulty, the bullet is much lighter, so as to afford but little resistance to the elastic fluid in making its escape, or if the powder is fired without any bullet at all; then, there being little or nothing to oppose the flame in its passage through the bore, it will expand itself with an amazing velocity, and its action upon the gun will cease almost in an instant, the strained metal will restore itself with a very rapid motion, and a sharp vibration will ensue, by which the piece will be much heated.

Of the effect of ramming the powder in the chamber of the piece.

The charge, consisting of 218 grains of powder, being put gently into the bore of the piece in a cartridge of very fine paper, without being rammed, the velocity of the bullets at a mean of the 40th, 41st, 42d, and 47th experiments, was at the rate of 1225 feet in a second; but in the 68th, 69th, and 70th experiments, when the same quantity of powder was rammed down with five or six hard strokes of the ram-rod, the mean velocity was 1329 feet in a second. Now the total force or pressure exerted by the charge upon the bullet is as the square of its velocity, and $\overline{1329}^2$ is to $\overline{1225}^2$ as 1,1776 is to 1; or
nearly

nearly as 6 is to 5 ; and in that proportion was the force of the given charge of powder increased by being rammed.

In the 71st experiment the powder was also rammed, but the vent, instead of being at the bottom of the bore, was at 1,3, and the velocity of the bullet was very considerably diminished, being only at the rate of 1080 feet in a second, instead of 1276 feet in a second, which was the mean velocity with this charge, and with the vent in this situation when the powder was rammed. See the experiments N^o 43, 44, 45, and 46.

When, instead of ramming the powder, or pressing it gently together in the bore, it is put into a space larger than it is capable of filling, the force of the charge is thereby very sensibly lessened, as Mr. ROBINS and others have found by repeated trials. In my 30th experiment the charge, consisting of no more than 165 grains of powder, was made to occupy 3,2 inches of the bore instead of 1,45 inches, which space it just filled when it was gently pushed into its place without being rammed ; the consequence was, the velocity of the bullet, instead of being 1100 feet in a second or upwards, was only at the rate of 914 feet in a second, and the recoil was lessened in proportion.

And from hence we may draw this practical inference, that the powder, with which a piece of ordnance or a fire-arm is charged, ought always to be pressed together in the bore ; and if it is rammed to a certain degree, the velocity of the bullet will be still farther increased. It is well known, that the recoil of a musket is greater when its charge is rammed than when it is not ; and there cannot be a stronger proof that ramming increases the force of the powder.

Of the relation of the velocities of bullets to the charges of powder by which they are impelled.

It appears by all the experiments that have hitherto been made upon the initial velocities of bullets, that when the weights and dimensions of the bullets are the same, and they are discharged from the same piece by different quantities of powder, the velocities are in the sub-duplicate ratio of the weights of the charges very nearly.

The following table will shew how accurately this law obtained in the foregoing experiments.

Charges.	Velocities		Difference.	N ^o of exp.
	Computed.	Actual.		
437½	1764	1764	—	3
330	1533	1594	+ 61	2
310	1486	1459	- 27	1
290	1436	1436	0	7
218	1232	1225	- 7	4
208	1216	1256	+ 40	3
165	1083	1087	+ 4	2
145	1018	1040	+ 22	2
104	860	757	- 103	2

The computed velocities, as they are set down in this table, were determined from the ratio of the square root of 437½ (the weight in grains of the largest charge of powder) to the mean velocity of the bullet with that charge and the vent at 0; viz. 1764 feet in a second, and the square root of the other charges expressed in grains. And the *actual* velocities are means of all experiments that were made under similar circumstances.

The fourth column shews the difference of the computed and actual velocities, or the number of feet in a second by which the actual velocity exceeds or falls short of the computed: and in the fifth column is set down the number of experiments with each charge, from the mean of which the actual velocity was determined.

The agreement of the computed and actual velocities will appear more striking, if we take the sum and difference of those velocities with all the charges except the first: thus,

Sum of the velocities, — 1764.

Computed.	Actual.	Difference.	N ^o of exp.
9864	9854	— 10	23

So that it appears, that the difference, or the actual velocity, was smaller than the computed by $\frac{1}{985.5}$ part only at a mean of 23 experiments.

But as by far the greater number of the experiments were made with the following charges, *viz.* 290, 218, 208, 165, and 145 grains of powder, let us take the sum and difference of the computed and actual velocities of those charges: thus,

Sum of the velocities		Difference.	N ^o of exp.
Computed.	Actual.		
5985	6044	+ 59	18

Here the agreement of the theory with the experiments is so very remarkable, that we must suppose it was in some measure accidental; for the difference of the velocities in repeating the same experiment is in general much greater than the difference of the computed and actual velocities in this instance; but, I think, we may fairly conclude, from the result of all these

trials, that the velocities of like *muskets* bullets, when they are discharged from the same piece by different quantities of the same kind of powder, are very nearly in the sub-duplicate ratio of the weights of the charges. Whether this law will hold good when applied to cannon balls, and bomb shells of large dimensions, I dare not at present take upon me to decide; but, for several reasons that might be mentioned, I am rather of opinion, that it will not; at least not with that degree of accuracy which obtained in these experiments.

Of the effect of placing the vent in different parts of the charge.

There have been two opinions with respect to the manner in which gun-powder takes fire. Mr. ROBINS supposes that the progress of its inflammation is so extremely rapid, "that all the powder of the charge is fired and converted into an elastic fluid, before the bullet is sensibly moved from its place;" while others have been of opinion, that the progress of the inflammation is much slower, and that the charge is seldom or never completely inflamed before the bullet is out of the gun.

The large quantities of powder that are frequently blown out of fire arms un-inflamed, seem to favour the opinion of the advocates for the gradual firing; but Mr. ROBINS endeavours to account for that circumstance upon different principles, and supports his opinion by shewing that every increase of the charge within the limits of practice produces a proportional increase of the velocity of the bullet, and that when the powder is confined by a great additional weight, by firing two or more bullets at a time instead of one, the velocity is not sensibly greater than it ought to be according to his theory.

If this were a question merely speculative, it might not be worth while to spend much time in the discussion of it; but as it is a matter upon the knowledge of which depends the determination of many important points respecting artillery, and from which many useful improvements may be derived, too much pains cannot be taken to come at the truth. Till the manner in which powder takes fire, and the velocity with which the inflammation is propagated, are known, nothing can with certainty be determined with respect to the best form for the chambers of pieces of ordnance, or the most advantageous situation for the vent; nor can the force of powder, or the strength that is required in different parts of the gun, be ascertained with any degree of precision.

As it would be easy to determine the best situation for the vent from the velocity of the inflammation of powder being known, so on the other hand I had hopes of being able to come at that velocity by determining the effect of placing the vent in different parts of the charge; for which purpose the following experiments were made.

A table of experiments, shewing the effect of placing the vent in different parts of the charge.

Weight of the charge of powder.	Space occupied by the powder.	Vent from the bottom of the bore.	Velocity of the bullet at a medium.	Recoil measured upon the ribbon at a medium.	Number of experiments.
Grains.	Inches.	Inches.	Ft. in a sec.	Inches.	
165	1,45	0	1087	14,465	2
...	...	1,32	1082	14,31	3
218	1,9	0	1225	17,93	4
...	...	1,3	1276	18,34	4
290	2,6	0	1427	22,626	3
...	...	1,3	1493	23,34	3
...	...	2,6	1460	23,286	4
...	...	0	1444	23,135	4
...	...	2,6	1413	24,5	3
310	2,7	0	—	24,69	1
...	...	1,32	—	24,95	1
...	...	2,65	—	24,9	1
330	2,9	0	1594	26,075	2
...	...	1,3	1625	26,4	2
...	...	2,6	1525	25,3	2
437½	3,9	0	1764	33,3	3
...	...	2,6	1751	32,866	3

By the foregoing experiments it appears, first, that the difference in the force of any given charge of powder which arises from the particular situation of the vent is extremely small.

With 165 grains of powder, and the vent at 0, the velocity of the bullet at a mean of two experiments (*viz.* the 20th and 21st) was 1087 feet in a second; and with the same charge, and the vent at 1,32 inches, the velocity at a mean of the 22d, 23d, and 24th experiments, was 1082 feet in a second; the

the difference, equal five feet in a second, is less than what occurred in a repetition of the same experiment.

With 218 grains of powder, and the vent at 0, the velocity at a mean in the 40th, 41st, 42d, and 47th experiments, was at the rate of 1225 feet in a second; and with the same charge, and the vent at 1,3, the velocity was 1276 feet in a second at a mean of four experiments, viz. the 43d, 44th, 45th, and 46th.

In the first set of experiments, with 290 grains of powder, the velocities were,

Vent at 0.	Vent at 1,3.	Vent at 2,6.
1414	1476	1502
1455	1520	1450
1412	1483	1433
		1454
<hr/>	<hr/>	<hr/>
3)4281	3)4479	4)5839
<hr/>	<hr/>	<hr/>
Means 1427	1493	1460

See the experiments from N° 48. to N° 57. inclusive.

In the second set the velocities were,

Vent at 0.	Vent at 2,6.
1419	1438
1460	1423
1462	1378
1436	
<hr/>	<hr/>
4)5777	3)4239
<hr/>	<hr/>
Means 1444	1413

See the experiments from N° 109. to N° 115. inclusive.

And

And taking the means of all the velocities in both sets in each position of the vent it will be,

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
Mean velocity	1436	1493	1437

The mean recoils in these experiments were,

Vent at 0.	Vent at 1,3.	Vent at 2,6.
22,88	23,34	23,61

In the experiments with 310 grains of powder the velocities of the bullets were not determined with sufficient accuracy to be depended on; but the recoils, which were measured with great nicety, were as follows, *viz.*

Vent at 0.	Vent at 1,3.	Vent at 2,6.
24,69	24,95	24,9

With 330 grains of powder the mean velocities and recoils were,

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
Velocities	1594	1625	1525
Recoils	26,075	26,4	25,3

In the experiments with $437\frac{1}{2}$ grains (an ounce avoirdupois) of powder the velocities and recoils were,

Vent at 0.		Vent at 2,6.	
Velocity.	Recoil.	Velocity.	Recoil.
1738	33,	1707	32,5
1824	33,3	1757	33,2
1728	33,6	1789	32,9
<hr/>	<hr/>	<hr/>	<hr/>
3)5291	3)99,9	3)5253	3)98,6
<hr/>	<hr/>	<hr/>	<hr/>
Means 1764	33,3	1751	32,866
			Secondly,

Secondly, From the result of all these experiments it appears, that the effect of placing the vent in different positions with respect to the bottom of the chamber is different, in different charges ; thus, with 165 grains of powder the velocity of the bullet was rather diminished by removing the vent from 0, or the bottom of the bore to 1,32 ; but with 218 grains of powder the velocity was a little increased, as was also the recoil. With 290 grains of powder the velocity was greatest when the powder was lighted at the vent 1,3 which was near the middle of the charge, and rather greater when it was lighted at the top, or immediately behind the bullet, than when it was lighted at the bottom. And by the recoil it would seem, that the velocities of the bullets varied nearly in the same manner when the charge consisted of 310 grains of powder.

With 330 grains of powder, both the velocity and the recoil were greater when the powder was lighted at the middle of the charge, than when it was lighted at the bottom ; but they were least of all when it was lighted near the top. And when *an ounce* of powder was made use of for the charge, its force was greatest when it was lighted at the bottom. But the difference in the force exerted by the powder which arose from the particular position of the vent was in all cases so inconsiderable (being, as I have before observed, less than what frequently occurred in repeating the same experiment) that no conclusion can be drawn from the experiments, except only this, that any given charge of powder exerts nearly the same force, whatever is the position of the vent.

And hence the following practical inference naturally occurs, *viz.* that in the formation of fire-arms no regard need be had to any supposed advantages that gun-smiths and others have hitherto imagined were to be derived from particular situations for

the vent, such as diminishing the recoil, increasing the force of the charge, &c. ; but the vent may be indifferently in any part of the chamber where it will best answer upon other accounts : and there is little doubt but the same thing will hold good in great guns, and all kinds of heavy artillery.

Almost every workman who is at all curious in fire-arms has a particular fancy with regard to the best form for the bottom of the chamber, and the proper position of the vent. They in general agree, that the vent should be as low or far back as possible, in order, as they pretend, to lessen the recoil ; but no two of them make it exactly in the same manner. Some make the bottom of the chamber flat, and bring the vent out even with the end of the breech-pin. Others make the vent slanting through the breech-pin, in such a manner as to enter the bore just in its axis. Others again make the bottom of the chamber conical ; and there are those who make a little cylindric cavity in the breech-pin, of about two-tenths of an inch in diameter, and near half an inch in length, coinciding with the axis of the bore, and bring out the vent even with the bottom of this little cavity.

The objection to the first method is, the vent is apt to be stopped up by the foul matter that adheres to the piece after firing, and which is apt to accumulate, especially in damp weather. The same inconvenience in a still greater degree attends the other methods, with the addition of another, arising from the increased length of the vent ; for the vent being longer it is not only more liable to be obstructed, but it takes a longer time for the flame to pass through it into the chamber, in consequence of which the piece is slower in going off, or, as sportsmen term it, is apt to hang fire.

The form I would recommend for the bottom of the bore is that of a hemisphere; and the vent should be brought out directly through the side of the barrel, in a line perpendicular to its axis, and pointing to the center of the hemispheric concavity of the chamber.

In this case the vent would be the shortest possible; it would be the least liable to be obstructed, and the piece would be more easily cleaned, than if the bottom of the bore was of any other form. All these advantages, and several others not less important, would be gained by making the bottom of the bore and vent of great guns in the same manner.

A new method of determining the velocities of bullets.

From the equality of *action* and *re-action* it appears, that the *momentum* of a gun must be precisely equal to the momentum of its charge; or that the weight of the gun, multiplied into the velocity of its recoil, is just equal to the weight of the bullet and of the powder (or the elastic fluid that is generated from it) multiplied into their respective velocities: for every particle of matter, whether solid or fluid, that issues out of the mouth of a piece, must be impelled by the action of some power, which power must *re-act* with equal force against the bottom of the bore.

Even the fine invisible elastic fluid that is generated from the powder in its inflammation cannot put itself in motion without re-acting against the gun at the same time. Thus we see pieces, when they are fired with powder alone, recoil as well as when their charges are made to impel a weight of shot, though the recoil is not in the same degree in both cases.

It is easy to determine the velocity of the recoil in any given case, by suspending the gun in an horizontal position by two pendulous rods, and measuring the arc of its ascent, by means of a ribbon according to the method already described, and this will give the momentum of the gun, its weight being known, and consequently the momentum of its charge. But in order to determine the velocity of the bullet from the recoil, it will be necessary to find out how much the weight and velocity of the elastic fluid contributes to it.

That part of the recoil which arises from the expansion of this fluid is always very nearly the same, whether the powder is fired alone, or whether the charge is made to impel one or more bullets, as I have found by a great variety of experiments.

If therefore a gun, suspended according to the method prescribed, is fired with any given charge of powder, but without any bullet or wad, and the recoil is observed, and if the same piece is afterwards fired with the same quantity of powder, and a bullet of a known weight, the excess of the velocity of the recoil in the latter case, over that in the former, will be proportional to the velocity of the bullet; for the difference of these velocities, multiplied into the weight of the gun, will be equal to the weight of the bullet multiplied into its velocity.

Thus if W is put equal to the weight of the gun,

U = the velocity of its recoil, when it is fired with any given charge of powder, without any bullet,

V = the velocity of the recoil, when the same charge is made to impel a bullet,

B = the weight of the bullet, and

v = its velocity,

It will be $v = \frac{V - U \times W}{B}$.

I

Let

Let us see how this method of determining the velocities of bullets will answer in practice.

In the 94th experiment the recoil, with 165 grains of powder, without a bullet, was 5,5 inches, and in the 95th experiment, with the same charge, the recoil was 5,6 inches. The mean is 5,55 inches; and the length of the rods by which the barrel was suspended being 64 inches, the velocity of the recoil ($= U$) answering to 5,55 inches measured upon the ribbon, is that of 1,1358 feet in a second.

In five experiments, with the same charge of powder, and a bullet weighing 580 grains, the recoil was as follows, *viz.*

The 20th experiment 14,73 inches

21st - 14,2

22d - 14,8

23d - 14,58

24th - 14,68

5)73, ($= 14,6$ inches at a mean.)

And the velocity of the recoil ($= V$) answering to the length is that of 2,9880 feet in a second: consequently $V - U$, or $2,9880 - 1,1358$ is equal to 1,8522 feet in a second.

But as the velocities of recoil are known to be as the chords of the arcs through which the barrel ascends, it is not necessary in order to determine the velocity of the bullet to compute the velocities V and U ; but the quantity $\overline{V - U}$, or the difference of the velocities of the recoil when the given charge is fired with and without a bullet, may be computed from the value of the difference of the chords, by one operation. Thus the velocity answering to the chord 9,05 is that of 1,8522 feet in a second, which is just equal to $\overline{V - U}$, as was before found.

The

The weight of the barrel, together with its carriage, was $47\frac{1}{4}$ pounds, to which three quarters of a pound is to be added on account of the weight of the rods by which it was suspended, which makes $W = 48$ pounds, or 336,000 grains, and the weight of the bullet was 580 grains. B is therefore to W as 580 is to 336,000, that is, as 1 is to 579,31 very nearly; and $v (= \frac{\overline{V-U} \times W}{B})$ is equal to $\overline{V-U} \times 579,31$.

The value of $\overline{V-U}$ answering to the experiments before mentioned was found to be 1,8522; consequently the velocity of the bullets ($= v$) was $1,8522 \times 579,31 = 1073$ feet in a second, which is extremely near 1083 feet in a second, the mean of the velocities, as they were determined by the pendulum.

But the computation for determining the velocity of a bullet upon these principles may be rendered still more simple and easy in practice; for the velocities of the recoil being as the chords measured upon the ribbon, if

c is put equal to the chord of the recoil expressed in English inches, when the piece is fired with powder only, and

C = the chord when a bullet is discharged by the same charge,

then $C - c$ will be as $V - U$; and consequently as $\frac{\overline{V-U} \times W}{B}$, which measures the velocity of the bullet, the ratio of W to B remaining the same.

If therefore we suppose a case in which $C - c$ is equal to one inch, and the velocity of the bullet is computed from that chord, the velocity in any other case, wherein $C - c$ is greater or less than one inch, will be found by multiplying the difference of the chords C and c by the velocity that answers to a difference of one inch.

The

The length of the parallel rods by which the barrel was suspended being 64 inches, the velocity of the recoiling to $C - c = 1$ inch measured upon the ribbon is 0,204655 parts of a foot in a second; and this is also, in this case the value of $V - U$; the velocity of the bullet is therefore $v = 0,204655 \times 579,31 = 118,35$ feet in a second.

Consequently the velocity of the bullet expressed in feet *per* second may in all cases be found by multiplying the difference of the chords C , and c , by 118,35, the weight of the barrel, the length of the rods by which it is suspended, and the weight of the bullet remaining the same, and this whatever the charge of powder may be that is made use of, and however it may differ in strength or goodness.

According to this rule the velocities of the bullets in the following experiments have been computed from the recoil; and by comparing them with the velocities shewn by the pendulum, we shall be enabled to judge of the accuracy of this new method of determining the velocities of bullets.

In the 76th and 77th experiments, when the piece was fired with 145 grains of powder and a bullet, the recoil was 13,25 and 13,15, or 13,2 at a mean; and with the same charge of powder, without a bullet, the recoil was 4,5 and 4,3, or 4,4 at a mean (see the 84th and 93d experiments). $C - c$ is therefore $13,2 - 4,4 = 8,8$ inches, and the velocity of the bullets $= 8,8 \times 118,35 = 1045$ feet in a second. The mean of the velocities as they were determined by the pendulum is that of 1040 feet in a second. In the 104th and 105th experiments the recoil was 12,92 and 13,28, and the velocity computed from the mean of those chords is 1030 feet in a second; but the velocity shewn by the pendulum was no more than about 900 feet in a second. As the recoil was so nearly equal to what

what it was in the 76th and 77th experiments before mentioned, when the velocities shewn by the recoil and by the pendulum were almost exactly the same, I am inclined to believe, that there must have been some mistake in determining the velocities by the pendulum in these last experiments, and that the velocity shewn by the recoil is most to be depended on.

With 290 grains, or half the weight of the bullet in powder, in the 48th, 49th, and 50th experiments, the recoil was 22,58, 22,92, and 22,38; and the recoil, with the same charge of powder, without a bullet, at a mean of the 60th and 99th experiments, was 10,66. The mean of the velocities of the bullets, computed from the recoil, is therefore 1416 feet in a second, and the velocity shewn by the pendulum was 1427 feet in a second: the difference is not considerable. The mean of the velocities in the 109th, 110th, 111th, and 112th experiments is by the recoil 1464, and by the pendulum 1444 feet in a second.

With 330 grains of powder the velocities of the bullets appear to have been as follows, *viz.*

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
By the recoil	1543	1620	1610
By the pendulum	1594	1625	1528

See the 62d, 63d, 64th, 65th, 66th, 67th, and 17th experiments.

The uniformity of the recoil was in all cases very remarkable. Thus, in the first set of experiments with 290 grains of powder (from the 48th to the 57th experiment inclusive), the recoil was,

Vent at 0.	Vent at 1,3.	Vent at 2,6.
22,58	23,21	23,06
22,92	23,76	23,26
22,38	23,06	23,26
		23,56
<hr/> 3)67,88	<hr/> 3)70,03	<hr/> 4)93,14
Means = 22,626	23,343	and 23,285

If now we take a mean of the 60th and 99th experiments, and call the recoil, without a bullet, 10,66 as before, the velocities will turn out,

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
By the recoil	1416	1501	1494
And by the pendulum they were	1427	1493	1494
The difference is only	- 11	+ 8	+ 34

The recoil was equally regular in the 117th and five succeeding experiments, when the charge was no less than 437½ grs. = 1 ounce avoirdupois in powder; and the velocities of the bullets determined from the recoil are very nearly the same as they were shewn by the pendulum. Thus, in the 117th, 118th, and 119th experiments the mean recoil was 33,3; and in the 120th, 121st and 122d experiments it was 32,866. And if the recoil without a bullet is called 17,9, as it was determined by the 123d experiment, which was made immediately after the experiments before mentioned, then will the velocities be,

	Vent at 0.	Vent at 2,6
By the recoil - -	1822	1771
And by the pendulum they were	1764	1751

The difference is only - +58 and +20 feet in a second, which is less than what frequently occurs in repeating the same experiment.

In the 11th, 12th, 13th, and 14th experiments, when the piece was fired with 310 grains of powder and a bullet, the recoil was 24,69, 24,95, 24,9, and 24,9: and in the 15th, 16th, 18th, and 19th experiments with 330 grains of powder, the recoil was 26,2, 26,2, 26,3, and 26,4. The regularity of these numbers is very striking; and though we cannot compare the velocities of the bullets determined by the two methods as we have done in other cases (as there are reasons to believe, that the velocities, as they are set down in the tables, are not much to be depended on, and as the recoil, with the given charge of 310 grains of powder without a bullet, is not known) yet the regularity of the recoil in these experiments affords good grounds to conclude, that the method of determining the velocities of bullets founded upon it must be very accurate.

But of all the experiments those numbered from 84 to 92 inclusive afford the strongest proof of the accuracy of this method. In those every possible precaution was taken to prevent errors arising from adventitious circumstances, and the weights of the bullets and their velocities were so various, that the uniform agreement of the two methods of determining the velocities in those trials amounts almost to a demonstration of the truth of the principles upon which this new method is founded.

By

By the following table the result of these experiments may be seen at one view.

The experiments.	Weight of the bullets.	The barrel heavier than the bullet.	The recoil.	Velocity of the bullet.		Differences.
				By the recoil.	By the pendulum	
Grs.	$\frac{W}{B} =$	$C =$	$v =$	$v =$		
84th and 93d			$c = 4,4$			
85th	90	3733,3	7,16	2109	1763	+ 346
86th	251	1338,6	9,62	1430	1317	+ 113
87th	354	949,15	11,03	1288	1136	+ 152
88th	600	560,	15,22	1240	1229	+ 11
89th	603	557,22	15,13	1224	1229	+ 5
90th	1184	283,78	21,92	1017	978	- 39
91st	1754	191,56	27,18	893	916	- 23
92d	2352	141,86	32,25	812	833	- 21

The charge of powder consisted of 145 grains in weight in each experiment.

In order to shew, in a more striking manner, the result of these experiments, and the comparison of the two methods of ascertaining the velocities of bullets, I have drawn the fig. 16. where the numbers that are marked upon the line AB are taken from A towards B, in proportion to the weights of the bullets; while the lines drawn from those numbers perpendicular from AB (as w , v , for instance, at the number 2352) and ending at the curve c , d , express their velocities, as shewn by the pendulum. The continuation of those lines on the opposite side of the line AB shew the recoil, and also the velocities of the bullets as determined from it; thus w , r , and the (dotted) lines

parallel to it, which end at the line g, f , express the recoil; and the portion of each of those lines that is comprehended between the line AB and the curve m, n (as w, u) is as the velocity of the bullet in the several experiments. The line A, c , denotes the weight of the charge of powder; and the line A, m , the velocity with which the elastic fluid escapes out of the piece, when the powder is fired without any bullet.

Upon an inspection of this figure, as well as from an examination of the foregoing table, it appears, that the velocities determined by the two methods agree with great nicety in all the experiments after the 87th; but in the 87th experiment, and also in the 86th, but particularly in the 85th, the difference in the result of these different methods is very considerable: and it is remarkable, that in those experiments where they disagree most, the velocities of the bullets, as determined by the pendulum, are extremely irregular; while, on the other hand, the gradual increase of the recoil as the bullets were heavier, and the great regularity of the corresponding velocities, afford good grounds to conclude, that this disagreement is not owing to any inaccuracy in the new method of ascertaining the velocities, but to some other cause that remains to be investigated.

But before we proceed in this inquiry, let us separate the five last experiments in the foregoing table; and, summing up the velocities determined by the two methods, we shall see by their difference how those methods agreed upon the whole, in this instance.

Experiments.	Weight of the bullets.	Velocity.		Difference.
		By the recoil.	By the pendulum.	
	Grs.			
88th	600	1240	1229	+ 11
89th	603	1224	1229	- 5
90th	1184	1017	978	+ 39
91st	1754	893	916	- 23
92d	2352	812	833	- 21
Sums and diff. of the velocities		5186	5185	+ 1

Here the difference in the result of the two methods does not amount to $\frac{1}{5000}$ th part of the whole velocity; but I lay no stress upon this extraordinary argument. I am sensible that it must in some degree have been accidental; but as the difference in the velocities, computed by these different methods, was in no instance considerable, not being in any case so great as what frequently occurred in the most careful repetition of the same experiment, and as the velocities, as determined by the recoil, were much more regular than those shewn by the pendulum, as appears by comparing the curves *g*, *f*, and *m*, *n*, (fig. 16.) with the crooked line *c*, *d*, I think we may fairly conclude, that this new method may with safety be relied on in practice.

The greatest difference in the velocities, as ascertained by the two methods, appears, in the instance of the 85th experiment, where the velocity determined from the recoil exceeds that shewn by the pendulum by 346 feet in a second, the former velocity being that of 2109 feet in a second, the latter only 1763 feet in a second; and in the two succeeding experiments, the velocities shewn by the pendulum are likewise deficient, though not in so great a degree.

This

This apparent deficiency remains now to be accounted for ; and, first, it cannot be supposed, that it arose from any imperfection in Mr. ROBINS'S method of determining the velocities of bullets ; for that method is founded upon such principles as leave no room to doubt of its accuracy ; and the practical errors that occur in making the experiments, and which cannot be intirely prevented, or exactly compensated, are in general so small, that the difference of the velocities in question cannot be attributed to them. It is true, the effect of those errors is more likely to appear in experiments made under such circumstances as those under which the experiments we are now speaking of were made, than in any other case ; for the bullets being very light, the arc of the ascent of the pendulum was but small, and a small mistake in measuring the chord upon the ribbon would have produced a very considerable error in computing the velocity of the bullet : thus, a difference of one tenth of an inch, more or less, upon the ribbon in the 85th experiment, would have made a difference in the velocity of more than 120 feet in a second. But independent of the pains that were taken to prevent mistakes, the striking agreement of the velocities determined by the two methods in the experiments which immediately follow, as also in all other cases where they could be compared, affords abundant reason to conclude, that the errors arising from those causes were in no instance very considerable.

But if both methods of ascertaining the velocities of bullets are to be relied on, then the difference of the velocities, as determined by them in these experiments, can only be accounted for by supposing that it arose from their having been diminished by the resistance of the air in the passage of the bullets from the mouth of the piece to the pendulum ; and this suspicion will

will be much strengthened when we consider how great the resistance is that the air opposes to bodies that move very swiftly in it, and that the bullets in these experiments were not only projected with great velocities, but were also very light, and consequently more liable to be retarded by the resistance on that account.

To put the matter beyond all doubt, let us see what the resistance was that these bullets met with, and how much their velocities were diminished by it. The weight of the bullet (in the 85th experiment) was 90 grains; its diameter was 0,78 of an inch, and it was projected with a velocity of 2109 feet in a second.

If now a computation be made according to the method laid down by Sir ISAAC NEWTON for compressed fluids, it will be found, that the resistance to this bullet was not less than $8\frac{1}{2}$ lbs. avoirdupois, which is something more than 660 times its weight. But Mr. ROBINS has shewn, by experiment, that the resistance of the air to bodies moving in it with very great velocity is near three times greater than Sir ISAAC has determined it, and as the velocity with which this bullet was impelled is considerably greater than any in Mr. ROBINS's experiments, it is highly probable, that the resistance in this instance was at least 2000 times greater than the weight of the bullet.

The distance from the mouth of the piece to the pendulum, as we have before observed, was 12 feet; but, as there is reason to think, that the blast of the powder, which always follows the bullet, continues to act upon it for some sensible space of time after it is out of the bore, and by urging it on counter-balances, or at least counter-acts in a great measure the resistance of the air, we will suppose, that the resistance does

not begin, or rather that the motion of the bullet does not begin to be retarded, till it has got to the distance of two feet from the muzzle. The distance, therefore, between the barrel and the pendulum, instead of 12 feet, is to be estimated at 10 feet; and as the bullet took up about $\frac{1}{9\frac{1}{2}}$ part of a second in running over that space, it must in that time have lost a velocity of about 335 feet in a second, as will appear upon making the computation, and this will very exactly account for the apparent diminution of the velocity in the experiment; for the difference of the velocities, as determined by the recoil and by the pendulum, $= 2109 - 1763 = 346$ feet in a second, is extremely near 335 feet in a second, the diminution of the velocity by the resistance as here determined.

If the diminution of the velocities of the bullets in the two subsequent experiments be computed in like manner, it will turn out in the 86th experiment $= 65$ feet in a second, and in the 87th experiment $= 33$ feet in a second; and making these corrections, the comparison of the two methods of ascertaining the velocities will stand thus:

	85th exp.	86th exp.	87th exp.
Velocities shewn by the pendulum,	1763	1317	1136
Add the diminution of the velocity	335	65	33
by the resistance of the air,			
	<hr/> 2098	<hr/> 1382	<hr/> 1169
Velocity by the recoil,	2109	1430	1288
	<hr/>	<hr/>	<hr/>
The difference =	+ 11	+ 48	+ 119

So that it appears, notwithstanding these corrections, that the velocities in the 86th and 87th experiments, and particularly in the last, as they were determined by the pendulum, are
still

still considerably deficient. But the manifest irregularity of the velocities in those instances affords abundant reason to conclude, that it must have arisen from some extraordinary accidental cause, and therefore, that little dependance is to be put upon the result of those experiments. I cannot take upon me to determine positively what the cause was which produced this irregularity; but I strongly suspect, that it arose from the breaking of the bullets in the barrel by the force of the explosion: for these bullets, as has already been mentioned, were formed of lead, inclosing lesser bullets of plaster of Paris; and I well remember to have observed at the time several small fragments of the plaster which had fallen down by the side of the pendulum. I confess, I did not then pay much attention to this circumstance, as I naturally concluded, that it arose from the breaking of the bullet in penetrating the target of the pendulum, and that the small pieces of plaster I saw upon the ground had fallen out of the hole by which the bullet entered. But if the bullets were not absolutely broken in pieces in firing, yet, if they were considerably bruised, and the plaster or a part of it were separated from the lead, such a change in their form might produce a great increase of the resistance, and even their initial velocities might be affected by it, for their form being changed from that of a globe to some other figure, they might not fit the bore, and a part of the force of the charge might be lost by the windage.

That this actually happened in the 87th experiment seems very probable, as the velocity with which the bullet was projected, as it was determined by the recoil, is considerably less in proportion in that experiment than in either of those that precede it in that set, or in those which follow it, as will ap-

pear upon inspecting the curvature of the line *m, n*, fig. 16. But I forbear to insist further upon this matter.

As I have made an allowance for the resistance of the air in these experiments, it may be expected that I should do it in all other cases; but, I think, it will appear upon enquiry, that the diminution of the velocities of the bullets on that account was in general so inconsiderable that it might safely be neglected: thus, for instance, in the experiments with an ounce of powder, when the velocity of the bullet was more than 1750 feet in a second, the diminution turns out no more than about 25 or 30 feet in a second, though we suppose the full resistance to have begun so near as two feet from the mouth of the piece; and in all cases where the velocities were less, the effect of the resistance was less in a much greater proportion: and even in this instance there is reason to think, that the diminution of the velocity as we have determined it is too great; for the flame of gun-powder expands with such an amazing rapidity, that it is scarcely to be supposed but that it follows the bullet, and continues to act upon it more than two feet, or even four feet, from the gun, and when the velocity of the bullet is less, its action upon it must be sensible at a still greater distance.

With 218 grains of powder the recoil appears to have been very uniform; but if the velocities of the bullets are determined from the recoil in the 40th and seven following experiments, when this charge was made use of, and from the recoil without a bullet in the 72d and 73d experiments, the velocities will turn out considerably too small, as we shall see by making the computation.

	Vent at 0.		Vent at 1,3.	
The re-coil in the	40th exp. was 18, and in the 43d exp. it was 18,3			
	41ft	- 17,71	- 44th	- 18,35
	42d	- 17,91	- 45th	- 18,35
	47th	- 8,1	- 46th	- 18,35
	<u>4)71,72</u>		<u>4)73,35</u>	
	Means =	17,93	and	18,34

And in the 72d and 73d experiments the recoil, with the same charge without a bullet, was 8,72, and $8,47 = 8,595$ at a medium, the velocities therefore turn out,

Vent at 0. Vent at 1,3.
 By the recoil 1105 - 1153
 instead of 1225 and 1276 as they were shewn by the pend.
 The difference 120 and 123 feet in a second amounts to near one twelfth part of the whole velocity.

This difference is undoubtedly owing to the recoil without a bullet being taken too great; for it is not only greater than it ought to be, in order that the velocities of the bullets may come out right; but it is considerably greater in proportion than the recoil with any other charge.

Thus, with 145 grains of powder the recoil was 4,4
 with 165 grains - - - it was 5,55
 290 grains - - - 10,66
 330 grains - - - 12,7
 and with $457\frac{1}{2}$ grains - - - it was 17,9

And if the recoil with 218 grains is determined from these numbers by interpolation, it comes out 7,5; and with that

value for C the velocities of the bullets in the before mentioned experiments appear to be,

	Vent at 0.		Vent at 1,3.
	1243	and	1283 by the recoil
which is extremely near	1225	and	1276 the velocities

shewn by the pendulum.

It is to be remembered, that the 72d and 73d experiments, from which we before determined the recoil with the given charge of powder without a bullet, were not made upon the same day with the experiments before mentioned; and it is well known, that the force of powder is different upon different days. And it is worthy of remark, that in those two experiments the strength of government powder appeared to be considerably the greatest. I mention these circumstances to shew the probability there is, that the recoil in those experiments, from some unknown cause, was greater than it ought to have been, or rather than it would have been, had the experiments been made at the same time when the experiments with the bullets were made; or at any other time under the same circumstances.

As this method of determining the velocities of the bullets did not occur to me till after I had finished the course of my experiments, and had taken down my apparatus, I have not had an opportunity of ascertaining the recoil, with and without a bullet, with that degree of precision that I could wish. If I had thought of it sooner, or if I had recollected that passage in Mr. ROBINS's new Principles of Gunnery, where he says, "The part of the recoil, arising from the expansion of
" the powder alone, is found to be no greater when it impels
" a leaden bullet before it, than when the same quantity is fired
" without any wad to confine it:" I say, if that passage had occurred

occurred to me before it had been too late, I certainly should have taken some pains to have ascertained the fact; but as it is, I think, enough has been done to shew, that there is the greatest probability that the velocities of bullets may in all cases be determined by the recoil with great accuracy; and I hope soon to have it in my power to put the matter out of all doubt, and to verify this new method by a course of conclusive experiments which I am preparing for that purpose.

In the mean time I would just observe, that if this method should be found to answer, when applied to musket bullets, it cannot fail to answer equally well when it is applied to cannon balls and bomb shells of the largest dimensions; and it is apprehended, that it will be much preferable to any method hitherto made public; not only as it may be applied indifferently to all kinds of military projectiles, and that with very little trouble or expence in making the experiment; but also because by it the velocities with which bullets are *actually projected* are determined; whereas by the pendulum their velocities can only be ascertained at some distance from the gun, and after they have lost a part of their initial velocities by the resistance of the air through which they are obliged to pass to arrive at the pendulum.

At the trifling expence of ten or fifteen pounds an apparatus might be constructed that would answer for making the experiments with all the different kinds of ordnance in the British service. The advantages that might be derived from such a set of experiments are too obvious to require being mentioned.

Of a very accurate method of proving gun-powder.

All the *eprouvettes*, or powder-tries, in common use are defective in many respects. Neither the absolute force of gun-powder can be determined by means of them, nor the comparative force of different kinds of it, but under circumstances very different from those in which the powder is made use of in service.

As the force of powder arises from the action of an elastic fluid that is generated from it in its inflammation, the quicker the charge takes fire, the more of this fluid will be generated in any given short space of time, and the greater of course will be its effect upon the bullet. But in the common method of proving gun-powder, the weight by which the powder is confined is so great in proportion to the quantity of the charge, that there is time quite sufficient for the charge to be all inflamed, even when the powder is of the slowest composition, before the body to be put in motion can be sensibly removed from its place. The experiment, therefore, may shew which of two kinds of powder is the strongest, when equal quantities of both are confined in equal spaces, and completely inflamed; but the degree of the inflammability, which is a property essential to the goodness of the powder, cannot by these means be ascertained.

Hence it appears, how powder may answer to the proof, such as is commonly required, and may nevertheless turn out very indifferent when it comes to be used in service. And this, I believe, frequently happens; at least I know complaints from officers of the badness of our powder are very common; and I would suppose that no powder is ever received by the

Board of Ordnance but such as has gone through the established examination, and has answered to the usual test of its being of the standard degree of strength.

But though the common powder triers may shew powder to be better than it really is, they never can make it appear to be worse than it is; it will therefore always be the interest of those who manufacture that commodity to adhere to the old method of proving it. But the purchaser will find his account in having it examined in a method by which its goodness may be ascertained with greater precision.

The method I would recommend is as follows. A quantity of powder being provided, which, from any previous examination or trial, is known to be of a proper degree of strength to serve as a standard for the proof of other powder, a given charge of it is to be fired, with a fit bullet, in a barrel suspended by two pendulous rods, according to the method before described, and the recoil is to be carefully measured upon the ribbon. And this experiment being repeated three or four times; or oftener if there is any difference in the recoil, the mean and the extremes of the chords may be marked upon the ribbon by black lines drawn across it, and the word *proof* may be written upon the middle line; or if the recoil is uniform (which it will be to a sufficient degree of accuracy, if care is taken to make the experiments under the same circumstances) then the *proof mark* is to be made in that part of the ribbon to which it was constantly drawn out by the recoil in the different trials.

The recoil, with a known charge of standard powder, being thus ascertained and marked upon the ribbon, let an equal quantity of any other powder (that is to be proved) be fired in the same barrel, with a bullet of the same weight, and every other circumstance alike, and if the ribbon is drawn out as far

far or farther than the proof mark, the powder is as good or better than the standard; but if it falls short of that distance, it is worse than the standard, and is to be rejected.

For the greater the velocity is with which the bullet is impelled, the greater will be the recoil; and when the recoil is the same, the velocities of the bullets are equal, and the powder is of the same degree of strength, if the quantity of the charge is the same. And if care is taken in proportioning the charge to the weight of the bullet, to come as near as possible to the medium proportion that obtains in practice, the determination of the goodness of gun-powder from the result of this experiment cannot fail to hold good in actual service.

Fig. 14. represents the proposed apparatus, drawn to a scale of one foot to the inch. *a, b*, is the barrel suspended by the pendulous rods *c, d*; and *r* is the ribbon for measuring the recoil.

The length of the bore is 30 inches, and its diameter is one inch, consequently it is just 30 calibres in length, and will carry a leaden bullet of about 3 ounces.

The barrel may be made of gun metal, or of cast iron as that is a cheaper commodity; but great care must be taken in boring it, to make the cylinder perfectly strait and smooth, as well as to preserve the proper dimensions. Of whatever metal the barrel is made, it ought to weigh at least 50 lbs. in order that the velocity of the recoil may not be too great; and the rods by which it is suspended should be five feet in length. The vent may be about one twentieth of an inch in diameter; and it should be *bouched* or lined with gold, in the same manner as the touch-hole is made in the better kind of fowling pieces, in order that its dimensions may not be increased by repeated firing.

The bullets should be made to fit the bore with very little windage; and it would be better if they were all cast in the same mould, and of the same parcel of lead, as in that case their weights and dimensions would be more accurately the same, and the experiments would of course be more conclusive.

The stated charge of powder may be half an ounce, and it should always be put up in a cartridge of very fine paper; and after the piece is loaded it should be primed with other powder, first taking care to prick the cartridge by thrusting a priming wire down the vent.

As it appears, from several experiments made on purpose to ascertain the fact, that ramming the powder more or less has a very sensible effect to increase or diminish the force of the charge; to prevent any inaccuracies that might arise from that cause, a ram-rod, such as is represented fig. 15. may be made use of. It is to be made of a cylindric piece of wood in the same manner as ram-rods in general are made, but with the addition of a ring C, about one inch and a half, or two inches in diameter, which, being placed at a proper distance from the end (*a*) of the ram-rod that goes up into the bore, will prevent its being thrust up too far. This ring may be made of wood, or of any kind of metal as shall be found most convenient. The other end of the ram-rod (*b*) may be 31 or 32 inches in length from the ring, and the extremity of it being covered with a proper substance, it may be made use of for wiping out the barrel after each experiment.

The machine (*f*) for the tape to slide through may be the same as is described by Dr. HUTTON in his account of his experiments on the initial velocities of cannon balls; as his method is much better calculated to answer the purpose than that proposed and made use of by Mr. ROBINS. It will also be

better for the axis of the pendulous rods to rest upon level pieces of wood or iron, than for them to move in circular grooves : only care must be taken to confine them by staples or some other contrivance, to prevent their slipping out of their places.

The trunnions, by means of which the barrel is connected with the pendulous rods, and upon which it is supported, should be as small as possible, in order to lessen the friction ; and for the same reason they should be well polished, as well as the grooves that receive them. They need not be cast upon the barrel, but may be screwed into it after it is finished.

In making the experiments, regard must be had to the heat of the barrel, as well as to the temperature of the atmosphere ; for heat and cold, dryness and moisture, have a very sensible effect upon gun-powder to increase or diminish its force. If therefore a very great degree of accuracy is at any time required, it will be best to begin by firing the piece two or three times merely to warm it ; after which three or four experiments may be made with standard powder, to determine anew the proof mark (for the strength of the same powder is different upon different days) ; and when this is done, the experiments with the powder that is to be proved are to be made, taking care to preserve the same interval of time between the firings, that the heat of the piece may be the same in each trial.

If all these precautions are taken, and if the bullets are of the same weight and dimensions, powder may be proved by this method with much greater accuracy than has hitherto been done by any of the common methods made use of for that purpose.

Of the comparative goodness, or value, of powder of different degrees of strength.

Let V denote the velocity of the bullet with the stronger powder, and put v equal to the velocity with the weaker, when the charges are equal, and the weight and dimensions of the bullets are the same, and when they are discharged from the same piece. If the charge is augmented when the weaker powder is made use of, till the velocity of the bullet is increased from v to V , or becomes equal to the velocity with the given charge of the stronger powder, the *value* of the charges may then be said to be equal; and consequently the weaker powder is as much worse than the stronger, or is of less value in proportion as the quantity of it required by the pound, to produce the given effect is greater.

But it is well known, that the velocities, with different quantities of the same kind of powder, are in the sub-duplicate ratio of the weights of the charges. The charges, therefore, must be as the squares of the velocities, and consequently the charge of the weaker powder must be to that of the stronger, when the velocities are equal, as VV is to vv . The weaker powder is therefore as much worse than the stronger as VV is greater than vv ; or the comparative goodness of powder, of different degrees of strength, is as the squares of the velocities of the bullets when the charges are equal.

The mean velocity of the bullets, as shewn by the pendulum in the 104th and 105th experiments, when the piece was fired with 145 grains of government powder, was 894 feet

in a second; and with the same quantity of double proof * battle powder (experiment N° 106) the velocity was 990 feet in a second. Now the squares of these velocities, which, as we just observed, measure the goodness of the powder, are to each other as 1 is to 1,2263, or nearly as 5 is to 6.

With 218 grains of government powder, the mean velocity in four experiments (*viz.* the 40th, 41st, 42d, and 43d) was 1225 feet in a second; and in the experiment N° 107. when the same quantity of double proof battle powder was made use of, the velocity was 1380 in a second; and $\overline{1225^2}$ is to $\overline{1380^2}$ as 1 is to 1,2691.

With 290 grains, or half the weight of the bullet in government powder in the 109th, 110th, 111th, and 112th experiments, the mean velocity of the bullet was 1444 feet in a second; but with the same quantity of the battle powder (experiment N° 116.) the velocity was 1525 feet in a second; $\overline{1444^2}$ is to $\overline{1525^2}$, as 1 is to 1,1153.

By taking a medium of these trials it appears, that double proof battle powder is better than government powder in proportion as 1,2036 is to 1, or nearly as 6 is to 5.

But if, instead of weighing the powder, we estimate the quantity of the charge by measurement, or the space it occupies in the bore of the piece, the comparative strength of battle powder will appear to be considerably greater, or its strength will be to that of government powder nearly as 4 is to 3; for the grains of this better kind of powder being more compact and nearly of a spherical form, a greater weight of it will lie in any

* This is called *battle* powder, not because it is used in battle or in war; but from *Battle*, the name of a village in Kent, where that kind of powder is made.

given space than of government powder, which is formed more loofely, and of various and of very irregular figures.

Now the common price of double proof battle powder, as it is fold by the wholefale dealers in that commodity, is at the rate of $\text{£. } 10$ *per* cwt. net, which is juft two fhillings by the pound; while government powder is fold at $\text{£. } 5 \text{ } 5s.$ *per* hundred, or one fhilling and $\frac{6}{10}$ th of a penny *per* pound; but battle powder is better than government powder only in the proportion of 1,2036 to 1, or of one fhilling and two pence to one fhilling and $\frac{6}{10}$ th of a penny; battle powder is therefore fold at the rate of ten pence by the pound, or $41\frac{2}{3}$ *per cent.* dearer than it ought to be; or thofe, who make ufe of it in preference to government powder, do it at a certain lofs of $41\frac{2}{3}$ *per cent.* of the money that the powder cofts them.

Of the relation of the velocities of bullets to their weights.

According to Mr. ROBINS's theory, when bullets of the fame diameter, but different weights, are difcharged from the fame piece by the fame quantity of powder, their velocities fhould be in the reciprocal fub-duplicate ratio of their weights; but as this theory is founded upon a fuppoftion that the action of the elaffic fluid, generated from the powder, is always the fame in any and every given part of the bore when the charge is the fame, whatever may be the weight of the bullet; and as no allowance is made for the expenditure of force required to put the fluid itfelf in motion, or for the lofs of it by the vent; it is plain that the theory is defective. It is true, Dr. HUTTON in his experiments found this law to obtain without any great error, and poffibly it may hold good with fufficient accuracy in many cafes; for it fometimes happens that a number of errors or
actions,

actions, whose operations have a contrary tendency, so compensate each other, that their effects when united are not sensible. But when this is the case, if any one of the causes of error is removed, those which remain will be detected.

When any given charge is loaded with a heavy bullet, more of the powder is inflamed in any very short space of time than when the bullet is lighter, and the action of the powder ought of course to be greater on that account; but then a heavy bullet takes up more time in passing through the bore than a light one, and consequently more of the elastic fluid, generated from the powder, escapes by the vent and by windage. It may happen, that the augmentation of the force, on account of one of these circumstances, may exactly counterbalance the diminution of it arising from the other; and if it should be found upon trial that this is the case in general, in pieces as they are now constructed, and with all the variety of shot that are made use of in practice, it would be of great use to know the fact: and possibly it might answer as well, as far as it relates to the art of gunnery, as if we were perfectly acquainted with, and were able to appreciate, the effect of each varying circumstance under which an experiment can be made. But when, concluding too hastily from the result of a partial experiment, we suppose with Mr. ROBINS, that because the sum total of the action or pressure of the elastic fluid upon the bullet, during the time of its passage through the bore, happens to be the same when bullets of different weights are made use of (which collective pressure is in all cases proportional to, and is accurately measured by, the velocity, or rather motion, communicated to the bullet) that therefore the pressure in any given part is always exactly the same, when the quantity of powder is the same with which the piece is fired; and from thence endeavour to
prove,

prove, that the inflammation of gun-powder is instantaneous, or that the whole charge is in all cases inflamed, and “ converted into an elastic fluid before the bullet is sensibly moved “ from its place ;” such reasonings and conclusions may lead to very dangerous errors.

It is undoubtedly true, that if the principles assumed by Mr. ROBINS with respect to the manner in which gun-powder takes fire, and the relation of the elasticity of the generated fluid to its density, or the intensity of its pressure upon the bullet as it expands in the barrel, were just, and if the loss of force by the vent and windage was in all cases inconsiderable, or if it was prevented, the deductions from the theory respecting the velocities of bullets of different weights would always hold good. But if, on the contrary, it should be found upon making the experiments carefully, and in such a manner as intirely to prevent inaccuracies arising from adventitious circumstances, that the velocities observe a law different from that which the theory supposes, we may fairly conclude, that the principles upon which the theory is founded are erroneous.

Let us now see how far these experiments differ from the theory. Those numbered from 84 to 92 inclusive were made in such a manner that no part of the force of the powder was lost by the vent, or by windage, as has already been mentioned, and all possible attention was paid to every circumstance that could contribute to render them perfect and conclusive.

A particular account of them with the means used for forming the bullets, and making them fit for the bore, and the contrivance for preventing the escape of the elastic fluid by the vent, &c. may be seen in the general table, p. 245. The following table shews the result of them.

N. B. The charge of powder was the same in each experiment, and consisted of 145 grains in weight.

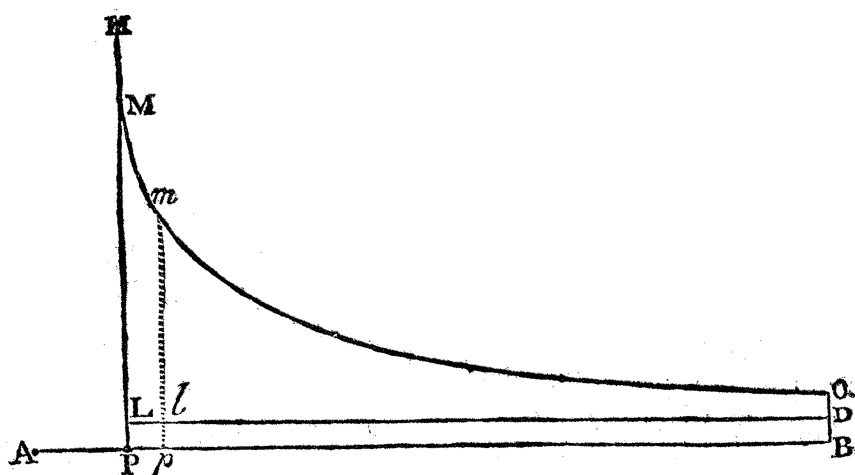
	Weight of the bullet.	Velocity of the bullet.		Difference.
		Actual.	Computed.	
85th exp.	90 grs.	2109	2109	—
86th	251	1430	1262	+ 168
87th	354	1288	1063	+ 225
88th	600	1240	817	+ 423
89th	603	1224	815	+ 409
90th	1184	1017	581	+ 436
91st	1754	893	478	+ 415
92d	2352	812	413	+ 399

The computed velocities, as they are set down in this table, were determined from the actual velocity of the bullet, as determined by the recoil in the 85th experiment; and the reciprocal sub-duplicate ratio of its weight to the weight of the bullet in each subsequent experiment; and in the last column is marked the difference between the experiment and the theory, or the number of feet in a second, by which the actual velocity exceeds the computed.

But in order that we may see this matter in different points of view, let the order of the experiments be now inverted, and let the computed velocities be determined from the actual velocity in the 92d experiment; and assuming the total or collective pressure exerted by the powder upon the bullet in that experiment equal to unity, let the collective pressure in the other experiments be computed from the ratio of the actual to the computed velocities, and the table will stand thus:

	Weight of the bullet.	Velocity of the bullet.		Difference.	Collective pressure.
		Actual.	Computed.		
92d exp.	2352 grs.	812	812	—	1,0000
91ft	1754	893	940	- 47	0,9020
90th	1184	1017	1145	- 128	0,7897
89th	603	1224	1604	- 380	0,5825
88th	600	1240	1608	- 368	0,5949
87th	354	1288	2093	- 805	0,3778
86th	251	1430	2486	- 1056	0,3310
85th	90	2109	4151	- 2042	0,2581

In the following figure let AB represent the axis of the piece, and AP the length of the space filled with powder; and at the



point P let the perpendicular PH be erected, upon which let PL and PM be taken from P towards H of such magnitudes that while PL expounds the uniform force of gravity, or the weight of the bullet, PM shall be as the force exerted by the powder

upon the bullet at the moment of the explosion. If now we suppose, that while the bullet moves on from P towards B, the line PM or pm , goes along with it, and that the point m is always taken in such a manner that the line pm , shall be to pl , or PL, as the force acting upon the bullet in the point p , is to its weight, till pm , coincides with QB, then will the area PMQB be to the area PLDB in the duplicate proportion of the velocities which the bullet would acquire when acted on by its own gravity through the space PB, and when impelled through the same space by the force of the powder, as may be seen demonstrated by Sir ISAAC NEWTON, in his Mathematical Principles of Natural Philosophy, book I. prop. 39.

Now what I call the collective pressure, or sum total of the action of the powder upon the bullet, is the measure of the area PMQB; and it is plain, from what has been said above, that its measures are in all cases to be accurately determined, when the weight and velocity of the bullet are known.

If all the powder of the charge was inflamed at once, or before the bullet sensibly moved from its place; and if the pressure of the generated fluid was always as its density, or inversely as the space it occupies, then would the line MQ be an hyperbola, the area PMQB would always be the same when the charge was the same, and consequently the velocities of the bullets would be as the square roots of their weights inversely. But it appears, from the before mentioned experiments, that when the weight of the bullet was increased four times, the action of the powder, or area PMQB, was nearly doubled; for in the 92d experiment, when four bullets were discharged at once, the collective pressure was as 1; but in the 89th experiment, when a single bullet was made use of, the collective pressure

pressure was only as 0,5825; and in the 85th, 86th, and 87th experiments, when the bullets were much lighter, the action of the charge was still less.

But though we can determine with great certainty, from these experiments, the ratio in which the action of the powder upon the bullet was increased or diminished, by making use of bullets of greater or less weight; yet we cannot from thence ascertain the relation of the elasticity of the generated fluid to its density, nor the quantity of powder that is inflamed at different periods before and after the bullet begins to move in the bore.

But assuming Mr. ROBINS's principles as far as relates to the elasticity of the fluid, and supposing that in all the experiments, except the 92d, a part only of the charge took fire, and that that part was inflamed and converted into an elastic fluid before the bullet began to move; upon that supposition we can determine the quantity of powder that took fire in each experiment; for the quantity of powder in that case would be as the collective pressure.

Thus, if the whole charge, = 145 grains in weight, is supposed to have been inflamed in the 92d experiment, the quantity inflamed in each of the other experiments will appear to have been as follows; *viz.*

	Weight of the bullet.	Velocity of the bullet.	Collective pressure.	Powder inflamed.
85th exp.	90 grs.	2109	0,2581	37 grs.
86th	251	1430	0,3310	48
87th	354	1288	0,3778	55
88th	600	1240	0,5949	86
89th	603	1224	0,5825	84
90th	1184	1017	0,7897	114
91st	1754	893	0,9020	131

But there are many reasons to suppose, that the diminution of the action of the powder upon the bullet, when it is lighter, is not so much owing to the smallness of the quantity of powder that takes fire in that case as to the *vis inertiae* of the generated fluid. It is true, that a greater portion of the charge takes fire when the bullet is heavy than when it is light, as I found in the very experiments of which I am now speaking; but then the quantity of unfired powder in any case was much too small to account for the apparent diminution of the force when light bullets were made use of.

If the elastic fluid, in the action of which the force of powder consists, were infinitely fine, or if its weight bore no proportion to that of the powder that generated it; and if the gross matter, or *caput mortuum*, of the powder remained in the bottom of the bore after the explosion, then, and upon no other supposition, would the pressure upon the bullet be inversely as the space occupied by the fluid: but it is evident that this can never be the case.

A curious subject for speculation here occurs: how far would it be advantageous, were it possible, to diminish the specific gravity of gun-powder, and the fluid generated from it, with-

out lessening its elastic force? It would certainly act upon very light bullets with greater force; but when heavy ones came to be made use of, there is reason to think, that, except extraordinary precaution was taken to prevent it, the greatest part of the force would be lost by the vent and by windage.

The velocity with which elastic fluids rush into a void space is as the elasticity of the fluid directly, and inversely as its density; if, therefore, the density of the fluid generated from powder was four times less than it is, its elasticity remaining the same, it would issue out at the vent, and escape by the side of the bullet in the bore, with nearly four times as great a velocity as it does at present; but we know from experiment that the loss of force on those accounts is now very considerable.

In the experiments N^o 76. and 77. when the piece was fired with 145 grains of powder, the velocity of the bullets at a medium was 1040 feet in a second; but in the 88th and 89th experiments, when the bullets were even heavier, and the piece was fired with the same quantity of powder, the mean velocity was 1232 feet in a second. The difference = 192 feet in a second, answers to a difference of force greater in the last experiments than in the first in the proportion of 14 to 10.

I know of no way to account for this difference, but by supposing that it was owing intirely to the escape of the elastic fluid by the vent, and by windage, in those experiments where the vent was open, and the bullets were put naked into the piece.

An elastic bow, made of very light wood, will throw an arrow, and especially a light one, with greater velocity than a bow of steel of the same degree of stiffness: but, for practice, I think it is plain, that gun-powder may *be supposed* to be so light

light as to be rendered intirely uselefs : and for some purposes it seems probable, that it would not be the worse for being even heavier than it is now made. Vents are absolutely necessary in fire-arms, and in large pieces the windage must be considerable, in order that the bullets, which are not always so round as they should be, may not stick in the bore ; and those who have been present at the firing of heavy artillery and large mortars with shot and shells, must have observed, that there is a sensible space of time elapses between the lighting of the prime and the explosion ; and that, during that interval, the flame is continually issuing out at the vent with a hissing noise, and with a prodigious velocity, as appears by the height to which the stream of fire mounts up in the air. It is plain, that this loss must be greater in proportion as the shot that is discharged is heavier ; and I have often fancied, that I perceived a sensible difference in the time that elapsed between the firing of the prime and the explosion, when bullets were discharged, and when the piece has been fired with powder only ; the time being apparently longer in the former case than the latter.

Almost all the writers upon gun-powder, and particularly those of the last century, gave different recipes for powder that is designed for different uses. Thus the French authors mention *poudre à mousquet*, *poudre ordinaire de guerre*, *poudre de chasse*, and *poudre d'artifice* ; all of which are composed of salt petre, sulphur, and charcoal, taken in different proportions. Is it not probable, that this variety in the composition of powder was originally introduced in consequence of observation that one kind of powder was better adapted for particular purposes than another, or from experiments made on purpose to ascertain the fact ? There is one circumstance that would lead us to suppose that that was the case.— That kind of powder

der which was designed for great guns and mortars was weaker than those which were intended to be used in smaller pieces: for if there is any foundation for these conjectures, it is certain, that the weakest powder, or the heaviest in proportion to its elastic force, ought to be used to impel the heaviest bullets, and particularly in guns that are imperfectly formed, where the vent is large, and the windage very great.

I am perfectly aware, that an objection may here be made, viz. that the elastic fluid, which is generated from gun-powder, must be supposed to have the same properties very nearly, whatever may be the proportion of the several ingredients, and that therefore the only difference there can be in powder is, that one kind may generate more of this fluid, and another less; and that when it is generated, it acts in the same manner, and will alike escape, and with the same velocity, by any passage it can find. But to this I answer, though the fluid may be the same, as undoubtedly it is, and though its density and elasticity may be the same in all cases at the instant of its generation, yet in the explosion, the elastic and un-elastic parts are so mixed and blended, that I imagine the fluid cannot expand without taking the gross matter along with it, and the velocity with which the flame issues out at the vent is to be computed from the elasticity of the fluid, and the density or weight of the fluid and the gross matter taken together, and not simply from the elasticity and density of the fluid. If antimony in an impalpable powder, or any other heavy body, was intimately mixed with water in a vessel of any kind, and kept in suspension by shaking or stirring them about; and if a hole was opened in the side or bottom of the vessel, the water would not run out without taking the particles of the solid body along with it. And in the same manner I conceive the solid particles that
remain

remain after the explosion of gun-powder are carried forward with the generated elastic fluid, and being carried forward retard its motion.—But to return from this digression.

As it appears from these experiments, that the relation of the velocities of bullets to their weights is different from that which Mr. ROBINS's theory supposes, it remains to inquire what the law is which actually obtains. And, first, as the velocities bear a greater proportion to each other than the reciprocal sub-duplicate ratio of the weights of the bullets, let us see how near they come to the reciprocal sub-triplicate ratio of their weights.

		Velocity of the bullet				
	Weight of the bullet.	Computed.	Actual.			Computed.
		Recip. sub-dup. ratio.	Error of the theory.		Error of the theory.	Recip. sub-trip. ratio.
92d	2352	812	—	812	—	812
91st	1754	940	+ 47	893	+ 2	895
90th	1184	1145	+ 128	1017	+ 4	1021
89th	603	1604	+ 380	1224	+ 54	1278
88th	600	1608	+ 368	1240	+ 40	1280
87th	354	2093	+ 805	1288	+ 239	1527
86th	251	2486	+ 1056	1430	+ 282	1712
85th	90	4151	+ 2042	2109	+ 301	2410

Here the velocities computed upon the last supposition appear to agree much better with the experiments than those computed upon Mr. ROBINS's principles; but still there is a considerable difference between the actual and the computed velocities in the three last experiments in the table.

As the powder itself is heavy, it may be considered as a weight that is put in motion along with the bullet; and if we suppose

suppose the density of the generated fluid is always uniform from the bullet to the breech, the velocity of the center of gravity of the powder or (which amounts to the same thing) of the elastic fluid, and the gross matter generated from it will be just half as great as the velocity of the bullet. If therefore we put P to denote the weight of the powder, B the weight of the bullet, and v its initial velocity; then $Bv + \frac{1}{2}Pv = \overline{B + \frac{1}{2}P} \times v$ will express the *momentum* of the charge at the instant when the bullet quits the bore.

If now, instead of ascertaining the relation of the velocities to the weights of the bullets, we add half the weight of the powder to the weight of the bullet, and compute the velocities from the reciprocal sub-triplicate ratio of the quantity $\overline{B + \frac{1}{2}P}$ in each experiment, the table will stand thus:

	Weight of the bullet and half the powder. $\overline{B + \frac{1}{2}P} =$	Velocity of the bullet.		Error of the theory.
		Actual.	Computed.	
92d exp.	$2352 + 72\frac{1}{2}$	812	812	—
91st	$1754 + 72\frac{1}{2}$	893	892	[- 1
90th	$1184 + 72\frac{1}{2}$	1017	1011	[- 6
89th	$603 + 72\frac{1}{2}$	1224	1243	+ 19
88th	$600 + 72\frac{1}{2}$	1240	1245	+ 5
87th	$354 + 72\frac{1}{2}$	1288	1449	+ 161
86th	$251 + 72\frac{1}{2}$	1430	1589	+ 159
85th	$90 + 72\frac{1}{2}$	2109	1999	[- 110

The agreement between the actual and computed velocities is here very remarkable, and particularly in the five first experiments, which are certainly those upon which the greatest dependence may be placed.

And hence we are enabled to determine the natures of the *mn*, and *gf* (fig. 16.); for since *B* (which expresses the weight of the bullet) is as the length taken from *A* towards *B* in the figure in the several experiments; and as the velocities are as the lines drawn perpendicular to the line *AB* from the places where those lengths terminate, as *w*, *u*, &c. ending at the curve *m*, *n*; if we put $a = \frac{1}{2}P$, $x = B$, and $y = wu$; then will the relation of x and y be defined by this equation:

$\frac{1}{\sqrt{a+x^3}} = y$. And if z be put to denote the line *wr*, and *o*, the recoil when the given charge is fired without any bullet, it will be $\frac{x}{\sqrt{a+x^3}} + b = z$ in the curve *gf*, x being the abscissa, and z the corresponding ordinate to the curve.

In the 92d experiment half the weight of the powder ($= a$) was $72\frac{1}{2}$ grains; the weight of the bullet was 2352 grains ($= x$); the recoil ($= z$) was 32.25 inches, and with the given charge without any bullet the recoil ($= b$) was 4.4 inches; if now from these *data*, and the known weight of the bullet in each of the other experiments in this set, the recoil be computed by means of the theorem $\frac{x}{\sqrt{a+x^3}} + b = z$, we shall see how the result of those experiments agrees with this theory: thus,

	Weight of the bullet.	Recoil		Difference.
		Actual.	Computed.	
92d exp.	2352	32,25	32,25	—
91st	1754	27,18	27,22	+0,04
90th	1184	21,92	21,85	-0,07
89th	603	15,13	15,33	+0,2
88th	600	15,22	15,29	+0,07
87th	354	11,03	11,87	+0,84
86th	251	9,62	10,21	+0,59
85th	90	7,16	7,02	-0,14
84th and 93d	0	4,4	4,4	—

Here the agreement of the actual and computed recoils is as remarkable as that of the actual and computed velocities in the foregoing table.

By the figure 17. may be seen at one view the result of all these experiments and computations. The numbers upon the line AB (as in the fig. 16.) represent the weights of the bullets, while the lines drawn from those numbers perpendicular to AB on each side, and ending at the curves *m*, *n*, are as the velocities of the bullets in the several experiments; the line AB being the axis of the curves, the lengths taken from A to the different numbers towards B ($=x$) the abscissa, and the perpendiculars ($=y$) the corresponding ordinates. The ordinates to the curve *bm*, are as the velocities computed from the theorem.

$\frac{1}{\sqrt{a+x^3}} = y$, and the ordinates to the curve *pn* (which is the

logarithmic curve, as it is $\frac{1}{\sqrt{x}} = y$) shew the velocities computed upon Mr. ROBINS's principles. The curve *gf* is drawn from

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the theorem $\frac{x}{\sqrt{a+x^3}} + b = z$; and the actual recoil is marked upon the ordinates to this curve by large round dots, which in all the experiments, except the 86th and 87th, very nearly coincide with the curve.

In the fig 18. the numbers upon the line AB, taken from A, denote the different charges of powder used in the course of the experiments, while the ordinates to the curve *cd*, express the velocities of the bullets, with the vent at o. The lines drawn perpendicular from the line AB to the line *ef*, represent the recoil with the several charges of powder, and a leaden bullet; and the portion of those lines that is comprehended between the line AB and the line *gh*, denotes the recoil when the given charge was fired without any bullet.

Having now shewn by experiment the relation of the velocities of bullets to their weights, when care is taken to prevent intirely the loss of force by the escape of the elastic fluid through the vent and by the windage, I shall leave it to mathematicians to determine from these *data* the properties of that fluid.

But, before I take my leave of this subject, I would just observe, that Mr. ROBINS is not only mistaken in the principle he assumes, respecting the relation of the elasticity of the fluid generated from gun-powder to its density, or rather the law of its action upon the bullet as it expands in the bore; but his determination of the force of gun-powder is also erroneous, even upon his own principles: for he determines its force to be 1000 times greater than the mean preffure of the atmosphere; whereas it appears, from the result of the 92d experiment, that its force is at least 1308 times greater than the

mean

mean pressure of the atmosphere, as will be evident to those who will take the trouble to make the computation.

Of an attempt to determine the explosive force of aurum fulminans, or a comparison between its force and that of gun-powder.

Having provided myself with a small quantity of this wonderful powder, upon the goodness of which I could depend, I endeavoured to ascertain its explosive force by making use of it instead of gun-powder for discharging a bullet, and measuring, by means of the pendulum, the velocity which the bullet acquired; and concluding, from the tremendous report with which this substance explodes, that its elastic force was vastly greater than that of gun-powder, I took care to have a barrel provided of uncommon strength, on purpose for the experiment. Its length in the bore is 13,25 inches, the diameter of the bore is 0,55 of an inch, and its weight 7 lbs. 2 oz. It is of the best iron, and was made by WOODON; and the accuracy with which it is finished does credit to the workman.

This barrel being charged with one sixteenth of an ounce (= 27,34 grains) of *aurum fulminans* and two leaden bullets, which, together with the leather that was put about them to make them fit the bore without windage, weighed 427 grains; it was laid upon a chaffing-dish of live coals, at the distance of about 10 feet from the pendulum, and against the center of the target of the pendulum the piece was directed.

Having secured the barrel in such a manner that its direction should not alter, I retired to a little distance, in order to be out of danger in case of an accident, where I waited in anxious expectation the event of the explosion.

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I had remained in this situation some minutes, and almost despaired of the experiment's succeeding, when the powder exploded, but with a report infinitely less than what I expected, the noise not greatly exceeding the report of a well-charged wind gun; and it was not till I saw the pendulum in motion that I could be persuaded that the bullets had been discharged. I found, however, upon examination, that nothing was left in the barrel, and from the great number of small particles of revived metal that were dispersed about, I had reason to think that all the powder had exploded.

The bullets struck the pendulum nearly in the center of the target, and both of them remained in the wood: and I found, upon making the calculation, that they had impinged against it with a velocity of 428 feet in a second.

If we now suppose that the force of *aurum fulminans* arises from the action of an elastic fluid that is generated from it in the moment of its explosion, and that the elasticity of this fluid, or rather the force it exerts upon the bullet as it goes on to expand, is always as its density, or inversely as the space it occupies; then, from the known dimensions of the barrel, the length of the space occupied by the charge (which in this experiment was 0,47 of an inch), and the weight and velocity of the bullets, the elastic force of this fluid at the instant of its generation may be determined: and I find, upon making the calculation upon these principles, that its force turns out 307 times greater than the mean elastic force of common air.

According to Mr. ROBINS's theory, the elastic force of the fluid generated from gun-powder in its inflammation is 1,000 times greater than the mean pressure of the atmosphere; the force of *aurum fulminans*, therefore, appears to be to that of gun-powder as 307 is to 1,000, or as 4 is to 13 very nearly.

Of the specific gravity of gun-powder.

To determine the specific gravity of gun-powder I made use of the following method. A large glass bucket, with a narrow mouth, being suspended to one of the arms of a very nice balance, and exactly counter-poised by weights put in the opposite scale, it was filled first with government powder poured in lightly, then with the same powder shaken well together, afterwards with powder and water together, and lastly with water alone, and in each case the contents of the bucket were very exactly weighed.

The specific gravity of gun-powder, as determined from these experiments, is as follows :

Specific gravity of rain water	-	-	1,000
Government powder, as it lies light in a heap, mixed	}	-	0,836
with air			
Government powder well shaken together	-	-	0,937
The solid substance of the powder	-	-	1,745

Hence it appears, that a cubic inch of government powder shaken well together weighs just 243 grains; that a cubic inch of solid powder would weigh 442 grains; and, consequently, that the interstices between the particles of the powder, as it is grained for use, are nearly as great as the spaces which those particles occupy.

MISCELLANEOUS EXPERIMENTS.

Of some unsuccessful attempts to increase the force of gun-powder.

It has been supposed by many, that the force of steam is even greater than that of gun-powder; and that if a quantity of water, confined in the chamber of a gun, could at once be rarified into steam, it would impel a bullet with prodigious velocity. Several attempts have been made to shoot bullets in this manner; but I know of none that have succeeded; at least so far as to render it probable that water can ever be substituted in the room of gun-powder for military purposes, as some have imagined.

The great difficulty that attends making these experiments lies in finding out a method by which the water can at once be rarified, and converted into elastic steam; and it occurred to me, that possibly that might be effected by means of gun-powder, by confining a small quantity of water in some very thin substance, and surrounding and inclosing it with powder, and afterwards setting fire to the charge. The method I took to do this was as follows. Having procured a number of air bladders of very small fishes, I put different quantities of water into them from the size of a small pea to that of a small pistol bullet, and tying them up close with some very fine thread, I hung up these little globules in the open air till they were quite dry on the outside. I then provided a number of cartridges made of fine paper, and filled them with a known quantity of powder, equal to the customary charge for a common horseman's pistol; and having loaded such a pistol with one of them
and

and a fit bullet, I laid it down upon the ground, and directing it against an oaken plank that was placed about six feet from the muzzle, I fired it off by a train, and carefully observed the recoil, and also the penetration of the bullet. I then took several of the filled cartridges that remained, and pouring out part of the powder, I put one or more of the little bladders filled with water in the center of the cartridge, and afterwards pouring back the remaining part of the charge, confined the water in the midst of the powder.

With these cartridges and a fit bullet, the pistol was successively loaded, and being placed upon the ground as before, and fired by a train, the recoil, and the penetration of the bullets were observed; and I constantly found, that the force of the charge was very sensibly diminished by the addition of the globule of water, and the larger the quantity of water was that was thus confined, the less was the effect of the charge; neither the recoil of the pistol, nor the penetration of the bullet, being near equal to what they were when the given quantity of powder was fired without the water; and the report of the explosion appeared to be lessened in a still greater proportion than the recoil or penetration.

Concluding that this diminution of the force of the charge arose from the bursting of the little bladder, and the dispersion of the water among the powder before it was all inflamed, by which a great part of it was prevented from taking fire, I repeated the experiments with highly rectified spirits of wine instead of water; but the result was nearly the same as before: the force of the charge was constantly and very sensibly diminished. I afterwards made use of etherial oil of turpentine, and then of small quantities of quicksilver; but still with no

better success. Every thing I mixed with the powder, instead of increasing, served to lessen the force of the charge.

These trials were all made several months before I began the course of my experiments upon gun-powder, which I have already given an account of; and though they were altogether unsuccessful, yet I resumed the inquiry at that time, and made several new experiments, with a view to find out something that should be stronger than powder, or which, when mixed with it, should increase its force.

It is well known, that the elastic force of quicksilver converted into vapour is very great; this substance I made use of in my former trials, as I have just observed, but without success. I thought, however, that the failure of that attempt might possibly be owing to the quicksilver being too much in a body, by which means the fire could not act upon it to the greatest advantage; but that if it could be divided into exceeding small particles, and so ordered that each particle might be completely surrounded by, and exposed to, the action of the flame of the powder, it would be very soon heated, and possibly might be converted into an elastic steam or vapour, before the bullet could be sensibly removed from its place. To determine this point I mixed 20 grains of æthiops mineral very intimately with 145 grains of powder, and charging the piece with this compound, it was loaded with a fit bullet and fired; but the force of the charge was less than that which the powder alone would have exerted, as appears by comparing the 76th and 77th experiments with the 79th.

Common *pulvis fulminans* is made of one part of sulphur, two parts of salt of tartar, and three parts of nitre; and if we may judge by the report of the explosion, the elastic force of this compound is considerably greater than that of gun-powder.

I was

I was willing to see the effect of mixing salt of tartar with gun-powder, and accordingly having provided some of this alkaline salt in its purest state, thoroughly dry, and in a fine powder, I mixed 20 grains of it with 145 grains of gun-powder; and upon discharging a bullet with the mixture, I found that the alkaline salt had considerably lessened the force of the powder. See experiment N° 78.

I next made use of *sal ammoniacum*. That salt has been found to produce a very large quantity of elastic air, or vapour, when exposed to heat under certain circumstances; but when 20 grains of it were mixed with a charge of gun-powder, instead of adding to its force, it diminished it very sensibly. See the 80th experiment.

Most, if not all, the metals, are thought to produce large quantities of air when they are dissolved in proper *menstrua*, and particularly brass, when it is dissolved in spirit of nitre. Desirous of seeing if this could be done by the flame, or acid vapour of fired powder, I mixed 20 grains of brass in a very fine powder, commonly called brass dust (being the small particles of this metal that fly off from the wheel in sharpening pins), with 145 grains of powder, and with this compound and a fit bullet I loaded my barrel and discharged it; but the experiment (N° 81.) shewed, that the force of the powder was not increased by the addition of the brass dust, but the contrary.

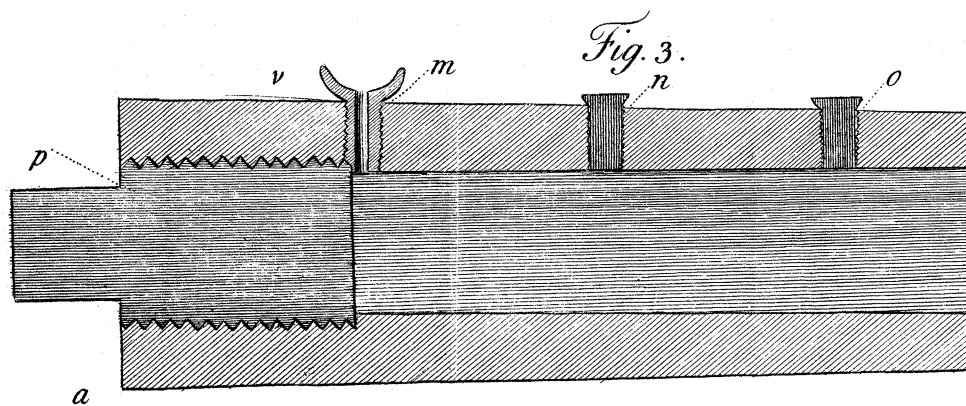
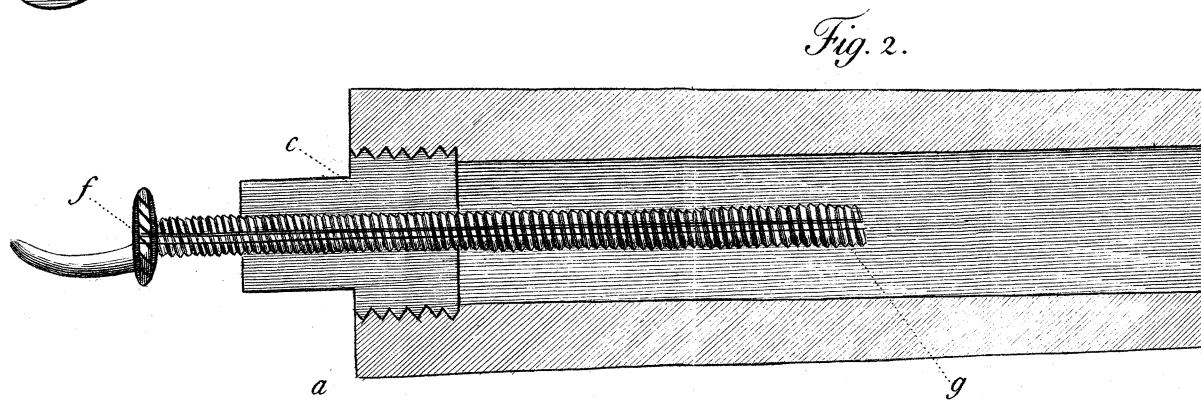
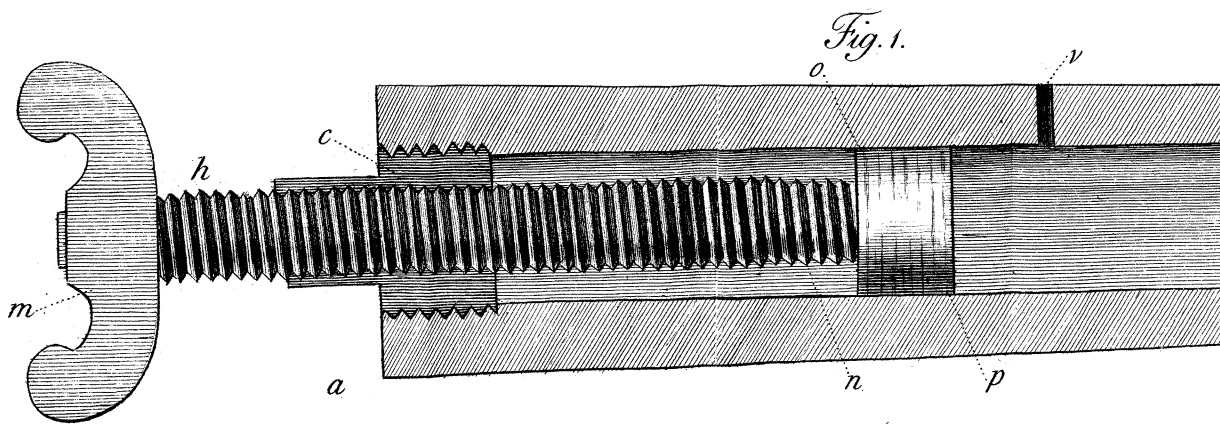
It seems probable, however, that neither brass dust nor æthiops mineral are of themselves capable of diminishing the force of gun-powder in any considerable degree, otherwise than, by filling up the interstices between the grains, and obstructing the passage of the flame, and so impeding the progress of the inflammation. And hence it appears, how earthy particles and

impurities of all kinds are so very detrimental to gun-powder. It is not that they destroy or alter the properties of any of the bodies of which the powder is composed, but simply, that by obstructing the progress of the inflammation, they lessen its force, and render it of little or no value. Too much care, therefore, cannot be taken in manufacturing powder to free the materials from all heterogeneous matter.

Of an attempt to shoot flame instead of bullets.

Having often observed paper and other light bodies to come out of great guns and small arms inflamed, I was led to try if other inflammable bodies might not be set on fire in like manner, and particularly inflammable fluids; and I thought if this could be effected, it might be possible to project such ignited bodies by the force of the explosion, and by that means communicate the fire to other bodies at some considerable distance; but in this attempt I failed totally. I never could set dry tow on fire at the distance of five yards from the muzzle of my barrel. I repeatedly discharged large wads of tow and paper, thoroughly soaked in the most inflammable fluids, such as *alkohol*, *ætherial spirit of turpentine*, *balsam of sulphur*, &c.; but none of them were ever set on fire by the explosion. Sometimes I discharged three or four spoonfuls of the inflammable fluid, by interposing a very thin wad of cork over the powder, and another over the fluid; but still with no better success. The fluid was projected against the wall as before, and left a mark where it hit; but it never could be made to take fire; so I gave up the attempt. If it had succeeded, probably it would have turned out one of the most important discoveries in the art of war that have been made since the invention of gun-powder.





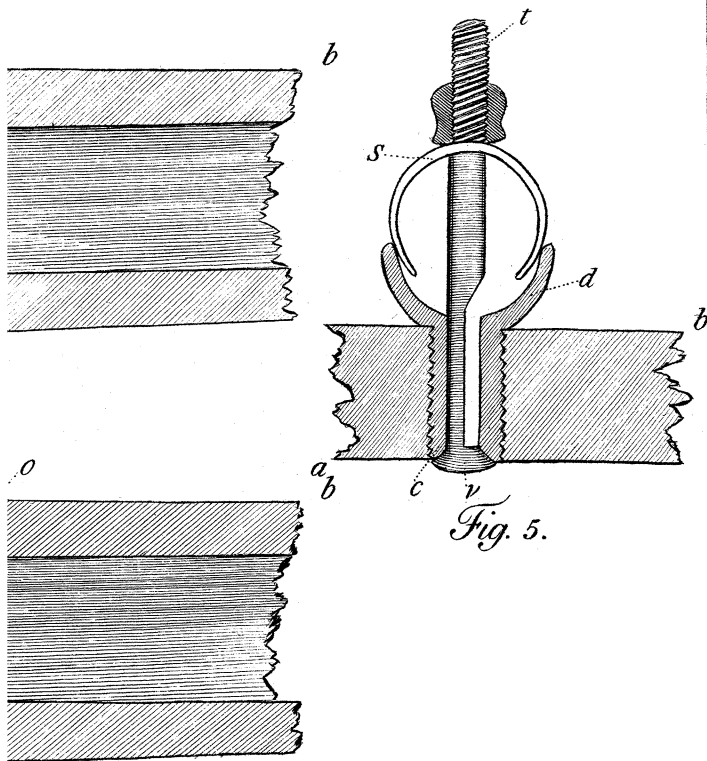
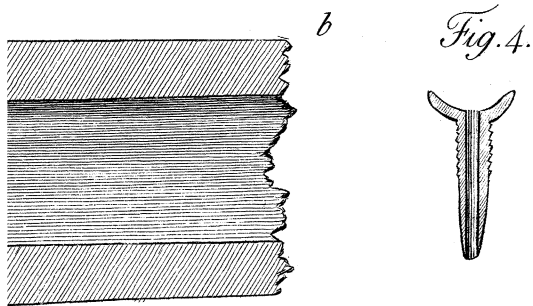


Fig. 6.

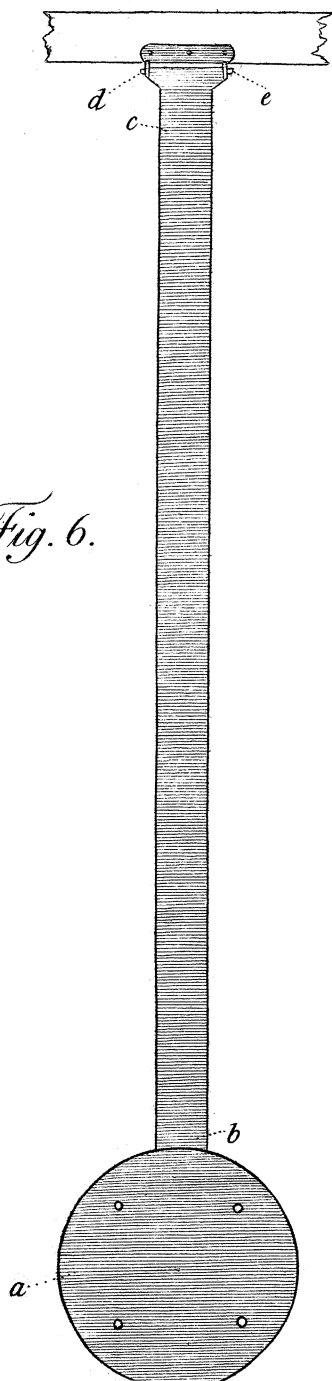


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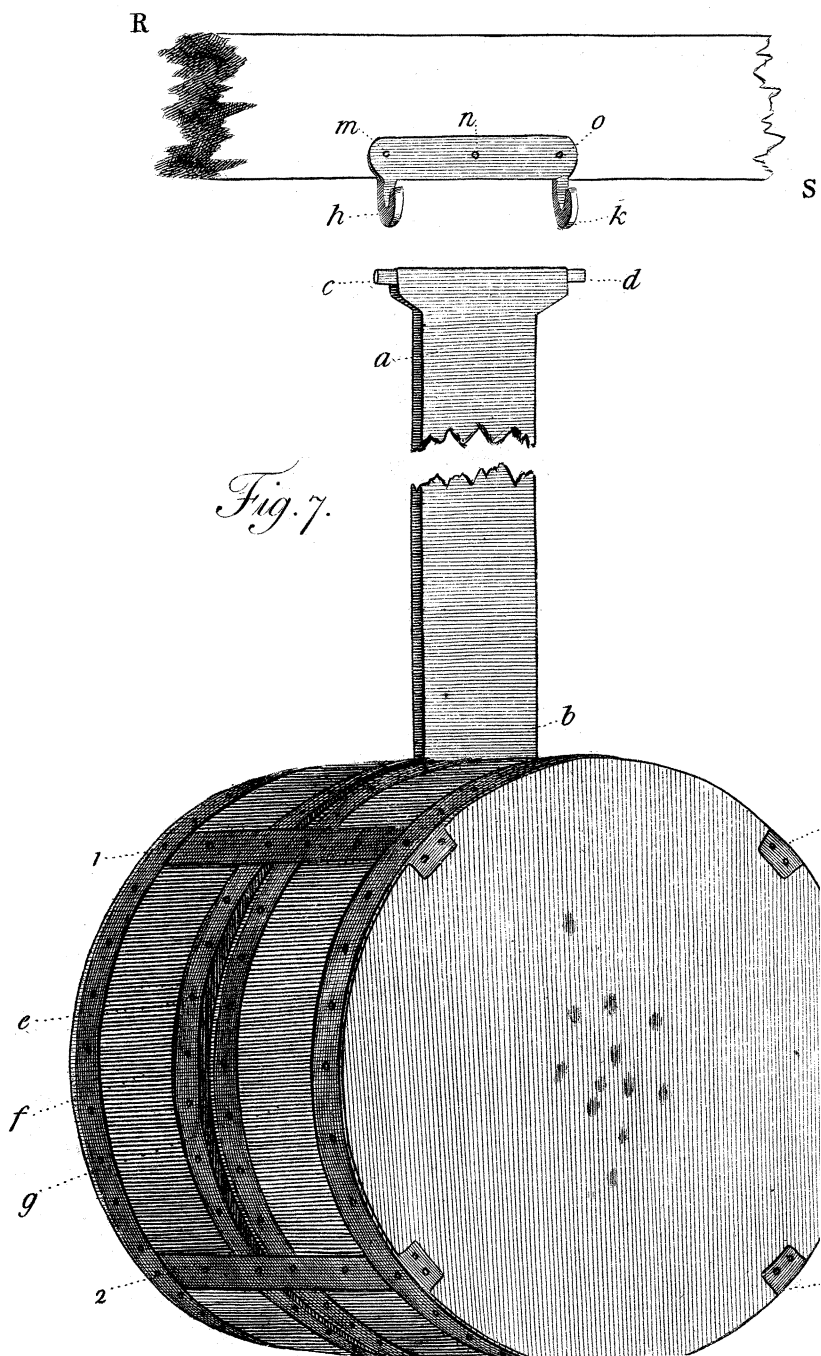




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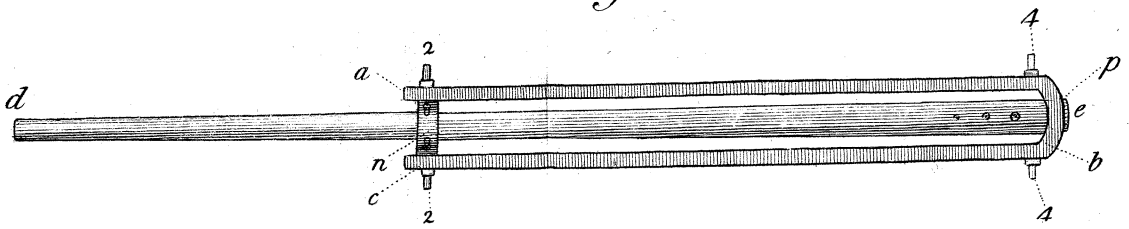


Fig. 9.

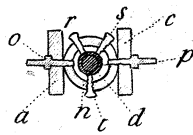


Fig. 10.

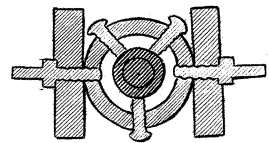
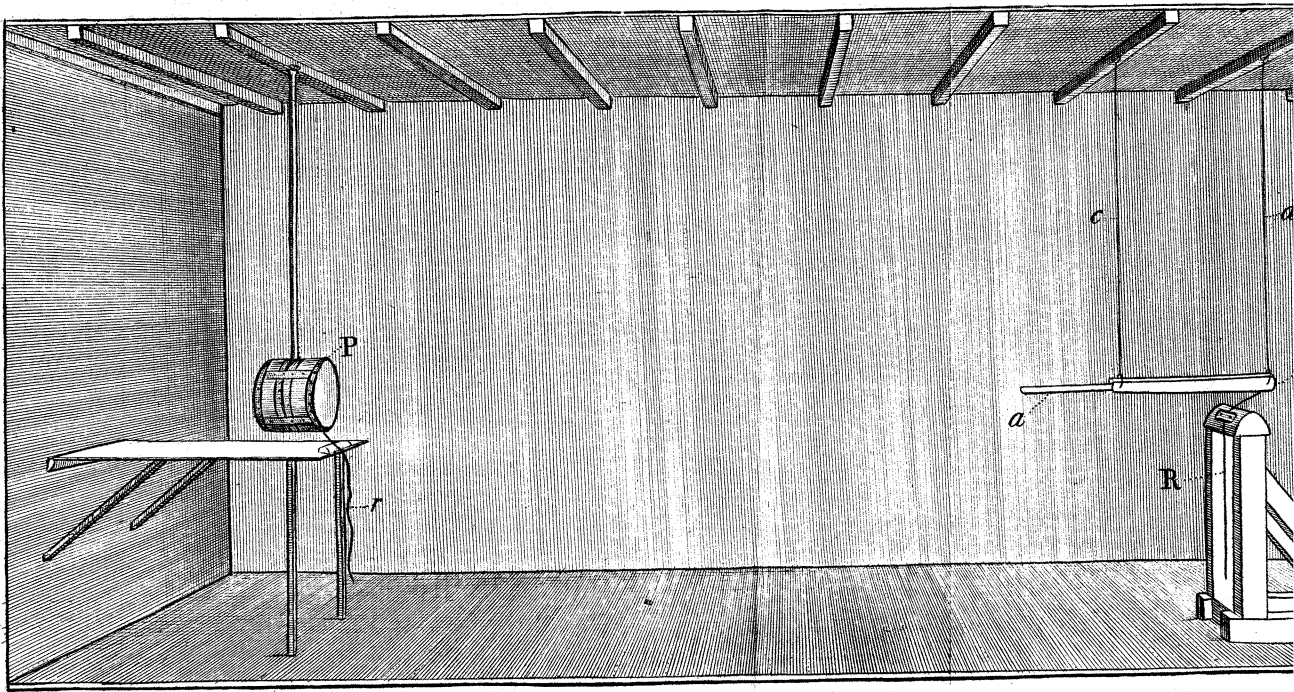


Fig. 12.



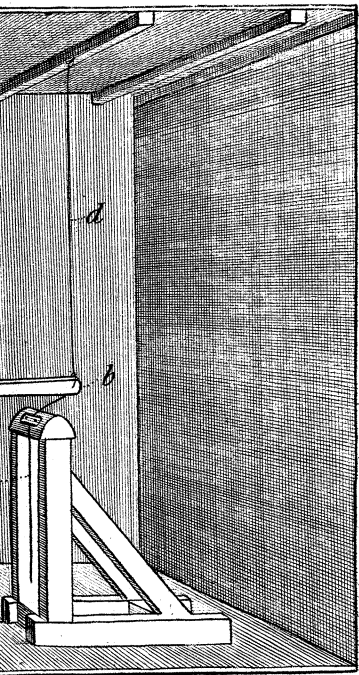


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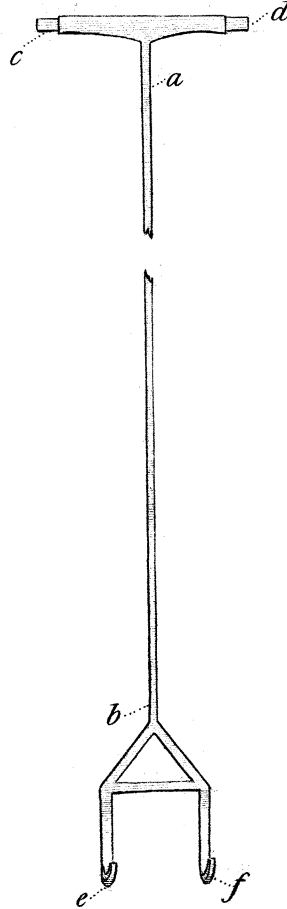
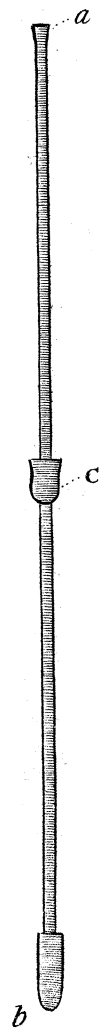


Fig. 13.



Fig. 15.



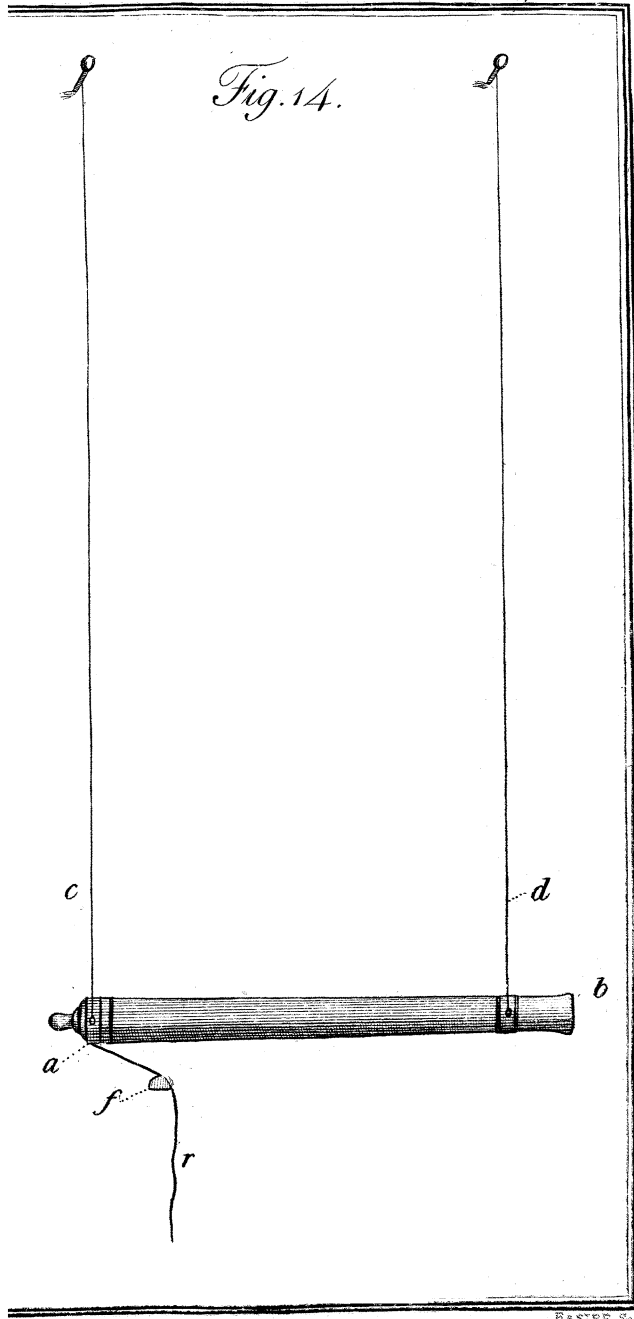


Fig. 16.

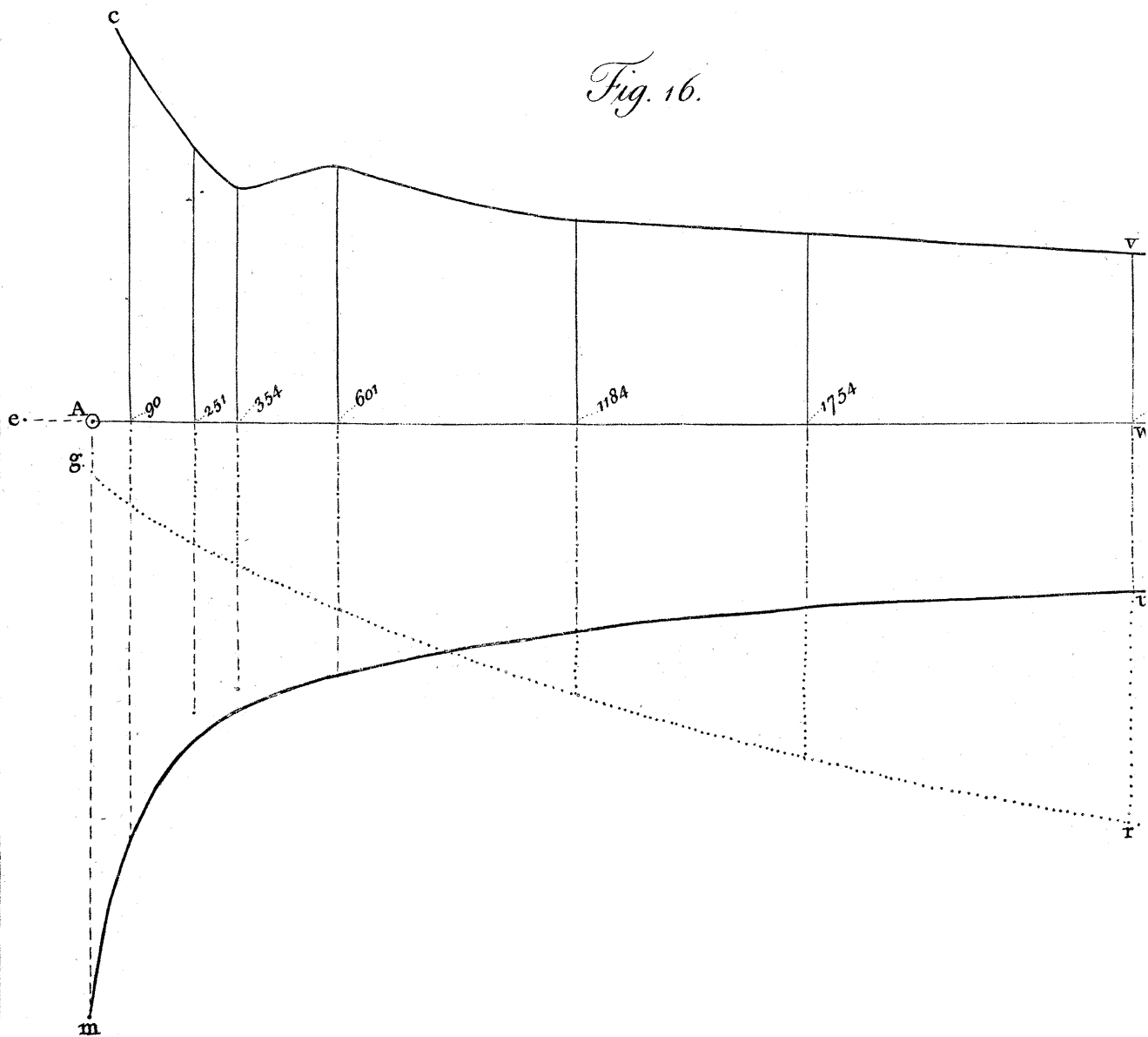


Fig. 17.

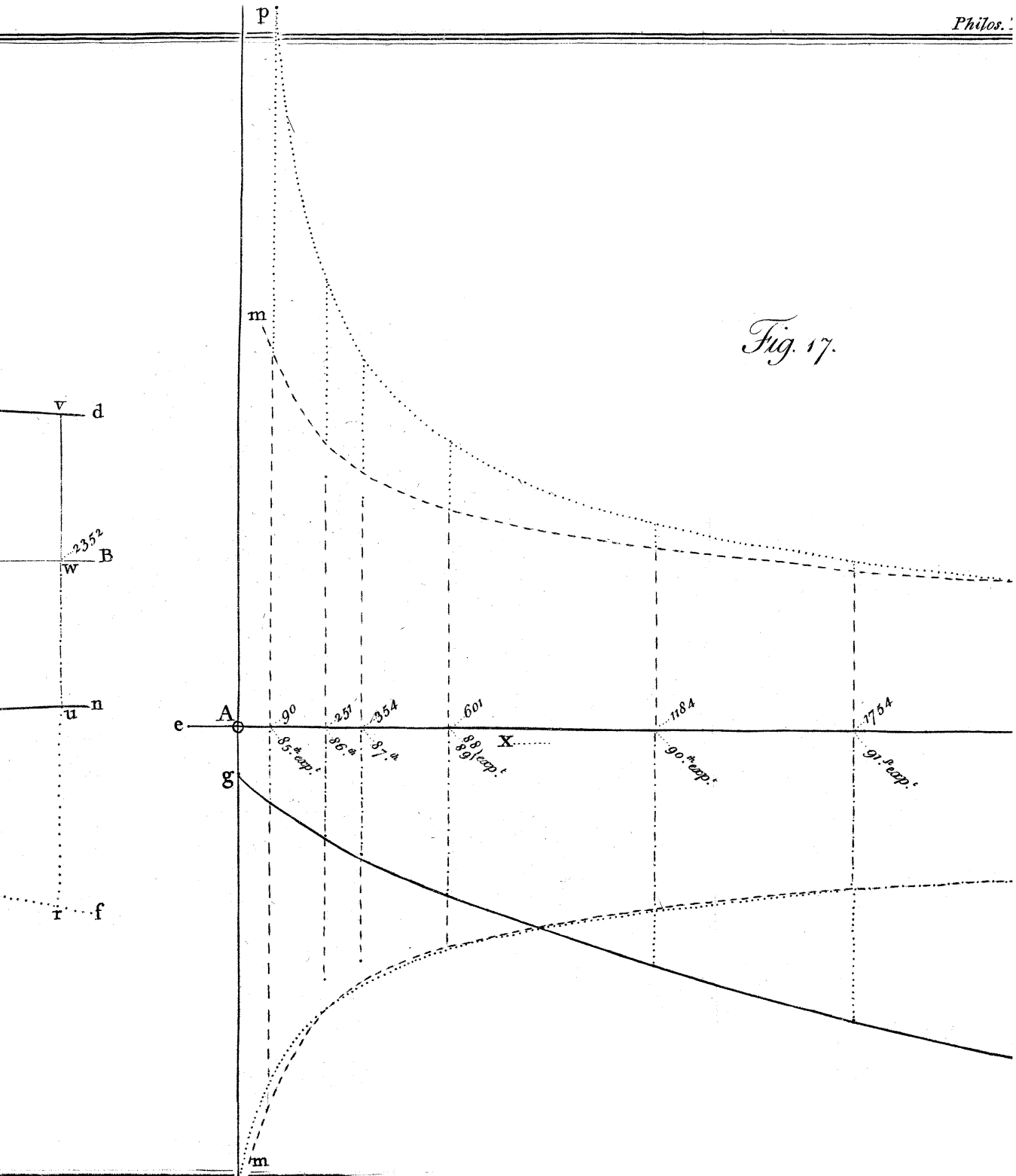
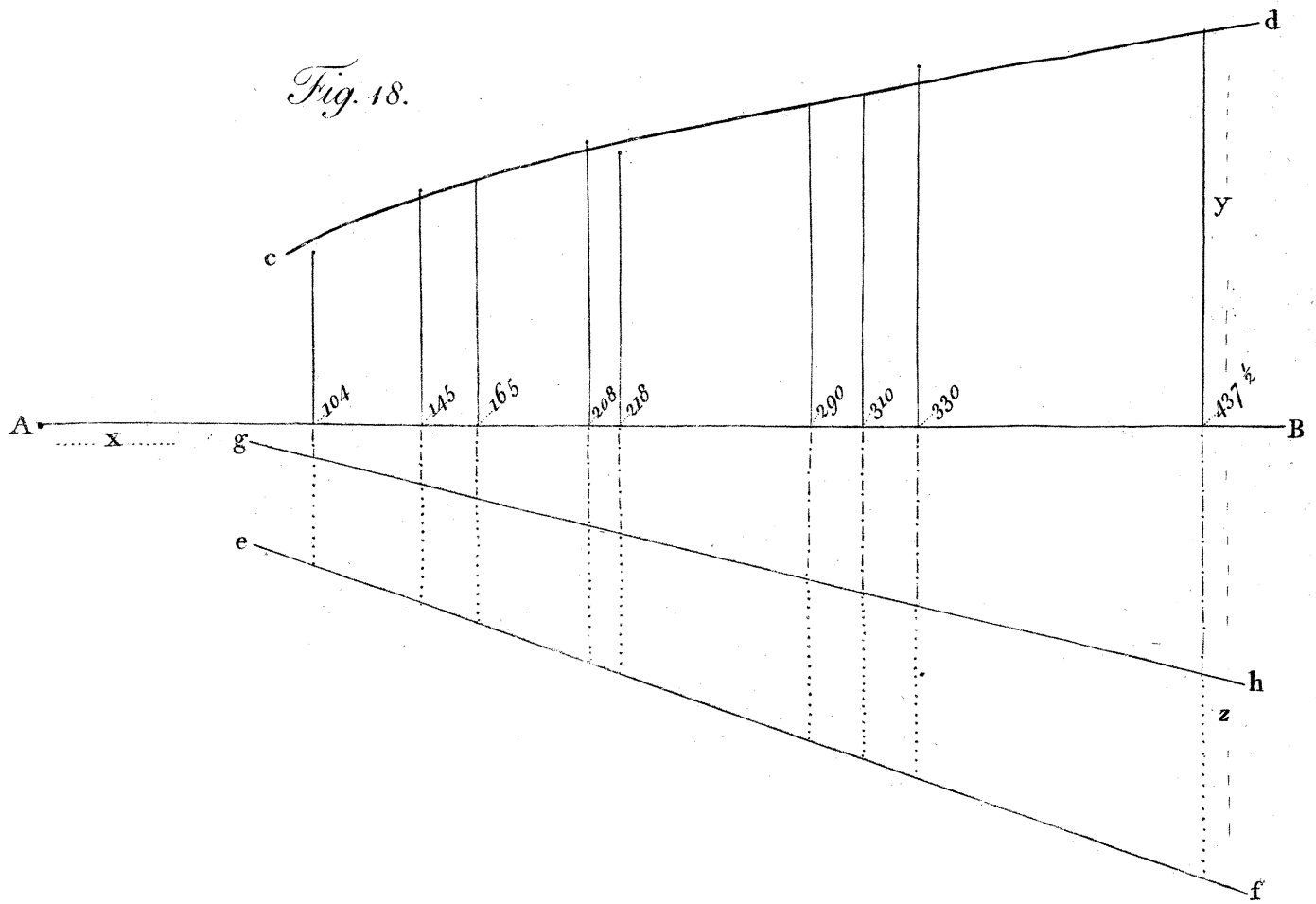
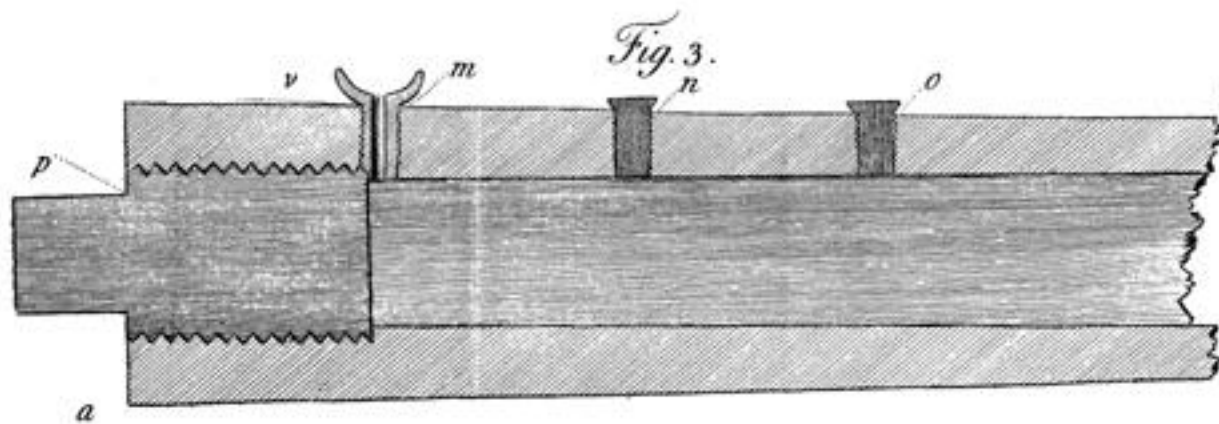
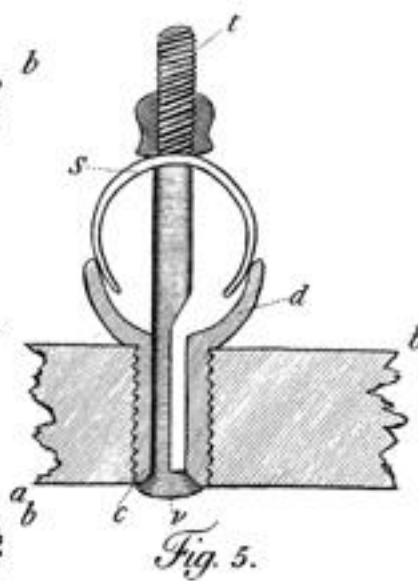
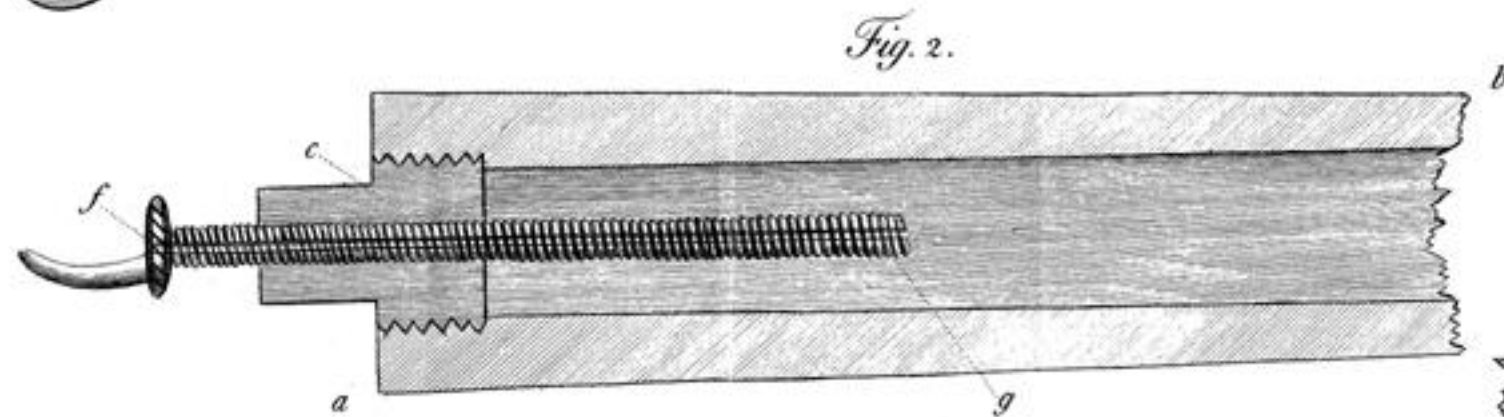
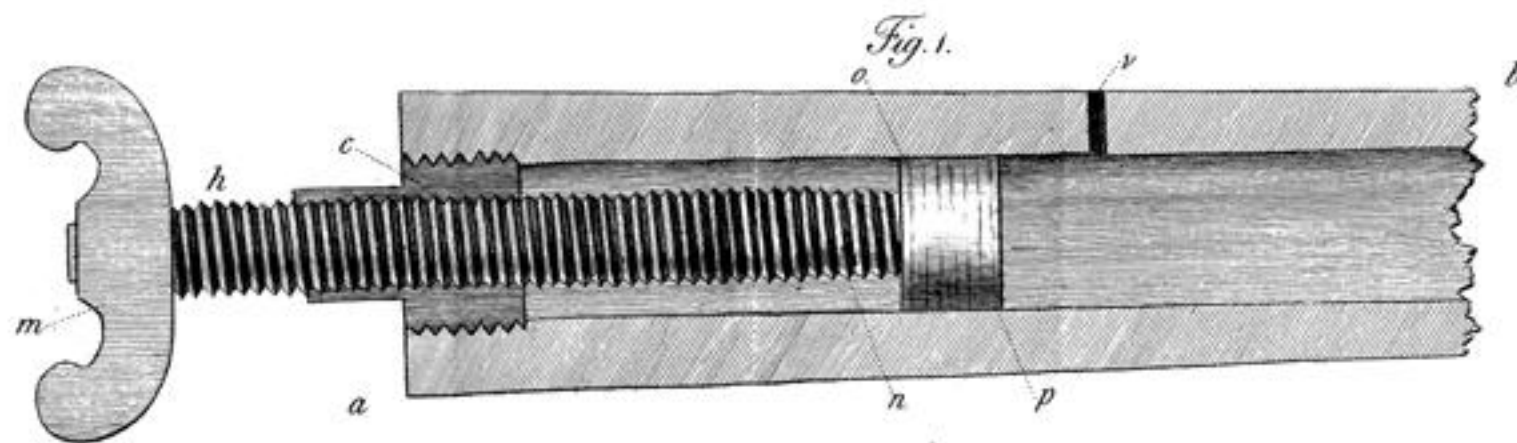


Fig. 18.





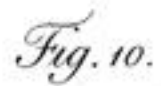
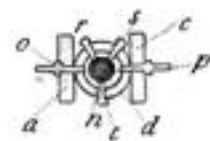
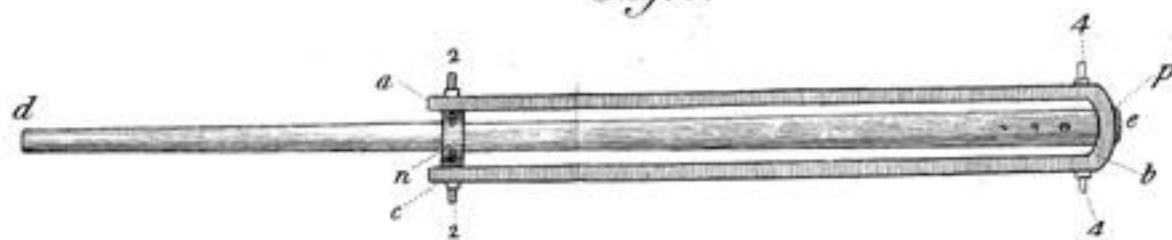
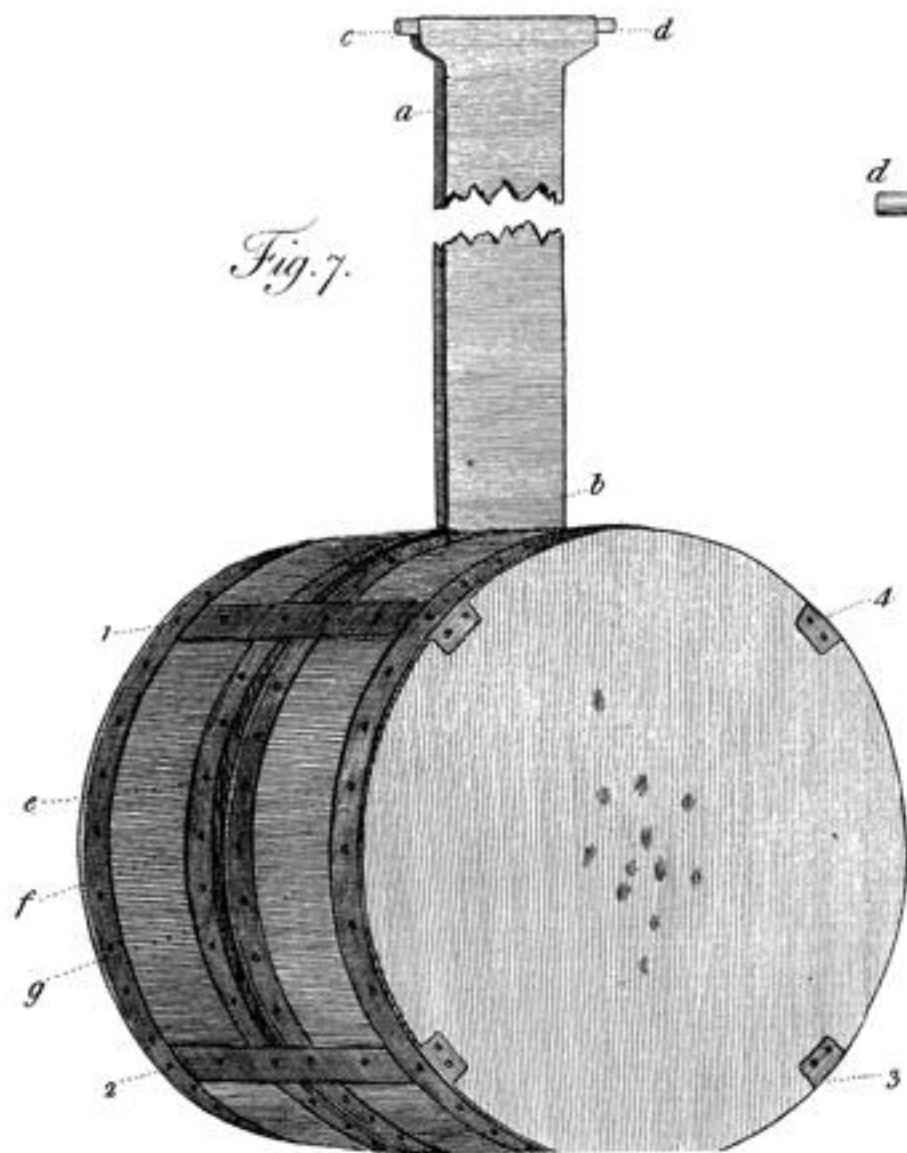
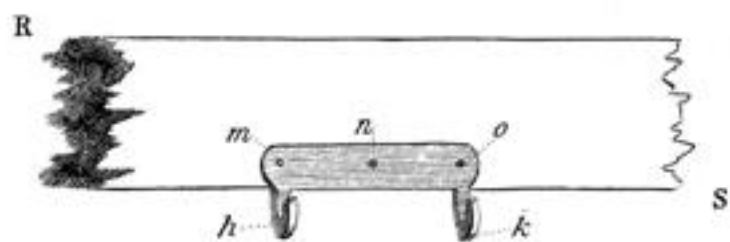
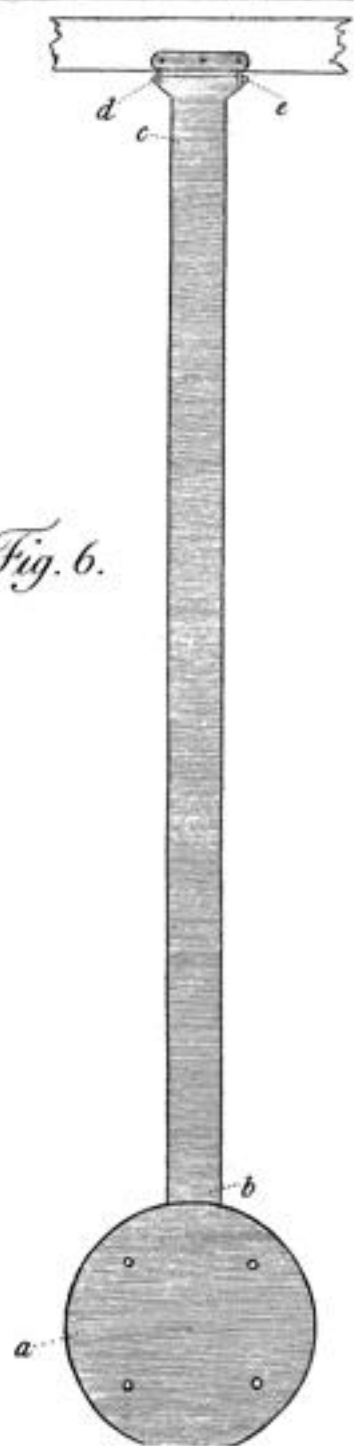


Fig. 12.

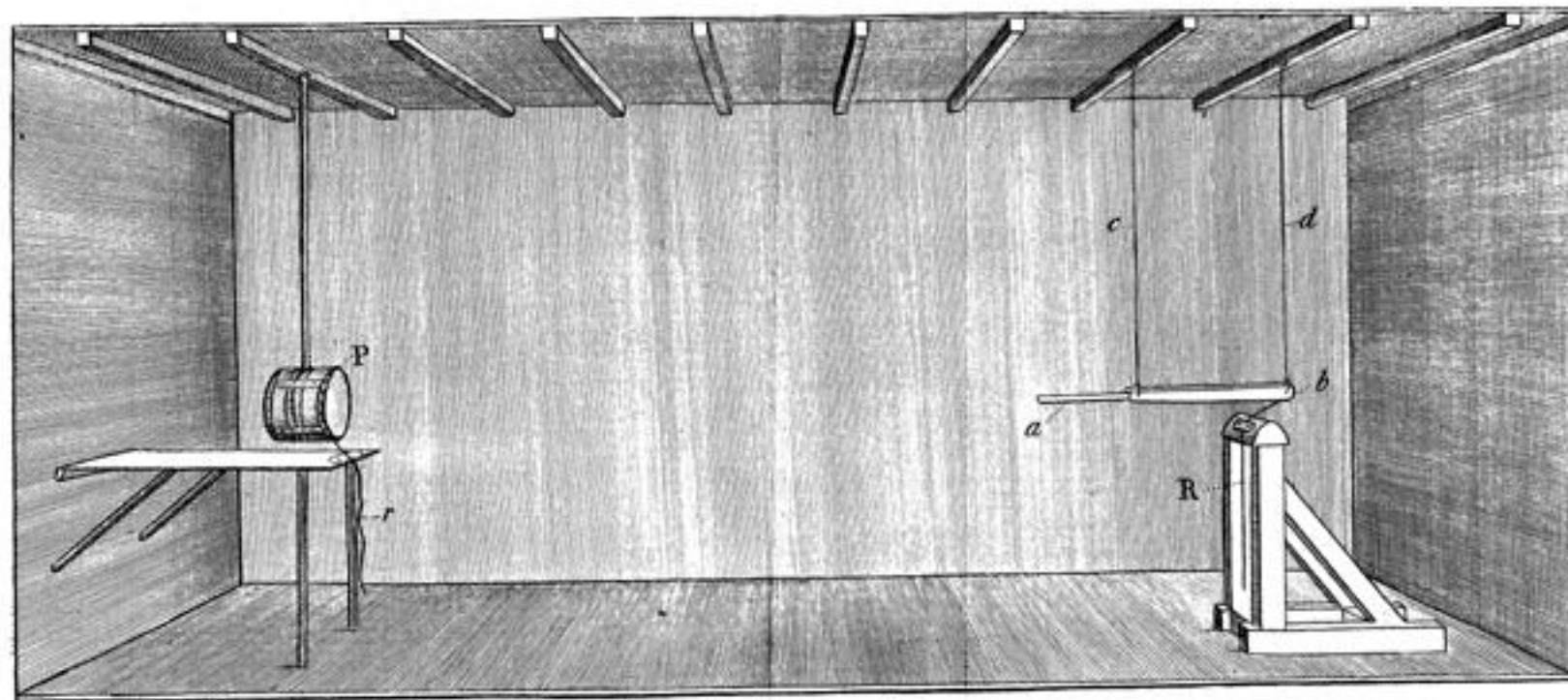


Fig. 11.



Fig. 13.



Fig. 15.



Fig. 14.

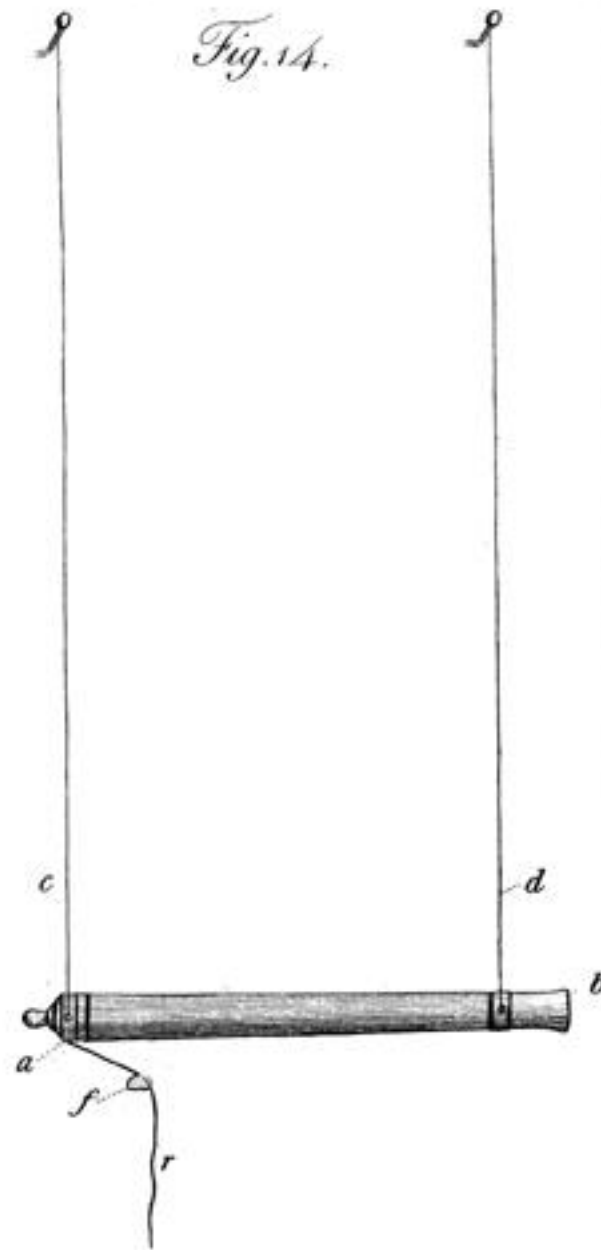


Fig. 16.

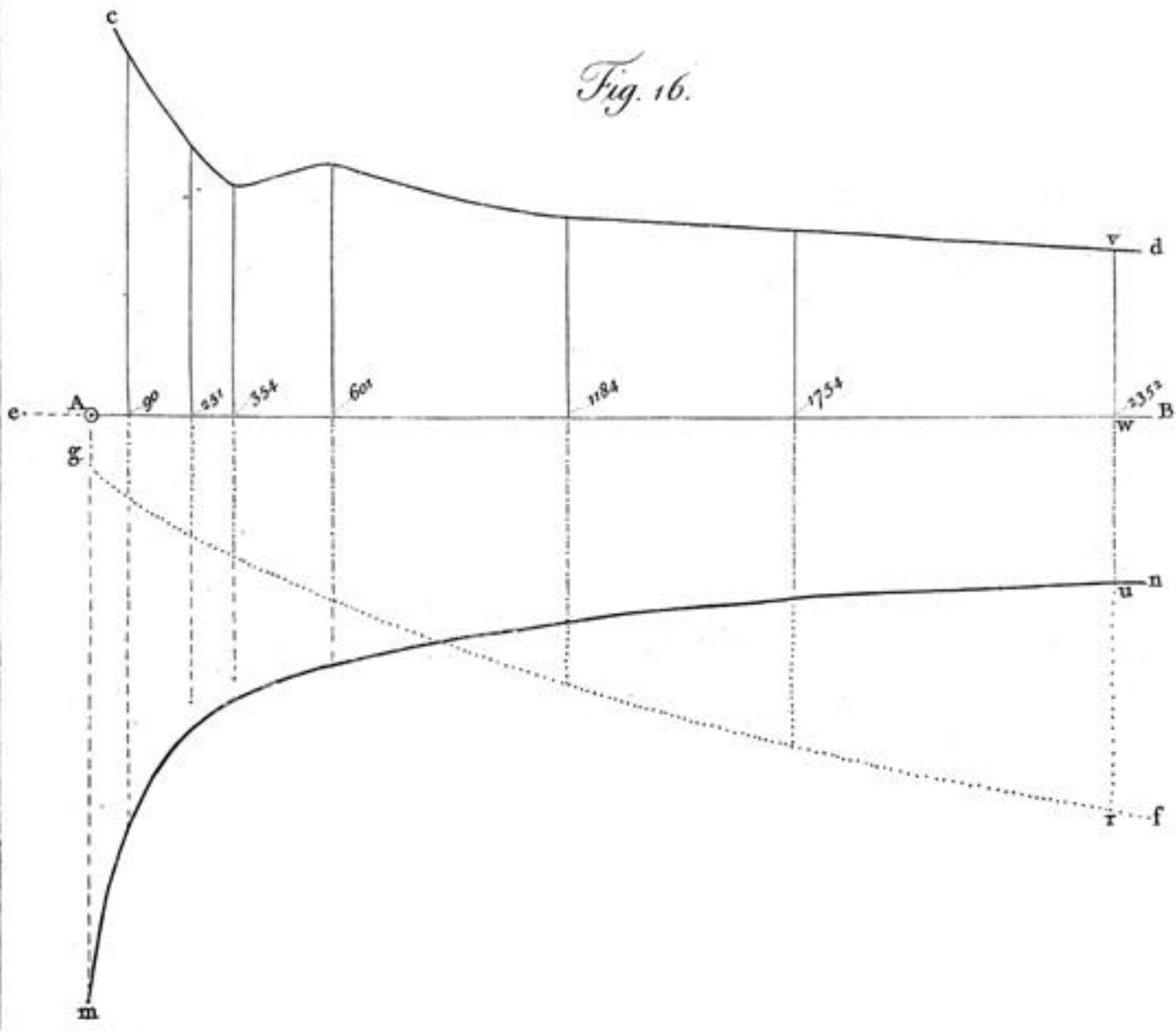


Fig. 17.

