R XXVI. *Account of a new Kind of inflammable Air or Gaſs, which can be made in a Moment without Apparatus, and is as fit for Exploſion as other inflammable Gaſſes in uſe for that Purpoſe; together with a new Theory of Gun-powder. By* John Ingen-Houſz, *Body Phyſician to their Imperial Majeſties, and F. R. S.*

Read March 25, 1779.

THE important diſcoveries on different kinds of air have opened a new field for one of the moſt pleaſing and intereſting ſcenes which ever were expoſed to the contemplation of philoſophers, and therefore could not fail of exciting in almoſt every lover of natural knowledge a decided curioſity to ſee the purſuit of ſuch ſtriking novelties, and in many an almoſt irreſiſtable temptation to imitate them, and to purſue farther the road already ſo far opened by the Rev. Dr. PRIESTLEY, Abbe FONTANA, Mr. LAVOISIER, and many other learned and ingenious men.

Who can, indeed, without the greateſt ſatisfaction, look (amidſt many other objects of admiration) upon the diſcovery

discovery of that new aerial fluid, which in purity and fitness for respiration so far surpasses the best atmospherical air, that an animal protracts his life five times as long, or even more, in it than in common air of the best quality?

Dr. PRIESTLEY, the first who discovered this wonderful fluid, extracted it from bodies which we should rather have suspected to have contained deleterious exhalations. He afterwards found it existed in many other bodies in which the most accurate observer never found any thing of an approaching nature.

When I consider the immense quantity of this pure aerial fluid, called by Dr. PRIESTLEY with so much propriety *dephlogisticated air*, which exists as it were in a solid state in nitre, in calcined metals, and even in some other of the most common substances, I cannot express the greatness of my expectation, as a physician, from such an important discovery [(a)]. I flatter myself, that ere long an easy and cheap method will be discovered by which such quantities of this beneficial air may be ob-

(a) Since Dr. PRIESTLEY's last publication on air, he discovered, that the same water which, if examined immediately, gives only a small quantity of bad air, yields spontaneously about ten times the quantity of pure dephlogisticated air after standing some time exposed to the sun. Of this I was an eye-witness. The important discoveries of Abbé FONTANA upon this subject, which he shewed me when I was last in Paris a year and a half ago, will soon be published by himself. He extracted this wonderful aerial fluid from different kinds of water by boiling them over a fire.

tained as will ſerve to cure ſeveral diſeaſes which reſiſt the power of all other remedies, and ſo prolong, as it were, human life. We may expect, with ſome degree of confidence, that this new element, when it ſhall be uſed for the benefit of reſpiration, will be found more fit than the beſt common air to free our body from that quantity of phlogiſton or inflammable principle which ſeems to exiſt ſometimes in too great a quantity in the maſs of our blood; or from which it ſeems ſometimes, as it were, to be let looſe in too great abundance, producing, perhaps, in conſequence fevers and other ſymptoms, the cauſes of which have not yet been clearly elucidated by the beſt medical writers.

This dephlogiſticated air, free from the inflammable particles with which the beſt common air is always infected, will probably be found capable of abſorbing a greater quantity of thoſe phlogiſtic particles with which the air coming from our lungs is always found to be pregnant, and thus of ventilating, as it were, much more expeditiouſly the maſs of our blood of that which a conſtant exertion of the organs of reſpiration is not always able to free it from in a ſufficient quantity.

Theſe important purſuits have led Dr. PRIESTLEY to the diſcovery of one of the benefits, and perhaps the principal, we derive from reſpiration; that function of the animal œconomy which is ſo important, that without its conſtant influence an animal, once born, has but a few moments to live.

The criterion of the degree of goodneſs of reſpirable air, by the quantity which is abſorbed or deſtroyed by the addition of nitrous air, is one of thoſe uſeful diſcoveries of Dr. PRIESTLEY's from which mankind will, perhaps, hereafter reap a conſiderable benefit.

The diſcovery of the various kinds of inflammable airs or gaſſes becoming powerfully exploſive, when they are mixed with a ſufficient quantity of common air, and ſtill more ſo when they are combined with dephlogiſticated air, is one of thoſe improvements in natural philoſophy which, giving occaſion to various amuſing and intereſting experiments, have caſt at the ſame time a new light upon ſome powerful agents, whoſe miſchievous force was known, though their nature was ſtill in the dark.

As thoſe inflammable airs have been of late years one of the principal philoſophical amuſements, I intend to lay before the Royal Society an eaſy method of producing, without any trouble or particular apparatus, ſuch quantity of an inflammable air or gaſs as may be required; to which I ſhall ſubjoin ſome conſiderations which have occurred to me about the nature of that wonderful ſubſtance gunpowder, which conveys death at ſuch an immenſe diſtance by its almoſt irreſiſtible exploſive force,

force, by which it propels metallic balls of a confiderable weight. To inveftigate the nature of this awful ingredient, by which the fate of empires is decided in our days, cannot be indifferent to any body who takes delight in inveftigating natural caufes.

Being at Amfterdam in November 1777, Meffieurs AENEAE and CUTHBERTSON, two ingenious philofophers of that city, were fo good as to fhew me fome curious experiments with explofive and inflammable airs of different kinds. They produced an inflammable air, by mixing together equal quanties of oil of vitriol and fpirit of wine, and applying heat to the phial containing the compound. A great quantity of white vapour was extricated, which, paffing up the inverted receiver filled with water, fettled at the top and depreffed the water, as other airs do. This air foon became clear, the white fumes being abforbed by the water. This air was eafily lighted in an open cylindrical glafs, and burnt almoft as clear as a candle, the flame defcending gradually lower and lower till it reached the bottom. A very little quantity of this air mixed with common or dephlogifticated air, for inftance, one fourteenth or one tenth part, and kindled by an electrical fpark, exploded with a very loud report, and fhattered the glafs to pieces in which it was kindled, when it did not find a ready vent.

They

They had contrived a kind of a piſtol for the purpoſe, conſiſting of a ſtrong cylindrical glaſs tube with a piſton adapted to it. To the end of this tube was fixed a braſs barrel, like that of a common piſtol: into this barrel a braſs bullet was put looſe, ſo that the barrel was placed a little above the level, to prevent the bullet rolling out. The barrel was directed to a board of oak at eight or ten feet diſtance. A proper quantity of common and inflammable air (produced in the manner above mentioned) being drawn into the glaſs tube by means of the piſton, it was fired by directing an electrical exploſion through it. The exploſion was very loud: the ball hit the board with ſuch a force that it made a ſtrong impreſſion in it, and recoiled with a conſiderable force, ſo as to hit the wall behind us, and to put us in ſome danger of being hurt by its rebounding force.

The ſame gentlemen told me, that this inflammable air had in ſome reſpects the advantage over the inflammable airs extracted from metals by the vitriolic or marine acid, and that extracted from mud or marſhes; becauſe this air being heavier than either of theſe airs, and even than common air, is not ſo eaſily loſt out of an open veſſel; and, that when it eſcapes into the open air, it agreably perfumes the room with the ſmell of *ſpiritus vitrioli dulcis* or æther; whereas the other inflammable airs,

 which

which from their leſs ſpecific gravity eſcape eaſily into the common air, yield an offenſive, diſagreeable ſtench.

Mr. AENEAE, having examined the ſpecific gravities of the different inflammable airs compared with common air, favoured me with the following reſult of his inquiries.

A veſſel, which contained the weight of 138 grains of common air, contained 25 grains of inflammable air extracted from iron by vitriolic acid, and 92 grains of inflammable air extracted from mud or marſhes, and 150 grains of that extracted from oil of vitriol and ſpirit of wine.

I was much pleaſed with the above mentioned experiment, and immediately thought that the operation of extracting this inflammable air or vapour could be diſpenſed with by employing vitriolic æther, which in reality is contained in the vapour expelled by heat from oil of vitriol and ſpirit of wine, which vapour, condenſed in the proceſs of diſtillation, yields æther. But I reſolved to defer making the experiment till I ſhould arrive in London, where I intended to make ſome ſtay to ſee my old friends, and acquire what medical and philoſophical knowledge I could.

Having arrived in this capital in the beginning of January 1778, I loſt no time in purſuing my idea. For this purpofe I poured fome drops of æther into a ftrong glafs tube, and directed an electrical explofion from a Leyden phial through it; but, to my mortification, no explofion happened. I then threw a bit of cotton, dipped in æther, into the fame tube, but it would not take fire. Though thefe firft trials proved unfuccefsful, I was too much perfuaded, that in fome way or other it muft fucceed, to be difcouraged. I tried it in feveral different ways, and at laft, before the end of January, I fucceeded once or twice in producing a loud explofion, by throwing into the tube a little bit of paper dipped in æther. But as the experiment often failed (of which I could then find no reafon), I did not venture to fhew it to my friends till I had hit upon a method, the certainty of which would prevent my being expofed to fome confufion by exhibiting an experiment which was fo apt to fail. However, I told Sir JOHN PRINGLE, Meff. NAIRNE and BLUNT, and fome few others of my friends, early in the fpring, that I had found out a method of firing an inflammable air piftol without being at the trouble of making inflammable air in the ordinary way; as I produced it at pleafure in an inftant, without any trouble or apparatus: and that I would fhew them the experiment as foon as I was fure of fucceeding conftantly. In the mean time I continued to produce this air before my acquaintance in the way I had ſeen it produced at Amſterdam. Soon after, hitting upon better and ſurer methods of ſucceeding, I began to ſhow it to thoſe who came to viſit me, and in the beginning of the ſummer I made no ſcruple of ſhewing it to every body.

The reaſons why I did not ſucceed in the beginning I found afterwards to be, either that I employed too great a quantity of æther, or that the air or vapour of the æther was not thoroughly incorporated with the other air; for the ſame numbr of drops of æther poured into the air piſtol, which would not produce an exploſion when the piſtol was not ſhaken, made a very loud one when it was forcibly agitated.

The ſureſt method of ſucceeding I find to be the following: I dip a ſmall glaſs tube, open on both ſides, and the bore of which is one twelfth of an inch in diameter into a phial containing æther, and when two or three drops of the liquid have entered the tube I apply my finger to the upper end of it, to keep the liquor ſuſpended. I take the tube out of the phial, and thruſt it immediately into a ſmall *caoutchouck*, or elaſtic gum bottle: this being done, I withdraw my finger from the tube, and take it out of the *caoutchouck*; thus the little quantity of æther, ſuſpended in the end of the tube, is dropped into the *caoutchouck*, the neck of which is to be

immediately

immediately inverted into the orifice of the air piſtol, and, after giving it a gentle ſqueeze, withdrawn out of it: after which, a bullet or a cork is to be thruſt into the mouth of the piſtol, when it is ready for firing. This whole operation may be performed in the ſpace of five or ſix ſeconds.

The conſiderable force of exploſion, and the loud report of the ordinary inflammable airs, induced Mr. VOLTA, of Como, to believe, that theſe airs might, perhaps, become a ſubſtitute to gunpowder. If this expectation had been well founded, the greateſt *deſideratum* would, I think, have been to find out a way to produce ſuch air at any time without trouble, and to carry it about in as little compaſs as poſſible: which two conditions I ſhould have pretty nearly fulfilled, as all the inflammable air requiſite for the exploſion of the piſtols contrived by Mr. VOLTA is contained in the bulk of one ſingle drop of æther; which drop, poured in the piſtol itſelf, is full ſufficient to produce a very powerful exploſion. But how far this expectation of Mr. VOLTA, as to the uſe of inflammable air in offenſive arms, is well grounded, I will attempt to explain in the ſubſequent part of this paper.

This inflammable air (which, perhaps, might more properly be called vapour, as it is abſorbable by water) has

has the principal properties of the other inflammable airs, *viz.* it will not inflame but where it is in contact with common or dephlogisticated air; and therefore only takes fire at the top of the vessel containing it, the flame going gradually downwards till the whole is consumed, if the vessel is of a cylindrical form, and pretty wide. If it is diluted with common air, but not sufficiently, it will burn as other inflammable air without exploding. Being sufficiently diluted with common air, especially with dephlogisticated air, it explodes with a very great report and a considerable force. It is unfit for respiration in a concentrated state, and is as mortal for an animal plunged into it as any other of the inflammable airs; though in a diluted state it seems to be rather pleasant to the organs of respiration.

It differs in some respects from the common inflammable airs; as, for instance, it is much heavier, as is already observed, than any of the other inflammable airs, and even than common air. It does not inflame or explode with so small a spark of electrical fire as the other inflammable airs, requiring the explosion of a Leyden phial to be fired with certainty, though one single inch of coated glass will be sufficient; so that a Leyden phial, containing twelve or fourteen square inches of coating, may fire an air pistol loaded with this kind of air several times,

times, if the charge be divided by taking it out with a fmall glafs tube, fitted up in the manner I defcribed in the paper I had the honour of laying before the Royal Society laft year, and which is inferted in the fecond part of the 68th vol. of the Phil. Tranf.; in which paper I defcribe a kind of an electrical match to light a candle with. This air being in contact with water is abforbed by it in a few days, though the water be not ftirred: and much fooner lofes its inflammability by contact with water than the other inflammable airs do. However, I found that in fuch a fituation this air had not yet loft all its explofive force in fix days, though the water in which the cylindrical glafs, ten inches long and one in diameter, was inverted, after I had poured into it five or fix drops of æther, had gradually afcended till, on the third day, it reached to the half of the height of the glafs: fo that it feems as if thefe drops of æther, by their expanding in the form of air, had forced out half of the common air contained in the glafs, in the place of which the water afterwards afcended in proportion as the air or vapour generated by the æther was abforbed by the water.

That this air is fpecifically heavier than common air, and does not readily incorporate with it, is eafily demonftrated by the following experiment. I poured five or fix drops of æther into a cylindrical glafs, ten inches long and

and one inch in diameter: the æther being ſoon evaporated, I clapped my hand upon the mouth of the glaſs, and inverted it to incorporate the air generated by the æther with the common air; after which I left the glaſs open during half an hour, when I dipped in it a piece of wax taper burning, ſtuck upon a bended wire. As ſoon as the taper reached the brim of the glaſs, a flame burſt out with a weak exploſion. In a quarter of an hour I again thruſt the wax taper into the ſame cylinder, and no flame was obſerved till the wax taper reached the place where the flame ended the firſt time. This ſecond exploſion did not ſet fire to the whole at the bottom of the glaſs. I again waited a quarter of an hour, and then again thruſt the wax taper into it, by which the remainder of this inflammable gaſs, which had remained ſettled all that time at the bottom, was exploded[b].

(b) It is remarkable, that æther, the moſt volatile liquor yet known, and ſo apt to ſpread itſelf through the air by a quick evaporation that a drop of very fine æther, which falls from the height of a few feet, is quite evaporated before it reaches the ground, and no glaſs ſtopper of itſelf is able to keep it from evaporating: it is remarkable, I ſay, that notwithſtanding this extreme volatility, the air or vapour, into which it changes by evaporation, ſhould be ſo far from participating of the ſame volatility, that it may be kept hours together in an open cylindrical veſſel without evaporating, mixing with the common air, or loſing its inflammability; ſo that this ſubſtance ſeems to undergo a ſudden metamorphoſis, and to change in an inſtant from the lighteſt of all liquors to one of the heavieſt of aerial fluids, fixed air, which being one half heavier than common air, according to the experiments of Mr. CAVENDISH, is probably much heavier than this æther air.

I found

I found that æther, in which as much urinous phofphorus is diffolved as will make it luminous in the dark, when fome drops are poured upon water; is very brifk in taking fire, when employed for an inflammable air piftol; but that the experiment, when repeated, will be apt to fail, becaufe the phofphoric acid which remains in the piftol, and by its nature attracts the humidity of the atmofphere, will foon fill the infide of the piftol with a coat of moifture, and prevent the electrical fpark from kindling the inflammable air.

It appeared, that a little camphire diffolved in æther increafes its explofive force, and makes it lefs apt to fail.

As this inflammable air is heavier than common air, it is clear, that the mouth of the air piftol fhould be kept upwards at the time of charging it: whereas it is better to invert the piftol when the ordinary inflammable airs are employed, which, being fpecifically lighter than common air, rife of themfelves in the piftol when its mouth is placed inverted upon the orifice of the veffel which contains them.

It is true, that the fqueezing the elaftic gum bottle, when placed upon the piftol, forces fome of the inflammable gafs out of it, which is loft in the common air; but notwithftanding this wafte, the inflammable air which remains in the piſtol is ſufficient to produce a loud report, which is all that is required. Indeed, one ſingle drop of the æther could be eaſily ſhaken out of the glaſs tube immediately into the piſtol, without making uſe of the elaſtic gum bottle; but this drop, evaporating into elaſtic air, leaves behind it a good deal of moiſture, whether inherent in the æther itſelf, or attracted from the atmoſphere. This moiſture, in the way I uſe to load the piſtol, remains in the elaſtic gum bottle, which is therefore always found moiſt when the experiment is repeated ſeveral times.

It was, indeed, known before this time, that æther and other volatile inflammable liquors ſpread by evaporating inflammable effluvia through the ſurrounding air, eſpecially when they are heated; and that theſe effluvia have ſometimes by the imprudent approach of a candle taken fire, and conveyed the inflammation to the liquor itſelf: but I never heard that any body employed theſe liquors inſtead of ordinary inflammable air in communicating to common air an exploſive quality, or in firing inflammable air piſtols, before I communicated the experiment to my friends

As it will, I think, appear very probable, by what will be ſaid hereafter, that little more than a pleaſing amuſement can be expected from the force of any inflammable

air;

air; the ready production of such inflammable air always ready for use, when an explosion is intended to be produced, may be of some importance to philosophers whose time must be sparingly taken up.

Comparative view of the expanding force of explosive air and gunpowder.

The force of gunpowder has been ascribed by Sir ISAAC NEWTON and all other philosophers to the sudden extrication of an amazing quantity of elastic permanent aerial fluid within a narrow space incapable of containing it; which quantity ought to be attentively attended to, in order to estimate the comparative power of the two substances.

BENJAMIN ROBINS, whose work, intitled, *New Principles of Gunnery*, passes in this country for a standard book, affirms, that gunpowder, when fired, generates a permanent elastic fluid of 250 times the bulk of the powder before it was fired. He found, that common air, which is heated by the contact of a red-hot iron, expands to four times its former bulk. Hence he concludes, that the elastic air, disengaged from gunpowder, must expand also to four times its dimension; and that it occupies about a thousand times the bulk of the powder in the moment of inflammation.

The learned Count SALUCE remarks (c), that the elastic air generated by the inflammation of gunpowder occupies, when cold, 222 times the bulk of the powder, which agrees, as he finds, with the computation made by Meſſ. HAUKSBEE, AMONTONS, and BELIDOR. This calculation he confirms in the *Melanges de Philoſophie et des Mathematiques de la Societé Royale de* Turin, which is a continuation of the former work. He is of opinion, that this elaſtic fluid is of the ſame nature with common air (which was likewiſe the opinion of Dr. HALES); and that the prodigious force of gunpowder depends upon the action of the fire on all its parts, by which this fluid exerciſes all the force of its elaſticity.

The extrication of ſuch a conſiderable quantity of a permanent elaſtic fluid by the firing of gunpowder has been put to a particular uſe by ſeveral philoſophers.

The celebrated Mr. DE LA CONDAMINE gives an account of a braſs air gun contrived by one Mr. MATY, of Turin; which he loaded with air condenſed by firing in it two ounces of gunpowder, which, by its inflammation, let looſe ſuch a quantity of air as was ſufficient to ſhoot a leaden bullet ſixty paces, and to repeat the proceſs

(b) Miſcellanea Philoſophico-Mathematica Societatis privatæ Taurinenſis, p. 125.

eighteen

eighteen times, the ftrength of the explofion diminifhing gradually as in other air guns (d).

In the learned work of Mr. ANTONI, an Italian gentleman, I find the fame experiment, the account of which is accompanied with a figure of fuch an air gun, in which the author fired one ounce of gunpowder, the barrel being very ftout, and of a fize capable of containing ten ounces. He afterwards let a quantity of this compreffed air out by a valve in the fame way as it is done in the common air guns. This one ounce of gunpowder yielded air enough to propel a leaden bullet through a board three lines thick, at the diftance of forty paces, and to repeat the procefs fixteen or eighteen times (e).

The difference of the quantity of elaftic fluid obtained from the firing of gunpowder by Mr. ROBINS and others might be owing to the difficulties attending the inveftigation, or to the different proportion of the ingredients ufed in the compofition of the powder; as it is well known, that gunpowder for the ufe of the army is made of five or fix parts of nitre to one of charcoal,

(d) Extrait d'un Journal de Voyage d'Italie, par M. DE LA CONDAMINE, inféré dans les Memoires de l'Academie Royale des Sciences de Paris, 1757, p. 405.

(e) Examen de la Poudre traduit de l'Italien de M. ANTONI, par M. le Vifcomte de FLAVIGNY, 1773.

and

and one of ſulphur; when ſeven parts of nitre are uſed, it is called *poudre d'artifice.*

The celebrated Mr. JOHN BERNOUILLI calculates the denſity of the air contained in a ſolid ſtate in gunpowder to be $\frac{1}{1000}$ of what this fluid is when it conſtitutes a part of our atmoſphere. But he does not conſider this air as exiſting in all the component ingredients of the gunpowder, but chiefly in the nitre: and Count SALUCE ſuppoſes, that that part of the gunpowder which contains this air conſtitutes a conſiderable part of its bulk (though ſomewhat leſs than the half). Let us now ſuppoſe, that part of the gunpowder which contains this air to be not much leſs than the half of the whole maſs (for it would be difficult to demonſtrate accurately to what proportion of the whole maſs this part amounts in reality). On this ſuppoſition we ſhall find, that the whole maſs of gunpowder contains a quantity of air in a ſolid ſtate which is reduced in bulk to near $\frac{1}{500}$, or, in other words, that one ſquare inch of gunpowder contains near 500 ſquare inches of air; which being heated in the moment of inflammation will expand to four times its diameter; ſo that according to this calculation gunpowder muſt expand in the moment of exploſion to near 2000 times its own bulk.

It ſeems very probable, that this calculation of Mr. BERNOUILLI is much nearer the truth than that of

Mr. ROBINS and Count SALUCE; but yet the evaluation of the two laſt mentioned writers, though ſhort of one half, proves in reality Mr. BERNOUILLI's calculations to be as juſt as can be expected, when it is conſidered, that this evaluation was made before the new diſcoveries upon the nature of nitre and charcoal. But this aſſertion will be better underſtood when I have explained the nature of gunpowder ſomewhat fuller.

If we continue to ſay, as we have hitherto done, that the charcoal taking fire decompoſes the nitre, and extricates from it that amazing quantity of elaſtic fluid which was ſhut up within its ſubſtance, we only ſay what we ſee in reality is the conſequence of ſetting fire to this ingredient. But this explanation does not convey a clear idea of the manner in which the extrication is carried on; nor of the reaſon why one ſingle ſpark of fire, thrown into an immenſe heap of gunpowder, ſhould almoſt in an inſtant ſpread the conflagration through the whole maſs. Neither does it explain clearly, why nitre and charcoal (which ſeparately yield no flame at all, though ever ſo much heated) when combined and intimately mixed together, explode with as loud a report as a large ordnance piece, ſurpaſſing even in loudneſs thunder-claps; nor why this forcible exploſion is accompanied by a moſt brilliant flame.

Nitre

Nitre is compofed of two different ingredients, *viz*. an acid, called from its peculiar nature the *nitrous acid*, and the vegetable alkali. Neither of thefe two ingredients are capable of inflammation; nay, they even extinguifh actual fire. When they are both combined and conftitute the neutral falt we fpeak of, they have not, even by their coalition in one body, acquired an inflammable quality, for nitre may be made red-hot in a crucible without fhewing the leaft appearance of inflammation, not even when a red-hot ftone or piece of iron is thrown into it. But if any common combuftible fubftance, as wood, charcoal, or fuch like, is thrown into the melted nitre, a flame iffues with a kind of explofion, though only at the very place where the two fubftances come into contact. The fame flame and explofion is obferved when cold nitre is thrown upon a combuftible body, in a ftate of real ignition, on a piece of red-hot charcoal for inftance.

The true reafon of this wonderful phenomenon has not been confidered hitherto with that degree of attention it deferves, and could not have occurred to any body before our modern philofophers had difcovered the nature of various kinds of air, and the manner of extracting them from bodies.

Inflam-

Inflammable air, the *gas flammeum* of VAN HELMONT, was confidered as an aerial fluid, fufceptible of inflammation by itfelf.

But we now know, that inflammable gas concentrated will not burn at all; but on the contrary extinguifhes flame. Mr. CAVENDISH was the firft who fet this matter in a proper light. He difcovered, by experiments, that a mixture of a fmall quantity of common air with a great proportion of inflammable air, as, for inftance, two parts of common air with eight parts of inflammable air, caught fire without noife, and confumed gradually; but that three parts of inflammable air and feven parts of refpirable air exploded with a very loud found.

It was Dr. PRIESTLEY's important difcovery which fuggefted to me the theory I intend to lay before the Royal Society.

This acute philofopher found, that, if inftead of common air, dephlogifticated air is mixed with a due proportion of inflammable air, the explofion is confiderably louder.

The principal ingredients of gunpowder, and thofe to which it owes its force, are nitre and charcoal; for thefe two ingredients, well mixed together, conftitute gunpowder at leaft equal if not fuperior in ftrength to common gunpowder (as I found by experience, and may be

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feen in the Memoire of Count SALUCE, inferted in the *Melanges de Philofophie et de Mathematiques de l'Acad. Royale de* Turin). The fulphur feems to ferve only for the purpofe of fetting fire to the mafs with a lefs degree of heat.

Nitre yields by heat a furprizing quantity of pure dephlogifticated air. Charcoal yields by heat a confiderable quantity of inflammable air. The fire employed to inflame the gunpowder extricates thefe two airs, and fets fire to them at the fame inftant of their extrication. Thus the difference between the inflammation of gunpowder and that of a mixture of inflammable air with dephlogifticated air in an ordinary air piftol (as thefe laft are now contrived for a philofophical amufement) feems to be, that the compound of the two airs in the air piftol takes fire, when already extricated and exifting in a fpace without compreffion or condenfation; that is to fay, when they are in no condition of exerting a much greater elafticity than what they acquired by the heat generated in the moment of their explofion; which heat can only expand them to four times their former bulk, according to Mr. ROBINS: whereas in gunpowder the two airs, exifting in a folid ftate before their extrication, and occupying, according to Mr. ROBINS, about $\frac{1}{250}$ of the fpace they take up after they are fet loofe, but moft probably

bably even leſs than $\frac{1}{500}$ (as will be ſeen by and by), are extricated all at once, when confined (as in fire arms) in a ſpace $\frac{1}{250}$ or rather $\frac{1}{500}$ times leſs than they can occupy when reduced to the temperature of the common atmoſphere, and of conſequence 2000 leſs than they can occupy when heated in the moment of inflammation; ſo that the difference of the exploſive force in the inflammation of the two compounds can be no leſs than as 4 is to 2000.

It muſt be here remembered, that air being a very compreſſible body, a moderate reſiſtance acting againſt its rarefaction eaſily overcomes the force of its expanſion, when this expanſion or rarefaction does not amount to more than four times its bulk (that ſuch a power ought not to be very great, we know by the force employed in ordinary wind guns and condenſing machines) whereas no condenſing machine has yet been contrived by which air could be condenſed to any thing approaching the ſtate of condenſation of this fluid as it exiſts in the ſubſtance of nitre.

It might be here objected, that air compreſſed to one tenth in a wind gun poſſeſſes a power not much ſhort of gunpowder, though only $\frac{1}{18}$ or $\frac{1}{20}$ of it is let looſe at a time; and that thus, inflammable air, though expanded only four times in the moment of inflammation, may exert a force approaching that of the wind gun, the whole mafs of the charge being employed in one and the fame explofion. This comparifon is very inadequate; for in the cafe of a wind gun the air compreffed to $\frac{1}{10}$ is ready to exert all the force of elafticity exifting in the whole mafs, and may therefore be compared to a ftrong fpring forcibly bent. But the inflammable air is far from exerting the force of expanfion and elafticity through its whole mafs at the fame inftant: for the inflammation is propagated through it fucceffively, beginning where the electrical fpark kindles it, and reaching gradually farther till the whole is confumed. Now as I have demonftrated, that inflammable air is reduced to more than half its bulk by inflammation, it muft follow, that that portion of it which is confumed the firft by the inflammation, leaving more room by its diminution, diminifhes in proportion the propelling powers of what remains ftill to be inflamed.

The very great difference between the explofive force of the two compounds is illuftrated by what happens after their inflammation. The compound of inflammable with common or dephlogifticated air, is very much reduced in bulk after inflammation. I found this by the following experiment: I fired a brafs inflammable air piftol (made by Mr. NAIRNE according to my directions) which had a pifton in the cylinder, by which a proper quantity

quantity of refpirable and inflammable air was drawn in. I had rammed into the barrel, adapted to it, a leaden bullet wrapped up in a piece of leather fo ftrongly that I did not expect the refiftance could be overcome by the explofion. I fired it by an electrical fpark; the inflammation took place, the piftol grew hot, the ball was not propelled, and the pifton was driven more than half way down the cylinder by the preffure of the atmofphere acting upon it when the explofive air was confumed by the inflammation.

The cafe is quite different in the firing of gunpowder, as there remains after its inflammation a mafs of air which occupies about 250 times the former bulk, according to Mr. ROBINS.

As, in the foregoing experiment, the compound of inflammable and common air was reduced above the half of its former bulk, it feems more than probable, that the quantity of dephlogifticated and inflammable air extricated in the firing of gunpowder muft alfo undergo a fimilar diminution by its inflammation; fo, that when there remains a mafs of air, 250 times the bulk of the gunpowder, the quantity of air extricated from the powder muft have been in reality not lefs than 500 times the bulk of the powder, which agrees nearly with the calculation of Mr. JOHN BERNOUILLI. Let us now

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ſee how far this computation agrees with the analyſis of gunpowder. Abbé FONTANA, ſo advantageouſly known by his important diſcoveries in natural philoſophy, more eſpecially by thoſe he has made on the various kinds of air, favoured me with the following reſult of his experiments. An ounce of nitre, expoſed to a great degree of heat for the purpoſe of extracting its air in the uſual way, yielded about 800 cubic inches of dephlogiſticated air. An ounce of charcoal, treated in the ſame way, gave about 150 cubic inches of air, partly fixed, partly inflammable, mixed with ſome common air.

Let us now calculate (without, however, being too ſcrupulous about the accuracy of the reſult) what quantity of elaſtic permanent fluid a cubic inch of ſolid gunpowder will give in the moment of deflagration: a cubic inch of ſolid gunpowder contains in weight 442 grains (which is 38 grains ſhort of an ounce Troy weight) of which 331½ grains is nitre, 55¼ charcoal, and as much ſulphur (ſuppoſing the proportion of the ingredients of the powder to be ſix parts of nitre to one of charcoal and one of ſulphur); 331½ grains of nitre will give about 552 cubic inches of dephlogiſticated air; 55¼ grains of charcoal will produce about 17 cubic inches of air, chiefly inflammable, according to the calculation of Abbé FONTANA.

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By this calculation, which will, perhaps, be found more accurate than the former, one cubic inch of ſolid gunpowder will yield above 569 cubic inches of permanent elaſtic fluid: I ſay, above 569 cubic inches, for I do not put into the account the elaſtic fluid which is generated by the ſulphur, nor that which charcoal, conſumed by the inflammation of the gunpowder, yields above the quantity mentioned, which it gives when heated in a glaſs veſſel, by which it is by no means conſumed, an ounce loſing by this operation only 60 grains of its weight.

As this elaſtic fluid will increaſe to four times its bulk, it follows, that one cubic inch of ſolid gunpowder will extricate in the moment of exploſion above 2276 cubic inches of elaſtic air. Which computation is not far from the reſult of my former calculation, and that of Mr. BERNOUILLI.

An accurate calculation of the expanſion of gunpowder would be a very difficult undertaking. The expanſion of the moiſture always contained in gunpowder, however dry, may alſo contribute its ſhare towards the amazing powers of this ingredient. Nitre contains from its nature a great ſhare of water, which is neceſſary for the cryſtallization of it, and charcoal is always found to contain it. We know, that very hot vapour is capable of occupying almoſt 2000 times the ſpace it did in the ſtate of cold water.

The generation of dephlogiſticated and inflammable air by the inflammation of gunpowder is the reaſon why this ingredient is almoſt the only one known, which does not want a free acceſs of common air to be conſumed by fire; and therefore it may be ſaid to feed, as it were, upon its own air.

This theory of gunpowder induces me to venture a new one of the *pulvis fulminans*, which conſiſts of three parts of nitre, of two of fixed alkaline ſalt, and of one of ſulphur. This powder much ſurpaſſes the force of gunpowder in exploding, with a very loud report, in the open air when it is heated to a certain degree. It is commonly ſaid, that in the heating of this powder the ſulphur joins with the alkaline ſalt and conſtitutes an *hepar ſulphuris*, which riſing up in bubbles confines the air contained in them, which air at laſt becomes ſo powerfully expanded that it overcomes and breaks through the reſiſtance of the coercive bubbles of the *hepar ſulphuris*, with all the force of its elaſticity; which ſudden emerſion muſt naturally occaſion a proportional ſound. But I think, that the nitre contained in this powder, being heated, yields its dephlogiſticated air when the melting ſulphur yields inflammable air; at the ſame time the ſulphur conſtitutes

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with the alkaline falt, an *hepar fulphuris*, which rifing in tough bubbles confines this explofive air generated. At length, however, the increafing heat, which fets fire to the fulphur, fets this explofive air on fire alfo; which then following its own nature explodes with fo much the more force from its having been entangled and confined within the bubbles of the *hepar fulphuris*.

After what has already been faid, it will not be difficult to explain, why a fingle fpark of fire propagates the combuftion with great rapidity through the whole mafs of gunpowder, however great. If we put a fingle grain of gunpowder upon a red-hot iron, we fee the particles of red-hot charcoal projected with great rapidity in every direction by the forcible explofion of the two airs extricated in the manner before explained. Thus, if one or more grains, among a heap of others, are fet fire to, the particles of red-hot charcoal being driven with great violence againft the furrounding grains communicate their heat to all the particles of charcoal they hit, which particles, by heating the particles of nitre in clofe contact with them, extricate their dephlogifticated air at the fame time that the charcoal yields its inflammable air; in confequence of which a more powerful explofion happens. This fecondary explofion projects with a much greater force the particles of charcoal furrounded by the explofive

 flame

flame of the two airs; and thus the conflagration ſpreads with a very great velocity through the whole maſs, though always by ſucceſſion. The quickneſs of this propagation of fire depends in a great meaſure upon the intervals or interſtices which remain among the grains of gunpowder, through which the particles of heated charcoal are driven in every direction, together with the flame of the two airs. Hence gunpowder reduced into impalpable powder, and rammed into a ſquib, does not inflame with an exploſion, but burns ſlowly farther and farther till the combuſtion reaches the extremity of the ſquib, where it meets a maſs of gunpowder in grains, when immediately a loud exploſion iſſues, by which the ſquib is ſhattered into rags. Hence the ſize of the grains of gunpowder muſt be proportionate to the ſize of the fire arms to which it is deſtined, the greateſt fire arms requiring in general grains of the largeſt ſize.

If this wonderful and awful ingredient had not been diſcovered by accident, could the ſecret have eſcaped a long while the penetration of our modern philoſophers, who have found out the way of combining the air of the two conſtituents after they had extricated them, without any regard to the known properties of gunpowder? Nothing more was to be done than combining the two ſubſtances inſtead of combining the two airs firſt ſeparated from them.

APPENDIX.

IN the foregoing paper I attempted to give a comparative view of the exploſive force of gunpowder and inflammable exploſive air, which latter I had found to be ſo far ſhort of the exploſive force of gunpowder as not to conceive any well grounded hope that it could ever become a ſubſtitute to this ingredient.

At that time I had not yet tried the effect of very pure dephlogiſticated air combined with that inflammable air, into which I had found that vitriolic æther is changed in an inſtant.

I muſt acknowledge, that I had but ſmall expectations from the force of theſe two airs combined; for as I had always obſerved, that æther air combined with common air is leſs briſk in taking fire, and leſs powerful in exploding, than inflammable air extracted from the vitriolic or marine acid, I thought that the ſame æther air combined with very pure dephlogiſticated air would alſo be leſs powerful than common inflammable air from metals. But how far experience contradicted this theoretical analogy will be ſeen in the following lines.

Abbé FONTANA was ſo good as to aſſiſt me in this purſuit. Having produced a good quantity of pure dephlogiſticated air from red precipitate by heat, we firſt filled a ſtrong two-ounce phial (the orifice of which was ſo wide that it could ſcarce be covered with the thumb, ſo that the bottle was almoſt cylindrical) with this air, in the uſual manner, by filling it firſt with water, inverting it, and letting the air riſe in it; which being done, we dropped one drop of æther (in which a ſmall quantity of camphire was diſſolved) into it, and ſhut it immediately with the thumb. After having given it ſome concuſſions, the orifice was applied to the flame of a candle, by withdrawing the thumb when the orifice was cloſe to the flame: the air inſtantly took fire, and exploded with ſuch a ſtrong report, that, if the phial had not been very ſtout, it would moſt probably have been ſhattered into pieces, notwithſtanding its wide orifice. We repeated the ſame experiment with the ſame ſucceſs.

I was the more aſtoniſhed at the uncommcn loud report (conſidering the wide orifice of the phial), becauſe, having often tried æther air in the ſame way with common air, I never found it explode with any

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confiderable degree of force; and therefore I found it neceffary, in order to procure a loud report, to kindle it by an electrical fpark directed through the piftol, when its orifice was fhut up by a cork, the refiftance of which was the chief caufe of the report.

This wonderful effect in an open veffel could not fail of giving me a good expectation of a very powerful effect, if this compound air was fhut up in an air piftol by a cork fqueezed into its orifice. As it had been now kindled twice by the flame of a candle, I wanted to kindle it by the fame means in an air piftol; for this purpofe we drilled a fmall hole in the fide of the piftol, which was made of tin, and contained about nine cubic inches of fpace. We filled it with dephlogifticated air in the fame manner as we had filled the phial by means of water; and after having poured into it one drop of æther by means of a glafs tube (in the manner above defcribed), we fhut the orifice by thrufting a cork into it, and kept a finger applied to the touch-hole which was drilled in the fide of the piftol. To avoid accidents if the piftol fhould burft, we thought it prudent to fqueeze the cork very gently into the orifice, fo that the refiftance fhould be very moderate. Abbé FONTANA wrapped a towel round the piftol for fecurity's fake, leaving only the touch-hole uncovered; which being brought near the flame of of a wax taper, the air inftantly took fire, and exploded with fuch a ftrong report, that his hearing, as well as mine, was much hurt by it. The cork, which was a very found one, flew to pieces againft the wall; and the Abbé felt fuch a confiderable fhock in his hands, that he did not think it fafe to repeat the experiment, unlefs a ftronger piftol could be procured.

Encouraged by fuch uncommon and unexpected effects, I went immediately to Mr. NAIRNE to inquire, whether he ftill had in his poffeffion a ftrong brafs air piftol, which he had made laft fummer according to my direction? I was lucky enough to find it: nothing was to be done to it but to drill a touch-hole in the left fide of it, in order to kindle it by a flame if required. This touch-hole was to be fhut up by a brafs male fcrew fitted exactly to it, when the piftol was intended to be fired by an electrical fpark.

The air box of this piftol was a cylinder four inches long and two inches in diameter. The fore part of the air box to which the piftol barrel fitted to receive a leaden ball or a cork, was fixed, had a broad fhoulder, which was faftened to the body of the air box by fix ftrong brafs fcrews, which never had been loofened by former explofions. A leaden bullet, wrapped up in leather, was forcibly rammed into the piftol barrel as far as the fcrew, which

joins

joins the barrel with the air box (as may be feen in the figure). The piftol was filled with pure dephlogifticated air (which was drawn-in by the pifton from an elaftic gum bottle), and one drop of æther being poured into it, the air within was kindled by an electrical fpark directed through it. The air took fire: the explofion was as loud as that of a common mufket, and the force fo great, that the whole fore part of the air box with the piftol barrel flew off, all the fix fcrews were broke, and the ftrong and tough metal of which they were made was rent. Three ftrong brafs fcrews, by which the bottom of the air box was fixed to the wooden handle, were loofened, and the whole frame of the piftol was out of order. The fubftance of the air barrel, where it was tore, was of the thicknefs of about a half crown piece.

Being now convinced, that though inflammable air from metals with dephlogifticated or common air, is far inferior to the force of gunpowder, the explofive force of the compound of dephlogifticated and æther air approaches it much nearer, I thought it worth while to fit the piftol up in fuch a manner as to be out of all danger of burfting. For this purpofe I defired Mr. NAIRNE to adapt, and folder to the fore part of the air box, a hollow cone of brafs, the extremity of which fhould terminate in the gun barrel.

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As the piſton could not reach to the extremity of this conical hollow (which conſequently muſt be always filled with common air), I deſired him to fix to the piſton an ivory cone, through which the two wires would paſs to meet one another at the ſurface of the cone, leaving an interſtice between them of about one line, through which the electrical ſpark ſhould leap and ſet fire to the air. This ivory cone ſhutting up exactly the whole cavity of the air box, no air could come into it but what was drawn in by the piſton.

The piſtol thus fitted up anſwered tolerably well. The figure joined to it will ſerve to give a better idea of the whole contrivance than could be well explained by words. The ſcale is in the proportion of one third of the real ſize.

The cone, inſtead of ivory, may be made of ſolid glaſs, which is a better non-conductor than ivory. The canals in the ivory, through which the two wires paſs, may be made wide enough to contain a glaſs tube, through which the wires paſs; or to be filled with a non-conducting cement, as ſealing wax, for the ſame purpoſe. The cone may even be made of braſs, provided two glaſs tubes are lodged in it, to give a paſſage to the two wires.

I kindle this piſtol ſometimes by putting in the touch-hole a little bit of a cotton thread ſoaked in moiſt gun-

powder

powder and dried afterwards; or a bit of thofe paper matches which the Chinefe put into thofe little fquibs, which go by the name of *India crackers*. I fometimes kindle it by holding the flame of a candle or a burning paper to the touch-hole. In this cafe it is to be obferved, that the touch-hole muft be kept upwards, if the piftol is loaded with inflammable air from metals, becaufe this air being lighter than common air, will rife out of the hole and meet the flame. The contrary muft be done when æther air is employed, it being heavier than common air, and thus difpofed to defcend and fall upon the flame kept under it.

To fill this piftol with any air, I commonly firft fill an elaftic gum bottle with it, the orifice of which is juft big enough to receive that part of the gun barrel which is fixed to the air box: thus, by fqueezing between my feet the elaftic gum bottle, I draw in at the fame time the air by drawing up the pifton. A bladder is alfo very fit for this purpofe, and has the advantage above an elaftic gum bottle in not requiring to be fqueezed to draw the air out of it.

Inflammable air from metals will rife in the piftol of itfelf, when its orifice is kept upon the bottle containing it.

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If the piſtol is deſtined to be always kindled by the flame of a candle or a match, as I have deſcribed, it would be better to have no piſton to it, as it may then be filled by the means of water, and the exploſive force will be ſo much the greater, as ſome of the flame makes eaſily its way over the leather of the piſton, and ruſhes out backward, which, I find, is often the caſe, if the bullet is rammed in the barrel ſomewhat too tightly.

It would, perhaps, not be an eaſy undertaking to give a ſatisfactory reaſon, why a drop of æther communicates to dephlogiſticated air a much ſtronger exploſive force than common inflammable air from metals. May it not be ſaid, that common inflammable air from metals, having only about one fifth of the ſpecific gravity of the dephlogiſticated air, the two fluids do not penetrate one another ſo readily and ſo intimately as the compound of dephlogiſticated and æther air, which are both nearly of the ſame ſpecific gravity, each being ſomewhat heavier than common air? for it ſeems not improbable, that the ſwiftneſs with which the flame is propagated through the maſs of this compound air, depends partly on the intimate mixture of the phlogiſton with the dephlogiſticated air. Might not this phenomenon be aſcribed to the greater bulk of inflammable air from metals compared with the ſmall compaſs which one ſingle drop

drop of æther occupies, which laſt ingredient, when pure, ſeems to be an eſſence of the inflammable principle of the ſpirit of wine, a pure phlogiſton concentrated in the form of a liquid? Indeed the inflammable air from metals ſeems to be rather a compound of phlogiſton and ſome kind of elaſtic permanent fluid than a pure inflammable fluid; for this air, after having loſt all its inflammability, by being kept a long while upon water, occupies ſtill a conſiderable ſpace, and is then become phlogiſticated air; that is to ſay, ſuch an air as is not to be diminiſhed by nitrous air, or to be inflamed.

Though I have no reaſon to alter my former aſſertion, that the force of gunpowder is proportionable to the ſudden extrication of a great quantity of the elaſtic fluid generated in the moment of conflagration, and the expanſion of this fluid by heat, communicated to it in the ſame moment of its extrication; and that the force of inflammable exploſive air can only be proportionable to the ſudden expanſion by heat in the moment of the inflammation (for no new extrication here takes place); yet I did not conſider enough in the account the ſuddenneſs of this expanſion, which may make a conſiderable difference in the force of the exploſion. And indeed the abovementioned experiments ſeem to demonſtrate, that the inflammation of the compound of pure dephlogifticated and æther air fpreads with fuch a velocity through the whole mafs as to be almoft inftantaneous.

It is well known, that mechanical power chiefly depends upon the velocity with which a body is endowed in the inftant of exerting it; or that the *momentum*, or force of a body, muft be computed by multiplying the quantity of matter into the velocity with which it moves. Thus, if this new compound of dephlogifticated and æther air expands with ten times greater velocity than any other inflammable explofive air, its force will be about ten times greater.

As it feems to be probable, from what is already faid that this compound of explofive air may be put to more ufes than that of an amufing experiment, I think it worth while for men engaged in this branch of natural philofophy to look out for a method of producing at pleafure any quantity of dephlogifticated air required. Confidering the rapid progrefs which is daily made on the important fubject of air, I cannot but flatter myfelf, that this great difcovery is not far off. The benefit which would arife from fuch a difcovery for animal life muft encourage every philofopher to purfue this object. Indeed, if we confider that nitre contains this wonderful aerial fluid in a moft concentrated ftate, and that the nitrous acid feems to be nothing elfe but this beneficial fluid

fluid combined with phlogifton, which feems to be imbibed by the vegetable alkali, when the acid is expelled by heat in the form of this air; that this beneficial aerial fluid exifts alfo, in a moft concentrated ftate, in bodies almoft every where to be found, as are calces of metal, principally that of iron; that common water contains it in great abundance, fo that the light and warmth of the fun extracts it to one fifteenth of the bulk of the water, as Dr. PRIESTLEY found, that even the mafs of our atmofphere is nothing elfe but this very air foiled with impurities. If we confider, I fay, all this, is it not reafonable to hope, that we are near the important inftant when this falubrious aerial fluid will be procured for many ufeful purpofes in a fufficient quantity, either by the difcovery of a ready way to let loofe this air from the bodies in which it is as it were imprifoned, or by filtrating or purifying common air from its impurities?

EXPLANATION OF THE FIGURE.

A *a* the piftol barrel.

B the large cylinder or air box.

b the place where the piftol barrel unfcrews from the air box.

c the piftol handle.

D the handle fixed to the piſton at *b b*, which is ſquare to prevent the piſtons turning round.

E the hole in the ſide of the air box.

e the ſcrew to ſtop the ſaid hole.

F a piece of braſs with a female ſcrew, which was fixed with three ſtrong ſcrews to the wooden handle.

f a ſcrew at the end of the air box which ſcrewed into the piece F.

G a piece of ivory fixed to the piſton.

K the piſton, with the piece of conical ivory fixed to it.

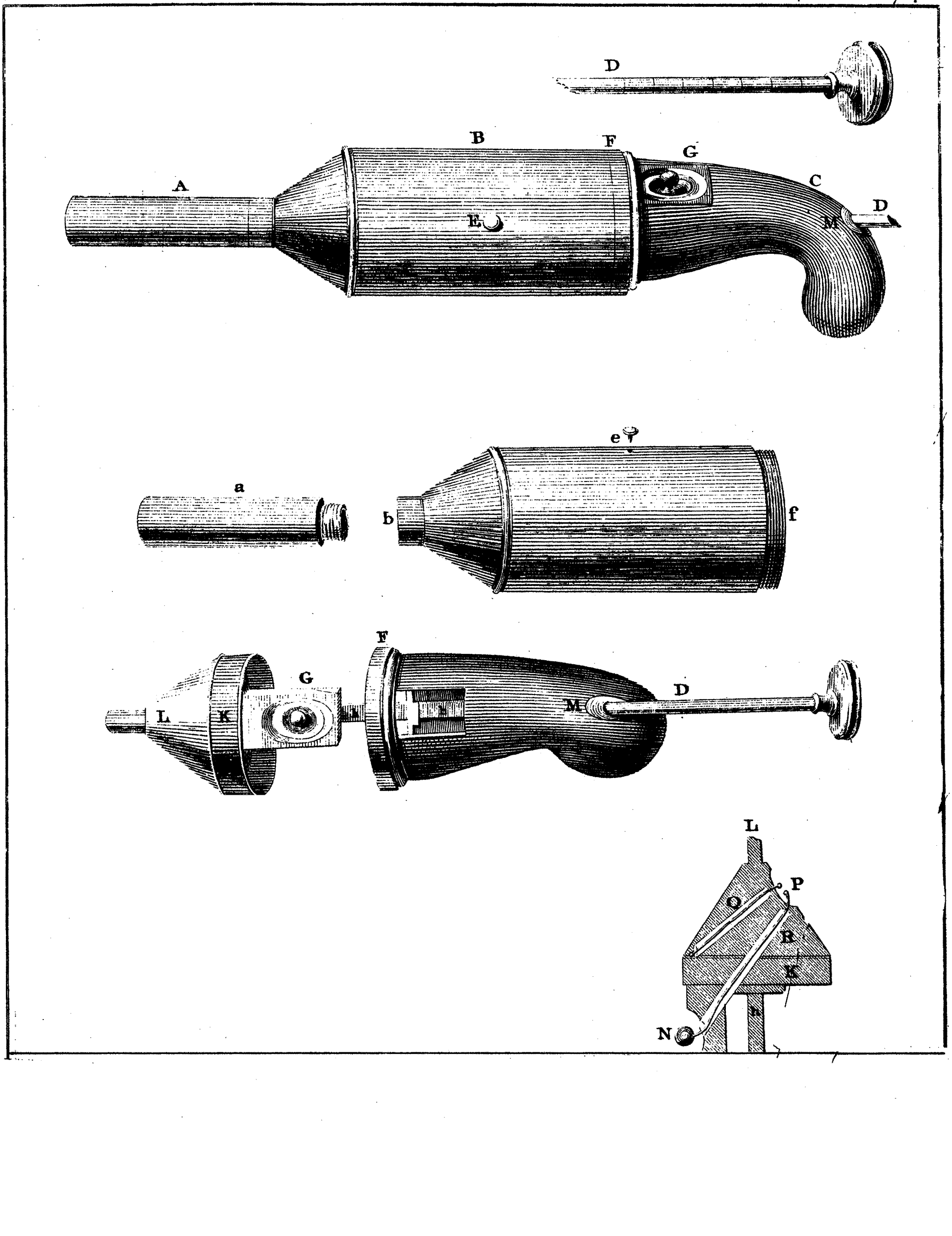
L the termination of the ivory cone which filled up the ſmall end of the air box.

M the perforation in the wooden handle, through which the braſs handle D paſſes.

N a braſs ball at the end of a wire, which paſſes down the canal R in the ivory cone.

O another piece of wire paſſing down the other canal, canals are filled with non-conducting ſubſtance.

P an interſtice between the two wires of about one line, through which the electrical ſpark, when given on the ball N, paſſes and ſets fire to the inflammable air in the air box.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