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Comprehending the theory and practice, with the application of chemistry; designed for exhibition and for war.

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For consistency and clarity, a space (when absent) has been placed between the number and the unit of weight lb. and lbs. giving for example '21 lbs.' in place of '21lbs.'

Fractions, usually in the form '14 3-4' in the original text, have been converted to the form '14$^3/_4$' in this etext.

Also, in a few larger tables with italic styling on some text, this italic styling has been removed, for consistency with the .txt version. In a few cases a word has been abbreviated to conserve table space: cal. = caliber; diam. = diameter.

Some instances of *Tome* in French citations have been changed to Tome (no italic), for consistency.

Some accents and spelling in French citations have been corrected.

For consistency, instances of 'fireworks' and 'fire works' have been changed to the predominant form 'fire-works'.

Obvious typographical errors and punctuation errors have been corrected after careful comparison with other occurrences within the text and consultation of external sources.

More detail can be found at the end of the book.

A

SYSTEM OF PYROTECHNY,

COMPREHENDING THE THEORY AND PRACTICE, WITH THE APPLICATION OF CHEMISTRY;

DESIGNED FOR EXHIBITION AND FOR WAR.

IN FOUR PARTS:

CONTAINING AN ACCOUNT OF THE SUBSTANCES USED IN FIRE-WORKS; THE INSTRUMENTS, UTENSILS, AND MANIPULATIONS; FIRE-WORKS FOR EXHIBITION; AND MILITARY PYROTECHNY.

ADAPTED TO THE

MILITARY AND NAVAL OFFICER, THE MAN OF SCIENCE AND ARTIFICER.

BY JAMES CUTBUSH, A.S.U.S.A.

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PHILADELPHIA:

PUBLISHED BY CLARA F. CUTBUSH.

1825.

To the Corps of Cadets, of the United States' Military Academy, West Point;

GENTLEMEN,

To you, a scientific and distinguished Corps, this work on Pyrotechny is respectfully dedicated. Your liberal subscription first encouraged me to undertake its publication; for which, accept my grateful thanks.

CLARA F. CUTBUSH.

ADVERTISEMENT.

In submitting the present work to the public, it may be proper to state some of the difficulties, under which it has been published, and to bespeak an indulgent allowance for any imperfections, which may be observed in the style or arrangement. As a posthumous work, it has been deprived of those final improvements and emendations, which are generally made by Authors, while their works are in progress of publication. While, however, the work has laboured under these disadvantages, the publisher has felt it her duty to make every arrangement, to supply, as far as possible, the want of the author's personal superintendence of the publication. This course was due to the scientific reputation of her late husband, as well as to the numerous and generous patrons of the work.

Philadelphia, April, 1825.

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INTRODUCTION. [xv]

In presenting this work to the public as a system of Pyrotechny, which, we have reason to believe, is the only full and connected system that has appeared, we may be permitted to remark, that, in our arrangement of the subject, we have appropriated separate heads for each article.

This plan, of the subject being considered in chapters and sections, and forming with the divisions of the work, a connected system of arrangement, enables the reader to have a full view of the whole, and, at the same time, all the facts in detail belonging to the chapter, or section under consideration. By referring to the Table of Contents, this plan will be seen without further comment. The arrangement of the different articles in this manner, necessarily comprehends in the onset all the substances, which are employed in various preparations. In considering this part of our subject, we have given the chemical characters, or peculiar properties of each substance respectively; by which a rationale of pyrotechnical effects may be the better understood, and, consequently, the action of bodies on each other better illustrated.

In this part we also comprehend the General Theory of Fire-works, which it may be proper to remark, we have drawn from the known effects of chemical action; so far, at least, as the laws, of affinity, which govern such action, are applicable to the subject. The importance of this inquiry, although having no relation to the mere manipulations of the artificer, can not be doubted; since a knowledge of chemistry has already improved the preparation of gunpowder, and its effects are now known to be owing to the formation of sundry elastic aeriform fluids. On this head, that of the application of chemistry to Pyrotechny, we claim so much originality, as, so far as we know, to have been the first, who applied the principles of chemistry.

It is not to be expected in every instance, that a rationale of the decomposition as it occurs, or the order in which it takes place, can be given with certainty; because, where a [xvi] variety of substances enter into the same preparation, which is frequently the case, the affinities become complicated, and the laws of action for that reason indeterminate, and frequently anomalous. But, on the contrary, in a variety of primary operating causes, by which effects analogous in their nature result, decomposition of course being the same, the causes are well understood, and the effects are thereby known, and duly appreciated.

This, for instance, is the case with a mixture of nitrate of potassa, charcoal, and sulphur, in the proportion necessary to form gunpowder; for, it is known, that the explosive effects of powder are owing to the sudden production of a number of gases, which suffer dilatation by the immense quantity of caloric liberated at the moment of combustion. Although the production of caloric by the inflammation of gunpowder is a case, which cannot be explained by the present received theory of combustion, as we have noticed in that article; yet we know that it is a fact, and that caloric is generated by the decomposition of the powder.

If we consider the primary cause of this decomposition, we naturally inquire into the products of the combustion, and endeavour to account for the production of the elastic aeriform fluids. We know that carbon has the property of decomposing nitric acid, and also nitrate of potassa; for, when it is brought in contact in the state of ignition with nitre, a deflagration will ensue, and carbonic acid be formed. The quantity of this acid is in the direct *ratio* to the quantity of oxygen required to *saturate* a given quantity of carbon; and therefore, by employing certain proportions of nitre and charcoal, the latter will decompose the former, and by abstracting its oxygen, on the same principle form carbonic acid, while the azote, the other constituent of nitric acid, will be set at liberty. Nor is this all, if we consider the action of sulphur. The sulphur must unite with one portion of the oxygen to produce sulphurous acid gas, and also with the potassa of the nitre, and form a sulphuret, a compound necessary to be formed, before we can explain the production of sulphuretted hydrogen gas, which results from the decomposition of water contained in the nitre. There also results, as a product, sulphate of potassa. In considering these products at large, it would be necessary to go into detail; and, as we have descanted largely on its combustion in [xvii] gunpowder, we accordingly refer the reader to the article on *Gunpowder*. It will be sufficient, however, to remark, that the *agent*, and consequently the cause, which produces the decomposition of nitrate of potassa, is carbon or charcoal. This, by uniting with the greater part of the oxygen of the nitre, produces, in a determinate proportion, carbonic acid gas. This gas, therefore, in conjunction with other gases, formed at the same time, all of which being expanded, causes what is denominated the *explosive effect* of gunpowder.

We have then a primary cause of the decomposition, and most of the effective force of gunpowder is owing to the carbonic acid; and it is found, that gunpowder made without sulphur is equally powerful as that with, since it adds nothing to its power.

Causes, therefore, chemically speaking, operate alike under similar circumstances. The materials made use of being equally pure, and used in the same proportion, the effect must necessarily be the same.

It is not only in the instance we have mentioned, but in every other, in which chemical action ensues, that this doctrine is tenable. We might, indeed, notice a number of cases of a similar kind; as, for instance, in the combustion of many incendiary preparations, as fire-stone, fire-rain, composition for carcasses, light-balls, and a variety of fire-works of the same kind. If we mix pitch, tar, tallow, &c. with nitrate of potassa, and burn the mixture, we have the combined action of two elementary substances, which enter into the composition of these bodies, namely, carbon and hydrogen. The products would be carbonic acid gas, and water; because the oxygen of the nitre would unite with the hydrogen, as well as the carbon. If we employ sulphur at the same time, another product would be sulphurous acid gas, and probably sulphuric acid; and if gunpowder be used, as in the *fire-stone* composition, then, besides these products, we would have those of the gunpowder.

As this subject, however interesting to the theoretical pyrotechnist, cannot be understood without a knowledge of chemistry, it is obvious, that that science is a powerful aid to pyrotechny. It is unnecessary to dwell on this head. We may add, nevertheless that, in order to understand the effect of all mixtures, or compositions made use of, it is necessary to [xviii] consider the nature of the substances employed, and the manner in which chemical action takes place, and consequently the products, which determine in fact the characteristic property of each species of fire-work, and the phenomena on which it is predicated. All products of combustion depend on the substances thus decomposed, and by knowing the effects, we may readily refer them to their proper causes.

With respect to *caloric*, it may not be improper to offer some remarks.[1] The hypothetical element of phlogiston having given way to the antiphlogistic theory at present received, our ideas respecting caloric are predicated on facts. Caloric is a term, which expresses heat, or matter of heat. In pyrotechny, we have merely to consider it in a free, or uncombined state; but as the subject is interesting, we purpose to notice it very briefly under the following heads: viz. its nature; the manner it is set in motion; its tendency to a state of rest; the changes it produces on bodies; and the instruments for measuring its intensity.

As to the nature of caloric, different opinions are entertained. We know the effect of heat: if we touch a substance of a higher temperature than our bodies, we call it hot, and *vice versa*. The one is evidently the accession, and the other the abstraction, of caloric. The latter is merely relative as respects ourselves; for the effect depends on our feelings, and the sensation of hot or cold is therefore governed by them.[2] Caloric, however, is considered to be a substance, composed of inconceivably small particles; but count Rumford and sir H. Davy are of a contrary opinion, namely, that it depends upon a peculiar motion and not on a subtle fluid. [xix]

As the effect of caloric, according to their view, depends on motion, the agencies by which this is effected are of the first importance. That it exists in all bodies in a state of rest, and in a greater or smaller quantity, and consequently in a relative proportion, is well known, and on this, the capacities of bodies for caloric is founded. The capacities of bodies for heat are changed by various means, and caloric is put in motion; and, according to its quantity, the bodies may be either cold or hot. When the surrounding bodies become heated, they receive this caloric thus set free, and, in this view, the absolute quantity of their heat is increased. This state of rest, to which caloric is subject, may be destroyed either by an increase or a diminution of the capacity of a body. If caloric be put in motion by causes of any kind, which influence the capacities of different bodies, a theory maintained by Davy, then as the capacity for heat is changed so is free heat produced. Diminish the capacity of a body, its excess will of course be given out, and distribute itself among the surrounding bodies, which become heated; but increase the capacity, and a different effect ensues. The body absorbs caloric, by which its capacity is increased, and cold is produced. Caloric, whether considered a substance, or an attribute, possesses, nevertheless, this property, that when it is given out, as in the mixture of sulphuric acid and water, which occupies a less space than both in a separate state, the sensation of heat follows; and when it is absorbed, as in the various freezing mixtures, or in a mixture of snow and common salt, the sensation of cold is excited. The causes, however, which set caloric in motion, or that produce heat, are [xx] such as combustion, condensation, friction, chemical mixture, and the like. It is remarkable, that these effects are invariably the same, and are affected by corresponding affinities. When a piece of iron is struck with a hammer, the percussion produces a condensation of the iron, its specific gravity is increased, and the iron finally becomes ignited. The condensation of air, in the condensing syringe, will set fire to tinder. The flint and steel produce a condensation; for the metal, although small, is sent off in scintillations in the state of ignition. That caloric is contained in bodies in the state of absolute rest, and is evolved by condensation, there is no doubt. Gunpowder, by percussion, in contact with pulverized glass, is inflamed; and it appears very probable, that it also contains caloric in a state of rest. The experiments of Lavoisier and Laplace, on the quantity of caloric actually absorbed in nitric acid, and in a latent state, (noticed in the article on *gunpowder*), are satisfactory. If caloric is not in that state in nitre, how are we to explain the sudden transmission or evolution of caloric in fired gunpowder, where no external agent in any manner can influence the formation, or disengagement of caloric? Friction or attrition produces heat; and the distributable excess of caloric, as it is called, although not satisfactorily accounted for, may arise from a condensation; which, however, is denied.

The Esquimaux Indians kindle a fire, very expeditiously, in the following manner: They prepare two pieces of dry wood, and making a small hole in each, fit into them a little cylindrical piece of wood, round which a thong is put. Then, by pulling the ends of this thong, they whirl the cylindrical piece about with such velocity, that the motion sets the wood on fire, when lighting a little dry moss, which serves for tinder, they make as large a fire as they please; but as the little timber they have is drift wood, this fails them in the winter, and they are then obliged to make use of their lamps for the supply of their family occasions. *Ellis's Voyage for the Discovery of a North-West Passage.*

Friction is, therefore, one means of producing distributable heat, which is also exemplified very frequently in the axis of a carriage wheel; of mill work; in the rubbing of wood, when turned on its axis in a lathe, by which turners ornament their work with black [xxi] rings; rubbing a cord very swiftly backwards and forwards against a post or tree, or letting it run over a boat, &c. as in the whale fishery; the motion of two iron plates against each other, pressing them at the same time, &c. The great object in the construction of machines is to avoid, or lessen the degree of friction. See Hatchette, Vince, and Gregory. Count Rumford (Nicholson's Journal, 4th edit. ii, 106), and professor Pictet (*Essai sur le Feu*, chap. ix.) have made some valuable experiments on heat evolved by friction.

The sun is one great source of caloric. In whatever mode it produces it, whether by giving it out from its own substance, by the action of light on the air that surrounds the globe; by the concentration of calorific rays by means of the atmosphere, acting as a lens; or by putting caloric in the distributable state, always pre-existing in some other, as in a state of rest, are questions, which, in our present state of knowledge, we are unable to solve. We know the fact, and that the caloric is of the same nature as that obtained by combustion.[3]

Combustion is a process by which caloric is put in a distributable state. The opinion of [xxii] Stahl and others, that all combustible bodies contained a certain principle called phlogiston, to which they owed their combustibility, and that combustion was nothing more than a [xxiii] separation of this principle, gave rise to the phlogistic or Stahlian theory, which was afterwards modified by Dr. Priestley. But his theory is equally untenable. Kirwan's opinion [xxiv] was no less vague, although he substituted hydrogen for phlogiston.

The Lavoiserian, or antiphlogistic theory overturned the Stahlian. According to this theory, a combustible in burning unites with oxygen, and heat and light are given out by the gas, and not from the combustible. According to a modified theory of the above, by Dr. Thomson, caloric is evolved by the gas, and light from the burning body. Without noticing the instances, in which this theory, as a general one, is insufficient to explain the cause of combustion, or of the production of heat and light, we will merely remark, that bodies which support combustion are called supporters, as oxygen gas, chlorine gas, &c. and those, that undergo this change, are named combustible bodies.

The products of combustion may be fixed or gaseous, and either alkalies, oxides, or acids; or, when chlorine is the supporter, chlorides, &c. A few examples will be sufficient. By the combustion of metals, iron for instance, we obtain a fixed product, and in the present [xxv] case an oxide of iron; by the combustion of antimony and arsenic, the antimonic and arsenic acids; by the combustion of charcoal, we have carbonic acid gas, a gaseous product; by the combustion of potassium or sodium, we obtain a fixed alkali, depending however on the quantity of oxygen; by the combustion of sulphur, phosphorus, &c. acids; and when metals are burnt in chlorine gas, chlorides are produced.

It is evident from facts, that, whatever theory may be assumed, combustion occasions the production of *free* caloric, or changes the *condition* of caloric, from quiescent to distributable heat. The conclusions drawn by Mr. Davy and others, appear to have been predicated on the absorption of the base, and development of caloric, as in oxygen gas, and the peculiar alteration in bodies implying a decrease in their capacity; and hence, as regards the products of combustion, they must necessarily possess a less capacity for heat than the mean capacity of their constituents.

Whether we regard heat as latent, in the acceptation of the term, as applied or used by Dr. Black, or quiescent, or in a state of rest, it is certainly evident, that combustion is a chemical change, and by it caloric passes from a combined to an uncombined state, and is thus made sensible, free, or thermometrical heat. Combustion may, as it certainly does, put quiescent heat in a distributable state; but this quiescent heat is the same in the present case, of which there can be no doubt, as latent caloric. The thermometer will only indicate as much caloric in the air as is in a distributable, or free state; but, if the same air be employed to supply, or support combustion, the heat, rendered appreciable by the senses and the thermometer, will be in the ratio of the decomposition of the oxygen gas of the atmosphere, and, of course, to the development of free caloric.

Chemical combination, such as occurs by the mixture of fluids, as alcohol and water, sulphuric acid and water, some of the gases, as muriatic acid gas with water, &c. evolves heat, and sometimes sufficient to boil water. In cases of spontaneous combustion, it would seem, that quiescent heat passes to the state of distributable heat; for if nitric acid, for instance, contains so large a quantity of quiescent heat, or fixed heat, as the experiments of Mr. Lavoisier make it appear, we may readily explain why spontaneous combustion ensues, [xxvi] when that acid is brought in contact with spirits of turpentine; because the chemical action of the acid on the carbon and hydrogen of the turpentine, which takes place, produces at the same time a corresponding change in the caloric itself, from a quiescent to a distributable state. If the same data be admissible with regard to the combination of the nitric acid with potassa, which we may judge to be the case by the experiments of Lavoisier and Laplace, (quoted in our article on *Gunpowder*), then, indeed, its mechanical union with charcoal, and sulphur, although in a common temperature no combustion ensues, will, at the temperature required to inflame the mixture, (about 700 degrees according to some), produce a decomposition altogether chemical; and while new products are formed, the caloric, necessary also for their generation, passes from a quiescent to a distributable state; and a portion of it goes into a new state of combination, also quiescent. We mean that portion which is necessary for the constitution of gaseous fluids. This fact is remarkable. By referring to the original state or condition of the caloric, if we admit that state in the present instance, (which appears the only mode of accounting for the emanation of free caloric by the combustion of gunpowder), it is easily perceived, that chemical changes, besides the usual supporters of combustion being concerned, as in ordinary cases of combustion, must produce a similar change in the state of combined or quiescent heat.

Predicating this opinion on the results of the experiments of MM. Lavoisier and Laplace, and seeing that gunpowder inflames *per se*, or without the aid of a gaseous supporter, we have no hesitation in risking it, in the present state of our knowledge concerning heat as our present belief and conviction. Although there is no satisfactory theory offered to explain all the instances of spontaneous combustion, yet it seems reasonable to conclude, that in many cases at least, that effect may take place by some chemical action, which, like the instances already quoted, may change quiescent into distributable heat. We have stated (See *Gunpowder*) some instances of spontaneous combustion, which have taken place merely in consequence of the charcoal. Some have attributed the effect to pyrophorus, and others to the presence of hydrogen in the coal, which, by absorbing and combining with oxygen and [xxvii] forming water, sets the caloric of the oxygen gas at liberty, and thus produces combustion. However this may be, there are other instances, that of cotton and oil, some kinds of wood, wood-ashes and oils, &c. which have produced spontaneous combustion.

We will only add, however, that until we can give a better theory, the effect in these instances may be attributed to chemical action, and *with it*, the change of caloric in the manner already mentioned. Chemical action in such cases appears necessary, although mechanical means, as percussion will produce heat.

Quiescent heat is also put in motion by electricity; but in what manner it acts, so as to produce that effect, is unknown. It is a powerful agent in nature, and calculated for important ends, of which we are ignorant. It is unnecessary to notice opinions concerning it. All electrics will yield it, such as glass, rosin, &c. and it may be collected in the usual manner by the prime conductor and Leyden jar. Galvanism, called also Galvanic electricity, produced by an arrangement of zinc, and copper plates in a pile, or trough, and placed in contact with some oxygenizing fluid, has the same effect of causing quiescent heat to become distributable, and is undoubtedly the result of chemical action. The peculiar character of this fluid, the nature of the two opposite poles, &c. have been, and continue to be, a subject of interest to the philosopher. The *deflagrator* of professor Hare of Philadelphia is an apparatus well calculated for many interesting experiments on galvanism. To that gentleman, we are also indebted for the compound blowpipe, which produces a very intense heat by the combustion of hydrogen in contact with oxygen gas. Notwithstanding professor Clark of England has laid claim to the apparatus, and the use of hydrogen gas in this way, the merit of the discovery is due to our learned and ingenious countryman.

Since heat is put in motion as a consequence of the increased capacity of a body, and, by combining with a substance whose capacity has been increased, becomes by degrees quiescent, according to the respective capacities of bodies; cold is an effect, which is occasioned by this change from a free to a combined or quiescent state. The absorption of heat, necessary for the generation of cold, if so we may consider it, takes place in every [xxviii] instance, where that effect is observed. The heat of surrounding bodies, in a distributable state, is now no longer characterised as such; and the consequence is, therefore, that that particular sensation, or effect follows.

Cold may be produced by saline mixtures, the salts for which having their full quantum of the water of crystallization; and by the evaporation of fluids, as water, alcohol and ether. In the one case, that of the freezing mixtures, we have seen, that the effect is produced by the *absorption* of heat; and with regard to the cold produced by fluids, even in *vacuo*, (where the effect is more instantaneous), the cause is attributable to evaporation; for the fluid changes from a liquid to an aeriform state, and during this transition robs the body, with which it was in contact, of a part of its caloric, and thereby reduces its temperature. Artificial ice is made on this principle.

The next subject with regard to heat, is the different modes in which it tends to a state of rest. There are some facts in relation to this subject worthy of notice; and particularly, that, in the tendency of caloric to become quiescent, after having been put in motion, bodies often increase in temperature. This tendency to a state of rest is effected either by the conducting power of bodies, or radiation. Heat radiates in all directions, and in quantities, according to the experiments of Leslie, more or less variable, which depend on the nature of the radiating surface. Hence that power, which bodies possess, called the radiating power, varies in different substances. Thus, the radiating power of lampblack is 100, while gold, silver, copper, and tin plate are 12, from which it appears that the metals distribute less heat by radiation. That caloric obeys the same laws as light, is obvious from Pictet's experiments with concave mirrors, where the calorific rays move in the same order, the angle of incidence being equal to the angle of reflection. It is also refracted; hence the concentration of the solar rays in a focus by the burning glass. Various experiments have been made with mirrors, and concave reflectors. The effect of the former in destroying the fleet before Syracuse, an experiment made by Archimedes, is a fact well authenticated in history. Concave reflectors have inflamed gunpowder. This subject, however, is noticed at large, [xxix] when speaking of mirrors as an incendiary in war.

That bodies conduct heat, and with different degrees of power, so that some are called good and others bad conductors, is well known. This property depends on the quantity of caloric, which a body receives, before it changes its state. Metals are considered good conductors, and glass, charcoal, feathers, &c. bad conductors. Hence bad conductors, as wool, &c. preserve the temperature of the body, or keep it *warm* in winter; and snow, for the same reason, prevents the action of intense cold on the ground. Liquids also conduct heat. Whether we consider caloric in this case carried, or transported, as it is more properly defined, the fact may be shown by several experiments. Ebullition, or boiling, is a phenomenon, which depends on the increment of temperature; for as water, for instance, receives caloric, until the thermometer indicates 212 degrees, the boiling point, mere evaporation ensues; but that temperature, under the usual pressure of the atmosphere, causes the formation of bubbles at the bottom of the vessel, as that part receives the degree of heat necessary for ebullition before any other; and these bubbles, as they form, rise in succession, and pass off in the state of steam, while the circumjacent fluid takes its place, and the process continues till all is boiled away. Water, when it passes off in the state of steam, which requires a degree of heat equal to 212 degrees of Fahrenheit, receives also 1000 degrees of non-distributable caloric, or latent heat; and however singular the fact may appear, the wise Author of Nature, it seems, has reserved a *store of caloric*, in this form, ready to be put in requisition, when necessity demands it, in a distributable shape.

Caloric, when in a state of rest, exists in different proportions, and although the actual temperature may be the same, yet the quantity of caloric in a quiescent state may be variable. There are several experiments, which are adduced to illustrate this fact. It results from experiment, that bodies receive heat according to their several capacities for it; hence, when any number of bodies are differently heated, the caloric, which becomes latent, does not distribute itself in equal quantities, but in various proportions, according, as we remarked, to their several capacities. Caloric, therefore, in a state of rest, is in relative [xxx] quantities; and as the capacity of bodies for heat is variable, and relative as to each other, the term *specific caloric* has been applied. From these conclusions, we may readily perceive what is implied by an equality of temperature. That it merely depends on the state of rest, which caloric necessarily comes to, and which is relative as respects the capacity of bodies, and nothing more, is a deduction very plain and obvious. Heat, in a state of motion, may be said to be progressing to a quiescent state; and equalization of temperature, although differently understood, may be considered an equalization of fixed caloric, according to the relative capacity of bodies, without regarding the equalization, which takes place of uncombined caloric, as is manifested by thermometrical instruments. In a word, by considering caloric in this view, that of tending to a state of rest, and uniting with bodies according to their respective capacities, we may account for many phenomena; as, for instance, the quantity of caloric which enters into ice, and becomes latent, during liquefaction. The quantity of caloric, in this respect, may be learnt by adding a pound of ice at 32 degrees to a pound of water at 172 degrees. The temperature will be much below 102 degrees, the arithmetical mean, viz. 32 degrees. It is evident that the excess of caloric has disappeared; and by deducting 32 degrees from 172 degrees, 140 degrees remain, which is the quantity of caloric that enters into a pound of ice during liquefaction, or the quantity required to raise a pound of water from 32 degrees to 172 degrees. This change of capacity appears to be absolutely essential to the well being of the universe, as affording a constant modification of the action of heat and cold, the effects of which would otherwise be inordinate. If this did not take place, the whole of a mass of water, which was exposed to a temperature above the boiling point, would be instantly dissipated in vapour with explosion. The polar ice, would all instantly dissolve, whenever the temperature of the circumambient air was above 32 degrees, if it were not that each particle absorbs a quantity of caloric in its solution, and thereby generates a degree of cold which arrests and regulates the progress of the thaw; and the converse of this takes place in congelation, which is in its turn moderated by the heat developed in consequence of the diminution of capacity, which takes place in [xxxi] the water during its transition to a solid state. The reason why boiling water in the open air never reaches a higher temperature than 212 degrees is evident, if we consider, that the capacity of those portions of liquid, which are successively resolved into a vapour, becomes thereby sufficiently augmented to enable them to absorb the superabundant caloric as fast as it is communicated.

The most obvious effect of caloric on bodies, is the change, which they undergo when exposed to its action.

That it acts constantly in opposition to the attraction of cohesion or of aggregation, by which bodies pass from a solid to a fluid, and from a fluid to an aeriform state, and produces also different changes in bodies,—are facts that come under our daily observation.

It occasions changes in the bulk of bodies; hence solids, liquids, and gases are expanded. The expansion, and subsequent contraction of atmospheric air, give rise to various winds, which are currents of air rushing from one point of the compass to another to maintain an equilibrium. The theory of the winds is predicated on this fact, although some have asserted, that they depend greatly on the diurnal motion of the earth. The air thermometer of Sanctorius, and the differential thermometer of Leslie, are founded on this principle, of the expansion of air. Fluids expand until they arrive at the boiling point, as is the case with water, alcohol, &c. The expansion of mercury, in a glass tube, furnished with a graduated scale, forms the mercurial thermometer, by the rise and fall of which, the different variations of temperature are marked.

Notwithstanding caloric has the property of expanding bodies, there are some exceptions to this law, which may be proper to notice. Water, for instance, at the temperature below 40° contracts at every increment of temperature until it reaches 40°, which is its maximum of density. Above 40° it expands, until it arrives at the boiling point. Alumina, or pure argillaceous earth, also contracts by heat; hence it is used in the pyrometer of Wedgwood, to measure by its contraction intense degrees of heat. Various saline substances, in the act of crystallization, also expand. Several of the metals, when previously melted, on cooling exhibit the same character; and water, in the act of freezing, exerts a powerful force by its [xxxii] expansion, competent to the bursting of shells, and the splitting of rocks.

The changes in bodies, produced by caloric, we have already noticed. We will only add, that fluids require different temperatures, called the boiling point, to make them boil, under the same atmospheric pressure. Water boils at 212°. Many observations have been made with respect to water, both in the state of ice, and the state of vapour. Besides the accession of 212 degrees of caloric, appreciable by the thermometer, in water in the state of steam, there is also an accession of non-distributable caloric, called *latent heat*, which is calculated at 1000°. In consequence of this circumstance, steam has been judiciously applied to various useful purposes, and particularly in a certain manner for the drying of gunpowder.

That chemical changes are produced by the agency of caloric, is a fact well known. It is supposed to occasion decompositions, according to the laws of affinity, by changing previous affinities, and causing new affinities to take place. Hence the operations by fire, whether the substances themselves are exposed in a dry state to the action of heat, or otherwise, produce new results, or compounds, which could not be made without it. This truth has long been obvious. In consequence of a knowledge of this fact, Dr. Black (*Lectures* vol. i, p. 12,) defined "chemistry to be the study of the effects of heat and mixture, with the view of discovering their general and subordinate laws, and of improving the useful arts."

Caloric as a powerful auxiliary, performing as it does an innumerable multitude of changes and effects, an agent by which the operations of the universe are maintained in order and harmony for universal good, exerts the same effect in the furnace of the chemist, as in the great laboratory of nature; and regulates, and determines all the consequences, which follow a succession of fixed, and appointed changes.[4]

We have thus, in this brief and hasty outline of the nature, principal effects, and properties [xxxiii] of caloric, detailed the leading facts on this subject; from which it will be seen, that caloric, so far as respects its generation by the combustion of different pyro-mixtures, and effects, generally, should form a part of Pyrotechny, and claim the attention of those, who are connected with the preparation of Fire-Works.

Respiration is also a process which puts quiescent heat in motion.[5]

In the second part of the work, we embrace the furniture of a laboratory, for the use of fire-workers, consisting of various tools and utensils.

Under this head, we also embrace sundry manipulations, such as the preparation of substances for use, the manner of forming mixtures, and various anterior operations. The formation of pasteboard for cases, the mode of forming as well as charging cases, different [xxxiv] modes of charging rockets, the dimensions of rammers, mallets &c. This preliminary ought to be well understood; as the successful practice of the art depends greatly on these operations. We may observe, however, that we have had occasion to repeat some of these manipulations in certain instances, to make them more intelligible; or rather to present, more in connection with the subject, a detail of minutiæ.

In the different compositions, the reader will bear in mind, that the copious collection of formulæ, both old and new, embraces all the facts, with which we are acquainted, concerning pyrotechnical preparations.

In most instances, where the importance of the subject required it, we designated, or set apart from the rest, formulæ, which have been *approved*, and particularly in France.

This is more particularly the case as it respects the fourth and last part, which appertains exclusively to Military Fire-Works. On this subject, permit me to remark, that fire-works, intended for the purposes of war, should be depended on; and for that reason, in order to produce a certain effect, the materials of which they are composed should be pure, weighed with accuracy in the proportions required, and carefully mixed according to the rules laid down. It is true, however, that while this nicety is required in particular cases, it is unnecessary in the formation of all fire-works. The composition for carcass and light-ball, for tourteaux, links, and fascines, and some others, do not require that precision; whereas the composition for fuses for bombs, howitzes, and grenades should be in every respect accurately made; for on the accuracy of the composition, must depend the time a fuse will burn, which is afterwards regulated by using more or less of the fuse, according to the time it will take for the shell to reach its destination, on which depends the skill of the bombardier. Accuracy, however, in making of preparations should be a general rule.

Viewing Pyrotechny either as a science or an art, there is undoubtedly required in its prosecution much skill and practice. A knowledge of the theory of fire-works may be readily acquired. The mere artificer or fire-worker, by constant habit and experience, may understand it is true how to mix materials, prepare compositions, charge cases, and perform all other mechanical operations; but it is equally certain, that, without a knowledge of [xxxv] chemistry, he cannot understand the theory. We would not say, that the workman should be a chemist, but that he should know enough to determine the purity of the substances he employs, and their respective qualities and effects; for if that principle were admitted, we might go further and say, that every person, who practices a chemical art, as the tanner, gluemaker, brazier, &c. should be a chemist, or that the art could not be conducted without a previous knowledge of chemistry, which we know is contrary to fact. This, however, may be said, that in *all* arts which are decidedly chemical, as that of *dying* for instance, chemical knowledge will enable the artist or operator to conduct his processes with better advantage, and correct any *old* routine, which is too often pursued, because it was handed down from generation to generation. Mr. Seguin in France facilitated the preparation of tanned leather, by adopting a new process altogether chemical. In a word, so far as chemistry is connected with the arts, and by which we explain the operations that take place, it is undoubtedly important; and with regard to Pyrotechny, it appears, in the way we have mentioned, to be indispensable. Chaptal (*Elements de Chimie*) observes, that the works of artificers frequently miscarry in consequence of their being unacquainted with the art.

In noticing this subject, we may be permitted to digress, while we state, that, being fully convinced of this truth, we have directed our labours in the Chemical Department of the United States' Military Academy to two distinct objects; *viz.* to theoretical and experimental chemistry, forming the first year's course, and chemistry in its application to the arts, manufactures, and domestic economy, constituting, along with mineralogy, the course of the second year. In addition to the usual applications, Pyrotechny, in the manner we have stated, and especially that branch which treats of military fire-works, has claimed our attention; and we have reason to believe, that this addition, to the usual course of chemical instruction, has considerably advanced the utility, especially to gentlemen designed for the army, of the application of chemistry.

The system of instruction adopted throughout the academy, in the different departments, (the plan of which may be seen in the new *Army Regulations*, article Military Academy), which, we have no hesitation in believing, is the most complete of any in the United States, [xxxvi] and by far the most extensive,[6] is so regulated, that each section of a class regularly recite, and are interrogated on each subject of instruction, so that, while an emulation to excel is thus excited, the comparative merit or standing of the cadets is thereby determined. Adopting the same system in the Chemical department, that of interrogation on the subject of the preceding lecture, has many peculiar advantages; so that, while the mind and memory of the pupil are thus exercised, a comparative estimate of the progress of each one is obtained during each week, by which we are enabled, as in other departments, to present a Weekly Class Report of their progress.

While we are indebted to the talents and industry of the professors and teachers of the Academy, for the flourishing condition it is now in, and the progress of the cadets in every branch there taught; it is but justice to remark, that for the present organization of the academy, as relates to the studies, which is obviously preferable to the old system, and also for the improvements in instruction, we are indebted to the present superintendent, Col. S. Thayer, of the U. S. corps of engineers.

Considering pyrotechny, abstract from the questions usually given, and forming a distinct branch, it may be proper to remark, that the interrogatories on this head have been minutely and satisfactorily answered. The following outline will exhibit the order in which such questions were put, observing, however, that they are merely in connection with this subject:

What is saltpetre? What is nitric acid? What is potash? What are the sources of saltpetre, and how is it obtained? How is it formed in nitre beds, extracted, and refined? What circumstances are necessary to produce nitre, and how does animal matter act in its production? What is the difference between the old and new process for refining saltpetre? What reagents are used to discover the presence of foreign substances in nitre? What are nitre caves? Where do they exist? What are the nitre caves of the Western country, and how [xxxvii] is nitre extracted from the earth? What proportion of nitre does the saltpetre earth of the nitre caves afford? What is the theory of the process for extracting saltpetre from nitrous earth, or nitrate of lime? What is sulphur? How is it obtained, and how is it purified for the manufacture of gunpowder? Of what use is sulphur in the composition of gunpowder? Does it add to the effective force of gunpowder? What is charcoal? What is the best mode of carbonizing wood for the purpose of gunpowder? What woods are preferred for this purpose? In the charring of wood, what part is converted into coal, and what gas and acid are disengaged? What is the use of charcoal in gunpowder? What is gunpowder? What are considered the best proportions for forming it, and what constitutes the difference between powder for war, for gunning, and for mining? How does the combustion of gunpowder take place? Can you explain why combustion takes place without the presence of a gaseous supporter of combustion, as gunpowder will inflame in vacuo? What are the products of the combustion of gunpowder? What gases are generated? To what is the force of fired gunpowder owing? What are the experiments of Mr. Robins on the force of gunpowder? How would you separate the component parts of gunpowder, so as to determine their proportions? What are gunpowder proofs? What is understood by the comparative force of gunpowder? What are eprouvettes? &c. In noticing in the same manner the preparations used for fire-works, and for war, as the rocket for instance, the following questions were propounded; *viz.* What is a rocket? How is it formed? Is the case always made of paper? What is the war rocket? What is the composition for rockets, and how does it act? What particular care is required in charging a rocket? What is the cause of the ascension of rockets? What is the use of the conical cavity, made in a rocket at the time it is charged, or bored out after it is charged? How do cases charged with composition impart motion to wheels, and other pieces of fire-work? What is understood by the rocket principle? What is the rocket stick, and its use? Is the centre of gravity fixed, or is it shifting in the flight of rockets? How are rockets discharged? What is the head of a rocket? What is usually put in the head? Are all rockets furnished with a head? What is understood by the furniture of a [xxxviii] rocket? How are the serpents, stars, fire-rain, &c. forming the furniture of a rocket, discharged into the air, when the rocket has terminated its flight, or arrived at its maximum of ascension? What forms the difference between a balloon, in fire-works, and a rocket? As the balloon contains also furniture, and is projected vertically from a mortar, how is fire communicated to it, so as to burst it in the air? Is the fuse used, in this case the same as that for bombs, howitzes, and grenades? What is the Asiatic rocket? The fougette of the French? In what seige were they employed with success by the native troops of India? What was the nature of their war-rocket? What is the murdering rocket of the French? Is the conical head hollow, or solid, blunt or pointed? Why is it called the murdering rocket? What is the Congreve rocket? Is Congreve the inventor, or improver of this rocket? What are Congreve rockets loaded or armed with? In what part is the load placed? Is the case made of paper or sheet iron? What are the sizes of Congreve rockets?

What are the ranges of Congreve rockets? What angle of elevation produces the best range? How are Congreve rockets discharged in the field, and what number of men are usually employed for that service? Are the Congreve rockets considered to be a powerful offensive weapon; and, if so, in what particular? What is a carcass rocket? As an incendiary, is the carcass rocket equal to the usual carcass thrown from mortars? What is the carcass composition made of? What is the Congreve rocket light ball? In large rockets, are their sticks solid, or bored and filled with gunpowder? Why is that expedient used? &c.

It is obvious, that the student, after obtaining a knowledge of each subject by the preceding lecture, accompanied with demonstrations, is enabled to detail minutely all the facts in relation to it.

Pyrotechny, as known at present, is confined to a few books, and scattered in a desultory manner, without any regular or connected system. In fact the works which treat on this subject are in French, or translations from the French on particular subjects, but generally very imperfect. As applied to the uses of war, we may indeed say, that the small treatise of Bigot, (*Traité d'Artifice de Guerre*), and Ruggeri (*Pyrotechnie Militaire*) are the only works. [xxxix] We have, therefore, consulted these authors, as will be seen in the pages of the work.

Roger Bacon, in his *Opus Majus*, has given some account of the Greek fire, and of a composition, which seems to have had the effect of our modern gunpowder.

Malthus (*Traité de l'Artillerie*) contains some formulæ for Military Fire-Works. Anzelet and Vanorchis, in their several works, have given some receipts for incendiary preparations. Henzion (*Recreations Mathématiques*) and Joachim Butelius have also something on the subject.

The celebrated Polander, Casimir Siemienowicz, has nothing of any moment, if we except the incendiary fire-rain, an account of which may be seen in the fourth part of our work. His book is considered, however, the best of the whole of them. Belidor, Theodore Duturbrie, &c. have mentioned some preparations; but their works are chiefly confined to artillery.

The improvement of Pyrotechny is ascribed to the Germans and Italians, and the French acknowledge, that they are indebted for a knowledge of it to the Italians. Be this as it may, it is certain, that it was known in China from time immemorial. Their acquaintance with gunpowder, before it was known in Europe, is a fact which appears to be generally admitted. For an account of the Chinese fire-works, and the origin of gunpowder in Europe, consult these articles respectively.

Whatever merit we may claim in this work, as the public will be able to judge impartially, it will be seen, by referring to the different chapters and sections, that we have endeavoured to form a system, by presenting a connected view of the whole subject.

Having noticed under separate heads, the particular use and application of each composition, we have added a chapter on the arrangement of fire-works for exhibition, together with the order to be observed. We may remark here, that we have enlarged in this part more perhaps than its merit or importance deserves; but, on reflection, we thought it better to embrace the whole subject, in order to form a more complete system in all its parts.

After going through the fire-works for exhibition, and noticing the different formulæ, and preparations, for arrangement, with the theory of effects, we consider, in the next place, a [xl] subject of more importance, that of Military Pyrotechny. We have adopted this arrangement, more on account of obtaining a better acquaintance with ordinary fire-works, before the reader is prepared for military works, which he will understand with more facility; for all the preliminary operations precede the practical part.

On this head, it will be sufficient to add, to what we have already stated, that we have given in each article, generally speaking, a variety of formulæ, with ample instructions for the preparation of each composition. The table of contents will exhibit the order in which they are treated.

In noticing the substances used in fire-works, in the first part, it will be perceived, that we have noticed some of them more extensively according to their importance; as for instance, *saltpetre*. Besides the different modes of obtaining saltpetre in Europe and elsewhere, and the means employed for refining it, we mention the saltpetre caves of the western country, which furnish an abundance of this article, and which contain an almost inexhaustible supply.

The extraction of saltpetre from the earth, (principally nitrate of lime), by using a lixivium of wood-ashes; the formation of rough, and subsequently of refined nitre; the various methods of refining saltpetre, and particularly that adopted in France; with sundry facts respecting the origin of nitre, and on the formation of artificial nitre beds; all claim our particular notice.

The extraction of sulphur from its combinations, and the means used for purifying it for the purpose of gunpowder, are also considered in the same manner.

The subject of charcoal, an essential constituent of gunpowder, claims, in like manner, particular attention. The various modes of charring, the woods employed, the quantity of coal obtained, the formation of pyroacetic acid in the process of carbonization, and many facts of the same kind are considered. These subjects, *viz.* nitre, charcoal, and sulphur, are highly important to the manufacturer of gunpowder.

A knowledge of the various processes for refining saltpetre; the best and most approved modes of carbonizing wood; the purification and quality of sulphur; the different processes for making gunpowder, with the proportion of the ingredients used in France and elsewhere; [xli] the granulation, glazing, and drying of powder, the use of the steam apparatus, and the different modes of proving it, and of examining it chemically; and the means of ascertaining the purity of nitre in any specimen of gunpowder; are, with others, subjects of particular interest to the gunpowder manufacturer.

With respect to the Theory of the explosion of gunpowder, we have noticed it at some length, and have added the experiments and observations of Mr. Robins, and of other persons, made at different periods.

In the consideration of the gaseous products, and the caloric evolved by the combustion of powder, we have taken a view of the gases produced, the cause of their production, the dilatation which they suffer, and the experiments of Lavoisier and Laplace, with regard to latent heat, and deducing therefrom some views of the probable cause of the production of caloric in fired gunpowder.[7]

Our observations respecting rockets, the theory of their ascension, of the Congreve [xlii] carcass and Asiatic rockets, and some others, are we apprehend sufficiently extensive. As it regards the different incendiary compositions, and their use in war, the reader will find ample instructions on these heads.

We may also remark, that we have given some of the more common, or general properties of the substances, employed in the composition of fire-works, without going into that detail, which belongs exclusively to works that treat of Chemistry. It was neither our design, nor have we given, for the reasons thus stated, *all* the chemical characters or properties of the substances so employed; and, therefore, have confined ourselves, generally speaking, to an enumeration of such properties as are connected with the subject, or are indispensably necessary to be known, before a rationale of the causes and effects can be understood.

It was our intention to accompany the work with plates, exhibiting the arrangement, &c. of fire-works, which, there can be no doubt, would have facilitated in particular the knowledge of forming, and arranging, certain pieces of fire-work; but, on second reflection, as such illustrations were connected more with fancy exhibitions, and have little or no relation to Military Fire-works, the most useful branch of Pyrotechny, we were finally of opinion, that the addition of plates would greatly enhance the price, without advancing or adding to the value of the work.

If, however, a second edition should be required, various figures in illustration of particular subjects may be added, either with a distinct explanatory chapter, or a reference from the articles themselves, with the necessary explanation, to the figures respectively.

It would require at least twenty-five plates to include all the figures we originally intended to have introduced.

Before concluding this introduction, it remains for us to remark, that, in forming this work, we consulted a variety of authors, but with little advantage, except some French works, which we shall notice. Chaptal (*Chimie Appliqué aux Arts*;) Bigot (*Artifice de Guerre*;) Morel (*Feux d'Artifice*;) Thenard (*Traité de Chimie*;) Ruggeri (*Pyrotechnie Militaire*;) MM. Bottée and Riffault (*Traité de L'Art de Fabriqué la Poudre à canon*;) Peyre (*Le Mouvement Igné*;) Biot (*Traité de Physique*, *Recherches Experimentales et Mathématique*, *sur les mouvement des Molecules de la Lumiere*, *&c.*;) M. Duloc (*Theorie Nouvelle sur le Mechanisme de l'Artillerie*;) the *Dictionnaire de l'Industrie*; the *Dictionnaire Encyclopedique des Arts et Metiers Mecaniques*, article *Art de L'Artificier*; *Œuvre Militaire*; *Archives des Découvertes*; *Système des Connoissances Chimiques par A. F. Fourcroy*; *Aide-Mémoire a l'usage des officiers d'Artillerie de France*. [xliii]

We examined various authors in English; and with regard to the origin of inventions, we found the learned, and valuable work of professor Beckman (*History of Inventions*) very useful, and likewise James's *Military Dictionary*. To the *Encyclopedia Britannica*, we are indebted for many interesting facts, and some extracts on fire-works for exhibition.

On the subject of mining, we consulted the *Treatise on mines for the use of the Royal Military Academy*, by Landmann.

We deem it necessary to observe, that, in collecting our formulæ for military fire-works, although we have sometimes extracted from the Strasbourg *Memoir*, the *Bombardier and Pocket Gunner*, and the *Military Dictionary* of Duane and James, we have generally followed Bigot; as the formulæ which he gives for the preparation of Military fire-works have been approved by the French government; and where any thing of importance occurred in Ruggeri, we have, for the same reason, extracted such formulæ from that author.

As respects the turtle, torpedo, and catamarin, submarine machines, it appears that Bushnel (*Trans. Am. Phil. Soc.*) claims the originality of the discovery from the date of his invention, although similar contrivances had long ago been suggested. Fulton's improvements, in the torpedo, are deserving of particular attention; but it is plain, that the Catamarin of the English is the same in principle and application as Fulton's torpedo, and that Fulton deserves the merit of it. Congreve, if we believe Ruggeri, was not the inventor of the rocket, which bears his name; for, according to him, it was invented about the year

1798 by a naval officer at Bourdeaux. It is certain, however, it was neither much known, nor used before the attack on Copenhagen. [xliv]

It is certain that the present incendiary fire-stone was taken from the recipe for fire-rain contained in the military work of Cassimir Siemienowicz, or that the fire-rain gave rise to a similar preparation. The idea of the *pyrophore*, mentioned in the *Archives des Découvertes*, must have originated from the use of the powder-barrel, and of similar means of defence. We might enumerate many other inventions, which owe their origin in the same way.

[Pg 1]

A SYSTEM

OF

PYROTECHNY.

CHAPTER I.

PYROTECHNY IN GENERAL.

Sec. I. Definition of Pyrotechny.

Pyrotechny is defined the doctrine of artificial fire-works, whether for war or exhibition, and is derived from the Greek, πυρ *fire*, and τεχνη *art*. In a more general sense, it comprehends the structure and use of fire-arms, and the science which teaches the management and application of fire in several operations.

Sec. II. General theory of Pyrotechny.

In the composition of artificial fire, various substances are employed, having different properties, and designed to produce certain effects characterised by particular phenomena. These substances are either inflammable, or support the combustion of inflammable bodies. As pyrotechnical mixtures are differently formed, and of various substances, the effects are also modified, although combustion, under some shape always takes place.

Combustion is either modified, retarded, or accelerated; and in consequence of the presence of certain substances, different appearances are given to flame. [2]

The conditions necessary for combustion are, the presence of a combustible substance, of a supporter of combustion, and a certain temperature. Thus, charcoal when raised to the temperature of 800° in the open air, takes fire. This elevation of temperature enables it to act chemically on the oxygen gas of the atmosphere; the latter, as it comes in contact, being decomposed. Now, as oxygen gas is a combination of oxygen and caloric, the caloric being in a latent state, the charcoal unites with the oxygen, and the phenomena of combustion ensue; that is, an evolution of *heat* and *light*. The caloric of the decomposed gas is given out in a free state, and, according to the theory of Dr. Thomson, (*Thomson's System of Chemistry*, vol. i.) the light proceeds from the burning body. We have then an instance of combustion, in which there is a combustible, a supporter of combustion, and an elevated temperature. The old theory of combustion, called the *Stahlian* theory, which presupposes an element called phlogiston, or a principle of fire, to exist in all bodies under some modification, would explain these effects by merely supposing, that combustion was nothing more than a disengagement of phlogiston; and that when a body had lost its inflammable principle, (as a metal, when oxidized), it became dephlogisticated. But, as it proved that phlogiston is a hypothetical element, and the anti-phlogistic doctrine clearly shows, that combustion is no other than a process which unites the supporter with the combustible, forming new products; it follows, that, in all changes of the kind, the same reasoning will apply, and the same principle be tenable.

The products of combustion depend on the nature of the substance burnt, and the supporter employed. Thus, in the instance just mentioned, the charcoal, by its union with oxygen, is changed into carbonic acid, which takes the gaseous state. We say then, that carbonic acid is the product of the combustion of charcoal, or, chemically speaking, of carbon. As resins, oil, &c. contain hydrogen, as well as carbon, the products in such cases would be water, as well as carbonic acid.

The chemical effects, therefore, which we consider in fire-works, forming the basis on which a theory of sundry phenomena may be formed, are no other than the result of the action of one body on another, according to the laws which govern such action, and the consequent operation of chemical combination. Combustion, in fire-works, may be considered a primary agent in *all effects* which characterise artificial fire. [3]

The second change, with respect to the appearance of the flame, the formation of stars, serpents, rain, &c. terms used in the art, is owing either to new chemical changes which the substances undergo, or to the decomposition of the products themselves. These effects, it is obvious, must be governed by the circumstances, under which the mixtures are made. Saltpetre, for instance, is the basis of fire-works, whether used in a separate state, or employed in mixture with charcoal and sulphur, as in gun-powder; and, from its composition, is adapted to all the purposes of the art, because it yields its oxygen very readily to all inflammable bodies. In consequence of the decomposition, it undergoes at an elevated temperature, when brought in contact with charcoal, sulphur, &c. and various substances which contain carbon, as pitch, rosin, turpentine, tallow, copal, and amber, combustion results, and, according to circumstances, is more or less rapid, and the flame also more or less brilliant.

When charcoal, in the state of ignition, is brought in contact with nitre, a deflagration takes place, because, at the temperature of ignition, it has the property of decomposing the nitric acid of the nitre; and as this process unites the carbon with the oxygen, in the proportion necessary to constitute carbonic acid, this acid is accordingly produced. When, therefore, we inflame a mixture of nitre, charcoal, and sulphur, or gun-powder, the whole or greater part disappears; and if we were to collect in a pneumatic apparatus, the products of the combustion, it would be found, that they are nearly altogether gaseous, and composed, as we shall speak hereafter, of sundry elastic aëriform fluids. This decomposition, the immediate effect of the charcoal on the nitric acid of the nitre, is the same as in the preceding instance, for carbonic acid gas is formed in both cases. We have then another instance of combustion, where a number of substances are concerned, and therefore, the products must be numerous.

We notice this subject more particularly, since, as in the different fire-works, nitre and inflammable bodies are used in different proportions, the result is always affected by the same laws of chemical decomposition; for the same substances, placed under similar circumstances of proportion, mixture, &c. afford the like results. If carbon alone be employed, carbonic acid gas is the result; if oil, tallow, rosin, or turpentine be used, we have then, as we had occasion to remark, water, as well as carbonic acid, by reason of the union [4]
of the hydrogen, which forms one of their constituent parts, with a part of the oxygen of the nitric acid.

Again, in a composition of mealed powder, rosin and sulphur, with or without the addition of saw dust, we infer, from the composition of the ingredients and the chemical action which subsequently takes place, that the products of combustion would be carbonic acid gas, sulphurous acid gas, water, sulphuretted hydrogen, and probably azotic, and nitric oxide gases. If the filings of steel, brass, zinc, or copper, enter into the composition, besides the products above-mentioned, there would be either an oxide of iron, an oxide of zinc, or, an oxide of copper, according as one or other of these metals are employed.

Copper, in fire-works, has the effect of communicating a green colour to the flame. M. Homberg, (*Collection Acad.*) observes, that the green colour in such cases is owing to the *dissolution* of the metal, which in fact is nothing more than the *effect* of its oxidizement.

The various compositions for brilliant fire, as the Chinese fire, owe their peculiar character to pulverised cast iron, and commonly to steel and iron filings. Now the effects in these cases are the same; for the same oxidizement ensues, more or less rapidly, which in fact distinguishes the kinds of brilliant fire. That of the Chinese is the most perfect, and next is the composition made with steel filings. It will be seen, however, that compositions generally are governed, in their respective appearances when inflamed, by the purity, as well as the proportion of other substances, which enter into them; and hence much of their effect depends on collateral circumstances, which we purpose to consider when we treat of the compositions individually.

That the light of certain burning bodies may be increased, is evident from these facts; and experiment has shown, that the intensity of the light of burning sulphur, hydrogen, carbonic oxide, &c. is increased by throwing into them, zinc, or its oxide, iron, and other metals, or by placing in them very fine amianthus or metallic gauze. Protochloride of copper burns with a dense red light, tinged with green and blue towards the edges. If the hydrogen of the oil acts in separating the chlorine from the copper, and the reduced copper is ignited by the charcoal, this appearance must necessarily ensue.

When solid matter is the product of combustion, as in the burning of phosphorus, zinc, iron, &c. the flame is remarked to be more intense. Flame may be modified under other [5] circumstances, as we will have occasion to mention hereafter. When, for instance, a wire-gauze safety-lamp is made to burn in a very explosive mixture of coal gas and air, the light is very feeble and of a pale colour; but when a current of coal gas is burnt in atmospheric air, the combustion is rapid and the flame brilliant.

Dr. Ure thinks it probable, (*Dictionary of Chemistry*, article combustion,) that, when the colour of the flame is changed by the introduction of incombustible compounds, the effect depends on the production, and subsequent ignition or combustion of inflammable matter from them. Thus he infers, that the rose-coloured light given to flame by the compounds of strontium and calcium, and the yellow colour given by those of barium, and the green by those of boron, may depend upon a temporary production of these bases, by the inflammable matter of the flame. It is inferred also, as a probable conclusion, that the heat of flames may be actually diminished by increasing their light, (at least the heat communicable to other matter), and *vice versa*; because, in the most intense heat, as in the compound blow pipe, or in Newman's blow pipe apparatus, in which a mixture of oxygen and hydrogen gases is compressed, the flame, although hardly visible in bright day light, instantly fuses the most refractory bodies; but the light of solid bodies ignited in it, is so vivid as to be painful to the eye.

Some curious facts with regard to flame, in connection with electricity, are given by Brande in the Phil. Trans. for 1814. He supposes that some chemical bodies are naturally in the resinous, and others in the positive electrical state. He supposes also, as a consequence, that the positive flame will be attracted, and neutralize the negative polarity, while the negative flame will operate a similar change by inducing an equilibrium at the positive pole. Thus he found, that certain flames were attracted by the positive ball of an electrical apparatus, and others attracted by the negative ball. The flame of sulphur and phosphorus is attracted by the positive pole, and the flame of camphor, resins, and hydrogen by the negative pole.

In relation to the production of flame, we may observe, that, as sundry solid and fluid substances are inflammable, the products of combustion depend on the composition of the substance made use of, and the condition under which it is burnt. As to gaseous substances that are inflammable, the base of some gases, we may remark, as carbon and hydrogen, [6] unite in the process of combustion with the base of other gases, (as oxygen;) and in other instances, the *gas* itself takes fire, and exhibits the phenomena of flame. Now carbonic acid gas extinguishes flame, although its base is inflammable; but hydrogen, as well as hydrogen gas, is inflammable, and when burnt in oxygen gas or atmospheric air produces water, which also extinguishes the flame of burning bodies.

As we will have occasion to notice a variety of aëriform fluids, especially when we treat of the aëriform products of fired gun-powder, a few remarks on this head may be useful at this time.

By the combustion of bodies, substances are generated that are either gaseous or solid, whence arises the variety of products. Of aëriform fluids, some are coloured, as nitrous acid vapour, (nitrous gas and oxygen), chlorine, and the protoxide and deutoxide of chlorine. The first is red, the rest yellowish-green, or yellowish. Some relight a taper, provided the wick remain ignited, as oxygen gas, protoxide of azote, and the oxides of chlorine. Others produce *white vapours* in the air, as muriatic acid, fluoboric, fluosilicic, and hydriodic. The inflammable gases, which take fire in the air by contact of the lighted taper, are hydrogen, hydroguret, and bihydroguret of carbon, carbonic oxide, prussine or cyanogen, called also carburet of azote, and phosphuretted, sulphuretted, arsenuretted, telluretted, and potassuretted hydrogen. Other gases are acid, and redden litmus, which, for that reason, are called acid gases, such as nitrous, sulphurous, muriatic, fluoboric, hydriodic, fluosilicic, chlorocarbonic, and carbonic acids; the oxides of chlorine, sulphuretted hydrogen, telluretted hydrogen, and carburet of azote. Some gases are destitute of smell, as oxygen, azote and its protoxide, and carbonic acid; while others have a strong and characteristic odour, as ammoniacal gas. Some gases are very soluble in water, and others but slightly soluble, such as fluoric, fluosilicic, carbonic, sulphurous, and muriatic acids, and ammoniacal gas. Alkaline solutions absorb some gases, as nitrous, sulphurous, muriatic, fluoboric, carbonic, hydriodic, fluosilicic, chlorine, chlorocarbonic, and the two oxides of chlorine, sulphuretted hydrogen, telluretted hydrogen, and ammonia. Alkaline gases are ammonia, and potassuretted hydrogen.

The character of gases is well defined. The compound gas of phosphorus and hydrogen takes fire spontaneously in the atmosphere, burning with a brilliant white flame; but there is another gas formed of the same substances, that does not inflame spontaneously, but is [7] inflammable, called subphosphuretted hydrogen. This gas has a strong smell of garlic or phosphorus, and is luminous in the dark. It may be this peculiar combination, which gives rise to the *ignes fatui*; but the permanent ignes fatui, observed in volcanic countries, are said to be the slow combustion of sulphur, forming sulphurous acid gas. Sir H. Davy found, that phosphuretted hydrogen produced a flash of light when admitted into the best vacuum that could be made by an excellent pump of Nairn's construction.

Naphtha in contact with red hot iron glows with a lambent flame at a rarefaction of thirty times, though its flame ceases at an atmospheric rarefaction of six. Camphor ceases to burn in an air rarefied six times, but, in a glass tube which becomes ignited, the flame of camphor exists under ninefold rarefaction; whereas phosphorus, according to the experiments of Van Marum, will burn, although the atmosphere be rarefied sixty times. Hydrogen gas will burn in a rarefied air, when it is four or five times less than the pressure of the atmosphere, and its flame be extinguished, when the pressure is between seven and eight times less; from which it is inferred, that the flame is extinguished in rarefied atmospheres, only when the heat it produces is insufficient to keep up the combustion. Olefiant gas (hydroguret of carbon) ceased to burn in an atmosphere, where its pressure was diminished between ten and eleven times. The flames of alcohol and of wax taper were extinguished in an atmosphere, where pressure was five or six times less without the wire of platinum, and seven or eight times less when the wire was kept in the flame. See *Flameless Lamp*. Several interesting conclusions may be drawn from these facts, which, to enumerate, would lead us beyond our design. It will be sufficient, therefore, to add, that although a supporter of combustion is necessary for that process, and flame may be differently modified, yet combustion ceases if the pressure of the atmosphere be diminished in certain ratios, as already noticed.

Besides nitre, other saline substances which contain oxygen feebly combined, have been used for the same purpose. Some years ago, it was proposed to substitute the hyper-oxymuriate, now called chlorate of potassa, for nitre in the formation of gun-powder. As chlorate of potassa, when mixed with sulphur, &c. produces combustion by percussion, or by the contact of fire, this effect is attributed to the same cause,—the separation of oxygen, not from azote, but from the chlorine of the chloric acid, Hence, when that salt is used in [8] fire-works, the result of the combustion is similar to that in which nitre is employed; at least as regards the union of the oxygen with the elementary principles of the inflammable body. On this subject, we shall make some remarks hereafter. Nitrate of soda, a salt which contains nitric acid, and similar to saltpetre in that particular, has been recommended also for fire-works. It has, however, several objections. Our object in noticing it at this time is to remark, that, when it is so employed, its effect is the same as nitrate of potassa, or saltpetre, by furnishing oxygen as the supporter of combustion. See *Nitrate of Soda*.

We are of opinion, that many of the nitrates might be advantageously employed in the manufacture of fire-works. Some, as nitrate of strontian, communicate a red colour to flame, as the flame of alcohol. Nitrate of lime also might be used.

All nitrates, as well as the different hyperoxymuriates, or chlorates, contain oxygen as an essential ingredient in the acid of their respective salts, which is readily given up to inflammable substances.

When nitrates are employed for fire-works, they should be free from moisture, or water of crystallization, unless otherwise required. The presence of water may, in many cases, prove injurious to the composition; and, consequently, the effect in those instances, may be influenced by this circumstance. The composition of nitric acid, and the action of carbon in the decomposition of the nitrates, or salts formed by the union of nitric acid with sundry bases, will claim our attention in the article on gun-powder.

With respect to the production of colours, some remarks on this subject may be here added.

Speaking of colours, Haüy (*Elementary Treatise of Natural Philosophy*, trans. ii. p. 253.) takes into view their formation according to the Newtonian doctrine; and in a note by the translator, several instances are given of the change of colour by oxidizement and other processes. Iron when exposed to heat in contact with atmospheric air gradually absorbs oxygen, and changes its colour. The colours produced depend entirely on the quantity of oxygen, and on the absorption of some of the rays of light, and the reflection of others. See *Iron*. The tempering of steel instruments depends on this property, and also the blueing of sword blades, and many similar operations. The first impression of fire usually developes a blue colour; a second degree produces a yellow; and, if the oxidizement augments, the iron [9] becomes red. The major part of the metals present similar phenomena.

In vegetables, the blue colour is formed by fermentation; and many of these colours are susceptible of passing to red by a greater quantity of oxygen, as they depend on the absorption of oxygen. It is thus that the green fecula of indigo becomes blue; turnsol, red by air and acids; and the protoferrocyanate of iron, blue when exposed to the air.

When meat putrefies, the first degree of oxygenation decides the blue colour; the red soon succeeds as the process goes on. It would seem that the maximum of oxidation determines the reflection of rays of every kind, in the same proportions as subsist in solar light, of which we have many instances in combustion.

The flame of burning bodies exhibits the same phenomena. It is blue when the combination of oxygen is slow; red when it is stronger, and white when the oxygenation is complete.

These facts lead to the conclusion, that the combination of oxygen, and its proportions, give birth in bodies to the property of reflecting corresponding rays of light; but, since the combination of oxygen in different proportions ought to change the thickness and density of the component laminæ, and, consequently, to produce variations in the colours, this doctrine is not easily reconciled with the received theory.

By considering the temperature necessary to inflame different bodies; the nature of flame, and the relation between light and heat, which compose it; the caloric disengaged in a free state during the combustion of bodies, and the causes, which modify the appearance of flame,—we may be enabled to account for the phenomena already noticed. Thus, phosphorus at 150°, and sulphur at 550°, are said to take fire, and two acid products are formed; at 800°, hydrogen gas explodes with oxygen, and produces water; and, according to Ure's view, the flame of combustible bodies may in all cases be considered as the combustion of an *explosive mixture* of inflammable gas, or vapour, with air; and as to the change of quiescent into distributable heat, and the causes that modify combustion and flame, the facts on these heads are numerous and very important.

Sec. III. Remarks on the Nature of particular Compositions.

The *spur fire*, which was invented by the Chinese, but brought to perfection in Europe, is remarkably beautiful when employed in some particular parts of fire-works. This fire was so [10] named from the effect it produces, that of forming scintillations, resembling a shower, or drops of rain, or the rowel of a spur. The *artificial flower pot* is formed of this fire. The *stars* and *pinks*, which it produces, are said to be brilliant. The composition of spur fire being saltpetre, lampblack, and sulphur, in the proportions we shall give hereafter, is similar in fact to that of gunpowder; for the lampblack acts in the same manner as common charcoal. As the lampblack, however, is extremely fine, and of a purer quality, its action on that account may be more powerful. While one portion of it decomposes the nitric acid of the nitre, with the oxygen of which it forms carbonic acid; another portion is thrown off in actual combustion, which puts on the appearance we have mentioned. Lampblack, it is to be observed, is a very impalpable powder, and takes fire with more facility than pulverised charcoal.

The lampblack, therefore, is consumed both by the oxygen of the nitre, and the oxygen gas furnished by the atmospheric air. With respect to the sulphur, it facilitates the combustion, as it is more readily inflamed, and it forms in the process of combustion, sulphurous acid gas. Spur fire has been improved by the addition of steel filings: They produce very brilliant scintillations, in the combustion of which, oxide of iron is formed.

With respect to the composition of rockets, the materials of which are united in different proportions, we will remark at this time, that as mealed powder, saltpetre, and charcoal constitute their principal ingredients, the chemical effect is similar to that we have stated. The combustion of such mixtures is attributed to the same cause; for whether we consider the composition of gunpowder, or the extra addition of saltpetre and charcoal, or the substitution of nitre for the gunpowder, the action must be the same, and therefore the products of combustion, similar. The action, however, as the effect evidently shows, is affected by the proportion of the substances employed, and by other circumstances which we shall notice hereafter. The different appearances, therefore, are owing entirely to the composition, as in *rocket stars*, *rains*, *gerbes*, *tourbillons*, *&c.*

It may appear surprising, that the combustion of gunpowder with other substances, previously well rammed in cases, as in the rocket, will give to the case a *momentum* of great velocity and force. This motion is regulated by the *balance* of the rocket; and its *power* depends upon the size of the case, and the compactness of the composition. There is nothing new, however, in the fact; for it is perfectly familiar with every one, if we consider the recoil [11] of a gun when fired, the powder having a resistance to overcome, as the ball, that the explosive effect of gunpowder is equal, and that the gases produced impel on all sides. Now the effect of a ball is as the difference of its weight with the weight of the gun; while the one being so much lighter is propelled forward with great celerity, and with a corresponding projectile force, the other suffers but little motion, which we term the recoil. The combustion of the materials, of which a rocket is composed, in a case, and in many fire-works where the cases are arranged on wheels, &c. which act on the rocket-principle, produces in like manner a force proportionate to the quantity of the material employed, and the manner it is driven in the case. The force in such instances is given to the rocket by the combustible substances; and the rocket itself when free, will ascend, or move in the direction required; or if small cases are fixed on wheels, which move on an axis, they communicate motion, as in the single vertical wheels, horizontal wheels, plural wheels, and the like, and may then be considered a moving power. That rockets are used as a missile weapon is well known. They were employed by the native troops of India against the British during the siege of Seringapatam in 1799. Mr. Congreve, the inventor of the *war-rocket* which bears his name, may have received his first idea of using rockets from this circumstance. This rocket will be described hereafter. The projectile force of the rocket is well calculated for the conveyance of case shot to great distances; because, as it proceeds, its velocity is accelerated instead of being retarded, as happens with every other projectile, while the average velocity of the shell is greater than that of the rocket only in the ratio of 9 to 8. The basis of this increase of power in the flight of rockets, induced Congreve to make a number of experiments, which resulted in their improvement, so far as they may be used of various calibres, either for explosion or conflagration, and armed both with shells and case shot. It may be sufficient to remark, that the 32 pr. rocket carcass, which has been used in bombardment, will range 3000 yards with the same quantity of combustible matter as that contained in the ten inch spherical carcass.

M. de Buffon, (*Mémoires de l'Académie*, 1740,) wrote an ingenious essay on sky rockets, in which he states the appendages which may be put to them.

If we inquire into the cause of the ascension of rockets, it will appear, that this apparently extraordinary effect, as we have already remarked, is owing to the decomposition, and the [12] consequent production and disengagement of a large quantity of gaseous fluid and caloric. The impelling power, as in the large Congreve rocket, of which we had occasion to speak, is regulated in proportion to its size, and the accuracy with which the materials have been driven.

The manner in which the flame, and, consequently, the gases are expelled from the orifice of a rocket, resembles the operation of an æolipile, which throws out the vapour of water, and sets in motion the air in its vicinity. As the more flexible must yield to the more solid body, so, in this respect, the gases produced are repelled by the air in contact with the orifice of the rocket. Thus it follows, that the rocket *displaces* a volume of air of a much greater weight than itself. The rocket then has upon the air, reasoning *a priori*, the same effect as the oars of a boat have upon water; and hence, the greater the volume of fire from the rocket, the greater is its velocity and ascent. The impelling force also increases as it consumes, being a uniformly accelerated motion.

It also appears, that a rocket sent in an horizontal direction will not pass over so great a distance, as when its motion is vertical; for, a rocket, directed in a line parallel to the horizon, passes through a medium of equal density, but if directed perpendicular to the horizon, from the moment it leaves the ground till it arrives at its greatest height, it penetrates and passes through an atmosphere whose density is continually decreasing, and consequently its impelling force meets with less resistance. But when we consider the increase of the force of the rocket, there is no comparison between that force, and the diminution of the density of the air.

From these premises it follows, that the ascension of rockets of all kinds is governed by one principle, namely, the disengagement of gaseous fluids and caloric, which displacing an equal volume of atmospheric air, operates by mutual contact.

Since, however, the air is heavier than the gases produced by the rocket, as the latter are greatly expanded, it is evident, that the gases will ascend; their specific gravity at the time of dilatation being less than that of the air.

The gases proceeding from the interior of the rocket, act therefore upon the air in the immediate vicinity of the orifice, and the rocket is consequently propelled, the stick guiding it in the direction given to it. If it were not for the rocket-stick or balance, its direction would be neither regular nor certain. Considering then, that, by the rocket-stick, the centre [13] of gravity is changed from the rocket itself to the stick, the motion is regulated in its perpendicular flight by the stick. The rocket-stick must be always of a proportionate length and weight to the rocket.

The motion given to rockets is always to be considered, for this depends upon the direction at first imparted; but the force of ascension is regulated by the size, and other circumstances which we have mentioned.

Assuming the principle of constant force acting upon the rocket, its velocity will increase with the time, and will be as the squares of the time, according to the principles of uniform accelerated motion; but if the force varies from uniformity, then the velocity and spaces will proportionably vary.

As action and re-action must be equal, the repulsion produced by the action of the gases upon the air is equal to the force impelling the rocket. The constant action produces equal acceleration of the motion.

On the subject of the condensation and dilatation of air, and the different pressures at a mean temperature, which is more or less connected with this inquiry, the reader may consult with advantage, the work of Mr. Biot, (*Traité de Physique*, &c. tome i, p. 110, and 141.) The conclusions of Mr. Robins on the gaseous products of gunpowder, and the elasticity of those products, may be seen by referring to the article on *gunpowder*.

It must be confessed, that the theory of rockets differs in many essential particulars from that of the usual projectiles; for the motion of rockets is more complicated than that of common projectiles, and is described to partake of all the anomalies that attend the accelerated motion arising from the rocket composition, and the uniform motion of the rocket-case, after the composition is expended. It is a fact, which appears to be established, that little or no advantage has yet been gained from the experiments that have been made with cannon, even where the angle of elevation, and the initial velocity of the ball were both accurately known. It seems totally useless to look for mathematical investigations, with respect to determining the ranges, &c. of military rockets; because, if we could determine, with the greatest accuracy, the point, position, and velocity of the rocket, at the moment when the composition was expended, the remaining part of its track would still be subject to all the inequalities attending on common projectiles. During the burning of the rocket, however, its motion might, by a series of experiments, be reduced to precise rules. As the principles of gunnery, or rather of projectiles, involve a number of collateral circumstances, [14] such as the exact momentum of any given ball when projected with a given velocity, and from a given distance, the subject is still not fully settled; but they are so far conclusive, that the resistance of the air to the same ball is as some function of the velocity. The remarks of Dr. Hutton on this head would be too lengthy. A rocket, however, is very different. The very medium, in this case, is the principal agent in producing the motion; and being enabled to ascertain all the successive energies of the propelling power, and the resisting force, we may thus far determine correctly. It is suggested, that a rocket fixed to the ballistic pendulum would determine its whole energy; but, in order to make the experiment more perfect, it is proposed to attach it to a wheel, or revolving body, and then to measure its successive energies by the motion of some weight attached to the revolving axis of the machine. It is worthy of remark, that it is impossible to accommodate or determine the motion of rockets by other projectiles; and, therefore, to ascertain their momentum, such a contrivance would be eminently useful.

Mr. Moore of the Royal Military Academy, Great Britain, (*Treatise on the motion and flight of rockets*,) who seems to have adopted the hypothesis of Dr. Desaguliers, respecting the momentum of the ignited composition, has given a variety of problems relative to the motion and flight of rockets in non-resisting mediums, some of which we purpose to notice.

Mariotte and Desaguliers have given two distinct theories of the motion of rockets. The latter ascribes their motion to the momentum of combustion, and the former to the elastic nature of the gaseous fluid, generated by the combustion, and the resistance of air. The observations of Desaguliers are the following: "Conceive the rocket to have no vent at the choke, and to be set on fire, the consequence will be, either that the rocket will burst in the weakest place, or if all the parts be equally strong, and be able to sustain the impulse of the flame, the rocket would burn out immoveable. Now, as the force of the flame is equable, suppose its action downwards, or that upwards, to lift 40 pounds; as these forces are equal, but their directions contrary, they will destroy each other's action. Imagine then the rocket opened at the choke; by this means, the action of the flame downwards is taken away, and there remains a force equal to forty pounds, acting upwards, to carry up the rocket and stick." This theory, however ingenious, is not altogether true; for it is asserted on the contrary, that the action of the flame or gas within the rocket, when closed, as supposed above, is conceived to arise wholly from the elastic nature of the gas, and the reaction it [15]
experiences against the ends and sides of the rocket-case; the whole of which ceases as soon as a free vent is given to the flame; and, therefore, if a rocket could be fixed in a vacuum, as the flame would, in that case, experience no resistance, there would be no reaction, and consequently, no motion would ensue. Some experiments, analogous to this position, have been made. We may merely add, with respect to Mariotte's theory, that he attributes the motion of the rocket to the resistance and reaction of the air, in consequence of which the propelling force will decrease as the velocity increases, owing to the partial vacuum left behind the rocket in its flight; so that the correct solution of the problem necessarily involves the integration of partial differences of the highest orders.

We may remark also, from the premises already established, that the first motion of the rocket, like all other motions not produced by a great momentary impulse, is slow; and before the stick is clear of the flame, gravity has been acting upon the rocket, and depressed it below its natural position, while the stick is prevented from being equally depressed, by the top of the frame; so that the angle of projection is in fact considerably less than the angle of the frame, or slope of the rocket's first position. In consequence of this, the rocket has the appearance of falling the moment after projection; and, for this reason also, the angle for producing the greatest range of a rocket exceeds very considerably that which gives the extreme range of a shell projected from a mortar. There are various propositions given by Mr. Moore respecting rockets, but to give the calculus, &c. would take up more room than we could appropriate to this abstract question. The nature of these propositions, however, may be given in a few words, *viz*: The strength or force of the gas from the inflamed composition of a rocket being given, as also the weight and quantity of the composition, the time of its burning, and the weight and dimensions of the case and stick, to find the height to which it will ascend, when projected perpendicularly upwards. After making the necessary calculation, he concludes by observing, that, having determined the height of the rocket, and its velocity, when the composition is just consumed, it follows that its whole height may be determined in the usual manner by the known formula, for the ascent and descent of heavy bodies. Another proposition is that of determining the path of a rocket near the earth's surface, neglecting the resistance of the air; and among others, for finding the horizontal range of a rocket, the angle of elevation, and the time the composition is on fire, [16] being given.

The observations of Mr. Peyre, (*Le Mouvement Igné*,) are confined principally to the effects of gunpowder; and although applied to the use of gunpowder, and the theory of its explosive effects, yet there is nothing in immediate relation with this subject. The generation of gaseous fluid, and its impelling power, and the consequent recoil of pieces, predicated in fact on the ingenious experiments and conclusions of Mr. Robins, may furnish some data on this head. But the principles of accelerated motion, on which the effective po