ESSAYS,

POLITICAL, ECONOMICAL,

AND

PHILOSOPHICAL.

VOL. II.

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POLITICAL, ECONOMICAL,

AND

PHILOSOPHICAL.

By BENJAMIN Count of RUMFORD,

KNIGHT OF THE ORDERS OF THE WHITE EAGLE, AND ST. STANISLAUS; *Chamberlain, Privy Counsellor of State, and Lieutenant-General in the Service of his Most Serene Highness the* ELECTOR PALATINE, *Reigning* DUKE *of* BAVARIA; *Colonel of his Regiment of Artillery, and Commander in Chief of the General Staff of his Army*; F. R. S. Acad. R. Hiber. Berol. Elec. Boicœ. Palat. et Amer. Soc.

VOLUME THE SECOND.

LONDON:

PRINTED FOR T. CADELL JUN. AND W. DAVIES IN THE STRAND.

1798.

CONTENTS

OF THE

SIXTH ESSAY.

CHAP. I.

CHAP. II.

CHAP. VI.

ESSAY VI.

OF

THE MANAGEMENT OF FIRE,

AND

THE ECONOMY OF FUEL.

ESSAY VI.

CHAP. I.

The Subject of this Essay curious and interesting in a very high degree.—All the Comforts, Conveniencies, and Luxuries of Life, are procured by the Assistance of FIRE *and of* HEAT.—*The Waste of Fuel very great.—Importance of the Economy of Fuel to Individuals, and to the Public.—Means used for estimating the Amount of the Waste of Fuel.—An Account of the first Kitchen of the House of Industry at Munich, and of the Expence of Fuel in that Kitchen, compared with the Quantity consumed in the Kitchens of private Families.—An Account of several other Kitchens constructed on various Principles at Munich, under the Direction of the Author.—Introduction to a more scientific Investigation of the Subject under consideration.*

NO subject of philosophical inquiry, within the limits of human investigation, is more calculated to excite admiration, and to awaken curiosity, than FIRE; and there is certainly none more extensively useful to mankind. It is owing, no doubt, to our being acquainted with it from our infancy,

 that

that we are not more ſtruck with its appearance, and more ſenſible of the benefits we derive from it. Almoſt every comfort and convenience which man by his ingenuity procures for himſelf, is obtained by its aſſiſtance; and he is not more diſtinguiſhed from the brute creation by the uſe of ſpeech, than by his power over that wonderful agent.

Having long been accuſtomed to conſider the Management of Heat as a matter of the higheſt importance to mankind, a habit of attending carefully to every circumſtance relative to this intereſting ſubject that occaſionally came under my obſervation, ſoon led me to diſcover how much this ſcience has been neglected, and how much room there is for very eſſential improvements in almoſt all thoſe various operations in which heat is employed for the purpoſes of human life.

The great waſte of Fuel in all countries muſt be apparent to the moſt curſory obſerver; and the uſes to which Fire is employed are ſo very extenſive, and the expence for Fuel makes ſo conſiderable an article in the liſt of neceſſaries, that the importance of the ſubject cannot be denied.

And with regard to the Economy of Fuel, it has this in particular to recommend it, that whatever is ſaved by an individual, is at the ſame time a poſitive ſaving to the whole community; for the leſs demand there is for any article in the market, the lower will be its price; and as all the ſubjects of uſeful induſtry—all the arts and manufactures, without exception, depend, directly or indirectly, on operations in which Fire is neceſſary, it is of

much

much importance to a manufacturing and commercial country to keep the price of Fuel as low as possible:—And even in countries where there are no manufactures, and where the inhabitants subsist entirely by agriculture, if wood be used as Fuel—as the proportion of woodland to arable must depend in a great measure on the consumption of fire-wood, any saving of Fuel will be attended with a proportional diminution of the forests reserved for fire-wood,—consequently, with an increase of the lands under cultivation,—with an increase of inhabitants,—and of national wealth, strength, and prosperity.

But what renders this subject peculiarly interesting, is the great relief to the poor in all countries, and particularly in all cold climates, and in all great cities in every climate, that would result from any considerable diminution of the price of Fuel, or from any simple contrivance by which a smaller quantity of this necessary article than they now are obliged to employ to make themselves comfortable, might be made to perform the same services. Those who have never been exposed to the inclemencies of the seasons,—who have never been eye-witnesses to the sufferings of the poor in their miserable habitations, pinched with cold and starving with hunger,—can form no idea of the importance *to them* of the subject which I propose to treat in this Essay.

To all those who take pleasure in doing good to mankind by promoting useful knowledge, and facilitating the means of procuring the comforts and conveniencies of life, theſe inveſtigations cannot but be very intereſting.

Though it is generally acknowledged that there is a great waſte of Fuel in all countries, ariſing from ignorance and careleſſneſs in the management of Fire, yet few,—very few, I believe,—are aware of the real amount of this waſte.

From the reſult of all my inquiries upon this ſubject, I have been led to conclude, that not leſs than *ſeven-eighths* of the heat generated, or which, *with proper management, might be generated*, from the Fuel actually conſumed, is carried up into the atmoſphere with the ſmoke, and totally loſt. And this opinion has not been formed haſtily; on the contrary, it is the reſult of much attentive obſervation, and of many experiments. But, in a matter of ſo much importance, I feel it to be my duty not merely to give the Public my *opinions*, but to lay before them the grounds upon which thoſe opinions have been founded; in order that every one may judge for himſelf of the certainty, or probability, of my deductions.

It would not be difficult, merely from a conſideration of the nature of heat,—of the manner in which it is generated in the combuſtion of Fuel, and the manner in which it exiſts when generated,—to ſhow that, as the proceſs of boiling is commonly performed, there muſt of neceſſity be a very great loſs of heat; for when the veſſel, in which the fluid to be boiled is contained, is placed over an open or naked fire, not only by far the greater part of the radiant heat is totally loſt, but alſo of that which exiſts

exists in the flame, smoke, and hot vapour, a very small proportion only enters the vessel; the rest going off with great rapidity, by the chimney, into the higher regions of the atmosphere. But, without insisting upon these reasonings, (though they are certainly incontrovertible,) I shall endeavour to establish the facts in question upon still more solid ground—that of actual experiment.

In the prosecution of the experiments necessary in this investigation, I proceeded in the following manner:—As the quantity of heat which any given quantity of any given kind of Fuel is capable of generating is not known, there is no fixed standard with which the result of an experiment can be compared, in order to ascertain exactly the proportion of the heat saved, or usefully employed, to that lost: Instead therefore of being able to determine this point *directly*, I was obliged to have recourse to *approximations*. Instead of determining the quantity of heat lost in any given operation, I endeavoured to find out with how much less Fuel the same operation might be performed, by a more advantageous arrangement of the Fire, and disposition of the machinery: And several extensive public establishments, which have been erected in Bavaria within these last six or seven years, under my direction, by order of His Most Serene Highness the ELECTOR PALATINE; particularly an establishment for the Poor of Munich (of which an account has been given to the Public in my First Essay); and the Establishment of a Public Academy for the education of 180 young men, destined for the service of the State in the different civil and military departments;—the economical arrangements of these eſtabliſhments afforded me a moſt favourable opportunity of putting into practice all my ideas relative to the Management of Fire; and of aſcertaining, by numerous experiments made upon a large ſcale, and often varied and repeated, the real importance of the improvements I have introduced.

That many experiments have been actually made in theſe two eſtabliſhments, during the ſeven years they have exiſted, will not be doubted by thoſe who are informed, that the Kitchen, or rather the Fire-place of the kitchen of the Houſe of Induſtry, has been pulled down and built entirely anew no leſs than *three times*, and that of the Military Academy *twice*, during that period; and that the forms of the boilers, and the internal conſtruction of the fire-places, have been changed ſtill oftener.

The importance of the improvements in the management of heat employed in culinary operations, which have reſulted from theſe inveſtigations, will appear by comparing the quantity of Fuel now actually uſed in thoſe kitchens, to that conſumed in performing the ſame operations in kitchens on the common conſtruction: And this will at the ſame time ſhow, in a clear and ſatisfactory manner, what I propoſed to prove,—namely, that in all the common operations in which Fire is employed, there is a very great waſte of Fuel.

The waſte of Fuel in boiling water or any other lipuid over an open fire, in the manner in which that

that procefs is commonly performed, and the great faving of Fuel which will refult from a more advantageous difpofition and management of the Fire, will be evident from the refults of the following Experiments, all of which were made by myfelf, and with the utmoft care.

Experiment, No. 1.

A copper boiler belonging to the kitchen of the Military Academy in Munich, 22 Rhinland inches in diameter above, 19¼ inches in diameter below, and 24 inches in depth, and which weighed 50 lbs. weight of Bavaria, (=61.92 lbs. Avoirdupois,) being fixed in its fire-place, was filled with 95 Bavarian meafures (= 28 Englifh wine-gallons) of water, which weighed 187 Bavarian pounds (= 232.58 lbs. Avoirdupois); and this water being at the temperature of 58° F. a fire was lighted under the boiler with dry beech-wood, and the water was made to boil, and was continued boiling two hours. The time employed and wood confumed in this Experiment were as follows:

	Time employed. Hours.	Min.		Wood confumed. lbs.
To make the water boil, - -	1	1	—	11
To keep the water boiling, - -	2	0	—	2½
Total,	3	1	—	13½

Expe-

Experiment, No. 2.

The fame boiler, containing the fame quantity of water at the fame temperature, being now removed to the kitchen of a private gentleman in the neighbourhood, (Baron de Schwachheim, a brother of the Commandant of the Academy,) and placed upon a tripod, a quantity of the fame kind of wood ufed in the former Experiment being provided, a fire was lighted under it by the gentleman's cook, (directions having been given to be as fparing as poffible of Fuel,) and it was made to boil, and continued boiling two hours.

The refult of the Experiment was as follows:

	Time employed. Hours.	Min.		Wood confumed. lbs.
To make the water boil, - -	1	31	—	45
To keep it boiling, - -	2	0	—	$17\frac{1}{2}$
Total,	3	31	—	$62\frac{1}{2}$

As in thefe two Experiments the fame boiler was employed;—as the quantity of water was the fame,—as alfo its temperature at the beginning of the Experiments,—and as it was made to continue boiling during the fame length of time, it is evident that the quantities of wood confumed fhow the relative advantages of the different methods employed in the management of the Fire. The difference of thefe quantities of Fuel is very great (the one being only $13\frac{1}{2}$ lbs. and the other amounting to no lefs less than $62\frac{1}{2}$ lbs.). And this ſhows how very conſiderable the waſte of Fuel really is, in the manner in which it is commonly employed for culinary purpoſes, and how important the ſavings are which may be made by introducing a more advantageous arrangement for the management of Fire. But great as theſe ſavings may appear to be, as ſhown by the reſults of the foregoing Experiments, yet they are in fact ſtill more conſiderable, as will be abundantly proved in the ſequel. In the Experiment, No. 2. in which the boiler was put over an open Fire, great care was taken to place the Fuel in the moſt advantageous manner; but, in general, little attention is paid to that circumſtance, and the waſte of Fuel is greatly increaſed by ſuch negligence: But in cloſed fire-places, upon a good conſtruction, as the *proper place* for the Fuel cannot be miſtaken, and as it is fixed and bounded on all ſides by a wall, the ignorance or inattention of thoſe who take care of the Fire can never be productive of any great waſte of Fuel; and this is an advantage of no ſmall importance attending theſe fire-places.

Experiment, No. 3.

A large copper ſauce-pan or *caſſerole*, 11½ inches in diameter above,—10½ in diameter below, and 3¼ inches deep, containing 4 meaſures of water, weighing $7\frac{15}{16}$ lbs. and at the temperature of 58° F. being placed in its cloſed fire-place, and a fire being made under it with ſmall pieces of dry beech-wood cut in lengths of about 4 inches, the water was made to boil, and was continued boiling two hours.

The reſult of the Experiment was as follows:

	Time employed. Hours.	Min.		Wood conſumed. lbs.
To make the water boil, - -	0	12	—	1
To keep it boiling, - - -	2	0	—	0¾
Total,	2	12	—	1¾

Experiment, No. 4.

The ſame ſauce-pan, containing the ſame quantity of water, and at the ſame temperature as in the laſt Experiment, was now taken from its proper fire-place, and placed upon a tripod; and a fire being made under it with dry beech-wood, the reſult of the Experiment was as follows:

	Time employed. Hours.	Min.		Wood conſumed. lbs.
To make the water boil, - -	0	28	—	6
To keep it boiling, - - -	2	0	—	5½
Total,	2	28	—	11½

The

The difference in the refults of thefe two Experiments is nearly the fame as that in the refults of thofe before mentioned, and they all tend to fhow, that in cooking, or boiling over an open fire, nearly *five times* as much Fuel is required, as when the heat is confined in a clofed fire-place, and its operation properly directed.

But I muft again repeat, what I have already obferved with refpect to the two former Experiments, as the Experiments No. 2. and No. 4. were both made with the utmoft care, the refults of them, compared with thofe which were made with the fame boilers placed in clofed fire-places, can give no adequate idea of the real lofs of heat, and wafte of Fuel, which take place in the common operations of cookery.

From feveral eftimates which I have made with great care relative to this fubject, founded upon the quantity of Fuel actually confumed in the kitchens of feveral private families, compared with the quantities of different kinds of food prepared for the table, it appears that at leaft *nine-tenths* of the wood actually confumed in common kitchens, where cooking is carried on over an open fire, might be faved, by introducing the various improvements I have brought into ufe in the kitchens which have been conftructed under my directions.

But it is not alone in kitchens, in which cooking is carried on over open fires, that ufeful alterations may be made; kitchens with clofed fire-places, and indeed all the kitchens which have yet been contrived,

trived, (as far as my knowledge extends,) are ſuſceptible of great improvement.

The various improvements that may be made in mechanical arrangements for the Economy of Fuel will appear in a ſtriking manner from a detail of the different alterations which have from time to time been made in the kitchen of the Houſe of Induſtry at Munich, and in that of the Military Academy, and of the effects produced by thoſe progreſſive improvements.

The Houſe of Induſtry being an eſtabliſhment of public charity, and the number of thoſe fed from the kitchen amounting from 1000 to 1500 perſons daily, the Economy of Fuel, in a kitchen upon ſo large a ſcale, became an object of ſerious conſideration; and I attended to this matter with peculiar pleaſure, as it ſo completely coincided with my favourite philoſophical purſuits.

The inveſtigation of Heat, and of the laws of its operations, had long occupied my attention, and I had been ſo fortunate, in the courſe of my Experiments upon that ſubject, as to make ſome diſcoveries which were thought worthy of being inſerted in the Philoſophical Tranſactions of the Royal Society of London; and for my laſt paper upon that ſubject, publiſhed in the Tranſactions for the year 1792, I had the honour to receive the annual Medal of the Society. I hope my mentioning this circumſtance will not be attributed to oſtentation. My motive in doing it, is merely to ſhow, that when I undertook to make the arrangements of which I am about to give an account, the ſubject was by no means new to me; but, on the contrary, that I was prepared, and in ſome meaſure qualified, for ſuch inveſtigation.

I conceive it to be the duty of thoſe who propoſe uſeful improvements for the benefit of mankind, not only to *merit*, but alſo to do every thing in their power to *obtain*, the confidence of thoſe to whom their propoſals are ſubmitted; and there appears to me to be a much greater degree of pride and arrogance diſplayed by an author *in taking it for granted* that the world is already ſufficiently acquainted with his merit and his qualifications to treat the ſubject he undertakes to inveſtigate, than in modeſtly pointing out the grounds upon which the confidence of the Public in his knowledge of his ſubject, and in his integrity, may be founded.

But to return from this digreſſion. In the firſt arrangement of the kitchen in the Houſe of Induſtry at Munich, which was finiſhed in the beginning of the year 1790, eight large copper boilers, each capable of containing about 38 Engliſh wine gallons, were placed in ſuch a manner in two rows, in a ſolid maſs of brick-work, 3 feet high, 9 feet wide, and 18 feet long, built in the middle of the kitchen, that, from a ſingle fire-place, ſituated at one end of this brick-work, by means of canals (furniſhed with valves or dampers) going from it, through the ſolid maſs of the brick-work to all the different boilers, theſe boilers were all heated, and made to boil with one ſingle fire; and though none of them

them were in actual contact with the fire-place, and some of them were distant from it near 15 feet, yet they were all heated with great facility, and in a short space of time, by the heat which, upon opening the valves, (which were of iron,) was made to pass through the canals.

Each boiler having its separate canal, and its separate valves, any single boiler, or any number of them, might be heated at pleasure, without heating the rest; and by opening the valves of any boiler more or less, more or less heat, as the occasion required, might be made to pass under the boiler;—and when no more heat was wanting for any of the boilers, or when the fire was too strong, by opening a particular valve, a communication with a waste-canal was formed, by which all the heat, or any part of it at pleasure, might be made to pass off directly into the chimney, without going near any of the boilers.

The Fire was regulated by a register in the door of the ash-pit, by which the air was admitted into the fire-place; and, when no more heat was wanted, the Fire was put out by closing this register entirely, and by closing at the same time all the valves or dampers in the canals leading from the fire-place.

The fire-place was of an oval form, 3 feet long, 2 feet 3 inches wide, and about 18 inches high, vaulted above with *a double vault*, 4 inches of air being left between the two vaults; and the Fuel was introduced into the fire-place by a passage

closed

closed by a *double* iron door, which door was kept constantly shut ;—and the Fuel was burnt upon an iron grate ; the air which supplied the Fire coming up from below the grate through the ash-pit.

The loss of heat in its passage from the fire-place to the boilers, was prevented by making the canals of communication *double*, one within the other ; the internal canal by which the heat passed, and which was 5 inches wide internally, and 6 inches high, being itself placed, and, as it were, *insulated*, in a canal still larger, in such a manner that the canal by which the heat passed, (which was constructed of very thin bricks, or rather tiles,) was *surrounded on every side* with a wall, 2 inches thick, of *confined air*. The surrounding canal being formed in the solid body of the mass of brick-work, this arrangement of the double canals was entirely concealed. The double canals and the double vault over the fire-place were intended to serve the same purpose, namely, *to confine more effectually the heat*, and prevent its escape into the mass of brick-work, and its consequent loss.

Having found, in the course of my experiments, that confined air is the best barrier * that can be opposed to heat, to confine it, I endeavoured to avail myself of that discovery in these economical arrangements, and my attempts were not unsuccessful.

Not only the fire-place itself, and the canals of communication between the fire-place and the boil-

* See Philosophical Transactions, 1792, Part I.

ers, were furrounded by confined air, but it was alfo made ufe of for confining the heat in the boilers, and preventing its efcaping into the atmofphere. This was done by making the covers of the boilers *double*. Thefe covers, (See the figures 1 and 2, Plate I.) which were made of tin, or rather of thin iron-plates tinned, were in the form of a hollow cone; the height of the cone was equal to about one-third of its diameter; and the air which it contained was entirely fhut up, the bottom of the cone being clofed by a circular plate or thin fheet of tinned iron. The bottom of the cone was accurately fitted to the top of the boiler, which it completely clofed by means of a rim about 2 inches wide, which entered the boiler; which rim was foldered to the flat fheet of tinned iron which formed the bottom of the cover. The fleam, generated by the boiling liquid, was carried off by a tube about half an inch in diameter, which paffed through the hollow conical cover, and which was attached to the cover, both above and below, with folder, in fuch a manner that the air with which the hollow cone was filled, remained completely confined, and cut off from all communications with the external air of the atmofphere, as well as with the fteam generated in the boiler.

In fome of the covers I filled the hollow of the cone with fur; but I did not find that thefe were fenfibly better for confining the heat than thofe in which the cone was filled fimply with air.

To

To convince the numerous ſtrangers, who from curioſity viſited this kitchen, of the great advantage of making uſe of double covers to confine the heat in the boilers, inſtead of uſing ſingle covers for that purpoſe, a ſingle cover was provided, which, as it was externally of the ſame form as the others, when it was placed upon a boiler, could not be diſtinguiſhed from them; but as its bottom was wanting, and conſequently there was no confined air interpoſed between the hot ſteam in the boiler and the external ſurface of the cover, on being placed upon a kettle actually boiling, this cover inſtantaneouſly became ſo exceedingly hot as actually to burn thoſe who ventured to touch it;—while a *double cover*, formed of the ſame materials, and placed in the ſame ſituation, was ſo moderately warm that the naked hand might be held upon it for any length of time without the leaſt inconvenience.

As it was eaſy to conceive that what was ſo exceedingly hot as to burn the hand, in an inſtant, upon touching it, could not fail to communicate a great deal of heat to the cold atmoſphere, which continually lay upon it, this Experiment ſhowed, in a ſtriking and *convincing* manner, the utility of my double covers; and I have ſince had the ſatiſfaction to ſee them gradually finding their way into common uſe.

It is perhaps quite unneceſſary that I ſhould inform my readers, that one principal motive which induced me to take ſo much pains in the arrangement of this kitchen, was a deſire to introduce uſeful improvements relative to the Management of Heat and the Economy of Fuel, into common practice. An eſtabliſhment ſo intereſting in all reſpects,—ſo important in its conſequences,—and ſo perfectly new in Bavaria, as a public Houſe of Induſtry upon a liberal and extenſive plan,—where almoſt every trade and manufacture is carried on under the ſame roof,—where the poor and indigent of both ſexes, and of all ages, find a comfortable aſylum, and employment ſuited to their ſtrength and to their talents; and where induſtry is excited, *not by puniſhments*, but by *the moſt liberal rewards*, and by the kindeſt uſage: Such an eſtabliſhment, I thought, could not fail to excite the curioſity of the Public, and to draw together a great concourſe of viſitors; and as this appeared to me a favorable opportunity to draw the public attention to uſeful improvements, all my meaſures were taken accordingly; and not only the kitchen, but alſo the bakehouſe,—the ſtoves for heating the rooms,—the lamps,—the various utenſils and machines made uſe of in the different manufactories,—all the different economical arrangements and contrivances for facilitating the operations of uſeful induſtry, were ſo many models expreſsly made for imitation.

But in the arrangements relative to the Economy of Fuel, beſides a view to immediate public utility, another motive, not much leſs powerful, contributed to induce me to pay all poſſible attention to the ſubject; namely, a deſire to acquire a more thorough knowledge relative to the nature of Heat, and

and of the laws of its operations; and with this view several parts were added to the machinery, which I suspected at the time to be too complicated to be really useful in common practice.

The steam, for instance, which arose from the boiling liquids, instead of being suffered to escape into the atmosphere, was carried up by tubes into a room immediately over the kitchen, where it was made to pass through a spiral worm, placed in a large cask full of cold water, and condensed, giving out its heat to the water in the cask; which water thus warmed, without any new expence of Fuel, was made use of next day, instead of cold water, for filling the boilers. That this water, so warmed, might not be cooled during the night, the cask that contained it was put into another cask still larger; and the space between the two casks was filled with wool. The cooling of the steam, in its passage from the boiler to the cask where it was condensed, was prevented by warm coverings of sheep-skins with the wool on them, by which the tubes of communication, which were of tin, were defended from the cold air of the atmosphere.

By this contrivance, the heat, which would otherwise have been carried off by the steam into the atmosphere and totally lost, was arrested in its flight, and brought back into the boiler, and made to work the second day.

By other contrivances, the smoke also was laid under contribution. After it had passed under the boilers, and just as it was about to escape by the

 chimney,

chimney, it was ſtopped; and, by being made to paſs under a large copper filled with cold water, was deprived of the greater part of the heat it ſtill retained: And thinking it probable that conſiderable advantages would be derived from drying the wood very thoroughly, and even heating it, before it was made uſe of for Fuel, the ſmoke from two of the boilers was made to paſs under a plate of iron which formed the bottom of an oven, in which the wood, neceſſary for the conſumption of the kitchen for one day, (having previouſly been cut into billets of a proper ſize,) was dried during 24 hours, previous to its being uſed.

In a ſmaller kitchen, (adjoining to that I have been deſcribing,) which was conſtructed merely as a model for imitation, and which was conſtantly open for the inſpection of the Public, five boilers of different ſizes, all heated by the ſame fire, were placed in a ſemicircular maſs of brick-work, and the ſmoke, after having paſſed under all theſe five boilers, was made to heat, at pleaſure, either an oven, or water which was contained in a wooden caſk ſet upright upon the brick-work.—A tube of copper, tinned on the outſide, which went through the caſk, gave a paſſage to the ſmoke, and this tube was connected with the bottom of the caſk by means of a circular plate of copper through which the tube paſſed, which plate cloſed a circular opening in the bottom of the caſk ſomewhat larger in diameter than the tube.

This

This circular plate was nailed to the bottom of the caſk, and the joining made water-tight by interpoſing between the metallic plate and the wood a ſheet of paſteboard; and the tube was faſtened to the plate with ſolder. This tube, (which was about 6 inches in diameter,) as ſoon as it had paſſed the circular plate, and entered the barrel, branched out into three ſmaller tubes, each about 4 inches in diameter, which, running parallel to each other through the whole length of the caſk, went out of it above, by three different holes in the upper head of the caſk, and ended in a canal which led to the chimney.

This tube, by which the ſmoke paſſed through the caſk, was branched out into a number of branches in order to increaſe the ſurface, by which the heat of the ſmoke was communicated to the water in the caſk. The caſk was ſupplied with water from a reſervoir placed in the upper part of the building, by means of a leaden pipe of communication from the one to the other; and the machinery was ſo contrived, that, when any water was drawn out of the caſk for uſe, it was immediately replaced from the reſervoir; but as ſoon as the water in the caſk had regained its proper height, the cold water from the reſervoir ceaſed to flow in it.

Nothing more generally excited the ſurpriſe and curioſity of thoſe who viſited this kitchen, than to ſee water actually boiled in a wooden caſk, and drawn from it boiling hot, by a braſs cock. I have been the more particular in deſcribing the manner in which this was done, as I have reaſon to think that a contrivance of this kind, or ſomething ſimilar to it, might, in many caſes, be applied to uſeful purpoſes. No contrivance can poſſibly be invented by which heat can be communicated to fluids with ſo little loſs; and as wood is not only an excellent non-conductor of heat itſelf, but may eaſily be ſurrounded by confined air, by furs and other like bodies which are known to be uſeful in confining heat, the loſs of heat, by the ſides of a containing veſſel compoſed of wood, might be almoſt entirely prevented.

Why ſhould not the boilers for large ſalt-works and breweries, and thoſe deſtined for other ſimilar proceſſes, in which great quantities of water are heated, or evaporated, be conſtructed of wood, with horizontal tubes of iron or of copper, communicating with the fire-place, and running through them, for the circulation of the ſmoke?—But this is not the place to enlarge upon this ſubject; I ſhall therefore leave it for the preſent, and return to my kitchens.

To prepare the ſoup furniſhed to the Poor from the kitchen of the Houſe of Induſtry, it was found neceſſary to keep up the fire near *five hours*, the ſoup, in order to its being good, requiring to be kept actually boiling above three hours.

The Fuel made uſe of in this kitchen was dry beech-wood; a cord of which, (or *klafter*, as it is called,) 5 Engliſh feet $8\frac{9}{10}$ inches long, 5 feet $8\frac{9}{10}$ inches high, and 3 feet $1\frac{1}{3}$ inches wide, and which

which weighed at an average about 2200 Bavarian pounds, (= 2724 lbs. Avoirdupois,) coſt at an average about 5¼ florins (= 9 s. 6¼ d. ſterling) in the market.

Of this wood the daily conſumption, when ſoup was provided for 1000 perſons, was about 300 lbs. Bavarian weight, or about $\frac{1}{7}$, or more exactly $\frac{1}{12}$ of a cord or clafter, which coſt 43 creutzers, (60 creutzers making a florin,) or about 1 s. 3½ d. ſterling: And this gives $\frac{1}{23}$ of a creutzer, or $\frac{1}{16}$ of a farthing, for the daily expence for Fuel in cooking for each perſon.

To make an eſtimate of the daily expence for Fuel in cooking the ſame quantity of the ſame kind of ſoup in private kitchens, we will ſuppoſe theſe 1000 perſons, who were fed from the public kitchen of the Houſe of Induſtry, to be ſeparated into families of 5 perſons each.

This would make juſt 200 families; and the quantity of wood conſumed in the public kitchen daily for feeding 1000 perſons, (= 300 lbs.,) being divided among 200 families, gives 1½ lbs. of wood for the daily conſumption of each family; and according to this eſtimate, 1 cord of wood, weighing 2200 lbs. ought to ſuffice for cooking for ſuch a family 1466 days, or 4 years and 6 days.

But upon the moſt careful inquiries relative to the real conſumption of Fuel in private families in operations of cookery, as they are now generally performed over an open fire, I find that 5 Bavarian pounds of good peas-ſoup can hardly be prepared

at

at a less expence of Fuel than 15 lbs. of dry beech-wood of the best quality; consequently, a cord of such wood, instead of sufficing for preparing a soup daily for a family of 5 persons for 4 years, would hardly suffice for so long a time as 5 months.

And hence it appears, that the consumption of Fuel in the kitchens of private families, is to that consumed in the first kitchen of the House of Industry at Munich, *in preparing the same quantity of the same kind of food*, (peas-soup,) as 10 to 1 *. But it must be remembered, that this difference in the quantities of Fuel expended is not occasioned *entirely* by the difference between the two methods of managing the Fire; for, exclusive of the effect produced by a given arrangement of the machinery, —with the same arrangement, the greater the quantity of food prepared at once, or the larger the boiler, (within certain limits however, as will be seen hereafter,) the less in proportion will be the quantity of Fuel required;—and the saving of Fuel which arises from cooking upon a large scale is very considerable. But I shall take occasion to treat this part of my subject more fully elsewhere.

The kitchen in the House of Industry was finished in the beginning of the year 1790. And much about the same time, two other public kitchens upon a large scale were erected at Munich, under my directions; namely, the kitchen belonging to

* Afterwards, on altering the kitchen of the House of Industry, and fitting it up on better principles, the Economy of Fuel was carried still farther, as will be seen in the sequel of this Essay.

the

the Military Academy, and that belonging to the Military Hall (as it is called) in the English garden, in which building near 200 military officers messed daily during the annual encampments,—for which purpose this building was erected.

There is likewise in the garden, (which is 6 English miles in circumference,) an inn—a farm-house, and a large dairy; and these establishments gave me an opportunity of constructing no less than four other kitchens;—namely, two for the inn, one for the farm-house, and one for the use of the dairy. And the uses for which these different kitchens were designed, and to which they were applied, were so various, as not only to include almost every process of cookery, but also to afford opportunities of performing the same operations upon very different scales, and consequently of making many interesting Experiments relative to the Management of Heat, and the Economy of Fuel.

That I did not neglect these opportunities of pursuing, with effect, a subject which had long engaged my attention, and to which I was much attached, will readily be believed by those who know what ardour a curious subject of philosophical investigation is capable of inspiring in an inquisitive mind.

As the Experiments I have made, or caused to be made, in the different establishments before mentioned, during the six or seven years that they have existed, are extremely numerous; it would take up too much time to give an account of them in detail; I shall therefore content myself with merely noticing

noticing the general results of them, and mentioning more particularly only such of them as appear to me to be most important. And in regard to the peculiar construction of the different kitchens above mentioned, as most of them have undergone many alterations, and as no one of them remains exactly in the same state in which it was first constructed, I do not think it necessary to be very particular in my account of them; I shall occasionally mention the principles on which they were constructed, and the faults I discovered in them; but when I shall come to speak of those improvements which have stood the test of actual experience, and which I can recommend as being worthy of imitation, I shall take care to be very exact and particular in my descriptions.

It will not be found very difficult, I fancy, from what has been said, to form a pretty just idea of the construction of the kitchen in the House of Industry above described, even without the help of a plan or drawing of it. That in the Military Academy was constructed upon a different principle: Instead of heating all the boilers from one and the same fire-place, almost every boiler had its own separate fire-place; and though the boilers were all furnished with double covers, similar to those made use of in the kitchen of the House of Industry, yet there was no attempt made to recover the heat carried off by the steam, but it was suffered to escape without hindrance into the atmosphere; it having been found, by the experiments made in the kitchen of the House

Houſe of Induſtry, that when the Fire is properly managed, that is to ſay, when the heat is but juſt ſufficient to keep the liquid boiling hot, or *very gently boiling*, the quantity of ſteam generated is inconſiderable, and the heat carried off by it not worth the trouble of ſaving. Each fire-place was furniſhed with an iron grate, upon which the wood was burnt, and the opening into the fire, as well as that which communicated with the aſh-pit, had in each its ſeparate iron door.

Finding afterwards that the iron door which cloſed the opening by which the wood was introduced into the fire-place, was much heated, and conſequently that it cauſed a conſiderable loſs of heat by communicating it to the cold atmoſphere with which it was in contact; in order to remedy this evil without incurring the expence of double doors, the iron door was removed, and in its ſtead was placed a hollow cylinder, or rather truncated cone, of burnt clay or common earthen-ware, which cone was 4 inches long, 6 inches in diameter internally, and 8 inches in diameter externally, at its larger end or baſe; and 5½ inches in diameter internally, and 7½ inches in diameter externally, at its ſmaller end: And being firmly fixed, with its axis in an horizontal poſition, and its larger end or baſe outwards, in the middle of the opening leading to the fire-place, and being well united with the ſolid brick-work by means of mortar, the cavity of this cone formed the opening by which the wood was introduced into the fire-place. This cavity

cavity being closed with a fit stopper of earthen-ware; as earthen-ware is a non-conductor of heat, or as heat cannot pass through it but with great difficulty, and very slowly, the external surface of this cone and its stopper were never much heated, consequently the quantity of heat they could communicate to the atmosphere was but very trifling. This contrivance was afterwards rendered much more simple, by substituting, instead of the hollow cone, a tile, 10 inches square, and about 2 ½ inches thick, with a conical hole in its center, 6 inches in diameter externally, and 5 ¼ inches in diameter within, provided with a fit baked earthen stopper. (See the Figures, N° 6, 7, and 8. Plate I.)

A perforated square tile is preferable to a hollow cylinder for forming a passage into the fire-place, not only because it is cheaper, stronger, and more durable, but also because it may, on account of its form, be more easily and more firmly fixed in its place, and united with the rest of the brick-work.

If proper moulds be provided for forming these perforated tiles and their stoppers, they may be afforded for a mere trifle. In Munich they are made of the very best earth, by the Elector's potter, and they cost no more than 24 creutzers, or something less than 9 d. sterling, for a tile with its stopper. I had several made of sand-stone by a stone-cutter, but they cost me 1 florin and 30 creutzers, or about 2 s. 9 d. sterling each.

Though those made of stone answered perfectly well, yet I found them not better than those made of earthen-ware; and as theſe laſt are much cheaper, and I believe equally durable, they ought certainly to be preferred. That the ſtopper may be made to fit with accuracy the hole it is intended to cloſe, (which is neceſſary, as will be ſeen hereafter,) they may be ground together with fine ſand moiſtened with water.

Senſible, from the beginning, of the great importance of being abſolutely maſter of the air which is admitted into the fire-place to feed the Fire, ſo as to be able to admit more or leſs at pleaſure, or to exclude it entirely; I took care, in all my fire-places, to cloſe very exactly the paſſage into the aſh-pit by a door carefully fitted to its frame, the air being admitted through a ſemicircular opening furniſhed with a regiſter in the middle of this door. This contrivance (which admits of no further improvement) is indiſpenſably neceſſary in all well-conſtructed fire-places, great or ſmall. (See the Figures from Fig. 9 to Fig. 16. Plate II.)

Having occaſion, in the courſe of my arrangements, to make uſe of a great number of boilers, and often of ſeveral boilers of the ſame dimenſions, I availed myſelf of that circumſtance to determine, by actual experiments, the beſt form for boilers, or that form which, with any given capacity, ſhall be beſt adapted for ſaving Fuel.

Two or more boilers of the ſame capacity, but of different forms, conſtructed of ſheet copper of the ſame thickneſs, were placed in cloſed fire-places, conſtructed as nearly as poſſible upon the ſame principles,

principles, and were ufed for a length of time in the fame culinary proceffes; and the quantity of Fuel confumed by each being noted, the comparative advantages of their different forms were afcertained. Some of thefe boilers were made deep and narrow;—others wide and fhallow;—there were fome with flat bottoms; others of a globular form; and others again with their bottoms drawn inward like the bottom of a common glafs bottle. The refults of thefe inquiries were very curious, and led me to a moft interefting difcovery:—They taught me not only what forms are beft for boilers; but alfo (what is ftill more interefting) *why* one form is preferable to another:—They gave me much new light with refpect to the *manner* in which flame and hot vapour part with their heat; and fuggefted to me the idea of a very important improvement in the internal conftruction of fire-places, which I have fince put in practice with great fuccefs.

But in order to be able to explain this matter in a clear and fatisfactory manner, and to render it eafier to be underftood by thofe who have not been much converfant in inquiries of this kind, it will be neceffary to go back a little, and to treat the fubject under confideration in a more regular and fcientific manner.

Though it was not my intention originally to write an elementary treatife on Heat, yet, as the firft or fundamental principles of that fcience are neceffary to be known, in order to eftablifh upon folid grounds

grounds the practical rules and directions relative to the management of Heat which will hereafter be recommended, it will not, I trust, be deemed either improper or superfluous, to take a more extensive view of the subject, and to treat it methodically, and at some length.

I have perhaps already exposed myself to criticism, by paying so little attention to method in this Essay, as to postpone so long the investigation of the elementary principles of the science I have undertaken to treat.—It may be thought that the part of the subject I am now about to consider should have preceded all other investigation;—that instead of occupying the middle of my book, it ought to have been discussed in the Introduction, or at least to have been treated in the beginning of the first chapter:—But if I have been guilty of a fault in the arrangement of my subject, it has arisen not from inattention, but from an error of judgment. Desirous rather of writing an *useful book*, than of being the Author of a *splendid performance*, I have not scrupled to transgress the established rules of elegant composition in all cases where I thought it would contribute to my main design, *public utility*:—And well aware that my book, in order to its being really useful, must be read by many who have neither time nor patience to labour through an elementary treatise upon so abstruse a subject, I have endeavoured to *decoy* my reader into the situation in which I wish him to be placed, in order to his having a complete view of the prospect I have prepared for him, rather than to force him into it. If I have ufed art in doing this, he muft forgive me; my defign was not only innocent, but fuch as ought to entitle me to his thanks and to his efteem. I wifhed to entice him on as far as poffible, without letting him perceive the difficulties of the road; and now that we have come on together fo far, and are fo near our journey's end, I hope and truft that he will not leave me.—To proceed therefore—

CHAP. II.

Of the GENERATION OF HEAT *in the* COMBUSTION OF FUEL.—*Without knowing what Heat really is, the Laws of its Action may be investigated.—Probability that the Heat generated in the Combustion of Fuel is furnished by the Air, and not by the Fuel.—Effects of blowing a Fire explained.—Of Fire-places in which the Fire is made to blow itself.—Of Air-furnaces.—These Fire-places illustrated by a Lamp on* Argand's *Principle.—Great Importance of being able to regulate the Quantity of Air which enters a closed Fire-place.—Utility of Dampers in the Chimnies of closed Fire-places.—General Rules and Directions for constructing closed Fire-places; with a full Explanation of the Principles on which these Rules are founded.*

WITHOUT entering into those abstruse and most difficult investigations respecting the Nature of FIRE, which have employed the attention and divided the opinions of speculative philosophers in all ages;—without even attempting to determine whether there be such a thing as an *igneous* fluid, or not;—whether what we call *Heat* be occasioned by the accumulation, or by the increased action of such a fluid;—or whether it arises merely from an increased motion in the component particles of the body heated, or of ſome elaſtic fluid by which thoſe particles are ſuppoſed to be ſurrounded, and upon which they are ſuppoſed to act, or by which they are ſuppoſed to be acted upon:—In ſhort, without bewildering myſelf and my reader in this endleſs labyrinth of darkneſs and uncertainty, I ſhall confine my inquiries to objects more uſeful, and which are clearly within the reach of human inveſtigation;—namely, the diſcovery of the ſenſible properties of Heat, and of the moſt advantageous methods of generating it, and of directing it with certainty and effect in thoſe various proceſſes in which it is employed in the economy of human life.

Though I do not undertake to determine *what Heat really is*, nor even to offer any opinions or conjectures relative to that ſubject; yet as Heat is evidently ſomething capable of being excited or generated, increaſed or accumulated, meaſured and transferred from one body to another; in treating the ſubject, I ſhall ſpeak of it as being *generated*, *confined*, *directed*, *diſperſed*, &c.; it being neceſſary to uſe theſe terms in order to make myſelf underſtood.

Though it is not known exactly *how much* Heat it is poſſible to produce in the combuſtion of any given quantity of any given kind of Fuel, yet it is more than probable that the quantity depends in a great meaſure on the Management of the Fire. It is likewiſe probable—I might ſay certain—that the Heat produced is furniſhed, not merely by the Fuel,

Fuel, but in a great meaſure, if not entirely, by the *air* by which the Fire is fed and ſupported. It is well known that air is neceſſary to combuſtion; it is likewiſe known that the pure part of common atmoſpheric air, or that part of it (amounting to about $\frac{1}{5}$ of its whole volume) which alone is capable of ſupporting the combuſtion of inflammable bodies, undergoes a remarkable change, or is actually *decompoſed* in that proceſs; and as in this decompoſition of pure air a great quantity of heat is known to be ſet looſe, or to become redundant, it has been ſuppoſed by many, (and with much appearance of probability,) that by far the greater part, if not all the heat produced in the combuſtion of inflammable bodies, is derived from this ſource.

But whether it be the air or the Fuel which furniſhes the heat, it ſeems to be quite certain that the quantity furniſhed depends much upon *the Management of the Fire*, and that the quantity is greater as the combuſtion or decompoſition of the Fuel is more complete. In all probability, the decompoſition of the air keeps pace with the decompoſition of the Fuel.

It is well known that the conſumption of Fuel is much accelerated, and the intenſity of the heat augmented, by cauſing the air by which the combuſtion is excited, to flow into the fire-place in a continued ſtream, and with a certain degree of velocity. Hence. blowing a fire, when the current of air is properly directed, and when it is not too ſtrong, ſerves to accelerate the combuſtion, and to increaſe

increaſe the heat; but when the blaſt is improperly directed, it will rather ſerve to derange and to impede the combuſtion than to forward it; and when it is too ſtrong it will blow the Fire quite out, or totally extinguiſh it. There is no fire, however intenſe, but may be blown out by a blaſt of air, provided it be ſufficiently ſtrong, and that as infallibly as by a ſtream of cold water. Even gun-powder, the moſt inflammable perhaps of known ſubſtances, may be actually on fire at its ſurface, and yet the Fire may be blown out and extinguiſhed before the grain of powder has had time to be entirely conſumed.

This fact, however extraordinary and incredible it may appear, I have proved by the moſt unexceptionable and concluſive experiments.

Fire-places may be ſo conſtructed that the Fire may be made to blow itſelf, or—which is the ſame thing—to cauſe a current of air to flow into the Fire: And this is an object to which the greateſt attention ought to be paid in the conſtruction of all fire-places where it is not intended to make uſe of an artificial blaſt from bellows for blowing the Fire. Furnaces conſtructed upon this principle have been called *air-furnaces*; but every fire-place, and particularly every cloſed fire-place, ought to be an air-furnace, and that even were it intended to ſerve only for the ſmalleſt ſaucepan, otherwiſe it cannot be perfect.

An Argand's lamp is a fire-place upon this conſtruction; for the glaſs tube which ſurrounds the wick

wick (and which diſtinguiſhes this lamp from all others) ſerves merely as a blower. The circular form of the wick is not eſſential; for by applying a flatted glaſs tube as a blower to a lamp with a flat or riband wick, it may be made to give as much light as an Argand's lamp; or at leaſt quite as much in proportion to the ſize of the wick, and to the quantity of oil conſumed, as I have found by actual experiment.

But it is not the light alone that is increaſed in conſequence of the application of theſe blowers;—the heat alſo is rendered much more intenſe;—and as the heat of any fire may be increaſed by a ſimilar contrivance, on that account it is that I have had recourſe to theſe lamps to aſſiſt me in explaining the ſubject under conſideration. In theſe lamps the fire-place is cloſed on all ſides, and the current of air which feeds the Fire riſes up perpendicularly from below the fire-place into the Fire. By ſurrounding the Fire on all ſides by a wall, the cold atmoſphere is prevented from ruſhing in laterally from all quarters to ſupply the place of the heated air or vapour, which, in conſequence of its increaſed elaſticity from the heat, continually riſes from the Fire, and this cauſes the current of air below (the only quarters from which it can with advantage flow into the Fire) to be very ſtrong.

But in order that a fire-place may be perfect, it ſhould be ſo contrived that the combuſtion of the Fuel, and the generation of the heat, may occaſionally be accelerated or retarded, *without adding to or diminiſhing the quantity of Fuel*; and, when the fire-place is cloſed, this may eaſily be done by means of a *regiſter* in the door which cloſes the paſſage leading to the aſh-pit;—for, as the rapidity of the combuſtion depends upon the quantity of air by which the Fire is fed, by opening the regiſter more or leſs, more or leſs air will be admitted into the fire-place, and conſequently more or leſs Fuel will be conſumed, and more or leſs heat generated in any given time, though the quantity of Fuel in the fire-place be actually much greater than what otherwiſe would be ſufficient.—Fig. 9. ſhews the form of the regiſter I commonly uſe for this purpoſe.

In order that this regiſter may produce its proper effect, a valve, or a *damper*, as it is commonly called, ſhould be placed in the chimney or canal by which the ſmoke is carried off; which damper ſhould be opened more or leſs, as the quantity of air is greater or leſs which is admitted into the fire-place. This regiſter and this damper will be found very uſeful in another reſpect, and that is, in putting out the Fire when there is no longer an occaſion for it; for, upon cloſing them both entirely, the Fire will be immediately extinguiſhed, and the half-conſumed Fuel, inſtead of being ſuffered to burn out to no purpoſe, will be ſaved.

Nearly the ſame effects as are produced by a damper may be produced without one, by cauſing the ſmoke, after it has quitted the fire-place, to descend several feet below the level of the grate on which the Fuel is burned, before it is permitted to go up the chimney.

There is another circumstance of much importance which must be attended to in the construction of fire-places; and that is, the proper disposition of the Fuel; for in order that the combustion may go on well, it is necessary, not only that the Fuel be in its proper place, but also that it be properly disposed; —that is to say, that the solid parts of the Fuel be of a just size, and that they be not placed too near each other, so as to prevent the free passage of the air between them, nor too far asunder; and if the fire-place can be so contrived, that solid pieces of the inflamed Fuel, as they go on to be diminished in size as they burn, may naturally fall together in the center of the fire-place without any assistance, it will be a great improvement, as I have found by experience. This may be done, in small fire-places, (and in these it is more particularly necessary,) by burning the Fuel upon a grate in the form of a segment of a hollow sphere, or of a dish. (See the Figures 3 and 4. Plate I.) All those I now use, except it be for fire-places which are very large indeed, are of this form; and where wood is made use of for Fuel, it is cut into small billets from 4 to 6 inches in length. Instead of a grate of iron, I have lately introduced grates, or rather hollow dishes or pans, of earthen ware, perforated with a great number of holes for giving a passage to the air.

These

These perforated earthen pans, which are made very thick and ſtrong, are incomparably cheaper than iron grates; and judging from the experience I have had of them, I am inclined to think they anſwer even better than the grates; indeed it appears to me not difficult to aſſign a reaſon why they ought to be better.

For large fire-places I have ſometimes uſed grates, the bars of which were common bricks placed edgewiſe, and theſe have been found to anſwer very well.

As only *that part of the air* which, entering the fire-place in a proper manner, and in a juſt quantity, and coming into actual contact with the burning Fuel, *is decompoſed*, contributes to the generation of heat; it is evident that all the air that finds its way into the fire-place, *and out of it again*, without being decompoſed, is a thief;—that it not only *contributes nothing* to the heat, but being itſelf heated at the expence of the Fire, and going off *hot* into the atmoſphere by the chimney, occaſions an actual loſs of heat; and this loſs is often very conſiderable, and the prevention of it is ſuch an object, that too much attention cannot be paid to it in the conſtruction of fire-places.

When the fire-place is cloſed on all ſides by a wall, and when the opening by which the Fuel is introduced is kept cloſed, no air can preſs in laterally upon the Fire; but yet, when the grate is larger than the heap of burning Fuel, which muſt often be the caſe, a great quantity of air may inſinuate

ſinuate itſelf by the ſides of the grate into the fire-place, without going through the Fire: But when, inſtead of an iron-grate, a perforated hollow earthen pan is uſed, by making the bottom of the pan of a certain thickneſs, 2, 3, or 4 inches, for inſtance, and making all the air-holes point to one common center, (to the focus or center of the Fire,) this furtive entrance of cold air into the fire-place will, in a great meaſure, be prevented.

This evil may likewiſe be prevented when circular hollow iron grates are uſed, by narrowing the fire-place immediately under the grate, in the form of an inverted, truncated, hollow cone, the opening or diameter of which above being equal to the internal diameter of the circular rim of the grate, and that below (by which the air riſes to enter the fire-place) about *one-third* of that diameter. (See the Figure 5. Plate I.) This opening below, through which the air riſes, muſt be immediately under the center of the grate, and as near to it as poſſible; care muſt be taken, however, that a ſmall ſpace be left between the outſide or underſide of the iron bars which form the hollow grate, and the inſide ſurface of this inverted hollow cone, in order that the aſhes may ſlide down into the aſh-pit.

As to the form and ſize of the aſh-pit, theſe are matters of perfect indifference, provided, however, that it be large enough to give a free paſſage to the air neceſſary for feeding the Fire, and that the only paſſage into it, by which air can enter, is cloſed by a good door furniſhed with a regiſter.

The

The neceſſity of being completely maſter of the paſſage, by which the air enters the fire-place, has already been ſufficiently explained.

It is perhaps unneceſſary for me to obſerve, that where perforated earthen pans are uſed inſtead of iron grates, the air-holes in the pans ought to be rather ſmaller above than below, in order that they may not be choaked up by the ſmall pieces of coal, and the aſhes which occaſionally fall through them into the aſh-pit.

One great advantage attending fire-places on the conſtruction here propoſed, is, that they ſerve equally well for every kind of Fuel. Wood, pit-coal, charcoal, turf, &c. may indifferently be uſed, and all of them with the ſame facility, and with the ſame advantages; or any two, or more, of theſe different kinds of Fuel, may be uſed at the ſame time without the ſmalleſt inconvenience;—or the Fire having been lighted with dry wood, or any other very inflammable material, the heat may afterwards be kept up by cheaper or more ordinary Fuel of a more difficult and ſlow combuſtion.—Some kinds of Fuel will perhaps be found moſt advantageous for making the pot boil, and others for keeping it boiling; and a very conſiderable ſaving will probably be found to reſult from paying due attention to this circumſtance. When the fire-place is ſo contrived as to ſerve equally well for all kinds of Fuel, this may be done without the leaſt difficulty or trouble.

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I have juſt ſhown, that narrowing that part of the fire-place which lies below the grate, ſerves to make the air enter the fire in a more advantageous manner. This conſtruction has another advantage, perhaps ſtill more important; the heat which is projected downwards through the openings between the bars of the grate, inſtead of being permitted to eſcape into the aſh-pit, (where it would be loſt,) ſtriking againſt the ſides of this inverted hollow *cone*, it is there ſtopped, and afterwards riſes into the fire-place again with the current of air which feeds the Fire, or it is immediately reflected by this conical ſurface, and, after two or three bounds from ſide to ſide, is thrown up againſt the bottom of the boiler.

But in order to be able to form a clear and diſtinct idea upon this ſubject, it is neceſſary to examine with care all the circumſtances attending the generation of heat in the combuſtion of inflammable bodies, and to ſee in what manner, or under what form, the heat generated manifeſts itſelf, and how it may be collected, accumulated, confined, and directed.

This opens a wide field for philoſophical inquiry; but as theſe inveſtigations are not only curious and entertaining, but alſo uſeful and important in a high degree, I truſt my reader will pardon me for requeſting his particular attention while I endeavour to do juſtice to this moſt intereſting, but, at the ſame time, moſt abſtruſe and moſt difficult part of the ſubject I have undertaken to treat.

The

The heat generated in the combuſtion of Fuel manifeſts itſelf in two ways; namely, in the hot vapour which riſes from the Fire, with which it may be ſaid to be *combined*, and in the calorific rays which are thrown off from the Fire in all directions.—Theſe rays may, with greater propriety, be ſaid to be *calorific*, or *capable of generating heat*, in any body by which they are *ſtopped*, than to be called hot; for when they paſs freely through any medium, (as through a maſs of air, for inſtance,) they are not found to communicate any heat whatever to ſuch medium; neither do they appear to excite any conſiderable degree of heat in bodies from whoſe ſurfaces they are reflected; and in theſe reſpects they bear a manifeſt reſemblance to the rays emitted by the ſun.

What proportion this *radiant heat* (if I may be allowed to uſe ſo inaccurate an expreſſion) bears to that which goes off from burning bodies in the ſmoke and heated vapour, is not exactly known; it is certain, however, that the quantity of heat which goes off in the heated elaſtic fluids, viſible and inviſible, which riſe from a Fire, is much greater than that which all the calorific rays united would be capable of producing. But though the quantity of *radiant heat* is leſs than that exiſting in the hot vapour, (and which, for the ſake of diſtinction, may be called *combined heat*,) the former is ſtill much too conſiderable to be neglected.

That the heat generated, or excited, by the calorific rays which proceed from burning bodies, is in

fact

fact considerable, is evident from the heat which is felt in a room warmed by a chimney Fire; for as all the heat, combined with the smoke and hot vapour, goes up the chimney, it is certain that the increase of heat in the room, occasioned by the Fire, is entirely owing to the calorific rays thrown into it from the burning Fuel.

The activity of these rays may be shown in various ways, but in no way in a more striking manner than by the following simple Experiment: When the Fire burns bright upon the hearth, let the arm be extended in a straight line towards the center of the Fire, with the hand open, and all the fingers extended and pointing to the Fire. If the hand is not nearer the Fire than the distance of two or three yards, except the Fire be very large indeed, the heat will scarcely be perceptible; but if, without moving the arm, the wrist be bent upwards so as to present the inside or flat of the hand perpendicular to the Fire, the heat will not only be very sensibly felt, but, if the Fire be large, and if it burns clear and bright, it will be found to be so intense as to be quite insupportable.

It is not, however, burning bodies alone that emit calorific rays. All bodies,—those which are fixed and incombustible, as well as those which are inflammable,—fluids as well as solids,—are found to throw off these rays in great abundance, as soon as they are heated to that degree which is necessary to their becoming luminous in the dark, or till they are red-hot.

Bodies

Bodies even which are heated to a lefs degree than that which is neceffary to their emitting *vifible* light, fend off calorific rays in all directions. This is a matter of fact, which has been proved by experiment. Do all bodies, at all temperatures,—freezing mercury as well as melting iron,—continually emit thefe rays in greater or lefs quantities, or with greater or lefs velocities?—Are bodies cooled in confequence of their emitting thefe rays?—Do thefe calorific rays always generate heat, even when the body, by which they are ftopped or abforbed, is hotter than that from which the rays proceeded?—But I forget that I promifed not to involve myfelf in abftrufe fpeculation.—To return then:—Whatever may be the nature of the rays emitted by burning Fuel, as *one* of their *known properties* is to generate heat, they ought certainly to be very particularly attended to in every arrangement in which the Economy of Heat, or of Fuel, is a principal object in view.

As thefe calorific rays generate heat in the body by which they are *ftopped or abforbed*, and not in the medium through which they pafs, it is neceffary to difpofe thofe bodies which are defigned for ftopping them, in fuch a manner that they may eafily and *neceffarily* communicate the heat they thus acquire to the body upon which it is intended that it fhould operate.

The clofed fire-places which I have recommended, and which will hereafter be more particularly defcribed, will anfwer this purpofe completely.

The

The Fire being closed in these fire-places, on every side, as well below the grate as laterally, and in short every where, except where the bottom of the boiler presents itself to the Fire, none of these rays can possibly escape; and as the materials of which the fire-place is constructed, (bricks and mortar,) are bad conductors of heat, but a small part of the heat generated in the combustion of the Fuel will be absorbed and transmitted by them into the interior parts of the wall, there to be dispersed and lost. But the confining of heat is a matter of sufficient importance to deserve being treated in a separate Chapter.

CHAP. III.

Of the Means of CONFINING HEAT, *and* DIRECTING ITS OPERATIONS.—*Of Conductors and Non-conductors of Heat.—Common Atmospheric Air a good Non-conductor of Heat, and may be employed with great Advantage for confining it—is employed by Nature for that Purpose, in many Instances—is the principal Cause of the Warmth of Natural and Artificial Clothing—is the sole Cause of the Warmth of Double Windows.—Great Utility of Double Windows and Double Walls—they are equally useful in Hot Countries as in Cold.*—ALL ELASTIC FLUIDS *Non-conductors of Heat.*—STEAM *proved by Experiment to be a Non-conductor of Heat.*—FLAME *is also a Non-conductor of Heat.*

THAT HEAT passes more freely through some bodies than through others, is a fact well known; but the cause of this difference in the conducting powers of bodies with respect to Heat, has not yet been discovered.

The utility of giving a wooden handle to a tea-pot or coffee-pot of metal, or of covering its metallic handle with leather, or with wood, is well known: But the difference in the conducting powers of various bodies with regard to Heat, may be shewn by a great number of very simple experiments;—such

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as are in the power of every one to make at all times and in all places, and almoſt without either trouble or expence.

If an iron nail and a pin of wood, of the ſame form and dimenſions, be held ſucceſſively in the flame of a candle, the difference in the conducting powers of the metal and of wood will manifeſt itſelf in a manner in which there will be no room left for doubt. As ſoon as the end of the nail, which is expoſed in the flame of the candle, begins to be heated, the other end of it will grow ſo hot as to render it impoſſible to hold it in the hand without being burnt; but the wood may be held any length of time in the ſame ſituation without the leaſt inconvenience; and, even after it has taken fire, it may be held till it is almoſt entirely conſumed; for the uninflamed wood will not grow hot, and, till the flame actually comes in contact with the fingers, they will not be burnt. If a ſmall ſlip or tube of glaſs be held in the flame of the candle in the ſame manner, the end of the glaſs by which it is held will be found to be more heated than the wood, but incomparably leſs ſo than the pin or nail of metal;—and among all the various bodies that can be tried in this manner, no two of them will be found to give a paſſage to Heat through their ſubſtances with exactly the ſame degree of facility.*

To

* To ſhow the relative conducting power of the different metals, Doctor Ingenhouz contrived a very pretty experiment. He took equal

To confine Heat is nothing more than to prevent its escape out of the hot body in which it exists, and in which it is required to be retained; and this can only be done by surrounding the hot body by some covering composed of a substance through which Heat cannot pass, or through which it passes with great difficulty. If a covering could be found perfectly impervious to Heat, there is reason to believe that a hot body, completely surrounded by it, would remain hot for ever; but we are acquainted with no such substance; nor is it probable that any such exists.

Those bodies in which Heat passes freely or rapidly, are called *Conductors* of Heat; those in which it makes its way with great difficulty, or very slowly, *Non-conductors*, or bad Conductors of Heat. The epithets, good, bad, indifferent, excellent, &c. are applied indifferently to *conductors* and to *non-conductors*. A good conductor, for instance, is one in which Heat passes very freely; a good non-conductor is one in which it passes with great difficulty; and an indifferent conductor may likewise be called, without any impropriety, an indifferent non-conductor.

equal cylinders of the different metals, (being straight pieces of stout wire, drawn through the same hole, and of the same length,) and dipping them into melted wax, covered them with a thin coating of the wax. He then held one end of each of these cylinders in boiling water, and observed how far the coating of wax was melted by the Heat communicated through the metal, and with what celerity the Heat passed.

Those

Thofe bodies which are the worft conductors, or rather the beft non-conductors of Heat, are beft adapted for forming coverings for confining Heat.

All the metals are remarkably good conductors of Heat;—wood, and in general all light, dry, and fpungy bodies, are non-conductors: Glafs, though a very hard and compact body, is a non-conductor. Mercury, water, and liquids of all kinds, are conductors; but air, and in general all elaftic fluids, *fteam* even not excepted, are non-conductors.

Some experiments which I have lately made, and which have not yet been publifhed, have induced me to fufpect that *water*, mercury, and all other non-elaftic fluids, do not permit Heat to pafs through them from particle to particle, as it undoubtedly paffes through folid bodies, but that their apparent conducting powers depend effentially upon the extreme mobility of their parts; in fhort, that they rather *tranfport* Heat than allow it a paffage. But I will not anticipate a fubject which I propofe to treat more fully at fome future period.

The conducting power of any folid body in one folid mafs, is much greater than that of the fame body reduced to a powder, or divided into many fmaller pieces: An iron bar, or an iron plate, for inftance, is a much better conductor of Heat than iron filings; and faw-duft is a better non-conductor than wood. Dry wood-afhes is a better non-conductor than either; and very dry charcoal reduced to a fine powder is one of the beft non-conductors known; and as charcoal is perfectly incombuftible when confined in a ſpace where freſh air can have no acceſs, it is admirably well calculated for forming a barrier for confining Heat, where the Heat to be confined is intenſe.

But among all the various ſubſtances of which coverings may be formed for confining Heat, none can be employed with greater advantage than common atmoſpheric air. It is what Nature employs for that purpoſe; and we cannot do better than to imitate her.

The warmth of the wool and fur of beaſts, and of the feathers of birds, is undoubtedly owing to the air in their interſtices; which air, being ſtrongly attracted by theſe ſubſtances, is confined, and forms a barrier which not only prevents the cold winds from approaching the body of the animal, but which oppoſes an almoſt inſurmountable obſtacle to the eſcape of the Heat of the animal into the atmoſphere. And in the ſame manner the air in ſnow ſerves to preſerve the Heat of the earth in winter. The warmth of all kinds of artificial clothing may be ſhown to depend on the ſame cauſe; and were this circumſtance more generally known, and more attended to, very important improvements in the Management of Heat could not fail to reſult from it. A great part of our lives is ſpent in guarding ourſelves againſt the extremes of heat and of cold, and in operations in which the uſe of Fire is indiſpenſable; and yet how little progreſs has been made in that moſt uſeful and moſt important of the arts,—the Management of Heat!

Double

Double windows have been in uſe many years in moſt of the northern parts of Europe, and their great utility, in rendering the houſes furniſhed with them warm and comfortable in winter, is univerſally acknowledged,—but I have never heard that any body has thought of employing them in hot countries to keep their apartments cool in ſummer;—yet how eaſy and natural is this application of ſo ſimple and ſo uſeful an invention!—If a double window can prevent the Heat which is *in* a room from paſſing *out of it*, one would imagine it could require no great effort of genius to diſcover that it would be equally efficacious for preventing the Heat *without* from coming *in*. But natural as this concluſion may appear, I believe it has never yet occurred to any body; at leaſt I am quite certain that I have never ſeen a double window either in Italy, or in any other hot country I have had occaſion to viſit *.

But the utility of double windows and double walls, in hot as well as in cold countries, is a matter of ſo much importance that I ſhall take occaſion to treat it more fully in another place. In the mean time, I ſhall only obſerve here, that it is the *confined air* ſhut up between the two windows, and not the double glaſs plates, that renders the paſſage

* When double windows are uſed in hot countries, to keep dwelling-houſes cool, great care muſt be taken to ſcreen thoſe windows from the ſun's direct rays, and even from the ſtrong light of day, otherwiſe they will produce effects directly contrary to thoſe intended. This may eaſily be done, either by Venetian blinds or by awnings. In all caſes where rooms are to be kept cool in hot weather, the leſs light that is permitted to enter them, the cooler they will be.

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of Heat through them so difficult. Were it owing to the increased thickness of the glass, a single pane of glass twice as thick would answer the same purpose; but the increased thickness of the glass of which a window is formed, is not found to have any sensible effect in rendering a room warmer.

But air is not only a non-conductor of Heat, but its non-conducting power may be greatly increased. To be able to form a just idea of the manner in which air may be rendered a worse conductor of Heat, or, which is the same thing, a better non-conductor of it than it is in its natural unconfined state, it will be necessary to consider *the manner* in which Heat passes through air. Now it appears, from the result of a number of experiments which I made with a view to the investigation of this subject, and which are published in a Paper read before the Royal Society *, that though the particles of air, *each particle for itself*, can receive Heat from *other bodies*, or communicate it to them, yet there is no communication of Heat *between one particle of air and another particle of air*. And from hence it follows, that though air may, and certainly does, *carry off* Heat, and *transport it* from one place, or from one body to another, yet a mass of air in a quiescent state, or with all its particles at rest, *could it remain in that state*,—would be totally impervious to Heat; or such a mass of air would be a perfect non-conductor.

Now if heat passes in a mass of air merely in consequence of the motion it occasions in that air,—if

* See the Philosophical Transactions, 1792.

it be *transported,—not suffered to pass,*—in that case, it is clear that whatever can obstruct and impede the internal motion of the air, must tend to diminish its conducting power: And this I have found to be the case in fact. I found that a certain quantity of Heat which was able to make its way through a wall, or rather a sheet of confined air $\frac{1}{2}$ an inch thick in 9 $\frac{3}{5}$ minutes, required 21 $\frac{2}{5}$ minutes to make its way through the same wall, when the internal motion of this air was impeded by mixing with it $\frac{1}{38}$ part of its bulk of eider-down,—of very fine fur, or of fine silk, as spun by the worm.

But in mixing bodies with air, in order to impede its internal motion, and render it more fit for confining Heat, such bodies only must be chosen as are themselves non-conductors of Heat, otherwise they will do more harm than good, as I have found by experience. When, instead of making use of eider-down, fur, or fine silk, for impeding the internal motion of the confined air, I used an equal volume of exceedingly fine silver-wire flatted, (being the ravellings of gold or silver lace,) the passage of the Heat through the barrier, so far from being impeded, was remarkably facilitated by this addition; the Heat passing through this compound of air and fine threads of metal much sooner than it would have made its way through the air alone.

Another circumstance to be attended to in the choice of a substance to be mixed with air, in order to form a covering or barrier for confining Heat, is the fineness or subtility of its parts; for the finer they are, the greater will be their ſurface in proportion to their ſolidity, and the more will they impede the motions of the particles of the air. Coarſe horſe-hair would be found to anſwer much worſe for this purpoſe than the fine fur of a beaver, though it is not probable that there is any eſſential difference in the chymical properties of thoſe two kinds of hair.

But it is not only the fineneſs of the parts of a ſubſtance, and its being a non-conductor, which render it proper to be employed in the formation of covering to confine Heat;—there is ſtill another property, more occult, which ſeems to have great influence in rendering ſome ſubſtances better fitted for this uſe than others; and this is a certain attraction which ſubſiſts between certain bodies and air. The obſtinacy with which air adheres to the fine fur of beaſts and to the feathers of birds, is well known; and it may eaſily be proved that this attraction muſt aſſiſt very powerfully in preventing the motion of the air concealed in the interſtices of thoſe ſubſtances, and conſequently in impeding the paſſage of Heat through them.

Perhaps there may be another ſtill more hidden cauſe which renders one ſubſtance better than another for confining Heat. I have ſhown by a direct and unexceptionable Experiment, that Heat can paſs through the Torricellian vacuum *, though with rather more difficulty than in air (the con-

* See my Experiments on Heat, publiſhed in the Philoſophical Tranſactions, vol. lxxvi.

ducting

ducting power of air being to that of a Torricellian vacuum as 1000 to 604, or as 10 to 6, very nearly); but if Heat can pass where there is no air, it must in that case pass by a medium more subtile than air; a medium which most probably pervades all solid bodies with the greatest facility, and which must certainly pervade either the glass or the mercury employed in making a Torricellian vacuum.

Now, if there exists a medium more subtile than air, by which Heat may be conducted, is it not possible that there may exist a certain affinity between that medium and sensible bodies? a certain attraction or cohesion by means of which bodies in general, or some kinds of bodies in particular, may, some how or other, impede this medium in its operations in conducting or transporting Heat from one place to another? It appeared from the result of several of my Experiments, of which I have given an account in detail in my paper before mentioned, published in the year 1786 in the LXXVIth Vol. of the Philosophical Transactions, that the conducting power of a Torricellian vacuum is to that of air as 604 to 1000:—but I found by a subsequent Experiment, (see my second Paper on Heat, published in the Philosophical Transactions for the year 1792,)—that 55 parts in bulk of air, with 1 part of fine raw silk, formed a covering for confining Heat, the conducting power of which was to that of air as 576 to 1284; or as 448 to 1000. Now, from the result of this last-mentioned Experiment, it it should seem that the introduction into the space through which the Heat passed, of so small a quantity of raw silk as $\frac{1}{56}$ part of the volume, or capacity of that space, rendered that space (which now contained 55 parts of air and 1 part of silk) more impervious to Heat than even a Torricellian vacuum.—The silk must therefore not only have completely destroyed the conducting power of the air, but must also at the same time have very sensibly impaired that of the etherial fluid which probably occupies the interstices of air, and which serves to conduct Heat through a Torricellian vacuum: For a Torricellian vacuum was a better conductor of Heat, than this medium, in the proportion of 604 to 448. But I forbear to enlarge upon this subject, being sensible of the danger of reasoning upon the properties of a fluid whose existence even is doubtful; and feeling that our knowledge of the nature of Heat, and of the manner in which it is communicated from one body to another, is much too imperfect and obscure to enable us to pursue these speculations with any prospect of success or advantage.

Whatever may be the *manner* in which Heat is communicated from one body to another, I think it has been sufficiently proved that it passes with great difficulty through confined air; and the knowledge of this fact is very important, as it enables us to take our measures with certainty and with facility for confining Heat, and directing its operations to useful purposes.

But

But atmoſpheric air is not the only non-conductor of Heat. All kinds of air, artificial as well as natural, and in general all elaſtic fluids, *ſteam not excepted*, ſeem to poſſeſs this property in as high a degree of perfection as atmoſpheric air.

That ſteam is not a conductor of Heat, I proved by the following Experiment: A large globular bottle being provided, of very thin and very tranſparent glaſs, with a narrow neck, and its bottom drawn inward ſo as to form a hollow hemiſphere about 6 inches in diameter; this bottle, which was about 8 inches in diameter externally, being filled with cold water, was placed in a ſhallow diſh, or rather plate, about 10 inches in diameter, with a flat bottom formed of very thin ſheet braſs, and raiſed upon a tripod; and which contained a ſmall quantity (about $\frac{2}{10}$ of an inch in depth) of water; a ſpirit lamp being then placed under the middle of this plate, in a very few minutes the water in the plate began to boil, and the hollow formed by the bottom of the bottle was filled with clouds of ſteam, which, after circulating in it with ſurpriſing rapidity 4 or 5 minutes, and after forcing out a good deal of air from under the bottle, began gradually to clear up. At the end of 8 or 10 minutes (when, as I ſuppoſed, the air remaining with the ſteam in the hollow cavity formed by the bottom of the bottle, had acquired nearly the ſame temperature as that of the ſteam) theſe clouds totally diſappeared; and, though the water continued to boil with the utmoſt violence, the contents of this hol-

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low cavity became so perfectly invisible, and so little appearance was there of steam, that, had it not been for the streams of water which were continually running down its sides, I should almost have been tempted to doubt whether any steam was actually generated.

Upon lifting up for an instant one side of the bottle, and letting in a smaller quantity of cold air, the clouds instantly returned, and continued circulating several minutes with great rapidity, and then gradually disappeared as before. This Experiment was repeated several times, and always with the same result; the steam always becoming visible when cold air was mixed with it, and afterwards recovering its transparency when, part of this air being expelled, that which remained had acquired the temperature of the steam.

Finding that cold air introduced under the bottle caused the steam to be partially condensed, and clouds to be formed, I was desirous of seeing what visible effects would be produced by introducing a cold solid body under the bottle. I imagined that if steam was a conductor of Heat, some part of the Heat in the steam passing out of it into the cold body, clouds would of course be formed; but I thought if steam was a *non-conductor* of Heat,—that is to say, *if one particle of steam could not communicate any part of its Heat to its neighbouring particles*, in that case, as the cold body could only affect the particles of steam *actually in contact with it*, no cloud would appear; and the result of the

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Experiment ſhewed that ſteam is in fact a *non-conductor of Heat*; for, notwithſtanding the cold body uſed in this Experiment was very large and very cold, being a ſolid lump of ice nearly as large as an hen's egg, placed in the middle of the hollow cavity under the bottle, upon a ſmall tripod or ſtand made of iron wire; yet as ſoon as the clouds which were formed in conſequence of the unavoidable introduction of cold air in lifting up the bottle to introduce the ice, were diſſipated, which ſoon happened, the ſteam became ſo perfectly tranſparent and inviſible, that *not the ſmalleſt appearance of cloudineſs was to be ſeen any where*, not even about the ice, which, as it went on to melt, appeared as clear and as tranſparent as a piece of the fineſt rock cryſtal.

This Experiment, which I firſt made at Florence, in the month of November 1793, was repeated ſeveral times in the preſence of Lord Palmerſton, who was then at Florence, and Monſ. de Fontana *.

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* The bottle made uſe of in this Experiment, though it appeared very large externally, contained but a very ſmall quantity of water, owing to its bottom being very much drawn inwards. As the hollow cavity under the bottom of the bottle (which, as I juſt obſerved, was nearly in the form of a hemiſphere, and 6 inches in diameter) ſerved as a receiver for confining the ſteam which roſe from the boiling water in the plate, it may perhaps be imagined that a common glaſs receiver in the form of a bell, ſuch as are uſed in Pneumatical Experiments, might anſwer as well as this bottle; I thought ſo myſelf, but upon making the experiment I found my miſtake. A common receiver will anſwer perfectly well for confining the ſteam, but the glaſs ſoon becomes ſo hot that the drops of water which are formed upon its internal ſurface, in conſequence of the condenſation of the ſteam, inſtead of running down the ſides of the receiver in clear

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In these Experiments the air was not entirely expelled from under the bottle; on the contrary, a considerable quantity of it remained mixed with the steam even after the clouds had totally disappeared, as I found by a particular Experiment made with a view to ascertain that fact; but that circumstance does not render the result of this Experiment less curious, on the contrary I think it tends to make it more surprising. It should seem that neither the mass of steam, nor that of air, were at all cooled by the body of ice which they surrounded, for if the air had been cooled, (in mass,) it seems highly probable that the clouds would have returned.

The results of these Experiments compared with those formerly alluded to, in which I had endeavoured to ascertain the most advantageous forms for boilers, opened to me an entirely new field for speculation and for improvement in the Management of Fire. They shewed me that not only cold air, but also hot air, and hot steam, and hot mixtures of air and steam, are non-conductors of Heat; consequently that the hot vapour which

transparent streams, form blotches and streaks, which render the glass so opaque that nothing can be seen distinctly through it; and this of course completely frustrates the main design of the Experiment; but cold water in the bottle keeping the glass cool, the condensation of the steam upon the sides of the hollow cavity formed by the bottom of the bottle, goes on more regularly, and the streams of water which are continually running down the sides of the glass, uniting together, form one transparent sheet of water, by which means every thing that goes on under the bottle may be distinctly seen.

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riſes from burning Fuel, and even the *flame itſelf, is a non-conductor of Heat.*

This may be thought a bold aſſertion, but a little calm reflection, and a careful examination of the phenomena which attend the combuſtion of Fuel, and the communication of Heat by flame, will ſhow it to be well-founded; and the advantages which may be derived from the knowledge of this fact are of very great importance indeed. But this ſubject deſerves to be thoroughly inveſtigated.

CHAP. IV.

Of the MANNER *in which* HEAT *is* COMMUNICATED *by* FLAME *to other Bodies.—Flame acts on Bodies in the same Manner as a hot Wind.—The Effect of a Blow-pipe in increasing the Activity of Flame explained, and illustrated by Experiments.—A Knowledge of the Manner in which Heat is communicated by Flame necessary in order to determine the most advantageous Forms for Boilers.—General Principles on which Boilers of all Dimensions ought to be constructed.*

IF FLAME be merely vapour, or a mixture of air and steam heated red-hot, as air and steam are both non-conductors of heat, there seems to be no difficulty in conceiving that Flame may, notwithstanding its great degree of heat, still retain the properties of its component fluids, and remain *a non-conductor of heat.* The non-conducting power of air does not appear to be at all impaired by being heated to the temperature of boiling water; and I see no reason why that property in air, or in any other elastic fluid, should be impaired by any augmentation of temperature however great. If steam, or if air, at the temperature of 212 degrees of Fahrenheit's thermometer, be a non-conductor

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of heat, why ſhould it not remain a non-conductor at that of 1000 degrees, or when heated red-hot? I confeſs I do not ſee how a body *could* be deprived of a property ſo eſſential, without being at the ſame time totally changed; and I believe nobody will imagine that either air or ſteam undergo any chymical change merely by being heated to the temperarature of red-hot iron. But without inſiſting upon theſe reaſonings, however concluſive I may think them, I ſhall endeavour to ſhow, from experiment and obſervation, in ſhort to *prove*, that Flame is in fact a non-conductor of heat.

Taking it for granted,—what I imagine will not be denied,—that air is a non-conductor of heat, at leaſt in the ſenſe I have uſed that appellation, I ſhall endeavour to ſhow that Flame acts preciſely in the ſame manner as a hot wind would do in communicating heat, and in no other way; and if I ſucceed in this, I fancy I may conſider the propoſition as ſufficiently proved.

The effect of a blaſt of cold air in cooling any hot body expoſed to it is well known, and the cauſes of this effect may eaſily be traced to that property of air which renders it a non-conductor of heat; for if the particles of cold air in contact with a hot body, could, with perfect facility, give the heat they acquire from the hot body to other particles of air by which they are immediately ſurrounded, and theſe again to others, and ſo on, the heat would be carried off *as faſt as the hot body could part with it*, and any motion of the particles

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of the air,—any wind, or blaſt, would not ſenſibly facilitate or haſten the cooling of the body; and by a parity of reaſoning it may be ſhown, that if Flame were in fact a perfect conductor of heat, any cold body plunged into it would always be heated *as faſt as that body could receive heat;* and neither any motion of the internal parts of the Flame, nor the velocity with which it impinged againſt the cold body, could have any ſenſible effect either to facilitate or accelerate the heating of the body. But if Flame be a non-conductor of heat, its action will be exactly ſimilar to that of a hot wind, and conſequently much will depend upon the manner in which it is applied to any body intended to be heated by it.—Thoſe particles of it *only* which are in *actual contact* with the body will communicate heat to it; and the greater the number of different particles of the Flame which are brought into contact with it, the greater will be the quantity of heat communicated: Hence the importance of cauſing the Flame to impinge with force againſt the body to be heated, and to ſtrike it in ſuch a manner that its current may be broken, and that whirlpools may be formed in it; for the rapid motion of the Flame cauſes a quick ſucceſſion of hot particles; and admitting our aſſumed principles to be true, it is quite evident that every kind of internal motion among the particles of the Flame by which it can be agitated, muſt tend very powerfully to accelerate the communication of the heat.

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