

An essay on the mystery of tempering steel : wherein the effects of that operation are fully considered / Extracted from the works of the celebrated Mons. Reaumur ; By J. Savigny.

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AN
E S S A Y

On the MYSTERY of

TEMPERING STEEL.

[Price 1s. 6d.]

ESSAYS

On the Measure of

TEMPERING STEEL

[Price 1s. 6d.]

A N
E S S A Y
On the MYSTERY of
TEMPERING STEEL.

WHEREIN
The EFFECTS of that OPERATION
are fully considered.

Extracted from the Works of the celebrated
Monf. REAUMUR.

By J. S A V I G N Y.

L O N D O N:
Printed for G. KEARSLEY, at No. 1. in *Ludgate-street*.
M.DCC.LXXI,

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Printed for G. Kearsley, at No. 2, in Lombard Street.

M.DCC.LXXI.

P R E F A C E.

TH E desire of accounting for the effects of our own operations, is extremely natural ; I have often been greatly mortified in not being able to assign any satisfactory reason to myself, why putting a piece of heated steel into cold water should occasion its becoming hard.

vi P R E F A C E.

hard. I failed not to make enquiries wherever I discovered the least probability of obtaining information, and looked into every *English* author, from whose works I could form the least expectation of gaining any knowledge herein ; but I found very few, even among the learned, who had attempted the explanation ; and what those have delivered, whom I have perused, never failed rather to increase than remove my doubts, by
making

P R E F A C E. vii

making the mystery still more mysterious.

My disappointments have sometimes suggested to me, that it is better for an author to be perfectly silent on abstruse points, than to treat thereon, unless he possesses both intention and ability to be very explicit.

I found myself reduced to the necessity of attempting the discovery by my own experiments; and though I cannot say this
proved

proved an unpleasing task, yet I must confess, it fell very short of affording me the knowledge I was in search of.

While I was engaged in this pursuit, I learned by accident, that a *French* author of great reputation had wrote upon the subject: having perused his works, I discovered a much more elaborate account of the matter, than any I before had met with. His thoughts seemed to
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P R E F A C E. ix

be delivered without the least disguise, his reasons supported by very ingenious experiments, and his writings through the whole appeared evidently calculated to investigate the knowledge I had hitherto searched for in vain. I thought it but justice to give this account of my author, lest the reader should condemn in him, what, very likely, may be owing to the inability of the translator.

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x P R E F A C E.

I made no doubt, but every mechanic who had any concern in the mysterious operation of hardening steel, would be as well pleased as myself, to have any information on the subject, and, if they should not receive, in perusing the following extract, so much satisfaction as the original is capable of affording, I flatter myself however, they will herein find the matter more copiously discussed, than in any other author, and that, if it should fail
of

P R E F A C E. xi

of affording a thorough conviction, as to the subject treated of, it will, notwithstanding, set it in such a light, as cannot fail to assist those, who may hereafter be in pursuit of the discovery. In this view, I ventured to hope the publication would stand excused, and that the propriety of the design would extenuate the defects of the production.

The operation by which steel is rendered hard, is of very an-

xii P R E F A C E.

cient date, has been practised in almost all countries, by numberless artists of different denominations, and yet, I believe, I may venture to assert, that, even to this day, there is not, among the whole catalogue of nature's secret workings, any effect produced, whose cause is so little understood; I no less honour Monsieur *Reamur*, for the bare attempt to elucidate so profound a mystery, than I admire the very

P R E F A C E. xiii

very great extent of his judgment.

I will not pretend to alledge however, that every reason advanced by him, carries such a degree of conviction with it, as to leave the mind without a doubt, nor do I believe, that he himself entertained that opinion of his arguments, even experiments themselves, however specious in appearance, do sometimes illude the mind, and betray us
into

into conclusions, which have at other times been found to be fallacious, but it should not appear wonderful, that the author of nature is capable of producing effects by means, which finite mortals cannot comprehend.

In all physical enquiries, our most determined conclusions have no other basis than supposition, from thence we reason, from thence produce arguments, and from thence draw inferences; if
our

P R E F A C E. xv

our conjectures are well grounded, the consequences become indubitable, but it is not at all surprizing, if, as we are totally uncertain in respect to primary causes, we should sometimes reason ourselves (if I may so express it) into error; I am sure my author appears to be thoroughly aware of this, and therefore, I presume, he took great pains to convince himself of the certainty of his hypothesis.

xvi P R E F A C E.

I have only to regret, that he now makes his appearance, under the disadvantageous circumstance of being translated by a man, who never had an opportunity of leaving his native kingdom, to improve himself in the language, from which the following pages are collected.

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A N

E S S A Y

On the MYSTERY of

TEMPERING STEEL.

TH E distinguishing character of steel, considered with respect to the offices it serves, consists in the peculiar property it has of becoming hard by means of tempering; a property so very essential to many arts, that without it they could not be exercised, an infinite number of tools and machines owing

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their

their use entirely to their hardness.

When we consider the simplicity of the process, by means of which we are capable of giving steel such a degree of hardness, at the same time considering the extensive use it is of in the world, we shall not hesitate to place it, as *Robault* has done, among the number of those most worthy our admiration.

Several naturalists have attempted to explain this phenomenon; but, as those attempts were made at a time when the nature of steel was not sufficiently known, it is not surprizing, that their accounts should have been unsatisfactory. They endeavoured to account for it, according to the established system respecting the general hardness of bodies,

which

which would by no means furnish a solution of the present enquiry, as it will be found, by the manner in which I shall endeavour to explain it, that steel, in becoming hard, departs from a fundamental law in that system, which supposes that bodies of a similar nature are so much the less hard, as they have more size with respect to the same quantity of matter, because, in this case, the parts being less united, cannot hold so well together. And it will appear, by the experiments which I have made, that steel never fails to increase in magnitude by means of hardening; or, to come nearer the truth, that tempering fixes in it that increase of magnitude which the fire occasioned.

The whole of the mystery of hardening steel, according to the general method, may be explained in very few words. A piece of steel is heated, and, becoming red, is suddenly plunged in cold water. This little process is sufficient to have given a considerable degree of hardness to the piece of steel, which, had it been left to remain and cool among the coals from which it received the heat, would have been still in a soft state, tender and yielding to the file. This is an indisputable fact; notwithstanding a mind (not pre-advised of the case) left to guess by which of these circumstances the steel had acquired the greater degree of hardness, would be tempted

tempted to pronounce in favour of the latter.

In the operation of tempering, we begin by giving a considerable degree of heat to the steel; we introduce in its substance innumerable particles of fire, which separate and detach its parts, and, in a word, enlarge its dimensions. In this state it is precipitated into cold water: the water very soon puts a stop to the action of the fiery matter, which had penetrated the steel; hence a part of the augmentation which the fire had occasioned, becomes fixed in the mass, it being impossible it should lose what it had acquired, unless the parts could return to the place they first possessed; and that is prevented by the heat yet retained

retained in the interior parts, which cannot receive the same degree of coldness at the instant the outward parts are affected: hence it appears, that one of the effects produced by tempering of steel, is to give it a greater degree of magnitude than it would have had, had it been suffered to cool of itself.

Water is the only body which in becoming hard (as in the instance of ice) apparently increases in volume; but this appearance, according to a very nice experiment made by Monsieur *Homburg*, will be found to be illusive, for he tells us, that, after having, with much time and pains, extracted most of the air contained in a quantity of water, he discovered that water in freezing always
decreased

decreased in bulk, and by this we may perceive, that what we before thought was occasioned by the body's becoming hard, was in reality owing to nothing else than the dilatation of the air which the water contained.

If the enlargement of steel, occasioned by tempering, should not, by what has been said, be sufficiently proved, it will appear less doubtful by the examination of a piece of steel that is broke, after having been tempered, which will be found to be more porous than before ; *
an

* This assertion must, at first sight, appear extraordinary ; as those who have hardened steel, never think that operation well performed, unless the grain of the steel appears to be much closer than that in a soft state ; but I believe, notwithstanding, Monsieur *Reamur* is perfectly right ; for
it

an experiment I have often tried will be a still further conviction of this truth; which is, to measure the dimensions of the steel before it is heated; and again, after it is hardened, when it will always appear to have gained some degree of magnitude; it has been observed by Mr.

Perrault,

it will appear, by what he says hereafter, that though the body of tempered steel seems of a texture much less porous than the steel which is not tempered; its grain is, nevertheless, considerably larger, and its appearance of closeness is owing entirely to the fluid matter which the heat had dispersed among its particles, and which became fixed in the interstices of the grain, by the sudden manner of cooling it; those who doubt this, need only quench a piece of steel that is heated much more than common, and they will find the grain extremely coarse; for the violence of the heat having driven the fluid matter from among its interstices, the size thereof will then be very discernable.

Perrault, that a piece of steel wire, after being tempered, would not pass through the same hole which it did before it was hard; this is what I have often tried, and have always found it prove the certainty of an augmentation: not, however, contented with this experiment, I was desirous to know, if possible, with more precision, how great this augmentation might be; to this end, I procured a piece of iron hollowed, so as to receive a piece of steel six inches long, two broad, and half an inch thick; after having hardened pretty highly, the piece of steel, which I had made to fit with the utmost exactness in this iron case, I found it had gained in length the twelfth part of an inch, there was

also an increase in the width and thickness, proportionable to what it had acquired in length: this admitted; the diameter of the volume of steel hardened to a certain degree, will be in respect to the measure of that untempered, in the proportion of 145 to 144, consequently the bulk of hardened steel to that which is not so, stands in a greater proportion than 49 to 48, for the cube of 145 is 3,048,625, that of 144 is 2,985,984, and the difference between one and the other is 62,641 (that is to say) steel in hardening, acquires at least a 48th of its original size.

It is then sufficiently proved, that tempered steel is of a texture more rare than that which is soft (i. e. not tempered.)

pered.) Now the causes which may be supposed likely to increase its hardness in augmenting its size, may be reduced to three; 1st, either the fire or water has added a matter to the steel, which occasions the increase, and unites its parts better together; or 2dly, on the contrary, the fire has driven from within the steel some kind of matter, which prevented the parts from being so well united as they otherways might be; or lastly, some changes have been occasioned in the body of the steel in the figure, or in the arrangement of its parts, by means of which those very parts obtain a better situation.

I attempted those experiments which I judged most likely to afford me in-

formation to which of these causes the effect might be ascribed; I was soon convinced that the first and second were to be utterly rejected; the first is not consistent with reason; the only matter which could insinuate itself into the steel during the instant of tempering, is water; now it does not appear possible, that the water could find a passage to penetrate through the steel; and moreover, water does not seem to be of a nature well adapted to occasion the hardness of steel; it is necessary for this purpose to have the addition of some matter, whose parts should be united in a stronger manner: I am now going to mention an experiment which might have rendered the foregoing arguments

guments unnecessary, and which will prove, that the augmentation which steel acquires, is not owing either to the introduction of water, or any other weighty substance.

I weighed in a very exact manner a piece of steel, which I reduced precisely to an ounce, and after having heated it to a full red, I quenched it in cold water; taking it thence, I wiped it quite dry, and weighed it again, when I found, not only that it had not gained any weight, but that it had even lost half a grain. Now it must be observed, that if the increase of its size was occasioned by the introduction of any substance, of an equal weight with itself, the piece of steel should have acquired a forty-eighth

eighth of its original weight, in consequence of having gained that in its size, as before mentioned, now if the acquired capacity of the steel had even been filled with parts of water, in that case, the increased weight would be very determinable, if considered in the proportion of weight, which that body bears to that of steel; again, if the introduction of water had any part in the hardening of steel, we may infer, that it would become still harder by being tempered in boiling water, as then the heat of the water would doubtless facilitate its own penetration; and yet we are well convinced, that boiling water will not give so great a degree of hardness to steel, as that which is perfectly cold; it is then

then pretty certain, that it is not by the introduction of any weighty substance, that steel in tempering, acquires an increase both of size and hardness; the loss of the half grain as mentioned, might possibly arise from some small flakes, which the heat had occasioned to fall from the steel, notwithstanding I took every precaution to prevent it, this is a circumstance however scarce worth attention, for the loss of so small a part as half a grain, is hardly to be considered as any loss at all.

What has been said in opposition to the introduction of water, will have the same force against that of the particles of fire, which it may be imagined remained confined in the steel, when the

water

water in cooling it, closed the pores of its outward surface; for in this case also, there must have been an increase of weight; it follows then, that during the instant of tempering, no matter whatever can enter the steel, unless it be of an impalpable and subtle nature.

In respect to the second explanation; I mean that which makes the hardening of steel depend on a matter, which the fire forces from amidst its particles, and to which the water prevented a return; I must own, this seemed at first very consonant to my own manner of thinking; it appeared natural enough, to conceive there might be air confined amidst the particles of untempered steel, and that this air tending to separate the

parts,

parts, might in some measure oppose their adhesion; but that the fire in rarifying the steel, expelled this air from among its particles, the return of which was effectually prevented, by the sudden manner of cooling it, though it would again have entered the steel, little by little, had it been suffered to cool by degrees; but lest any one should adopt this notion, as I myself was tempted to do, I will mention an experiment, which convinced me of its fallacy. I contrived means, after having given a very sufficient heat to a piece of steel, to let it cool in a space free from air; now the reader will readily conceive, that if the hardness of steel was occasioned by means of preventing the re-entrance of air, steel

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cooled

cooled in this manner, should be as hard as when quenched in water, the circumstances with respect to their effect, being pretty near the same. I will not enter into a minute relation of every article of management I used on this occasion, it is sufficient to say, that the tube in which the steel was laid to cool, was so effectually stopped, (after having been rarified within) as to prevent the communication of any outward air; having repeated this experiment several times, I always found that the steel was just in the same state, as it would have been had it cooled in the open air.

Since then the hardness of steel is not produced, either by the introduction of a new matter, or by the expulsion of
air,

air, we must therefore search for the cause in the alteration, which its texture undergoes ; in this light, both *Robault* and *Perrault*, believed they had made the discovery ; the first insists, that the texture of steel is rendered more uniform by tempering, on account, that the water puts a stop to the action caused by the fire, at an instant, when the parts were nearly in a state of fusion, and that these parts have not time therefore to unite themselves, so as to become larger, and thereby leave certain intervals in the steel, wherein the teeth of a saw, or those of a file, might easily engage ; but probably this author never had sufficient opportunity to examine tempered steel, after it had been broke, or he

would certainly have observed, that the higher steel is tempered, the more its grain is enlarged, and the greater the space of division is between each grain, the more also it is hard; if then steel becomes harder by being quenched in water, it is not therefore that the space between its parts are smaller, but that in reality each grain is become in itself more hard, and that the parts of each grain are better united.

Perrault has acknowledged, that the grains of steel became harder by tempering, notwithstanding the operation left intervals between them; he attributes this hardness of the grains, to the pressure of a subtle matter, which he admits to be the general cause of hardness

in bodies, and is of opinion, that the sudden manner in which steel is cooled by tempering, serves to enclose this matter; if this was the case, the matter thus confined, would have its liberty to escape, and doubtless would do so, when the piece of steel was broke, and the broken surface then should become soft in an instant, but we find on the contrary that it always preserves its hardness; the manner in which he supposes a subtle matter to act herein, is as unsatisfactory in this particular, as it is when considered as a general cause; it is no easy matter to content Philosophers on this important question.

Independent of any general cause of hardness, I believe it will be possible to
discover

discover the occasion of the hardness of steel, by means of the assistance I have derived from the examinations I have made into the nature of that metal, an account of which has been heretofore delivered to the Royal Academy at *Paris*; we shall thereby be able to conceive the reason why the action of tempering has so great an effect upon steel, in proportion to what it has on iron; and this, we find, cannot be accounted for according to Mr. *Perrault's* explanation.

It is well known, that the principal difference between iron and steel is, that the latter is very considerably more impregnated with particles of sulphur and salt, than we find the other to be.

Now

Now it seems most reasonable to suppose, that wherein we find these two bodies to differ from each other, we may there expect to find the occasion of that difference which the same treatment produces in each; it must be then owing to the sulphur and salts, which the steel possesses in greater quantity than the iron, by which it acquires the property of becoming hard. I shall endeavour to explain in what manner it may occasion the steel to become hard, when it is cooled suddenly, and why, on the contrary, it leaves it soft, when it is suffered to cool by slow degrees.

It is necessary to remember, that both iron and steel have an aptness to im-
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bibe sulphur as they acquire heat, but that too violent a heat may again deprive them of it : for the present, to avoid as many unnecessary circumstances as possible, let us take under consideration one single grain of steel, which has not been tempered. This grain may be discovered to be no other than a collection of other grains, which we will here term the molecules. These molecules are discoverable by the microscope, and appear themselves to be composed of other parts, which we will suppose are of an elementary nature. To carry our ideas so far as the subject would permit, we might stretch this division much further ; but it may be sufficient for the present purpose to let it rest here ;

here. We have then under our consideration a single grain of steel, the molecules it is composed of, and the elementary parts of those molecules; Now, in exposing to the fire the piece of steel which contains the grain, (at present the object of our consideration) we shall find, that the sulphur and salts, contained in the molecules, will be sooner melted than the molecules themselves, and are by the heat drove from among the parts in which they were contained, and take place amidst its vacancies. Thus the matter, which the heat had expelled from within the molecules, now fills up the spaces between them : it is pretty evident then, that, when a grain of steel has received

a certain degree of heat, the vacant spaces of the molecules, of which it is composed, are in part filled up by a sulphurous matter, which they did not before contain, and which has been extracted from the molecules themselves. In this state the piece of steel, which contained the forementioned grain, is suddenly plunged in water, and, in that instant, we fix at once the sulphur and salts, which were in a state of fusion, and thereby depriving them of their fluidity, they are no longer in a condition to re-enter the cells, from which they were drove. Thus the small interspaces of the molecules are better filled up, and by a matter which we may suppose almost as hard as we please.

The

The molecules of this single grain, therefore, will hold better with each other, and the grain of steel will be more difficult to divide or break; or, (what is the same thing) the grain is become more hard. The same effect, doubtless, must have been produced to all the other grains contained in the piece of steel, which received the same degree of heat, and thus the whole body becomes hard.

The pyrites, which is a sort of sulphurous stone, well known among naturalists, inclines us to believe, that parts of sulphur and salt mixed together, may have a considerable degree of hardness, it being acknowledged, that the pyrites is, in itself, hardly any thing more than

salt and sulphur ; and yet, notwithstanding, it is so very hard, that it was formerly made use of for many purposes, to which iron is now appropriated. When I speak of the sulphur natural to iron and steel, I would not be understood to mean that of a pure and simple nature : on the contrary, I consider it as a sort of common sulphur, like unto that of the pyrites, which is known to contain a great quantity of salt.

But, admitting the sulphurous matter, we have been speaking of, had a less degree of hardness than what we suppose it to have, it cannot, however, (by filling up the intervals of the molecules)

fail

fail of uniting them better together ; and it appears very certain, that the hardening of steel is produced by means of fixing a fluid matter, which flows among the interstices of its parts, and which is not of a simple nature, but is, doubtless, strongly impregnated with particles of salt.

Nothing can serve better to explain, and at the same time confirm, what has been said, than the manner of tempering steel or iron, by inclosing either in an iron box, together with such ingredients as will best serve the purpose of producing more than an ordinary hardness ; such, in short, as abound most with sulphurous and saline matter.

ter*. These are set in fusion by the heat, and, entering the steel, fill up not only

* This operation is termed, by those who perform it, case-hardening, and with much reason, as the thing which is to be hardened, is heated in a case, usually made of iron. The ingredients commonly inclosed to assist the process, are shreds of worn leather, pieces of horn, foot, &c. These substances, which contain a great quantity of the sulphurous matter, being heated for a certain length of time, are deprived of that matter by the piece of iron which they encompass, and which, according to the *French* author, has a natural thirst to imbibe such. When it is judged that the heat has been sufficient to produce the effect, the thing intended to be made hard is taken out and quenched in water, and it is then found to be as resistable to the file as even steel. It must be acknowledged, that this circumstance is greatly in favour of our author's doctrine, it being hardly possible to conceive a stronger proof of the certainty of his hypothesis.

This

only the interstices, but also the molecules themselves. In this state it is taken from out the box, and quenched in water, and by this means it will become harder by the same degree of heat, than if it had been heated in the common manner. Our explanation assigns the reason for this difference, and the difference, at the same time, confirms our explanation; for the grains of steel, thus incased, and thus supplied, are more penetrated with sulphur and salts, than those which are heated directly on the coals; and by being cooled suddenly, more of those matters

This process, however, is commonly used with iron only, steel being capable of receiving a sufficient degree of hardness by the methods ordinarily practised for that purpose.

matters consequently become fixed in the steel, in the one case, than in the other. This method used, even with iron, occasions a hardness about its surface, approaching to that of steel; the reason of which is very obvious, for, during the time it was heating, the interstices were filled with the sulphurous matter in which it lay, and that matter being fixed on the exterior parts, by being quenched in water when in a state of fusion, occasions a degree of hardness nearly equal to that of steel.

There is, however, a difficulty, which seems to occur, *viz.* That the means by which steel becomes hard, should, at the same time, render it brittle, and
more

more easy to separate than untempered steel. This appears necessary to allow, when we consider, that in stretching two pieces of steel of equal diameters, the one tempered, and the other not, the piece which is hard will break by a less degree of force than the other. To explain which, it must be remembered, that as steel increases in size by tempering, without the addition of any metallic body to occasion that increase, the number of points therefore which come in contact, are less in steel, after tempering, than before; consequently, the whole of the steel is, in one sense, weaker after being hardened than before. It seems, however, difficult to admit, that tempered steel, which resists

incomparably more to the file, should be weaker when extended, than steel which is not hard ; for, notwithstanding that steel becomes fragil by tempering, yet that does not, however, sufficiently prove, that the junction of its parts should be weaker. The stroke of a hammer, for example, which will break a piece of thick glass, will not do the same to a piece of straw ; but the same piece of glass suspended will support a considerable weight, and the straw only a light one.

To be more certain on this head, I had recourse to an experiment. After having tempered part of a piece of steel wire, and marking that part which received the greatest degree of heat, I
fixed

fixed one of the ends, and to the other hung a considerable weight, which I increased till the wire broke afunder. Having repeated this experiment several times, I constantly found the fracture happen in the part which was hardened, and generally where it had partook of the greatest heat, and which consequently was the hardest. I repeated this trial so often, and with so many precautions, as left me without a doubt concerning it. It is not easy to ascertain how much the force necessary to break a piece of tempered steel in this manner, is less than what is required with steel that is not tempered; but, I am convinced, the difference is very considerable, and much more than

might be expected, in proportion to the augmentation it acquires in size.

Thus, by the very means, the steel acquires a property to resist friction or pressure, it becomes more fragil, hence there appears a kind of compensation, which gives it in one sense what it looses in the other.

Notwithstanding the grains of steel themselves do hold less powerfully together after being tempered than before, it might, nevertheless, be expected they would resist more to the file or chizel, as we find is the case, because the parts of which each grain is composed, are in themselves much better united than before tempering. When a file acts upon a piece of steel, it does not take away
the

the grains entire, as will appear by viewing the surface of steel that has been broke asunder, which, however, even and close, still discovers much more ragged particles than the surface of steel that has been filed, which is a sufficient proof that the separation happened between the grains, and not in the grains themselves; a chizel, likewise, cannot cut steel without dividing the grain, it can hardly be supposed to direct its way precisely between two grains; thus, the better united the parts are, which compose the grain, the more they will resist to the file or chizel, which are the methods commonly used to prove its hardness.

Notwithstanding

Notwithstanding hardened steel may be weaker in one respect than the steel which is soft, its grains may, nevertheless, have a more powerful adhesion with each other, although it must be allowed that the amount of force, upon the whole, is less in steel which is tempered, than in that which is not so; to render this still more clear, it is necessary to remember that it has already been proved that steel enlarges by being tempered; this enlargement supposes an increase of magnitude in each grain, and we will here desire the reader to figure to himself two pieces of steel of equal size, the one tempered, the other not; in the former he will find the grain larger, and consequently
not

not so numerous as in the other; the parts, therefore, which come in contact in the tempered steel, will not be so many in number as in the piece that is not hard, and consequently, not having so many points of hold, will be easier caused to separate; but notwithstanding the weakness of its force, considered collectively, we may, however, easily imagine that it would be more difficult to separate one of the grains from its neighbour, in the piece tempered, than in that which is not tempered, for the increased size of its grain occasions it to have a greater space of contact with the adjoining one, though the contact, not being so often repeated in the same degree of space, leaves tempered steel,
upon

upon the whole, much more fragil than that which is soft; and it will always appear, that the larger the grain of steel is after hardening, the greater will be its degree of hardness.

Thus every phænomenon regarding the tempering of steel, is sufficiently accounted for, we perceive the reason why steel becomes hard by tempering, why it becomes harder by being tempered hotter, and also why it happens to be less yielding, and more brittle after tempering; this consequence indeed, might well be expected from the circumstance of its augmentation, for in bodies of the same matter, and equal quantity, that will always be the most flexible, which is composed of the smallest parts; a cylinder of glass,
for

for example, will be very brittle; and yet the same glass drawn into threads, will form a skaine of a very flexible nature, and the more so, as the threads of which it is composed are smaller. Untempered steel may be compared to the mass formed of the smallest parts, and that which is tempered, to the other.

It remains to examine, why steel which has been hardened, will again become soft by being heated, or (which is the same thing,) why it would have remained soft, if instead of being plunged in water, it had been left to cool among the coals, from which it received the heat.

It has already been remarked, that both iron and steel have an eagerness to imbibe the sulphur and salts, which the

heat causes to float in those bodies, and by degrees, as the action of the fire grows weaker, part of the fluid matter, which had been forced from the molecules re-enters, if the heat diminishes by very slow degrees, the greater quantity will return, thus, the more the means of cooling the steel are procrastinated, the less it approaches that state, which tempering would have brought it to, on the contrary, the more sudden the means are of cooling it, the harder it will be.

Notwithstanding, we have all along spoke of tempering, as a very sudden operation, it must not however, be considered as instantanious; neither steel nor iron becomes cold immediately, upon their being plunged in water, on the
 contrary,

contrary, they preserve a considerable heat for some time, and if the piece that is tempered, is pretty substantial, we may perceive that it retains its redness for some time, under the water, and during the space the steel is undergoing the change, from a soft body to a hard one, it is easy to conceive, that part of the sulphurous matter, which the fire had set in agitation, regains the place from whence it had been drove.

It may happen (according to the difference of steel) that, that which is tempered, after having been made white hot, may not have more sulphur dispersed in its parts, than other steel which is only heated red; this last remark explains a fundamental rule, respecting the
different

different degrees of hardness, steel may receive by tempering, *viz.* that of different pieces of steel tempered at the same degree of heat, that will always be the hardest, whose parts contain the greatest quantity of the sulphurous, and saline matter.

F I N I S.