IX. *Experiments and observations on the developement of magnetical properties in steel and iron by percussion:—Part II.* *By* WILLIAM SCORESBY, *Jun. F. R. S. E. &c. Communicated by Sir* HUMPHRY DAVY, *Bart. Pres. R. S.*

Read January 29, 1824.

HAVING had the honour of laying before the Royal Society a Paper on the "Developement of Magnetical Properties in Steel and Iron by percussion,"* I beg permission to add to that Communication an account of other experiments; in which much higher degrees of magnetic energy were obtained by percussion, in the employment of new combinations of rods of iron not previously magnetic.

It was shown in the former paper, that the extraordinary developement of magnetism, by this process, arose from the use of a large bar of iron, or soft steel, first rendered magnetic by hammering, in the position of the dipping needle, or in the direction of the magnetic force; for, on applying a similar quantity of percussion to the same bar whilst held on a mass of brass or stone, or even on a bar of iron laid in the plane of the magnetic equator, the polarity elicited did not exceed the twenty-ninth part of that obtained by the use of the vertical rod of iron.

In the subsequent experiments I had two principal objects

* Philosophical Transactions for 1822, p. 241.

in view. First, to try, by a new combination of auxiliary rods of iron, to attain still higher degrees of magnetic energy: and, Secondly, to endeavour to ascertain on what circumstances, as to the magnitude of the rods of iron, and the quality, size, and temper of the steel wires, the highest success of the experiment depends.

In the experiments formerly detailed, a single rod of iron was used, and the steel bars or wires were hammered upon it, whilst both were held in a vertical position; in which case the magnetism of the iron, after hammering, was employed in aid of the power of percussion for the developement of the magnetism of the steel bars. But the magnetism of the iron rods was communicated only to the lower, or *north* end of the steel bars, the polarity of the upper, or *south* end, being merely consequential. Hence it appeared probable, that, were the steel bars or wires placed between two rods of iron, and thus subjected, either directly, or indirectly, through the medium of the upper rod, to percussion, they would derive the advantage of the magnetism of both rods of iron acting consistently, and at the same time, upon their northern and southern poles, so as, I apprehended, by the use of equal rods of iron, to *double* the quantity of attraction formerly developed in the steel.

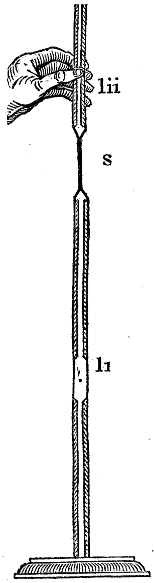
As, however, two long rods of iron were not so easily managed as a long one for below and a shorter for above, I prepared my rods on this plan, though with the expectation of sacrificing a proportion of power.

The rods I ordered for the experiment were of the respective lengths of three feet and one foot, and an inch in diameter. The weight of the former was 8lbs. and of the latter $2\frac{2}{3}$lbs. The end of the larger rod (I i*), designed to be kept upward, was made conical, with the view of concentrating its magnetic force; but this was truncated at the diameter of a quarter of an inch, and a shallow hole drilled in the centre for steadying the steel wires when hammered, the lower ends of which wires were rounded into a blunt point, so as to fit the depression in the top of the iron rod. The lower end of the shorter rod (I ii), was constructed in a similar manner.

As I could not hammer this conical extremity of the large iron rod without destroying its form and face, I made use of another iron rod (I iii), corresponding in size and weight with the rod (I ii), but having its lower extremity hollowed like a cup, to fit upon the conical termination of the larger rod (I i.) The larger rod was generally hammered before each experiment through the medium of this shorter rod, (I iii), which not only served to preserve the other rod from injury, but at the same time tended to augment its magnetism.

In experiments with this apparatus, then, after eliciting some magnetic energy in the rod I i, by hammering it in the way just described, the steel wire intended for receiving the magnetism was placed between the two rods, with the conical

* To prevent circumlocution, I have distinguished the rods and wires used in the following experiments by the initial letters descriptive of the substance of which they were composed, connected with a number to distinguish the different bars and wires of the same quality. Thus I, signifies an iron rod or bar; and S, a steel bar or wire; S *u*, steel untempered, or in the state in which the wire was drawn; and S *t*, steel tempered, or softened by heating to redness, and slowly cooled.



terminations [I i and I ii], the whole three substances forming a continuous straight line, in a vertical position, as in the annexed figure. The upper end of the upper rod (I ii), being now beaten with a small hammer,* acquired magnetical properties, which were communicated to the steel wire, whilst the lower rod receiving some influence from the percussion, performed a similar office. This kind of experiment I have, in the subsequent details, denominated the *compound process;* whilst the hammering of a wire upon the principal rod (I i), only, without the use of the second rod, is called the *simple process.*

To give the experiments the best chance, I made use entirely of steel wire, such as is employed by watch-makers, which I found, from several comparisons and experiments, that I did not think it necessary to detail here, had a much higher capacity for magnetism thus developed, than any other steel that I tried: and for obtaining the best effect, in the trial of the lifting power produced in the steel wires by percussion, I procured a series of nails of different weights, made of good iron, with flat heads, so as to stand with their points upward, in which position they are the most readily lifted; and after blunting their points, I gave them some degree of polish for improving the contact.

* The hammer employed in all the subsequent experiments weighed eleven ounces, inclusive of the shaft. Some trials were made with a larger hammer; but its tendency to bend the wires was so great, as more than to counterbalance the advantage it gave of a more speedy developement of magnetic energy. This larger hammer, however, (weighing twenty-five ounces), was generally used for beating the iron rods before the different experiments, when it was of decided advantage.

These nails were of the following weights in grains:—$1\frac{1}{2}$, 4, $5\frac{3}{4}$, $7\frac{1}{2}$, 18, 37, 73, 88, 112, 186, 246, 326, 389, and 482.

In trials of the lifting power of the steel wires, in the subsequent experiments, the weight of the largest nail that could be lifted is set down.* In some instances a small weight was added to the nail, when the difference between this and the next in the series was considerable; in this case, the lifting power is stated at the weight of the nail, *plus* the number of grains of the appended weight.

FIRST SERIES,

for determining the superiority of the Compound process over the Simple process, when employed for the developement of magnetism in steel wires by percussion; and for the trial of the general effect of Temper on the magnetic attraction elicited.

The apparatus consisted of the iron rods I i, I ii, and I iii, together with various steel wires.

EXPERIMENT No. I.

[July 1.]

Steel wire S u i, [namely, steel wire untempered]. Length, 5 inches; diameter, $\frac{1}{8}$th of an inch; weight, 167 grains.

This wire was hammered, for a length of time, on the *simple process*, and only lifted 36 grains.

* I am perfectly aware that the lifting power of a magnet is by no means a certain measure of its magnetic force, and that the comparative lifting powers of magnets of various sizes do not afford an exact measure of their relative degrees of magnetic energy; but this mode of trial was employed both on account of the impossibility of making accurate observations on magnetic intensities at sea, where

The hammering being continued for some time longer, by the *compound process*, the lifting power was sensibly augmented; but it yet refused 73 grains.

No. II.

The same steel wire (S t i) softened by heating to redness.

a. By simple process.

After 5 blows this wire now lifted 73 grains.
4 more blows - - - 186.

The wire being now bent was straightened, by which it lost a great part of its magnetism ; it was therefore raised to a lifting power of 186 grains, as before, by a number of very slight blows.

10 gentle blows were now struck, but its lifting power was still - - - - 186 grains.
20 more blows increased its attractive force very sensibly; but it still refused the nail of 246 grains.

These last 30 blows having been productive of very little effect, the power was considered as being sufficiently near the maximum by this process, to serve as a comparison with the compound process.

b. By Compound process.

20 slight blows on the upper iron rod, I ii, now increased the lifting power of the wire to 246 grains.
And 20 more slight blows raised its power to 326.
But 60 more slight blows produced no higher effect.

these experiments were made, and also on account of this being the most palpable and striking test of the high force of attraction attained by the process.

No. III.

[July 2.]

Same wire as in the last experiment [S *t* i].

a. Simple process After repeatedly hammering this wire upon the bar I i, it now lifted 246 grains ; but its power could not be farther increased.

b. Compound process. The lifting power, by often hammering, was now raised to $326 + 19 = 345$ grains.

No. IV.

[July 10.]

Wire S *t* i, *the same as in the last experiment.*

The compound process was, on this occasion, continued for a length of time, the bars I i and I iii being repeatedly hammered together, but no additional lifting power could be obtained.

No. V.

[July 10.]

Larger wire, S *u* i i ; *length,* 12 *inches ; diameter,* $\frac{1}{6}$*th of an inch.*

This wire being hammered in its untempered state, with 20 or 30 smart blows, by the simple process, only lifted $7\frac{1}{2}$ grains.

No. VI.

The same wire as in the last experiment, tempered by heating to redness. [S *t* i i.]

a. Simple process.

By 2 smart blows, with a small hammer, it now lifted - - - - - - 37 grains.

4 more very strong blows - -	73 grains.
10 more - - - - -	186
8 more - - - - - -	246
6 more [wire began to bend] - -	326
4 more - - - - - -	326

No. VII.

The wire last used (S *t* ii), *not being regularly softened, was again put through the fire, and all its magnetism destroyed.*

a. Simple process.

By 2 strong blows only, it was now made to lift	186 grains.
4 more - - - - - -	246
30 lighter blows - - - -	326
20 more [began to bend] - - -	326

b. Compound process.

After 20 blows on I ii, (the magnetism before given not being destroyed, though much weakened by straightening it) it lifted 326 grains much more freely than before, but refused the next larger nail of 389 grains.

No. VIII.

A piece of the same wire as that used in the last experiment, 2½ inches in length. [S *t* iii.]

a. Simple process.

After being repeatedly hammered by this process, its lifting power was raised to 56 grains.

Hammered several times, at intervals, for a minute or two together, without increasing its power to lift 88 grains.

b. Compound process.

After 12 smart blows, under this process, the lifting power was augmented to 186 grains.

SECOND SERIES,

for ascertaining more exactly the comparative effects of a difference of temper on wires of the same quality and dimensions, and of the relative advantages of the different processes for the developement of magnetism by percussion in equal wires.

The apparatus consisted of the three iron rods (I i, I ii, and I iii,) with five new wires, from the same piece, of equal sizes, each of them being five inches in length, and 145 grains in weight; namely, S *u* iv, S *t* iv, S *t* v, S *t* vi, and S *t* vii.

EXPERIMENT No. IX.

New steel wire, S *u* iv *(untempered); not in the least degree magnetic.*

a. Simple process.

5 smart blows struck on this wire whilst held on bar I i, (which bar had previously been struck 20 hard blows with the large hammer, through the medium of the bar I iii) occasioned a lifting power of 37 grains.

b. Compound process.

[Magnetism of the wire destroyed.]

5 smart blows on this process, (each of the bars I i and I ii having been previously hammered whilst held vertically in the hand) produced a lifting power of $37 + 18 = 55$ grains, and very nearly 73 grains.

No. X.

New Steel wire S *t* iv *(softened), not at all magnetic.*

5 hard blows struck on this wire whilst held on the equator, or middle of the bar I i, (this bar lying horizontally instead of standing vertically as in the other experiments) produced only a lifting power of 4 grains

No. XI.

Similar wire to the last, S *t* v, *not in the least magnetic.*

5 blows struck on this wire, whilst held upon I i, both the bar and wire being in a vertical position, and both being freed from magnetism immediately before the experiment excepting the magnetism of position, occasioned a lifting power of 37 grains, and that with difficulty.

No. XII.

A wire similar to the last in every respect, S *t* vi ; *not in the least degree magnetic.*

a. Simple process.

5 blows were struck on this wire, held in the same position as in the last experiment on I i, the bar I i having been previously struck 20 hard blows with the large hammer, through the medium of I iii, by which treatment a lifting power was given to the wire of 112 grains.

The magnetism of the wire being destroyed again, the same experiment was repeated, and somewhat harder blows struck, by which, with 5 blows, a lifting power of 186 grains was obtained.

No. XIII.

Another wire exactly similar to the last in size, quality, and temper.

b. Compound process.

5 blows on this process, through the medium of I ii, (both the bars I i and I ii having been previously hammered to the same extent as before) produced a lifting power of 246 + 19 = 265 grains.

THIRD SERIES,

for determining the effect of larger iron bars.

In place of the rod I i, *a large bar of iron* (I iv) *was substituted. Its length was* 8 *feet, and its diameter* $1\frac{3}{4}$ *inches. The rest of the apparatus (rods* I ii *and* I iii*) was the same as before.*

No. XIV.

[July 14, &c.]

Wire S*t* i *being* 5 *inches in length,* $\frac{1}{8}$*th in diameter, and* 164 *grains in weight,* which, with the former apparatus, was made to lift* 345 *grains.* [*See Experiments* II. III. *and* IV.

a. Simple process.

Though the magnetism of this wire was nearly destroyed before this experiment, a few smart blows on I iv, gave it a ready lifting power of 326 grains.

* The weight of this wire was originally 167 grains; but it was reduced 3 grains by occasionally filing the end.

The experiment being repeated the next day, (July 15), when the bar, I iv, had become more magnetic by use, the wire readily lifted - - - - 389 grains.

A few more blows raised its power to - 482

Additional hammering - - 482 + 19 = 501

Experiment repeated, July 16, 482 + 51 = 533

b. Compound process.

After a few smart blows the lifting power of this wire was now raised to - - - 482 + 103 = 585.

Process continued by a number of blows 482 + 122 = 604.

After a variety of repetitions of this process, the large bar, I iv, having become strongly magnetic, the lifting power of the wire was augmented to 482 + 187 = 669 grains, being above *four* times its own weight.

No. XV.

[July 14 to 18]

A new untempered wire (S *u* iii), *from the same piece as* S *t* i, 4½ *inches in length; weight*, 150 *grains.*

a. Simple process.

After a few smart blows, this wire lifted - 246 grains.

On repeated hammerings, its lifting power was augmented to - - - - 326

The process repeated the next day, - - 389

Again repeated on another day - - 482

b. Compound process.

On the first application of this process, by a few hard blows, there was no accession of power, the lifting power continuing at - - - - - 482 grains.

But on repeating the process several times on the following day, the power rose to 482 + 120 = 602.

This process was again tried some days afterwards, and applied with considerable labour, the hammering being continued for half an hour together, sometimes by one process and sometimes by the other. At the commencement of the operations it was found to have retained of its former energy a lifting power of 389 grains. This was considerably augmented, but it never reached quite so high as before.

No. XVI.

Wire S t ii, 12 inches in length and one-sixth of an inch in diameter; being the same that was used in experiments V. VI. *and* VII. *when the maximum lifting power obtained was between 326 and 389 grains.*

a. b. Both processes alternately.

After a little hammering this wire now lifted 389 grains.

But after many repetitions on the same day [July 15] it refused 482 grains, though its former power was somewhat increased.

a. Simple process.

Some days after the preceding trial, when the great bar, I iv. had become strongly magnetic (after the conclusion of experiment No. XIV), this long wire was again subjected to experiment, when its lifting power was increased to 482 + 180 = 662 grains.

A piece of this wire, four inches in length, was now cut off, and the larger part was thrice hammered by the simple process, when its lifting power was 482 + 90 = 572, being a loss of 90 grains.

GENERAL REMARKS.

The results of the foregoing experiments were, in general, satisfactory, though there were some trifling anomalies, which will be noticed in their order. The chief points I had in view were tolerably well determined; but the investigation is so far from being complete, that what has been done, as is often the case in such researches, opens a much wider field of enquiry than I at first contemplated. I proceed, however, to state the chief results obtained, consisting of such deductions as I trust the experiments will be considered legitimately to warrant.

1. One principal object of enquiry in these experiments was, to prove the effect of a combination of rods of iron, on a plan previously arranged, for augmenting the magnetic power by percussion. The result was, in the main, perfectly agreeable to my expectations. For, by the employment of such a combination, which I have denominated the *compound process*, the magnetism developed was always more or less increased, but the proportion of augmentation was by no means regular, nor is the law by which it is governed very obvious. In experiment No. II, the maximum effect of the simple process was an attractive force capable of lifting between 186 and 246 grains; whilst the compound process readily augmented the lifting power to 326 grains. And on repeating the trial, (Experiment III.) on the simple process, the wire obtained a lifting power of 246 grains, which the compound process increased to 345. But the advantage was the most obvious in experiment No. VIII, when a very short piece of wire was used. In this case, whilst the simple pro-

cess only occasioned an attractive power capable of lifting between 56 and 88 grains, though the wire was repeatedly hammered, the compound process augmented the lifting power, by 12 blows, only, up to 186 grains, indicating three times the former magnetic energy.

But, on the other hand, in experiment No. VII, the application of the compound process to a very long wire, was productive of very little advantage. Nor was the compound process of so evident an advantage in the third series of experiments: in this case, however, the failure of effect was probably occasioned by the very small size of the upper rod, I ii, in comparison of the magnitude and mass of the lower.

2. Another object of enquiry in these investigations was the effect or relation of *temper*, in connection with the degree of magnetic energy developed. The result with the first apparatus, was conformable to the law of magnetics in general; namely, that the *softer* the temper the more susceptible the steel becomes of the magnetic condition. By a comparison of experiments No. I. with II., V. with VI., and IX. with XII. and XIII., the advantage of softening the wire is very obvious. In the first instance, a steel wire in the state in which it was drawn could only be made to lift between 36 and 73 grains; but the same wire, on being softened, readily lifted 186 grains, after nine blows on the simple process, and after 80 blows by both processes, its lifting power was augmented to 326 grains, being nearly twice its own weight, and at least five times the power it acquired in its untempered state. But this difference of susceptibility for receiving the magnetic energy, is rendered still more obvious by a comparison of the second set of experiments (No. V. and VI.) A long wire, untempered, being struck 20 or 30

smart blows by the simple process, only acquired a lifting power of between $7\frac{1}{2}$ and 18 grains; whilst the same wire, after being softened and subjected to a similar treatment, lifted 326 grains. And in the third set of experiments (IX, XII, and XIII,) the result was analogous. The untempered wire, by 5 blows on the simple process, lifted only 37 grains, and by the same number of blows on the compound process, 73; whilst a similar wire tempered lifted, after exactly the same treatment, 186 grains by the simple process, and 265 by the compound process.

The same result was indeed always obtained in various other experiments, not included in the preceding details, yet there is one in the third series [No. XV.] which is apparently at variance with this conclusion. The difference of effect, however, (the untempered wire in this instance having received an equal power to that of the softened wire of a similar kind), was evidently owing to the employment of a very powerful apparatus, the large bar of which had become highly magnetic from long continued use in these experiments. Hence a greater action upon bars of harder temper was to be expected, conformable to what occurs with the use of a powerful apparatus in the ordinary modes of giving magnetism to steel.

The facility with which magnetism may be developed in softened wires by this process is very striking. The first five blows, in experiment No. II, by the simple process, produced a lifting power of 73 grains, nearly one-half the weight of the wire;—the first two blows, in experiment No. VII, also by the simple process, produced, in a long wire whose magnetism had been totally destroyed by heating to redness, a lifting power of 186 grains; and the first 5 blows, in experiment No. XIII, on a new wire by the compound process, occasioned in this wire, of only 145 grains weight, a lifting power of 265 grains.

3. The increased magnetic energy developed by the use of larger bars of iron (a fact indeed which it was reasonable to expect) is quite satisfactory in all the comparative experiments. The long wire S *t* ii, by the *small* apparatus was made to lift between 326 and 389 grains, being the highest effect produced on it [Experiment No. VII.]; but on applying it to the *large* apparatus, its lifting power was at length augmented to 662 grains. [Experiment XVI.] And by the small apparatus, the highest power that could be given to the wire S *t* i, was a capability of lifting a weight of 345 grains [Experiments II, III, IV,]; but on using the large apparatus, the same wire [Experiment XIV.] was eventually made to lift 669 grains, being above *four* times its own weight. This was the highest effect produced. The advantage, however, of the large apparatus, was the most striking in the case of untempered wires. An untempered wire, S *u* i, had its lifting power, by the first apparatus, with difficulty raised to nearly 70 grains, [Experiment I.] whilst a similar, but somewhat shorter wire, S *u* iii, was, by the use of the large apparatus, readily made to lift 246 grains; and by continuing the process on several different days, its power was at length increased to 602 grains. [Experiment XV.]

4. It would appear from experiments IV. and XV, that in the use of any one apparatus there is a limit to the power which it is capable of developing; whereas, from the great augmentation of effect obtained by the use of a larger apparatus, it becomes probable, that were iron rods sufficiently

large employed, there would be no limit to the attractive force developed in the steel wires, until they were magnetised to saturation. The quantity of effect produced by an iron bar seems to be in some certain proportion to the amount of its own magnetic energy, as indicated by its action on a compass needle, but not in the proportion of its lifting power.

5. It is a well known fact in magnetics, that the capacity of steel for magnetism is increased by time—by repeated renewals of the magnetising process at intervals—and by keeping the magnet under constraint, either by the contact of other magnetic substances, or by the use of conductors between the opposite poles. Hence I expected, that a wire magnetised by percussion to a maximum for the time, might have its power subsequently increased, day after day, in consequence of its capacity being increased by a repetition of the process. To a certain extent this was the case; but when the iron bars had acquired their maximum energy, and the wires were then hammered until there was a decided suspension of increase of energy, no future repetition of the process, however laboriously conducted, gave me any additional power. [Experiments No. IV. and XV.]

On the first view of the subject, I was at a loss to account for the suspension of the augmentation, when I had calculated on an increased capacity for magnetic energy, with the continuation of the process, agreeable to the known laws of magnetics; but I eventually perceived that the analogy, with the ordinary communication of magnetism, was not complete. It was evident that the suspension of augmentation did not arise from the want of capacity in the *steel* for magnetism, the wires not being near a state of saturation; but it arose from the incapability of the *iron rods* attaining, or retaining, more magnetic energy. The maximum, in their conditions, it would appear, determines the maximum in the condition of the steel. But I apprehend, had I used very large rods, capable of communicating magnetism to the wires *above* the point of their saturation, then the usual analogy would have been complete, and I should, progressively, have attained higher and higher degrees of polarity.

As the phænomenon of the progressive elevation of the point of saturation in magnets became a matter of some thought and consideration with me, I may be excused, perhaps, for including here the substance of my reflections on this subject, and especially as some change, similar to what takes place in magnets having their saturated point raised by renewals of the magnetising operation, &c., also takes place in the disposition of steel bars or wires for polarity, by percussion. For, as a magnet having its poles reversed, will not, at first, by the same apparatus and process as that from which it originally derived its power, acquire the same intensity as before; so, in wires magnetised by percussion, with the same end always held downward, the inversion of the poles will not be accompanied by equal power as before. Respecting this phænomenon, I may suggest the following explanation.

The natural condition of iron is without polarity. It acquires polarity by certain modes of treatment, or juxta-position with magnetic substances; until which it evinces no attractive property. In this state its magnetic properties are neutral, and there is no tendency in the iron to develope polarity. But if it be rendered magnetic, no matter by what cause, as it is now in a state of constraint or violence, there is a tendency to return to the state of neutrality. In soft iron, the return to its former condition, is almost instantaneous on the removal of the disturbing cause; but in steel, the restoration to its former state is resisted by a force proportionate to the hardness of its temper. Soft steel readily acquires polarity, but it is evanescent; and hard steel receives polarity with difficulty, but it is very permanent. Though in all magnetised substances there is a force always acting towards the restoration of the condition of neutrality, yet, when the magnetism has been highly developed, it produces a permanent change in the point where the force ceases to act. This point we may call the state of *quiescence*, being the state of a magnetic substance, when the different magnetisms, though not perfectly neutralised, are yet, as it were, balanced. In the natural condition of a substance, capable of some permanency of magnetism, the neutral and quiescent states are coincident, but after every magnetising operation, if the denomination of the poles be always preserved the same, they are farther and farther removed; hence arises an increasing capacity for magnetic energy. If, for the sake of illustration, a piece of steel somewhat soft be magnetised: on the removal of the cause (provided no artificial means be used to keep it up), the polarity will gradually diminish until it comes to the quiescent condition, or the state where the resistance natural to the metal has no returning force to oppose. Suppose, in this state, it yet has polarity capable of lifting the weight of an ounce of iron, and that in its highest or saturated state of magnetism it lifted 20 ounces. On being again magnetised by the same means and process, it will now have increased its capacity to near 21 ounces. By thus continuing the process, and using means to retain the magnetism developed, the quiescent point may perhaps be raised as high as the original state of saturation; that is, to a lifting power of 20 ounces, when its saturated lifting power will approach to 40 ounces. But to effect this, it will be necessary to continue the poles always the same; for on every inversion of the poles, the point of quiescence will return somewhat towards the point of neutrality, and the magnetic energy will be proportionably diminished. On the first change of the poles, the magnetic energy, in a state of saturation, will be diminished by about the difference of the points of quiescence and neutrality, or nearly as much as in experiments with the same poles always preserved, the magnetic energy is augmented. Thus, when in the above example, the point of quiescence has a lifting power of 5 ounces, capable, when magnetised to saturation, of being raised to 25 ounces, on inversion of the poles it will only have a capacity for 15 ounces. These, most probably, are not the exact powers, for it is likely that the augmentation of force, which takes place on repeatedly magnetising at certain intervals beyond the point of quiescence, may diminish in a geometrical ratio, as the point of quiescence recedes from the point of neutrality; otherwise there would be no limit whatever to the power of a magnet. The law, however, not having been determined, I have used in the above examples an arithmetical ratio, merely for the sake of illustration.

This doctrine is the same when applied to the developement of magnetism by percussion, as by any other process, and easily explains why, on the first trial, especially with a weak apparatus, or with bars not perfectly softened, such great effects should not be produced as by numerous repetitions of the same process at different times. The proof as to the cause being the removal of the point of quiescence from that of neutrality, is, I think, quite conclusive. For in an experiment, (one among many to the same effect), made with the wire S *t* i, I found that when 5 blows with a hammer, on the compound process, with the north end of the wire downward (commencing when the attractive force was almost totally destroyed), gave it a lifting power of 326 grains; the same nnmber of blows, with the south end down, (also commencing when the attractive force was very nearly neutralised), gave it only a lifting power of 2 grains. In short, I have raised the point of quiescence so high above the point of neutrality, that a long and severe hammering, south end of the wire downward, only destroyed the original attractive force, but did not produce inversion of poles.

6. The foundation of this process for the developement of magnetism in steel, is the employment of such magnetism of large rods of iron as can be derived from juxta-position of the great magnet, the earth. And the high effects produced seem to depend on the disposition which percussion gives to the ferruginous particles for assuming that condition to which we give the name of *magnetic*. The iron rod employed, as soon as placed in a vertical position, or in the direction of the dipping needle, acquires polarity from the earth; but the natural resistance of its particles to the state of constraint which it must be in when magnetic, prevents its receiving the full power that the earth is disposed to communicate. Percussion, by producing a vibration among the particles of

the metal, seems to overcome this resistance; and, at the same time, disposes the iron for the retention of the magnetism acquired. Now, on placing a wire or bar of soft steel upon this rod of iron, its magnetic virtue occasions some developement of the same power in the steel, which is increased by the tendency that percussion has to aid its developement in the steel, the same as it previously elicited in the iron. By continuing this treatment, the polarity of the steel is progressively augmented until it has acquired a maximum, depending, not so much on its own capacity for magnetism, as on the capability of the iron to develope it. But this condition, it has been shown, is only a maximum so long as the same iron bar or bars are used, and so long as their magnetic energy obtains no augmentation; for if by any means their polarity be increased, the attractive force of the steel wires will rise in proportion. From the whole phænomena viewed in connection, it seems, that the simple general fact is this:—that percussion applied to magnetisable substances in contact with one another, disposes them to an *equality of condition.*

If this view of the subject be correct, we have a satisfactory explanation of some of the phænomena, which were otherwise obscure. We see why large bars, or wires of steel, (though they acquire a greater quantity of magnetic energy, as shown by their higher action on a compass needle, than small ones) do not attain any higher lifting powers than much smaller wires. [Compare Experiments III. with VII., and XIV. with XVI.] And, above all, we have an explanation of the apparently contradictory propositions—that percussion diminishes, and has a tendency to destroy the energy of magnets; and that percussion has a tendency to develope polarity in iron and steel not previously magnetic. Both these propositions are undoubtedly true; but they are under different conditions. Percussion, whilst it diminishes the energy of a magnet when held alone, or even upon an iron bar, would probably augment its energy if it were placed with consistent poles in contact with a more powerful magnet, which is the condition of wires magnetised by percussion; because, if they be hammered upon a substance not magnetic, little or no energy is developed. [See Experiment No. X.] These different effects would appear to be the necessary result of a tendency to equality of condition—a tendency which is precisely similar in respect to bodies of unequal temperatures when placed in contact, or even in juxta-position. For as a hot body placed near, or among, cold substances of greater mass and capacity than itself, has its temperature brought down nearly to the state of the colder substances, whilst a cold body has its temperature raised by contact with hot substances; in like manner, a strong magnet hammered upon an iron rod, has its energy brought down towards the condition of the iron; and a bar not magnetic, or slightly so, hammered upon the same rod, has polarity developed in it, and raised progressively up to the condition of the iron.

As I apprehend it would be in vain to attempt to produce such strong magnetic effects, as we derive from percussion, by the simple use of the same bars and apparatus in any of the known modes of *touching*, it becomes probable that this process might be applied, in connection with other modes of magnetising, for giving increased power to magnets. The extraordinary power of KNIGHT's magnets are well known; though the secret of their manufacture died with him, and no effect at all comparable, has, I believe, been since produced. Is it not probable that he may have employed a process of this description?*

* I am indebted for this thought to a suggestion of Sir H. DAVY's, in a conversation on these experiments.

W. S. *Junr.*

On board the ship Baffin, off Iceland,
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