

Latitude. North.		Longitude. West.		Sun's Alti- tude.	Variation. West.	
o	'	o	'		o	'
28	55	39	28	27	5	23
29	8	40		26	7	12
31	10	44	46	30	8	6
31	7	46	45	22	4	46
30	42	49		38	4	40
30	29	49	48	22	4	
30	31	52	10	25	4	49
30	18	53		25	4	45
30	23	55		25	4	22
30	58	57	30	22	4	52
37	9	68		38	4	50

VI. *Some Thoughts and Conjectures concerning the Cause of Elasticity*, by J. T. Desaguliers, LL. D. F. R. S.

A Ttraction and Repulsion seem to be settled by the Great CREATOR as first Principles in Nature; that is, as the first of second Causes; so that we are not solicitous about their Causes, and think it enough to deduce other Things from them. If Elasticity was admitted as a first Cause, (as it is by some) it is thought we should admit of too many principal Causes in Nature, which is contrary to the Rules of good Philosophy. Philosophers therefore have endeavour'd to deduce Elasticity from Attraction, or from Repulsion, or from both. It is observ'd, that the same Particles that repel each other strongly,

Z

will

will attract other Particles very strongly; as appears by many Chemical Dissolutions, especially by the alternate Dissolution and Precipitation of Metals in acid *Menstruums*. The Reverend and Learned Dr. *Hales* has proved this many Ways, in his *Vegetable Statics* and *Hæmæstatics*. The Elasticity of Air seems to consist wholly in the repulsive Power of its Particles, which do not touch one another while the Air is in its elastic State; and if those Particles be brought nearer and nearer together, the Effect of their repulsive Force will increase, the Air's Elasticity being always proportionable to its Density by Compression, which Property will be preserv'd, though compress'd Air be kept a Year or two; notwithstanding Mr. *Hauksbee* in his *Physico-mechanical Experiments* says, that Air will lose part of its Spring by being very much compress'd. But the Air with which he try'd it, must have been fill'd with moist Vapours; and it is well known, that the Steam of Liquors will lose its Elasticity, especially where its Heat decays. I have kept several Wind-Guns, strongly charg'd, for half a Year together, in which the Air had lost none of its Elasticity: Others have found the Air as strong after a Year; and I have been told by a Person of Credit, that a Wind-Gun having been laid by and forgotten for seven Years, when it was found, discharg'd its Air as many times, and with as much Force, as it used to do. Now, though Air, compress'd by any external Force, does always increase in Elasticity, as it diminishes in Bulk; yet it may, by Fermentation, diminish its Bulk very much, without gaining any more Elasticity: For if another Fluid, whose Parts repel one another, but attract the Parts of Air, be mix'd

mix'd with Air, the Repulsion of any two Particles of Air will be diminish'd, in proportion as a Particle of the other Fluid, insinuating itself between them, attracts them towards itself on either Side. The same thing will happen to the other Fluid, in respect of the Particles of Air, which mixing with its Particles, do in the same manner destroy their Repulsion. Thus, if we allow an Attraction strong enough between the Parts of two elastic Fluids, it is possible, that by Fermentation a Solid may be made out of two elastic Fluids, which would have still continued fluid without such a Mixture. We are taught by Chemistry, to mix Fluids together, which immediately coalesce into a Solid. When Brimstone Matches are burning, the *Effluvia* of the Sulphur repel each other to great Distances, as may be known by the sulphureous Smell upon such an Occasion. Now, though these Particles repel each other, they attract the Air very strongly, as appears by the following Experiment :

Take a tall Glass Receiver clos'd at Top, holding about four Quarts of Air, and having put its open End over a Bundle of Brimstone Matches on Fire, standing up in the Middle of a large Dish with Water in it, (to keep the Air from coming in at the Bottom of the said Receiver) you will observe, that not only as soon as the Matches are burnt out, but a good while before, the Air, instead of being expanded by the Flame of the Brimstone, will retire into less Compass, the Water beginning to rise from the Dish up into the Receiver, and continuing so to do till some time after the Matches are burnt out ; so that there will be in the Receiver only three Quarts of Air, instead of four (more or less, in proportion

portion to the Quantity of Brimstone burnt): And this plainly happens by some of the *Effluvia*, or little Parts of the Sulphur, attracting some of the Particles of the Air, so as to make an unelastic Compound, that precipitates into the Water. If the Elasticity of the Air is quite lost when the Repulsion of its Particles is taken off, or sufficiently counteracted, it must follow, that its Elasticity depends upon Repulsion: And that this is often the Case, appears by a great Number of Dr. *Hales's* Experiments, of which I will mention but a few. The Doctor took a Cubic Inch of Mutton-Bone, and having put it into his Gun-Barrel Retort, he distill'd out of it two or three hundred Cubic Inches of Air into a large glass Bottle, the Weight of which Air, together with the Ashes of the Bone left, weigh'd as much as the whole Quantity of Bone did at first. Now the Air had been confin'd in that Bone, together with many sulphureous Particles, in such manner, that the mutual Attraction of the Sulphur and the Air had alternately destroy'd each other's repulsive Force, and brought those Substances into a little Compass; but the Fire in the Distillation separated them from each other, so as to restore them, in a great measure, to their usual Elasticity. This appear'd by bringing a Candle near the Mouth of the Bottle that held this reviv'd Air; for every time the Candle was brought near, the Air took Fire, and flash'd out of the Bottle with a sulphureous Smell. The Air may be consolidated in many hard Bodies, so as to be there quite void of Elasticity, and there do the Office of a Cement, till by the Action of Fire, or some particular Fermentations, it is again restor'd to its perfectly elastic State.

This

This is the Meaning of the Doctor's Words, when he says, that some Bodies *absorb*, and others *generate* Air; and the same Bodies do sometimes absorb, and at other times generate Air. He found more or less Air in almost every solid Substance that he try'd; but, what was most remarkable, he found that the *Calculus humanus* (or Stone taken out of a Man's Bladder) was made up of above half its Weight of Air.

Some have endeavour'd to solve Elasticity by Attraction only; as for Example: If the String *AB* (TAB. I. Fig. 1.) be consider'd as made up of Particles lying over one another in the manner represented at *ADB*; it is plain, that if the Point *D* be forcibly brought to *C*, the Parts will be pull'd from each other; and when the Force, that stretch'd the String, ceases to act, the Attraction of Cohesion (which was hinder'd before) will take place, and bring back the String to its former Length and Situation after several Vibrations. Now, though this seems to agree pretty well with the *Phænomena* of a String in Motion, it will by no means solve the Elasticity of a Spring fasten'd at one End, and bent either way at the other, like a Knife or Sword-blade, as in Fig. 2. For if such a Spring be bent from *A* to *a*, the Particles on the Side *C*, which now becomes convex, will be farther asunder at *F*, while the Particles at *D*, carried to the concave Part *E*, will come closer together: So that the Attraction, instead of making the Spring restore itself, will keep it in the Situation in which it is, as it happens in Bodies that have no Elasticity, where perhaps only Attraction obtains. Thus a Plate of Lead, a Plate of Copper, and a Plate of soft Iron, stands bent.

But

But the most probable way of solving the Elasticity of Springs, is to consider both a repulsive and an attractive Property in the Particles, after the manner of the black Sand, which is attracted by the Loadstone, and has been shewn by the learned and ingenious Professor *Petrus van Muschenbrook*, to be nothing else but a great Number of little Loadstones.

Fig. 3. Let us suppose a Row of round Particles touching one another only in the Points c in a Line from A to B . It is plain, from what Philosophers have shewn, concerning the Attraction of Cohesion, that upon the least Shake, or Alteration of the Position of a strait Line, these Particles will run together, and form a Sphere, in which the Globules will have more Points of Contact. But if these Particles have Poles like Magnets in the opposite Places mark'd n, s , so that all the Poles n, n, n , &c. repel one another; and all the Poles s, s, s , &c. do likewise repel one another, the Line AB will continue strait; for if by any Force the said Line BA be put into another Position, as into the Curve ba , then the Poles nn , &c. being brought nearer together, (while the Poles ss , &c. are farther asunder) will repel one another more strongly, and thereby hinder the Globules from running together towards the concave Part; and the Spring, left to itself, (all this while supposing one End, as b, B , or β , fix'd) will restore itself, throwing its End a back to A , and so on to α , by the first Law: Then being in the Position $\alpha \beta$, the Poles s, s , &c. are brought nearer together, whose Repulsion, thus increas'd, throws back α to A , and so on forward, the Line of Particles performing several Vibrations round B .

May not a Spring of Steel, or other Springs, consist of several Series of such Particles, whose Polarity and Attraction acting at the same time, will shew why such Bodies, when they have been bent, vibrate, and restore themselves?

If we take a Plate of Steel, and make it so hot till it looks white, and then immediately quench it, we thereby fix the Metal in a State very near Fluidity, so that the Particles which the Fire had almost brought to Roundness, have but a very small Contact; as appears by the Fragility of the Steel thus harden'd, which breaks like Glass, and has a short Grain. Steel, thus harden'd, is highly elastic; for what Workmen call *hard*, is the most *elastic*: as appears by the Congress of high-harden'd Steel Balls, which return, in their Rebound, the nearest to the Place we let them fall from; and, next to Glass, have the quickest Elasticity of any thing we know.

That we may not be thought to have given an imperfect Account of the Elasticity of a Steel Spring, because such an one as we have describ'd wants Toughness, and will immediately fly when bent to any Degree; we must beg Leave to consider farther the Properties of the round Particles, or little Spheres, of Steel, in which we have suppos'd a Polarity.

Let us suppose *AB* (Fig. 4.) to be two little Spheres or component Particles of Steel, in which, at first, we will suppose no Polarity, but only an Attraction of Cohesion. Then, whether the Particles have their Contact at *c, d, e, n*, or at *δ, ε, s*, their Cohesion will be the same; and the least Force imaginable will change their Contact from one of those Points to another; because in the rolling of these little Spheres, they

they do not come into more or less Contact in one Situation than another. But if we suppose the Point n in each Spherule to be a Pole with a Force to repel all the other Points n in any other Spherule, and likewise s another Pole, repelling the other Points s ; the Spherules will cohere best, and be at Rest in that Position where the Points c, c , are in Contact, and n and s at equal Distances on either Side. For if the Spherules be turn'd a little, so as to bring the Points d, d , into Contact, as in Fig. 5. the Poles n, n , being brought nearer, act against each other with more Force than the Points s, s , which are now farther off, and consequently drive back the Spherules to the Contact at c, c , beyond which continuing their Motion, they will go to d, d , Fig. 6. and so backwards and forwards, till at last they rest at c, c , which we may call *the Point of Equilibrium for Rest* in a Spring. Now there are, besides this, two other *Points of Equilibrium*, beyond which the Spring may break, which are the Points e, e towards n , and ϵ, ϵ towards s ; see Fig. 7. that is, when the Spherules have their Poles n, n brought very near together, the mutual Repulsion increases so, that the Attraction at the Contact is not able to hold them, and then they must fly asunder, the Spring breaking. We suppose the Points e, e , to be the Points of Contact, beyond which this must happen; but that if the Contact be ever so little short of it, as between e and d , the Spherules will return to their Contact at c , after some Vibrations beyond it, as has been already said. This is the Reason why I call e , (in one of the Spherules) and its correspondent Point ϵ on the other Side c , *the Points of Equilibrium*; for if the Spring be bent

bent towards *a* (Fig. 3.) so that the Spherules, like *A* and *B*, (Fig. 7.) touch beyond *e*, the Spring will break: Likewise if the Spring be bent the other way, till the Spherules touch beyond *e*, then it will break the other way. Now when the Spherules touch at *e, e*, or at *ε, ε*, the Spring is as likely to return to its first Position as to break; for which Reason I have call'd the Points *e* and *ε*, *Points of Equilibrium*, as also having known by Experience, that a Spring left bent to a certain Degree, has, after some time, broke of itself.

From all this it appears, that Spherical Particles will never make a tough Spring; therefore the Figure of the Particles must be alter'd, in order to render it useful; and this is what is done in bringing down the Temper of the hard Steel, and *letting down a Spring*, as it is call'd. What Change ought to be made in the Particles, we shall first shew; and then consider how far that is done by those who make Springs.

If the Parts suppos'd Globules, as in Fig. 3. are now flatten'd at *c*, where the Contact is, so as to put on the Shape *n e d c δ e s*, (as in Fig. 8.) the Contact will be much increas'd, and reach from *d* to *δ*, so that in bending the Spring there will still remain a great Contact in the Particles, and the Points of *Equilibrium* for breaking (*viz.* *e, e* above, and *ε, ε* below) will be remov'd nearer to the Poles *n*, or *s*, than when the Particles are round; the Consequence of which will be, that the Spring must be bent much farther, to be in Danger of breaking, than in the former Supposition; as may be seen in Fig. 9. where two Particles being open'd about the Point *d* as a

A a

Centre,

Centre, the attracting Points $c, c,$ and $d, d,$ have still some Force to help to bring back the Particles to their whole Contact; because in this Shape of the Particle the attracting Points c, c, d, d are remov'd but in Proportion to their Distance from the angular Point d ; whereas if the Particles had been spherical, and the Line d, d an Arc of a Circle, the attracting Points $c, c,$ and $d, d,$ would have remov'd from one another farther than in Proportion to twice the Square of the Distance from $d,$ (as in Fig. 5.) and so have afforded very little Help for bringing back the Particles to their Contact. A Row of Particles in the Spring thus condition'd, is to be seen in the natural State at $B, A,$ Fig. 10. and bent at b, a in the same Figure. Here it is to be observ'd, that if in this Figure of the Particles you would bend the Spring to bring the Particles to touch at their Point of *breaking Equilibrium*, you must open them so much on the contrary Side, that the Spring will be bent far beyond any Uses intended to be made of it, as appears by Fig. 11. where two Particles are brought to touch at the equilibrating Point e ; and by Fig. 12. where many Particles being put into that Condition, the Spring is brought round quite into a Circle.

Now the common Practice in making Springs is the most likely to produce this Effect requir'd in the Particles; for the hard Spring, whose Particles were round, or nearly so, is heated anew, and whilst it is cooling gently, the mutual Attraction increases the Contact, so that the Particles grow flatter in those Places where before they had but a small Contact; and lest this Contact should become too great, the Spring's Softening is stopp'd by quenching it in Water,

or

or Oil, or Grease. Another way of making Springs, is to begin and shape them in cold unelastic Steel, and then having heated them to a small Degree, for Example, to a Blood red Heat, immediately to cool them in some proper Liquors. This also settles the Particles in their oblong Figure, through which they must pass before they become round, or nearly so, in a white Heat. That Particles of Steel are fix'd in the Figures which they have at the Instant of dipping, will not appear strange, when we consider, that dipping red-hot Steel in cold Liquors, in a particular Position, makes it magnetical. If it be ask'd, How we account for making Springs only with hammering, it is easily answer'd, That we can make Iron and Steel magnetical only with hammering; and if we can give and destroy Poles in the whole Piece, there is no Improbability to think we can give Poles to little Parts; or rather bring into a particular Situation the Poles which they have; for if the Poles that we have consider'd be plac'd quite irregularly, there will be no Elasticity at all. Agreeable to this, Springs may be made of other Metals than Iron or Steel, though not so perfect, by Hammering; for it will be sufficient for the little Particles to have Poles that attract and repel one another, driven by the Hammering into a regular Order.

N. B. *This, apply'd to the Vibration of a String, will better solve its several Cases than Attraction alone; and the Elasticity of Glass is just the same as that of a very brittle Steel-Spring.*





