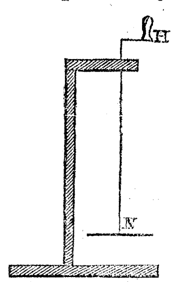
XVI.—*On the elasticity of threads of glass, with some of the most useful applications of this property to torsion balances.* *By* WILLIAM RITCHIE, *A.M. F.R.S., Rector of the Royal Academy of Tain.*

Read March 18, 1830.

1. FROM facts connected with crystallization and elasticity, it seems extremely probable, that the atoms of matter do not attract each other indifferently on all sides. There appears to be peculiar points on their surfaces which have a more powerful attraction for each other, than for other points on the same molecule. This property is not peculiar to the atoms of ponderable matter, but seems also to belong to those of light and heat. It is as impossible to prove directly the existence of this property, as it is to prove the existence of atoms themselves; but on account of the satisfactory manner in which it enables us to explain the phænomena of crystallization and elasticity, it is now generally adopted.

2. If the atoms of solid bodies be slightly displaced by any mechanical means, they will endeavour to return to their former state of aggregation when the disturbing cause is removed. This property belongs in very different degrees to different substances. In lead it scarcely exists, and but slightly so in soft copper. In brass, iron and silver, especially when drawn into wires, it exists in a considerable degree. But all these substances have limits beyond which the property does not hold. If for example an iron wire be twisted several times, it will not return exactly to its former state, but remain partially twisted. In threads of glass, on the contrary, there seems to be no limit to this property, whilst the thread remains entire. Let a fine glass thread be suspended from a moveable index, and let a light horizontal needle of wood or straw be fixed to its lower extremity as in the annexed figure. If the thread be now twisted by means of the handle H, whilst the needle N is prevented turning round, and then allowed to untwist itself, the needle will return exactly to its former position after it has ceased to oscillate.



If the vitreous molecules be held together by the attraction of their poles or points of greatest affinity, it is obvious that these points will be displaced by torsion along the whole line of communication. The points of greatest attraction thus displaced, will therefore endeavour to regain their former state of stable equilibrium, and the thread will of course untwist itself till the needle returns to its former position. It would be curious to ascertain if a thread of glass, twisted as much as it can safely bear, and kept in that position for several months or years, would return exactly to its former position, or whether the atoms might not in course of time take up a new state of stable equilibrium.

3. The number of times a thread of glass may be twisted without breaking, will of course depend on its length and diameter. It is almost incredible the number of times a thread of a substance so brittle as glass may be twisted, before the points of greatest attraction of the vitreous molecules be actually removed beyond the sphere of attraction, or in other words, before the thread be broken. I have succeeded in drawing threads of glass of such extreme tenuity, that one of them, not more than a foot long, may be twisted nearly a hundred times without breaking. Hence it is obvious, that if a thread could be drawn so fine as to consist of a single line of vitreous molecules, torsion could have no tendency to displace the points of greatest attraction, and this elementary thread might be twisted for ever without breaking. In that case the compound molecules of glass would only turn round their points of greatest attraction, like bodies revolving on a pivot,

4. It is difficult to prove by direct experiment some of the laws of torsion established by Coulomb, as belonging to metallic wires, on account of the difficulty of procuring threads of glass of a uniform diameter throughout their whole length. It is difficult, for example, to prove by experiments, that the force of torsion of a glass thread is directly as its length, and inversely as the fourth power of its diameter. Fortunately, however, the only property which we are to employ in the construction of the following instruments, can be proved by direct experiment. This property is, within certain limits, common to all elastic threads, namely, "that the force of torsion, or that force with which a thread tends to untwist itself, is directly proportional to the number of degrees through which it has been twisted*."

* Biot, Traité de Physique, tom. i. p. 486.

This property may be established by the following methods.

1st, Let a horizontal needle of glass, or of any substance not magnetic, be fixed to the lower extremity of a fine thread of glass, and then made to oscillate: it will be found that these oscillations are isochronous, even when the thread has been twisted through several circumferences. Now this isochronism may be proved to belong only to an elastic thread possessing the property enunciated in the preceding proposition.

2ndly, Suspend a magnetic needle in a horizontal position, by a similar glass thread, over the centre of a large circle having its circumference divided into degrees. Twist the thread by means of the key as in the common torsion balance, and note the degrees of torsion and the corresponding deviations of the needle from the magnetic meridian, and it will be found that the sines of the deviations are proportional to the corresponding degrees of torsion;—a property which can only belong to elastic threads possessing the property in question*.

5. This perfect elasticity of torsion belonging to threads of glass, may be applied with decided advantage to the electric and magnetic balances of COULOMB. All that is necessary in those cases is to substitute a thread of glass of the proper degree of fineness, for the silver wires employed with so much success by the ingenious inventor. The application of this property to the construction of a galvanometer and delicate balance, is, I believe, new, and therefore I have ventured to lay a description of them before the Society; but before doing this, it may not be improper to describe the best method of making the glass threads employed in the construction of these instruments.

Heat the end of a clean thermometer tube at the flame of a blowpipe, and draw it out till it be of the thickness required for fixing in the hole in the end of the torsion key, as in the annexed cut. 

Direct the flame of lamp on the tube at A, till the glass has become sufficiently soft. Remove it from the flame, and draw it out rapidly till it be of the length and fineness required. By separating the thread from the tube, we shall thus have a thread of any degree of fineness, terminated by two thicker portions, which may be securely fixed with cement or sealing-wax as circumstances may

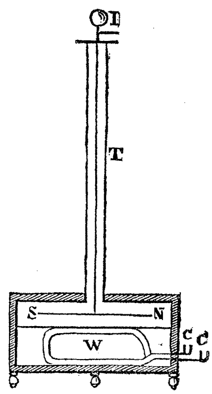
* BIOT, Traité de Physique, tom. iii. p. 29.

require. Simple as this may appear, it requires some practice in manipulation to do it well; it will therefore be necessary to draw several threads of different lengths and degrees of fineness, and afterwards select those best adapted to the instrument to which it is to be applied.

6. Description and use of the torsion galvanometer.

Take a fine copper wire and cover it with a thin coating of sealing-wax. Roll it about a heated cylinder an inch or two in diameter, ten, twenty, or any number of times, according to the delicacy of the instrument required. Press together the opposite sides of the circular coil, till they become parallel and about an inch or an inch and a half long. Fix the coil in a proper sole, and connect the ends of the wires with two small metallic cups for holding a drop of mercury. Paste a circular disc of paper, divided into equal parts, horizontally on the upper half of the coil, and having a black line drawn through its centre and in the same direction with the middle of the coil. Fix a small magnet, made of a common sewing-needle or piece of steel wire, to the lower end of a fine glass thread, whilst the upper end is securely fixed with sealing-wax in the centre of a moveable index, as in the common torsion balance. The glass thread should be inclosed in a tube of glass, which fits into a disc of thick plate glass, covering the upper side of the wooden box containing the coil and magnetic needle.

The whole will be obvious from the simple inspection of the annexed vertical section of the instruments, in which W is the coil of wire, C C′ the cups, T the glass tube containing the thread, I the index turning in the centre of a divided circle to mark the degrees of torsion, and N S the magnetic needle.



By means of this instrument we may compare with great accuracy the relative quantities of currents of voltaic electricity circulating along the wires of the coil. For this purpose place the needle directly above the line drawn on the paper, and consequently directly above, and in the direction of the wires forming the upper side of the coil. Cause a current of voltaic electricity to circulate along the wires, and the needle will of course be deflected. Twist the glass thread, by turning the index, till the needle be brought to its former position, and note the number of degrees of torsion; untwist the thread, and repeat the experiment with another current; and the quantities of electricity circulating round the wires will be directly proportional to the number of degrees through which the thread has been twisted. By this contrivance it is obvious that the currents always act with the same mechanical advantage on the needle; and consequently their deflecting forces, which are counterbalanced by the elastic force of torsion, must be directly as the number of degrees through which the thread has been twisted. In the common galvanometer, the deflecting force acts with diminished mechanical advantage as the needle deviates from the coil. When it has been deflected nearly 90 degrees from the original position, an additional power will produce scarcely any effect, and consequently the instrument ceases to give indication of a more energetic current.

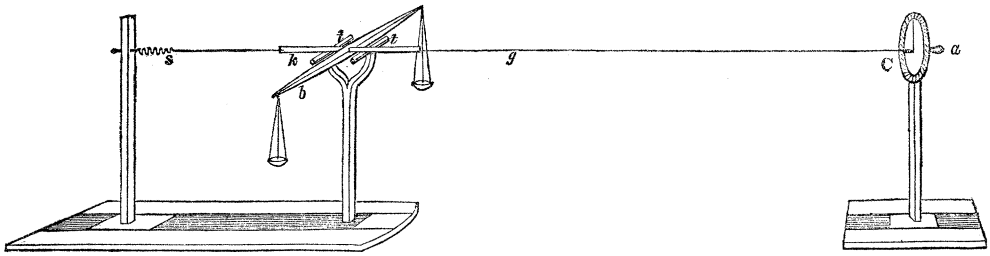
This instrument appears to me well adapted to many interesting investigations connected with voltaic electricity; but these could not properly be introduced in this paper, and may therefore form the subject of another communication.

7. We shall now describe another application of the elasticity of glass threads for ascertaining the weight of very minute portions of matter. The chemist in some of his most refined analyses has frequently to ascertain the weights of minute portions of matter, which by the ordinary process is a work of time and labour. A balance of the most delicate and perfect kind is also required, which, from its expense, frequently prevents the young chemist from prosecuting his experimental researches.

The balance which I am now to propose may be made at a trifling expense, and it will give the weights of small quantities of matter to a degree of accuracy seldom attained by the most perfect hydrostatic balances.

Prepare a small wooden beam, very light and about a foot or fifteen inches long, into the centre of which fix a steel blade having a smooth edge, like the blade of a fine penknife. To one extremity of the blade and in the line of its edge a fine thread of glass is to be securely fixed, whilst the other end of the thread is to be secured with sealing-wax in the centre of a small cylindrical key, passing through the centre of a vertical circle divided into degrees, or any convenient number of equal parts. To the other end of the fulcrum, and also in the line of the edge, a fine thread formed of a few fibres of untwisted silk is to be attached, whilst its other extremity is to be fixed to a spiral spring formed of fine brass wire, in order to keep the glass thread properly stretched. The knife edge is made to rest on two small portions of thermometer tube, placed parallel to each other on the top of an upright support. Portions of a still smaller steel blade are to be fixed, nearly in the same straight line with the edge of the fulcrum and at the ends of the beam, for suspending the scales. In one end of the beam a fine sewing-needle is to be fixed, for the purpose of pointing out, on a divided scale, the position of the beam when nearly horizontal. A similar needle is to be fixed in the cylindrical key, for pointing out the number of degrees of torsion which the thread has suffered.

The annexed figure represents a perspective view of the instrument seen obliquely, in which *b* is a beam, *g* the glass thread, *k* the knife edge fulcrum, *t t'* the thermometer tubes for supporting the beam, *s* the spiral spring with its attached silk thread, *c* the divided circle, and *a* the torsion key.



Having thus described the balance itself, we shall now explain the manner of employing it; first, for the determination of very small weights, and secondly, for heavier ones.

1st. To determine the weight of a small quantity of matter by employing only one weight, suppose a grain.—Twist the glass thread by turning the torsion key through two or three circumferences, according to the degree of torsion which it will bear without the risk of breaking. Put brass filings or other convenient counterpoise, into one of the scales till the beam be brought to a position nearly horizontal, the index of the torsion key pointing to zero on the divided circle. Place the body to be weighed into the scale, which is to be raised by untwisting the glass thread. Turn the torsion key till the elastic force of the thread raise the weight, and carefully observe the point on the scale at which the needle, in the end of the beam, becomes stationary. Note the number of degrees of torsion which the thread has suffered. Remove the weight, and untwist the thread till the beam returns to its horizontal position. Put a small known weight into the same scale, and turn the torsion key till the beam be raised to its former horizontal position, and observe the number of degrees of torsion:—then will the degrees of torsion give the ratio of the known and unknown weights. For example, if the thread suffered a torsion of 1500 degrees to raise the body B, and 1000 to raise one grain, then 1000 : 1500 : : 1 grain : 1.5, the weight of the body. If the body required only 50 degrees of torsion to raise it, then its weight would be $\frac{50}{1000}$ or .05 of a grain.

2ndly. When the body to be weighed is much heavier than a grain, the best way will be to ascertain its weight within a grain by the method of double weighing, and then apply the principle of torsion for ascertaining the fraction of a grain. Suppose the body to weigh nearly 100 grains, twist the thread through two or three circumferences exactly as in the former method. Bring the beam to a horizontal position by small shot or filings. Put the body into one of the scales, and shot or filings into the other, till the body be exactly counterpoised. Remove it, and substitute known weights till they be nearly equal to the weight of the body. Turn round the torsion key till the beam be brought to a horizontal position, and note the degree of torsion.

Put a grain into the scale, and observe the additional number of degrees of torsion necessary to bring the beam to its horizontal position; and we thus get the fraction of a grain which the body exceeds the known weights employed. If for example the body weighed nearly 100 grains, and it required a torsion of 50 degrees to raise the scale when 99 grains had been put into it after the body had been removed, and also that the thread required an additional torsion of 1000 when one grain had been placed in the same scale, then the weight of the body will be $99\frac{50}{1000}$ or 99.05 grains.

8. It is of course necessary to prevent the agitation of the air acting on the balance and its scales, and therefore the whole may be inclosed in a box as in the common balance. It is not necessary, however, to inclose the glass thread and the divided circle, and therefore the thread may be made to pass through a hole in the back of the box, and removed when the balance is not in use. It is useful to have a number of threads of glass of different degrees of

fineness, having small brass tubes cemented on their ends for the purpose of attaching them to the fulcrum and torsion key.

The method now described may appear somewhat tedious, but it is only so in appearance, as the oscillations do not continue so long as in a delicate balance without the torsion thread. In some delicate experiments with this balance, I have used threads of glass about ten feet long, so that in raising a weight of one grain, the glass thread suffered a torsion of at least 5000 degrees. Hence a very small fraction of a grain may be determined with an extraordinary degree of accuracy. From the perfect elasticity of torsion which glass possesses, and from the ease with which threads of any length and fineness may be procured, I am fully convinced that, for all delicate investigations connected with torsion balances, threads of this substance will be found to possess decided advantages.