The late C. Neumann, in his pamphlet *Ueber die Principien der Galilei-Newtonschen Theorie* (Leipzig, 1870), like Newton, postulates an "absolute rest." He does so by assuming that there is a "Körper Alpha," an ideally existing body which is absolutely at rest and absolutely rigid, with respect to which the First Law of Newton holds good.

Streintz criticises this rather unintelligently, I think, for it is evident in reading Neumann's essay that this is merely an awkward and metaphorical way of stating the theory of an "Abstract Dynamics."

### Note C.—*The Parallelogram of Force.*

Force being defined kinetically, it is hardly necessary to demonstrate this proposition. It follows as easily from the parallelogram of accelerations as that does from the parallelogram of velocities, or the parallelogram of velocities from the parallelogram of steps.

This applies primarily to forces acting on a particle, but it is easy to extend the theorem to "forces acting on a body," as defined in the Essay.

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## LVII. *On the Production, Properties, and some suggested Uses of the Finest Threads.* *By* C. V. Boys, *Demonstrator of Physics at the Science Schools, South Kensington* *.

I HAVE lately required for a variety of reasons to have fibres of glass or other material far finer than ordinary spun glass; I have therefore been compelled to devise means for producing with certainty the finest possible threads. As these methods may have some interest, and as some results already obtained are certainly of great importance, I have thought it desirable to bring this subject under the notice of the Physical Society, even though at the present time any account must of necessity be very incomplete.

The subject may be naturally divided, as in the title, into three parts.

### 1. *Production.*

The results of the natural methods of producing fibres by living things, as spiders, caterpillars, and some other creatures, are well known; but it is useless to attempt to improve on Nature in this direction by our own methods.

Fibres are also produced naturally in volcanoes by the rushing of steam or compressed gases past melted lava, which is carried off and drawn out into the well-known Pelés hair. The same process is employed in making wool from slag, for

* Communicated by the Physical Society: read March 26, 1887.

clothing boilers, &c.; but in each of these cases the fibres are matted together, they are not adapted to the requirements of a Physical Laboratory. By drawing out glass softened by heat by a wheel we obtain the well-known spun glass.

There is a process by which threads may be made which is natural in that natural forces only are employed, and the thread is not in any way touched during its production. This is the old, but now apparently little-known experiment of electrical spinning. If a small dish be insulated and connected with an electrical machine and filled with melted rosin, beeswax, pitch, shellac, sealing-wax, Canada balsam, guttapercha, burnt india-rubber, collodion, or any other viscous material, the contents will, if they reach one edge of the dish, at once be shot out in the most extraordinary way in one, two, or it may be a dozen threads of extreme tenuity, travelling at a high speed along "lines of force." If the material is very hot, the liquid cylinders shot out are unstable and break into beads, which rattle like hail on a sheet of paper a few feet off. As the material cools, the beads each begin to carry long slender tails, and at last these tails unite the beads in twos and threes; but the distance between the beads is far greater than that due to the natural breaking of a cylinder into spheres, as after the first deformation of the surface occurs which determines the ultimate spheres the repulsive force along the thread continues, and drags them apart many times their natural distance. As the temperature continues to fall and the material to become more viscid, the beads become less spherical, and the tails less slender, and at last a perfectly uniform cylindrical thread is formed. If sealing-wax is employed, and a sheet of paper laid for it to fall on, the paper becomes suffused in time with a delicate rosy shade produced by innumerable fibres separately almost invisible. On placing the fingers on the paper, the web adheres and can be raised in a sheet as delicate and intricate as any spider's-web.

It is interesting to see how these fibres fly to any conducting body placed in their path. If the hand is held there it is quickly surrounded by a halo of the finest threads. If a lighted candle is placed in the way, the fibres are seen by the light of the candle to be rushing with the greatest velocity towards it, but when a few inches off they are discharged by the flame, they stop, turn round, and rush back as fast into the saucer whence they came. The conditions for the success of this beautiful experiment are not very easily obtained*.

Fibes spun by the electrical method are so brittle that they

* If the wick of the candle is connected with the opposite pole of the machine, the threads at one stage are sure to return to the saucer.

do not seem to be of any practical use. It is possible, however, that this method might be available for reducing to a fine state of division such of the rosins or other easily fusible bodies as cannot readily be powdered mechanically.

On returning to bodies which, like glass, require a high temperature for their fusion, to which the electrical method is inapplicable, we find that the only method practically available is that of drawing mechanically. It would seem that if finer threads than can be formed by the ordinary process of glass-spinning were required, it would be necessary to obtain a higher speed, to have the glass hotter, and to have as small a quantity as possible hot. I put this idea to a test by mounting at the back of a blowpipe-table a pair of sticks which could be suddenly moved apart by a violent pull applied to each near their axes. By these means the upper ends were separated about 6 feet, and the motion was so rapid that it was impossible to follow it. A piece of glass drawn out fine was fastened to the end of each stick, and the ends of these heated by a minute blowpipe-flame. They were immediately made to touch and allowed to fly apart. In this way I obtained threads of glass about 6 feet long, finer than any spun glass I have examined. By using the oxyhydrogen jet with the same apparatus, still finer threads were produced. It was evident then that the method was right; but some more convenient device which also would make long threads would be preferable.

There are several ways of obtaining a high speed, the most usual depending on an explosive; but it would be difficult to arrange in a short time a gun which could be used to shoot a projectile carrying the thread which would not also destroy the thread by the flash. It is possible that an air-gun could be so arranged. Rockets when at the period of most rapid combustion have an acceleration which is enormous. Thus a well-made 2-oz. rocket is at one part of its flight subject to a force of over 3 lb. in gravitative measure. This force, acting on such a body for 10 seconds only, would, neglecting atmospheric resistance, starting from rest, carry it more than 6 miles. The acceleration is about 28 times that due to gravity on the earth, or about the same as that on the sun. Anyone who will stay in a room with a lighted two-ounce rocket, having no stick or head, will obtain a more vivid notion of the value of gravity on the sun than in any other way I know.

A rocket is perhaps more available for thread-drawing than a gun, but it does not seem altogether convenient. One other method, however, is so good in every respect, that there seems no occasion to try a better. The bow and arrow at once supply a ready means of instantly producing a very high velocity, which the arrow maintains over a considerable distance. For the special purpose under consideration, the lightest possible arrow is heavy enough. I have made arrows of pieces of straw, which may be obtained from wool-shops, a few inches long, having a needle fastened to one end for a point. Arrows made in this way travelled the length of the two rooms in which I made these experiments—about 90 feet—in what seemed to be under half a second. They completely pierced a sheet of card at that distance, which I put up thinking that a yielding target might damage them less than the wall, and were then firmly stuck unharmed in the wall behind; in every way they behaved so well that I do not think a better make of arrow possible.

The bow I used was a small cross-bow held in a vice with a trigger that could be pulled with the foot. The first bow was made of oak, the first wood that came to hand. I then made some bows of what was called lance-wood (it was unlike any lance-wood I have seen); but the trajectory was at once more curved, the arrow took perceptibly longer to travel, and the threads produced were thicker. As the arrow is so light, the only work practically that the bow has to do is to move itself; that wood then which has the highest elasticity along the fibres for its mass is most suitable; in other words, that wood which has the greatest velocity of sound is best. I therefore made bows of pine, and obtained still higher velocities and finer threads than I could obtain with oak bows.

With a pine bow and an arrow of straw I have obtained a glass thread 90 feet long and $\frac{1}{10000}$ inch in diameter, so uniform that the diameter at one end was only one sixth more than that at the other. Pieces yards long seemed perfectly uniform.

A fragment of drawn-out glass was attached to the tail of the arrow by sealing-wax, and heated to the highest possible temperature in the middle, the end being held in the fingers. With every successful shot the thread was continuous from the piece held in the hand to the arrow 90 feet off. The manipulation is, however, difficult, but another plan equally successful has the advantage of being quite easy. It is not necessary to hold the tail of glass at all; if the end of the tail only be heated with the oxyhydrogen jet until a bead about the size of a pin's head is formed, and the arrow shot, this bead will remain behind on account of its inertia, and the arrow go on, and between them will be pulled out the thread of glass.

Prof. Judd has kindly given me a variety of minerals which I have treated in this manner. Some behave like glass and draw readily into threads, some will not draw until below a certain temperature, and others will not draw at all, being either perfectly fluid like water, or when a little cooler perfectly hard.

Among those that will not draw at all may be mentioned Sapphire, Ruby, Hornblende, Zircon, Rutile, Kyanite, and Fluorspar.

Emerald and Almandine will draw, but care is required to obtain the proper temperature. In the case of the Garnet Almandine, if the temperature is too high, the liquid cylinder, if formed, breaks up, and a series of spheres fall on the table in front of the bow. At a slightly lower temperature the thread is formed, but it is beaded at nearly regular intervals for part of its length.

Several minerals, especially complex silicates as Orthoclase, draw very readily, but that which surpasses all that I have tried at present is Quartz, which, though troublesome in many ways at first, produces threads with certainty. It required far more force to draw quartz threads than had been previously experienced. The arrow, instead of continuing its flight, hardly disturbed by the drag of the thread, invariably fell very low, and was not in general able to travel the whole distance. So great is the force required that I split many arrows before I succeeded at all. I have obtained threads of quartz which are so fine that I believe them to be beyond the power of any possible microscope. Mr. Howes has lent me a $\frac{1}{15}$-in. Zeiss of excellent definition, and though, on looking at suitable objects, definite images appear to be formed on which are marks corresponding according to the eyepiece-micrometer to $\frac{1}{100000}$ inch, yet these threads are hopelessly beyond the power of the instrument to define at all. On taking one that tapers rapidly from a size which is easily visible, the image may be traced until it occupies a small fraction of one division, of which 13·4 correspond to $\frac{1}{1000}$ inch on the stage; then the diffraction bands begin to overlap the image until it is impossible to say what is the edge of the image. Having reached this stage, the thread may be traced on and on round the most marvellous convolutions, the diffraction-fringe now alone appearing at all, but getting fainter and apparently narrower until the end is reached. That a real thing is being looked at is evident, for if the visible end is drawn away the convolutions of fringes travel away in the same direction. It is impossible to say what is the diameter of these threads; they seem to be certainly less than $\frac{1}{100000}$ inch for some distance from the end.

It might be possible to calculate what would be the appearance presented by a cylinder of given refractive power, and 1, 2, 3, &c. tenths of a wave-length of any kind of light in diameter, when seen with a particular microscope. By no other means does it seem possible to find out what the true size of the ends of these threads really is.

## 2. *Properties.*

I can at present say very little of the properties of these very fine fibres; I am now engaged with Mr. Gregory and Mr. Gilbert in investigating their elasticity. The strength goes on increasing as they become finer, that is, when due allowance is made for their reduced sectional area, and it seems to reach that of steel, about 50 tons to the inch in ordinary language; but on this point I have not yet made any careful experiments.

The most obvious property of these fibres is the production of all the colours of the spider-line when seen in a brilliant light. The most magnificent effect of this sort I have seen, was produced by a thread of almandine. One of these the length of the room, even though illuminated with gas-light only, was glistening with every colour of the rainbow. In attempting, however, to wind it up, it vanished before me. It is of course only visible in certain directions.

The chief value of threads to the physicist lies in their torsion. Spun glass, as is now well known, cannot be used for instruments of precision, because its elastic fatigue is so great that, after deflection, it does not come back to the original position of rest, but acquires a new position which perpetually changes with every deflection. If left alone, this position slowly works back towards a definite place more rapidly as it is further from it.

To compare threads made of different materials, I made a flat cell in which a galvanometer-mirror, made by Elliot Bros., might hang, being attached to the lower end of the thread. The upper end was secured to a fixed support, and a fixed tube protected the length of the fibre from draught. The cell, which could be moved independently of the rest, was protected by a cover. By means of a lamp and scale, the exact position of rest of the mirror could be determined with great accuracy. On turning the cell round as many times as might be desired, the mirror was turned with it, and could be left any time in any position. On turning the cell back again, the mirror was allowed to come to its new position of rest, air-resistance of the cell bringing about this result in a few swings. By this means I hoped quickly and accurately to determine the fatigue in a variety of threads, but an unforeseen difficulty arose which I cannot yet explain. When the cell was moved round slightly so as not to touch the mirror, the mirror moved at first in the same direction as was to be expected, but it came to rest in a new position, to reach which it had to move in the opposite direction to the movement of the cell. Whichever way the cell was shifted, the mirror always went the other to find its position of rest. Thinking that it or the cell were electrified, I damped both by breathing on them, but with no result, and the next day the same effect was observable. So great was this effect that I could set the cell with greater accuracy by watching the spot of light than by the pointer carried by the cell working over a 4-inch circle.

Thinking that magnetism might have something to do with this effect, I brought a horseshoe-magnet near the mirror, when it was instantly deflected through a large angle. An examination of the cement used (Loudon's bicycle cement) showed that it was magnetic. Of many cements examined, sealing-wax was more nearly neutral than any other. Bicycle cement and electrical cement were strongly magnetic; all others except sealing-wax strongly diamagnetic. The apparatus was therefore taken to pieces and carefully cleaned. It was put together with as small a quantity of sealing-wax as possible, and the mirror was attached to a fragment of thin pure copper wire, which again was fastened by a speck of sealing-wax to the thread. Even then the same kind of effect as that already described occurred. Still a magnet deflected the mirror, but not so much, and the cell was practically neutral; yet, when the cell was turned a little, the mirror changed its position of rest.

Without pursuing this question further, I put a window in the protecting tube and turned the mirror by means of a small instrument passed up from below. Thus neither window nor support were moved. A piece of spun glass nearly 9 inches long gave a period of oscillation to the mirror of 2·3 seconds about. A lamp and millimetre-scale were placed 50 inches from the mirror. As all the observations were expressed in tenths of a millim., to about which extent they can be trusted, it is convenient to employ one scale of numbers of which one tenth millim. is the unit. One complete turn of the mirror is very nearly 160,000 on this scale. If the mirror is moved through 160,000 in either direction and held for one minute, and then allowed to take its new position, the change in the position of rest is as soon as it can be read about 370. This is reduced in about three minutes to 110. If the mirror is moved through three turns, 480,000 of the scale, and held one minute, the position of rest is at first moved about 1100, which falls in three minutes to about 400. I have given these figures, not because the effect is not perfectly well known, but to serve as comparison figures to those that are to follow. They can only be properly represented on a time-diagram.

A piece of the same fibre that was used in the last experiment was laid in a box of charcoal and heated in a furnace to a dull red heat and allowed to cool slowly. This was examined in the same way as the last. The effect of a movement of 160,000 for one minute was now only about 60, which was reduced to about 45 in three minutes. The change for 480,000 lasting one minute was at first about 250, which fell to about 180 in three minutes.

Annealed spun glass then shows far less of this effect than spun glass not annealed, but it is slower in recovering. It is possible that if time were given, it would show as great an effect as plain glass. The only mineral from which at the present time I have obtained any valuable results in this direction, is quartz. Here the effect of the usual minute at 160,000 was only 7, in the place of 370 for glass, at 320,000 only 17, and 640,000 only 32, which in four minutes fell to 22. This fibre was as usual fastened at each end by sealing-wax. When this experiment was made, the thread had only just been fastened. The same fibre treated previously in the same way, but some days after fastening, did not even show this effect; but as this was before I had completed the proper cell, the observations cannot so well be trusted. After a complete turn, there was not a movement of one tenth of a millim., nor had the position changed this much in 16 hours. It is as yet too soon to be sure, but this seems to point to the possibility of the very slight effect observed being largely due to the sealing-wax. Whether this is so or not does not much matter, the behaviour of the quartz thread approaches sufficiently near to that of an ideal thread, to make it of the utmost value as a torsion-thread. I hope shortly to be able to bring results of carefully conducted experiments on the elastic fatigue of quartz and other fibres before the notice of this Society.

A thread of annealed quartz behaves like a thread of quartz not annealed. That it was affected by the process of annealing is evident, because in the first place it was very rotten and difficult to handle, and in the second a piece of quartz fibre, which was wound up, retained its form. By this test, quartz can only be partly annealed in a copper box, as any form is not retained perfectly; at a temperature above that of melting copper, quartz seems to perfectly retain any form given to it.

It is probable that a body hung by a fibre of quartz and vibrating in a perfect vacuum would remain twisting backwards and forwards for a far longer time than a similar body hung by a glass thread, also that the most perfect balance-spring for a watch would be one of quartz. I have a piece of quartz drawn out to a narrow neck which just cannot hold up its head; this keeps on nodding in all directions for so long a time, even in the air, as to make it evident that the material has very unusual properties.

3. *Uses.*

As torsion-threads these fibres of quartz would seem to be more perfect in their elasticity than any known; they are as strong as steel, and can be made of any reasonable length perfectly uniform in diameter, and, as already explained, exceedingly fine. The tail ends of those that become invisible must have a moment of torsion 100 million times less than ordinary spun glass; and though it is impossible to manipulate with those, there is no difficulty with threads less than $\frac{1}{10000}$ inch in diameter.

I have made a spiral spring of glass of about 30 turns which weighs about one milligram; this, examined by a microscope, would show a change in weight of a thing hung by it of one 10 millionth of a gram. Since this has been annealed its elastic fatigue is that of annealed glass, and therefore very small. I have succeeded in doing the same thing with a quartz fibre, but the difficulties of manipulation are very great in consequence of the rottenness of annealed quartz. The glass spring can be pulled out straight, and returns perfectly to its proper form.

Since these fibres can be made finer than any cobweb, it is possible that they may be preferable to spider-lines in eyepieces of instruments; they would in any case be permanent, and not droop in certain kinds of weather.

Those who have experienced the trouble which the shifting zero of a thermometer gives, might hope for a thermometer made of quartz. When made, it would probably be more perfect in this respect than a glass thermometer, but the operation of making would be difficult.

These very fine fibres are convenient for supporting small things of which the specific gravity is required, for they weigh nothing, and the line of contact with the surface of the water is so small, that they interfere but little with the proper swing of the balance.

It seemed possible that a diffraction-grating made of fibres side by side in contact with one another would produce spectra which would be brighter than those given by a corresponding grating of ordinary construction, because not only is all the light which falls on the surface brought to a series of linear foci forming the bright lines instead of being half removed, as is usually the case, but the direction of the light on reaching these lines is not normal to the grating as usual, and therefore in the direction of the central image, but spreading, and thus in the direction of all the spectra. I picked out a quantity of glass fibre not varying in diameter more than one per cent., and made a grating in this way covering about one eighth of an inch in breadth. This not only showed three spectra on each side, and a quantity of scattered light, but all the spectra were closely intersected by interference-bands, such as are seen when a Newton's ring of a high order is seen in a spectroscope. This is probably due to a cumulative error in the position of the fibres, for they were spaced by being pushed up to one another with a needle-point, or to light passing between the fibres in a few places where dust particles keep them apart.

A diffraction-grating made of these fibres, spaced with a screw to secure uniformity, and of a thickness equal to the spaces between them (and one of 1000 lines to the inch could be easily made) would be far more perfect for the number of lines than any scratched on a surface; that is, for investigation on the heat of a spectrum, such a grating would be preferable to a scratched one, as there is no uncertainty as to the grating or to the substance of which it is made *. If the transparency of the fibres interfered they could be rendered opaque by metallic deposit without visibly increasing their diameter.

There is one use to which the fibres of quartz tailing-off to a mere nothing might be applied, namely as a test-object for a microscope. Theory shows that no microscope can truly show any structure much less than $\frac{1}{100000}$ inch, or divide two lines much less than this distance apart. Natural bodies such as Diatoms &c. have this advantage, that they can be obtained in any quantity alike, but no one knows what the real structure of these may be. Nobert's bands are good in that we know the number of lines in any band, but as to the individual appearance of the lines and spaces it is impossible to say anything. These fibres have the advantage that we have a single thing of known form, which tapers down from a definite size to something too small even to be seen. Though it may be possible to calculate the size from the appearance of the fringes, yet whether the size is known or not, at each

* See 'Heat,' by Prof. Tait, p. 268.

point we have a definite thing of known form which can be examined by a series of microscopes, and the point up to which it can be clearly seen observed for each.

I have thought it worth while to bring this subject forward in this very incomplete form, because there are already results of interest and there is so much prospect of more, that it is likely that Members may be glad to investigate some of the questions raised.

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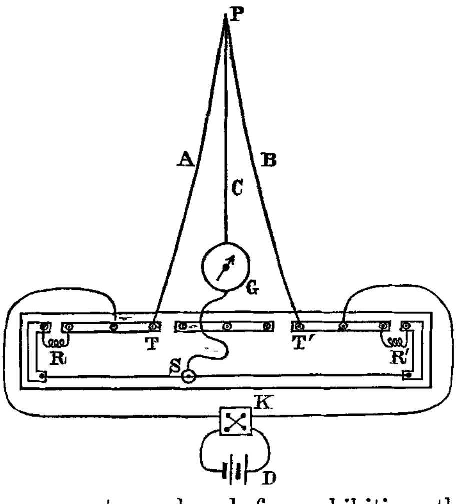
## LVIII. *On the Electrical Resistance of Vertically-suspended Wires.* By SHELFORD BIDWELL, *M.A., F.R.S.**

FROM the experiments to be described in this paper, it appears probable that the electrical resistance of vertically-suspended copper and iron wires alters to a small extent with the direction of the current traversing them. If the wire is of copper, the resistance is slightly greater when the current goes upwards than when it goes downwards; while, on the other hand, the resistance of an iron wire is apparently greater for downward than for upward currents†.




The arrangement employed for exhibiting this effect is shown in the annexed diagram. A wire, A B, of the material

* Communicated by the Physical Society: read March 12, 1887.

† Venturing to imitate the fanciful analogy used by Sir William Thomson, who, in discussing the thermoelectric effect now universally associated with his name, speaks of the "specific heat" of electricity, we may perhaps also speak of the "specific gravity" of electricity, and say that (like its specific heat) it is positive in copper and negative in iron.