Simon's Description of his Apparatus

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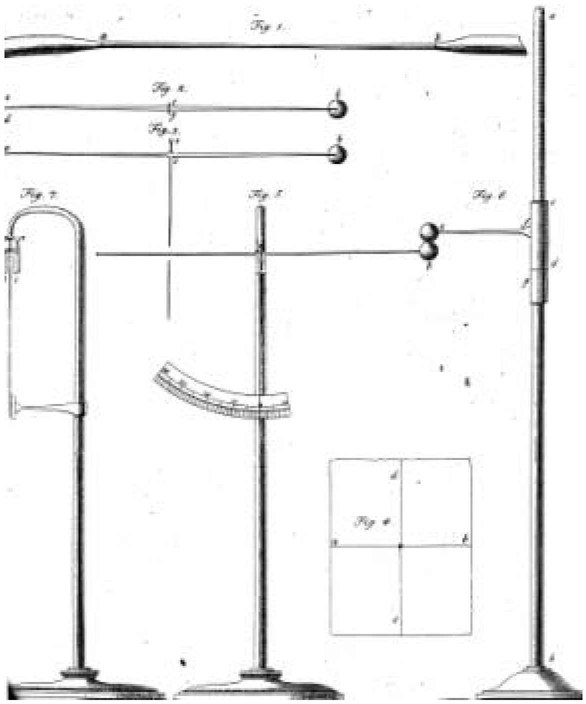

Apparatus

After a number of experiments whose results were unsatisfactory, it seemed to me that an extremely sensitive balance, built from the best electrical non-conductor, would be the most suited for my purpose; therefore, after several preliminary experiments, I gave it the following arrangement.

In the manner in which one obtains hair tubes, one draws thin tubes from solid, approximately 0.3 Zoll [in diameter] glass rods, as shown in Table III, fig. I.[1] From several such tubes I chose those which, after having broken off the strong strings, had come out straight and were approx. 9 Zoll long. [2] These rods were broken exactly in the middle, and among several halves, those pairs were chosen which had equal weights at equal lengths. One such pair produced the two arms of the balance. They were put together as in Fig. 2 and were joined at *c* through melting. To this balance, as in Fig. 3, a tongue *cd* = ½ *ab*was melted, which also consisted of hair-like drawn glass rods. In order to properly align the tongue with the balance arm, two perpendicularly crossed lines, pulled on a horizontal surface (a wooden board), served; I aligned the balance arm and the tongue along these.

Thereupon I coated the entire beam, tongue excluded, with melted shellac and proceeded to the fastening of the axes [i.e. to producing the crosspiece that carries the beam], for which again I used an extremely fine hair rod. This [crosspiece] is lain across the upper surface [of the beam], since the arm has such a small diameter, and [the crosspiece] is fastened [there] with shellac, for which the existing shellac film is sufficient (see Fig.2, *cg*.)[3] In order to keep the axes in proper alignment, I again laid the

[1] . 1 Zoll = 2.634 cm

[2] . Drawing these tubes over a Bunsen burner gives stringlike ends separated by a straighter middle portion. To make these take a test tube, heat it in the middle while pulling from both ends; remove it from the flame when the desired rod diameter has been produced at the middle (i.e. the smalles diameter you want). It should take about 1-3 seconds to produce a 9 inch rod.

[3] Simon is referring here to the cross-piece of glass that he fastens on the very top of the fabricated beam *ab*; this cross-piece acts as the pivot arm for the beam. Fig. 2 is a view of *ab* from above; *cg* is the pivot-

beam on a plane surface (Fig. 4) in such a way that the tongue went through a hole which was located at the intersection of the perpendicular lines *ab*, *cd*, and such that the beam sank to the surface with its entire weight [strength] along *ab*. Afterwards a hair-rod pointing in the direction *cd* was placed over it [the beam *ab*], and soldered to it by means of a hot wire; this rod was chosen much longer than the length of the axes, and afterwards the superfluous ends were broken off.[4] At the same time, another glass rod with a small metal knob was installed above the axes to compensate the weight of the tongue (Fig. 3, *e*).[5]

The holder for this balance consists of a bent glass rod, which is cemented into a wooden leg [using the sort of putty employed for glassware]; above are carried the pans, and in the middle an arm to which a quadrant [protractor] is fastened. Here too everything is made of glass or shellac, as for example the pans, which are made of shellac plates *b*, *c* melted onto the glass stirrup *a* (Fig.7); the points at which they touch the axes are filed clean.[6] The quadrant is also made of glass, and it's fastened with shellac to the glass arm. On one side the quadrant shows 40, on the other only 10 degrees.

After the instrument was so ready that the overlaid beam [i.e the tongue] pointed exactly to 0 [on the quadrant], a small, ¾ Zoll long glass rod was installed in such a way that it has the same weight as a cleanly worked sphere of elderberry, 0.4 Zoll in diameter; both were then fastened to the ends of the balance beam, as in Fig. 2: the glass rod [*ed*] cemented (with putty) hanging ring-shaped weights, and the sphere stuck on in such a way that the tongue pointed exactly at 0, as previously.

The instrument which I thus obtained has the following dimensions in its separate parts:

Length of the balance beam *ab*, Fig. 2	8	Zoll
Diameter of the beam at the ends	0.02	
Diameter of the beam in the middle	0.04	
Diameter of axes	0.005	
Length tongue	4	
Diameter of tongue at top	0.02	
Diameter of tongue at bottom	0.01	
Entire height of stand	12	

piece. It is visible from the side in Fig. 7, where its ends sit on top of the sharpened shellac 'pans' *b* and *c*, which accordingly bear the entire weight of the beam+tongue apparatus.

[4] . Here Simon describes his procedure for fastening the balancing cross-piece referred to immediately before. This method ensures that the cross-piece will sit nicely on top of the beam and can be easily fastend to it just by melting a bit the shellac that already coats the beam and sticking on the crosspiece, while the tongue stickes down through the hole in the board on which *ab* is laid.

[5] . This is a very small counter-balance to the weight of the tongue; it's apparently stuck on directly to the melted shellac. In Fig. 3, the cross-piece *cg* lie orthogonally to the page through point *c*; in Fig. 2 the counterweight terminating in *e* would stick directly out of the page and be centered on *cg*. The counterwight is visible in Fig. 7, which is a sideview, immediately beneath the curve of the glass stirrup at *a*.

[6] Simon here describes the pivots ('pans') for his balance-beam. They consist of small shellac plates filed to points at the top (where the crosspiece of the balance beam is laid) and melted to a curved glass 'stirrup' which itself is melted on to the end of the curved glass rod that's inserted into the wooden base (Fig. 7).

The weights are made of small, fine wire rings. On this balance, 0.1 Gran[7] yields a deflection of almost 25 degrees, and 0.01 Gran a turn of 2.5 degrees, so that between these limits the overweight of the tongue that is necessary for the device to swing nevertheless does not have the effect of obviating our conclusion that every degree [of swing] corresponds to 1/250= 0.004 Gran [of weight added to the end *a*]; this is the more so in that experience teaches that deflections within [less than] 15 degrees are the best for observations. Since every degree takes up the space of almost one line[8] (or, more exactly of 5/6 of a line) whereas one can very probably distinguish a ¼ [line] with the unaided eye, one can therefore observe deflections of 0.0001 gran very well.

The *Coulomb torsion balance* exceeds by far this ordinary balance in sensitivity, since with it a moment of 1/24000 Gran is expressed by 5 degrees, which take up 6 lines.[9] Meanwhile, as a result of the experiments, I found the sensitivity of my balance to be sufficient for observing results without substantial error.

To use this balance one also needs a stand to hold a second elderberry sphere - equal in size to the one on the balance - on an insulating arm that can be adjusted up and down in height. Fig. 6 shows an illustration of it along with the balance. *ab* is a calibrated glass rod, 0.3 zoll in diameter, along which a 1 inch glass tube *cd*, padded with velvet, can slide in such a way that it stays immobile in any position. In its center it holds the 3 Zoll long horizontal arm *ef*, which is made of a glass wire and covered and fastened with shellac, and at whose end *e* an elderberry ball is stuck on. The stand is marked into equal parts from *d* to *a;* under the tube *dc* there is an additional short piece of a similarly prepared tube *g*, which serves as an index.

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[7] 1 Gran = .8 gm
[8] 1 line = 2.26 mm. So Simon claims easy eye observation to about a half millimeter.
[9] According to this, it seems that Coulomb's torsion balance can measure the effect of a weight (i.e. a force) about two thousand times smaller than Simon's can.