Description of a new Levelling Instrument

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The practical and exact determination of a perpendicular plane at a given earth radius tested and still tests the astuteness of physicists and mechanics. It is of great interest to know the correct position of this plane relative to which not only the height of stars is estimated and the height of mountains assessed, but on which a great number of studies and ordinary operations are also based, so that there is the almost continual necessity of having to draw a horizontal line with major or minor precision according to the importance of the research.

Nature offers means of arriving at this knowledge in the surfaces of stagnant water or in the constant direction which heavy bodies take when they fall towards the centre of our globe. Thus from the first the natural horizons of fluids or plumb lines have been used for the various applications, as the most obvious aids and the easiest to come to mind. But the need for a greater precision and a greater ease have led in the course of time to more refined aids from mechanics and optics, so that we now have such a large number of different instruments which can lead us to determine the horizontality of a line that it would be tedious and difficult to mention them all. Among the most famous there are the air bubble level, the artificial horizons, Kater's collimator, Ramsden's siphon level, Picart's pendulum level, Cassini's reflection level and many others.

However, amidst so much abundance of instruments, the wishes of some operators do not seem satisfied enough. The best machines - used for large operations of levelling such as those undertaken, to give some examples, in emptying large swamps or in feeding one river into another - due to their high price and to the delicacy which they require in their care and use, cannot be had by every agronomist whose needs go no further than plotting a lawn or draining his own farm. Nor can they be found in the possession of every surveyor who simply works at outlining an excavation or a canal, at the construction of a city street or other, similar jobs.

When small or medium extents of land have to be levelled even engineers who own quality instruments refuse to use them. In this case the air bubble, which lengthens the operation uselessly, is accused of being too sensitive, the telescope is said to be so forceful that it does not allow objects at various distances to be seen, and other more or less well-founded oppositions are called into play depending on the nature of the instrument. At the end the small bottle level, dating as far back as Vitruvio, is used, and despite its imperfections, known to all, it is still often preferred because easy to manage and because in it the line parallel to the horizon can be found because immediately indicated by the equilibrium of the fluid, without the need of any rectification or movement of screws.

This behaviour in our most skilled experts leads us to presume that a new level, which possesses the good qualities of those of the small bottle level without having the same defects, which can be used to level a table or a floor, or a field or other very large extension, which can compete in exactness with the best which are in use by us, which is of a very small volume and, also important, of a very slim price, would have to be favourably welcomed by those whose professions require such instruments, or by those who while simply taking care of work on their own land wish to best direct the waters and flatten the lands of their farms.

I will give a brief description of this new level here and, by showing it to you already constructed allow you, learned colleagues, to judge for yourselves if it really possesses those qualities which seems to recommend it to me.

Captain Kater's Collimator suggested the idea of a float over mercury with a telescope to me. Since, as I had the pleasure of witnessing in London, the Collimator is meant to determine with a great deal of exactness the numbering principle of astronomical circles, i.e., the position of the zero point, with the form and size given it by the famous English author it could be used only imperfectly in ordinary levelling. A considerable quantity of mercury would have been inconvenient to transport, and the size of the telescope would have caused another relevant obstacle for the variations of the focal length coming from the various distances of the objects. For when the axis of the telescope is exactly parallel to the horizon in the case of a faraway object, it would lose its parallelism if aimed at a nearby object, because of the lengthening of the tube necessary to distinct sight, which would disturb the equilibrium of the float. It was therefore necessary to modify the construction while following the same principle, and I reached this goal by using an achromatic Galilean telescope of only one inch in length, which magnifies objects by about four times, and which allows you to see the threads of a grid thanks to a particular stratagem I thought up.

Figure 5 shows the level that we could call the floating level at life-size. AB is an iron wheel over which the telescope CF is mounted, using the stand D. In H there is a screw which goes through the width of the wheel in order to keep the axis of the telescope parallel to the horizon when all the system is in equilibrium over the mercury. This requires an experiment which can be done with the reciprocal levelling of two points at a certain distance from each other, or in other ways already known[1]. When this rectification has been done once either by the artist or by the operator, it would be very rare to have to repeat it because the simplicity and the small size of the instrument keep it from altering in form over time.

There is a circular diaphragm with two crossed threads between the object-glass C and the eyepiece F. Until now it has been impossible to place a Galilean telescope in any mathematical or physical instrument when one wished to collimate with this instrument because it was impossible to attach threads to it, but since I made the eyepiece F convex at the edges and concave only in a small central area, the obstacle has been removed. The threads are visible to that portion of the pupil which takes in the convex part, while the central part presents external objects as enlarged.

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[1] For greater speed I locate the adjustment of the floating levels by comparing the axis of the sight of their telescopes with the axis of the telescope of another level which is rectified with one position only in front of a window. Whoever does not have this convenience should determine two horizontal points distant, e.g., one hundred meters from each other, which can be reached using the same non-adjusted floating level. One must only stand in the middle of the base indicated, and by then pointing the sight at the extremities of the same, the meeting places with the targets situated there will clearly be on the same horizontal plane and can be used for the verification desired.

Without measuring any base the same end can be reached this way: Two positions M and N, conveniently located and reasonably separated, are chosen, and two divided poles - or the same pole used first here and then taken there - placed on them. Suppose that the height of the objective lens of the telescope at the first position is equal to A, and collimating the sight to pole N indicate the number P. Transport the level to position N and here suppose that the height of the objective lens is equal to B. Pointing the sight now at pole M indicate number Q. The real horizontal plane, which passes through the centre of the objective lens in the real last position will cut pole M at the height $\frac{Q+A}{2}$ - (P - B). So if the telescope is sighted higher, loosen screws X of support D and tighten screw H. If sighted lower, loosen screw H and tighten screws X until the balanced float collimates on pole M at the height expressed by the formula $\frac{Q+A}{2} - (P - B)$.

Once the person observing can see the threads, tube F is made to enter or exit until the parallax has been eliminated and then it is fixed stably with the pressure screw E when this is rotated around itself so that one of the threads becomes horizontal. Nor will there be any need to move it because the short focal length of the objective allows one to see near as well as far away objects with almost the same distinctness. The float with its telescope mounted in iron can be closed for transport into a wooden box half a decimetre tall, the lower part of which contains the separated mercury, and the entire instrument with its case weighs less than 16 ounces, that is less than an old French pound.

I would like to speak now about the degree of precision that can be expected from the floating level. I would say that it depends on two circumstances: the visual power of the telescope and the exactness of its axis when it is in equilibrium. From the test which I made at first about the variation of the line of collimation, it seemed I would have to give up this instrument because I realized that the aiming point changed considerably when the float was taken away from or put back onto the mercury. This error, however, since it was due to the very slight curved form which the surface of the small quantity of fluid metal used by me took, I was able to avoid with a pin attached to the bottom of the box and which fit into a hole just a bit larger made under the wheel. In this way the float could not rotate around, because held by the pin with its two prongs, but it was free enough, maintaining a constant distance from the edges of the box without suffering measurable deviations. As regards the power of the telescope, which magnifies about four times, we can easily judge an angular difference of a half minute. If the totality of this error were to be made in every observation, which is always improbable, with the floating level one can measure positions of two hundred meters with the certainty of not falling into an error greater than 29 millimetres. I believe that a greater precision can not be hoped for from the air bubble levels used in our land because even though it is true that they are equipped with a telescope with a greater magnifying power, it is also true that the sensitivity of the air bubble does not correspond to the degree of power of this telescope, and overestimates the mobility of the bubbles when the movement of a millimetre indicates a deviation of half a minute[2].

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[2] In volume VII of the new Giornale dei letterati published in Pisa in 1803 there is a paper by Eng. Alessandro Nini about his *level floating in water*. The weight of this instrument is said to be fourteen pounds and seven ounces, and that of the water to be thirteen pounds and two ounces, besides the weight of the box containing the fluid, which is not mentioned. The volume is also about five hundred times larger than my floating level. With all of this the instrument of Nini was approved by Padre Ximenes, who before the work was finished had said to the author "that many mathematicians had had the thought of constructing a floating level but none of them had managed to reach the desired result, and that the last attempt to make a level of this kind had been in Milan but this had been found to be more defective than others frequently used".

The Royal Imperial Physics Laboratory in Florence still has an early level which is called the level of Cavaliere Litta, which consists of two cylindrical, communicating, metal vessels containing water. Another two cylinders full of air which support the two ends of a horizontal telescope are immersed into these two vessels. But even if the dimensions here are much smaller than those proposed by Nini the instrument is still sizeable and also unusable at the slightest breath of wind.

Sustaining a telescope in fluid is therefore not a new solution, but in order to take advantage of this idea for levelling, the volume of the float had to be considerably diminished and of an invariable form. I was able to practice this improvement principally thanks to the application of the Galilean telescope which I had been the first to reduce, using a particular stratagem, for geodetic uses.