The Pocket Cephalometer, or *Compass of Coordinates*, Allowing One to Very Rapidly Obtain the Diverse Diameters, Angles and Profiles of the Head, and To Reproduce in 3-D Any Solid Figure

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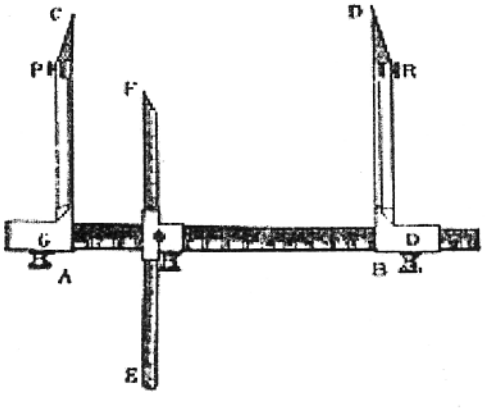

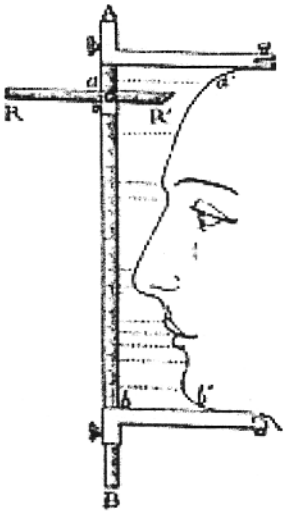

86, rue de Courcelles
Paris, France
August 2, 1929

My dear friend,

You asked me if I still had a copy of Le Bon's pocket cephalometer paper. I save way too much, and so not surprisingly I was able to discover and dig out from my piles the paper in question, which I've enclosed for you.

With respect to this work, here's what I remember. About a week before the March 21, 1878 meeting of the Anthropology Society, Le Bon informed me that he would not be able to attend; nonetheless, he hoped I would stand in for him in case there was any special mention of his paper and his pocket cephalometer invention. I consented, of course, and consequently, to make me more conversant about this instrument and its usage, the master provided me a tutorial on its operation.

The very first, and most important, thing Le Bon taught me was how to quickly measure the subject's cephalic index. The antero-posterior diameter is found by laying the pocket cephalometer's left ruler on the glabella and then sliding the instrument's right ruler until it reaches the most prominent point of the occiput; the right and left rulers are similarly adjusted in measuring the skull's transverse diameter. It is all so easy. Well, in less than a minute my cephalic index was precisely determined—79.8.

Now, at the meeting itself on the 21st, Doctor Broca acknowledged receipt of Le Bon's paper, and it was included in the Society's Bulletins for that date. Regrettably, nothing more was said about if, for Monsieur de Ujfalvy gave a talk about his travels in Kohistan, and the cephalic index measures he obtained of the inhabitants there were undoubtedly the product of a substantially greater effort than had he used the pocket cephalometer.

Wishing you good cheer, I remain, as ever,

Your friend,
Robert

The Pocket Cephalometer, or *Compass of Coordinates*, Allowing One to Very Rapidly Obtain the Diverse Diameters, Angles and Profiles of the Head, and To Reproduce in 3-D Any Solid Figure

I. DESCRIPTION OF THE INSTRUMENT.

The instruments used up to now in anthropology laboratories to measure the diverse diameters, curves and angles of the head, either upon the living or upon skeletons, are complicated, expensive and by no means portable. What has resulted is that the majority of anthropological measurements have only been effectuated upon skeletons, and it is most rare to see a travelling scientist bring back any craniometric measures of races visited by him. Taking central Africa as an example, already thoroughly travelled through by many explorers, information on head measurements is wanting in a nearly absolute way.

A simple, inexpensive instrument, easy to handle and extremely portable would obviously render important services.

The instrument that I have fancied, and which has been manufactured from my designs by a master builder, Monsieur Molteni, entirely realizes the conditions that I have just enumerated. It is extremely portable being that, as will be demonstrated, it can be stored in a carry case possessing ordinary dimensions. Its operation and handling is very easy because only a few minutes of use is sufficient in order for one to succeed in supplying himself the desired information. Finally, its price is not at all high.

I have bestowed upon this cephalometer the name *compass of coordinates*, by reason of the geometric principles upon which it is founded. One knows that in analytic geometry coordinates are named for the elements which permit for the fixing of the position of a point or a series of points either upon a plane or in space. Given two axes set perpendicular to each other, the horizontal one or *axis of the abscissas*, the other or *axis of ordinates* being vertical, the position of various points are determined whenever one knows their distance from these two axes, that is to say, when one knows their abscissas and ordinates. These distances constitute the coordinates of these points. If one can imagine a third axis bisecting the two others, the position of a point in space can be determined if one knows its coordinates, meaning its distances from these three axes.

My pocket cephalometer, or *compass of coordinates* (see Figure 1), is composed of a 25 centimeters long steel ruler (AB), detachable at its center in a way so that it is able to be separated into two parts. Upon this ruler slide fairly friction-free two other vertical metallic rulers (AC and BD) of 12 centimeters height, susceptible to being immobilized by the tightening of each's screw, and a small graduated ruler (EF), possessing scale marks along its entire length; one can likewise immobilize ruler EF at a pinch. Rulers AC and BD only move in lateral directions; they are terminated at their

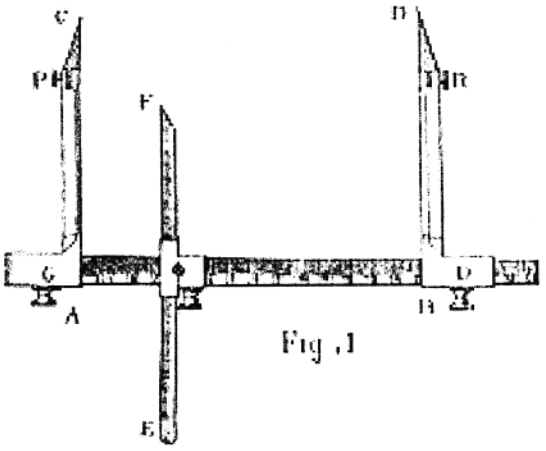

Fig. 1

upper part by movable points C, D like those of a compass and which leave, when one removes them, grooves through which points C and D can be set by the pressure of a threaded screw. Small ruler EF, wholly possessing the lateral movement of the two others, and remaining like them perpendicular to the large ruler AB, is also endowed with top to bottom and bottom to top movements which give to it the possibility of sliding itself above the level of ruler AB. This double movement quality allows small ruler EF to follow the contours of a curve while always remaining constantly perpendicular to large ruler AB upon which it places itself. If, for example, one set with the threaded screw the two vertical rulers about the end points of the diameter of a cylinder, one would be able with the small ruler to pass across and carefully examine the entire half-circumference of this cylinder, with the small ruler being obliged to remain constantly in contact with the cylinder during this process. Because small ruler EF is graduated, it's sufficient to observe how many millimeters it has sunk down below or risen above the large ruler, assuming it has surveyed a given space, in order to obtain the ordinates of the different points of the curve, elements which will allow for the reconstructing of the shape on paper by very simple graphical methods.

Despite its simplicity, this process will take too long in actual practice; and, as I shall soon demonstrate, I have had no recourse but to complete the data-collecting by much more rapid means.

II. USAGE OF THE INSTRUMENT.

This pocket cephalometer permits one to immediately obtain all the diameters, curves, and cephalic angles of the head that one is in the habit of measuring. I shall now briefly indicate the manner of its usage.

As a general observation, I must point out that the small ruler's scale should be set even with and pressed lightly against the points where the rulers are coincident with the sought after divisions of the head (without taking into consideration projecting or recedeable parts that these divisions can contain and which, however, the design of the instrument compensates for). It is only necessary to take care to set on the left side vertical ruler AC which must be stationed on this side, and which to that end is indicated in Figure 1 by the letter *G*. As for the small ruler, it must be positioned in a way such that its pressure screw lies in front of the observer. Once the rulers are thus arranged, and the apparatus fixed in place, one can accurately determine the three main head measures on the same plane. Here now is the way in which the pocket cephalometer can be of service.

Diameters of the Head. -- The principal diameters that it is useful to measure on the head are, as one knows, the antero-posterior and transverse diameters and the vertical diameter. Because the first two can be calculated as easily upon the head as on the skull, one only needs to be careful in removing the points of the instrument whenever one operates upon the living. The vertical diameter is measured on a skeleton from the occipital foramen to the top of the skull; but, because the occipital foramen is not accessible on the living, one should take as a reference mark either the ear cavity or the top of the tragus's convexity. I believe that one can obtain an even more certain reference mark by choosing the lower rim of the middle partition of the nose, which pretty much corresponds from my observations to being even with the lower margin of the occipital foramen.

In order to measure the antero-posterior and transverse diameters of the head with the instrument, one must first lay the left branch (ruler AC), whose bottom edge must coincide with the zero mark of the horizontal ruler, on one of the end points of the diameter being measured, and then slide the other branch (ruler BD) until it reaches the other end point of the diameter. One now renders the instrument immobile with the pressure screw, and it only remains for one to read at the level reached by ruler BD's lower edge the number of millimeters indicated by the large ruler.

In order to obtain the vertical diameter, one first removes the right branch (ruler BD) and then places the left branch upon the top of the head. The large ruler being now in a quite vertical position, which with its upper knob a plumb line can be easily established, one next brings the small ruler even with the reference mark, that is to say, even with the ear cavity or, as I have recommended and as is indicated in Figure 3, even with the bottom rim of the nose. With the small ruler being held in place by the pressure screw, there is nothing more to do but to read on the large ruler the number of millimeters indicated: this number represents the vertical height sought.

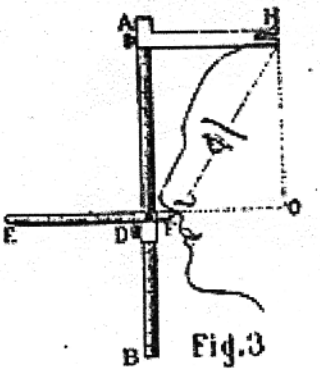

Fig.3

I have to remark that this instrument is the only one, outside of the bulky instruments in the laboratories that can only collect data there, which enables the vertical height of the head to be measured. It might seem at first sight that this measurement can be effectuated with calipers; but, it is sufficient to reflect for but an instant in order to realize that this idea is quite impossible. In fact, it is evident that the top of the skull and the ear cavity, where the lower part of the nose acts as the reference mark, are not in the same plane; their distance measured by calipers is an oblique line--such as FH (in Figure 3), hypotenuse of right triangle FHO whose vertical side HO represents the height of the skull, a height that can clearly be determined because length AD=HO, and AD is produced and shown by my instrument.

The height of the head substantially influences its volume, and in anthropology this fact is of considerable importance. It is obvious that the volume of a solid substance, such as a cylinder for example, can only be evaluated by knowing its height. It is simply the difficulty of measuring this height upon the living that has caused it to be neglected up till now.[1] Although my instrument is mainly intended to collect measurements upon the living, I should point out that one can employ it on the skull with as much ease as if one used calipers. By reason of the length and height of its sections the pocket cephalometer can, in fact, attain all the points that are accessible to calipers. It accommodates, for example, being inclined a little to the right or the left in the taking of the diameter proceeding from the lower edge of the occipital foramen to the nasofrontal seam, a diameter which appears at first sight, because of the projection of the nose bone, unattainable for an instrument possessing parallel sections.

Measurement of Cephalic Angles. -- The most commonly used of the cephalic angles is the facial angle of Camper. It is determined, as one is aware, by the intersection of two lines, one being horizontal, running from the ear cavity to the lower part of the nostrils, the other being more or less inclined upon the first, passing through the most projecting point on the forehead and the lower portion of the nose's dividing membrane. With various observers this latter reference mark is replaced either by the lower edge of the alveolar ridge or by the part of the face which juts out the most.

As I shall soon proceed to explain, because the pocket cephalometer enables one to obtain an exact profile of the head, nothing is more simple than to measure upon this profile with a protractor, like one does on the profiles of skulls sketched in craniography, the facial angle and the various cephalic angles having the ear cavity for a reference mark, such as the auricular frontal angle, for example.

If one desires to limit himself to determining the facial angle of a person without bothering to obtain his profile, this can be easily accomplished by the following operation. It will be sufficient, given the instrument's precise capability of measuring the vertical height of the head, to measure the distances existing 1) between the ear cavity and the lower portion of the nose's dividing membrane, 2) between the ear cavity and the most projecting part of the forehead, and finally 3) between this latter point and the lower part of the nostrils. These three lengths represent the sides of a triangle that one can then construct and draw on paper by elementary geometric methods, and upon which one may measure the angle sought.

For the reason already mentioned above, it will once again prove quite impossible, as one might propose in error, to determine with calipers the lengths destined to serve as the basis of the preceding triangle. The facial angle, in fact, is contained in the middle plane of the head--an inaccessible plane--but still my instrument supplies the projection. The distances that separate the forehead and nose from the ear, taken with ordinary calipers, represent the sides of an oblique plane--sides naturally longer than those obtained in the vertical plane.

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1 During the meeting of the Anthropology Society where I first introduced the members to my pocket cephalometer, a learned traveller, Monsieur de Ujfalvy, presented to the Society a great number of cephalic measurements of races examined by him; but, lacking portable instruments the vertical height of the head was unable to be measured. At this same meeting Colonel Duhousset told me that the usefulness of knowing this height had led him to build a special instrument so that he could measure it.

Measurement of the Profile and Circumference of the Head. -- One may be able with this cephalometer to construct and draw point by point the profile of any region of the head, by trying to find, with the help of the small movable ruler and the two other stationary ones, the ordinates of each of these points; but, this approach is slow and tedious. I resort to other means, as I have stated, to determine the various points of the face that I wish to know exactly.

In order to obtain an exact profile of the head and face, I operate in the following manner: having retracted the small ruler and the two points that terminate the extremities of the two branches (rulers AC and BD) of the instrument, and opening as widely apart as possible the latter, the subject's head is inserted perpendicularly inside the restraint that terminates the right branch; I then set with the pressure screw a thin lead strip of 1 millimeter thickness, 5 millimeters width, and 60 centimeters length upon this branch's lower extremity. Next, with the right hand applying the extremity of this branch upon the nape of the neck at a point even with the external occipital protuberance, one can now follow and pursue with the lead strip held in the left hand all the contours of the head as far as the top of the nose. Having arrived at this point, one exercises caution by making sure to pass the strip over the face in such a way that it does not squish down the soft parts that are unable to resist its pressure; exercising such caution, one continues on a little farther, bringing the strip under the chin as far as the neckline. The strip's end is then set by means of the second branch of the compass, producing a suitable end point. With the branches of the instrument being now immobilized in a definitive fashion, I withdraw the cephalometer from the head, and the lead strip fastened at the two branches' extremities in an invariable way is now placed upon a sheet of paper. It only remains to follow with a pencil the circuit created by the lower edge of the strip in order to accurately obtain, minus the details of the face (which one can complete, as I shall soon reveal), the contour of the head. One can assure himself by repeating this operation several times that the lead strip perfectly preserves the contours upon which it is molded.

The entire circumference of the skull and its transverse curve can be taken in the same way with a thin lead strip. The curved line formed by the latter is held in place at the two end points of its diameter by the branches of the compass.

The only inconveniences the lead strips present are the darkening of the skin a little bit and their sometimes snapping and breaking, which can happen if one does not take the precaution of passing them through the flame of a gas lamp in order to anneal them whenever they have been in use for some time. I have conducted research to see if they could be replaced, but I have not found anything quite as satisfactory. Iron wire of 1 millimeter thickness covered with silk, like the kind employed to conduct electrical currents, and pure silver wire having a diameter of 1/3 millimeter are, after the strips of lead, what seems to me best to use.

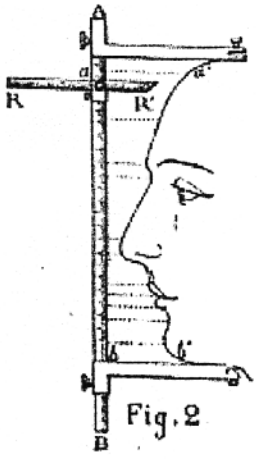

Fig. 2

Profile of the Face. -- By means of the preceding operation one obtains the exact contour of the head, but not that of the face. Should one have an interest in obtaining the latter, which is useful notably in precisely determining the degree of prognathism (more or less great) of the various races, I suggest one proceed in the following way, which is to apply the previously expounded principles of analytic geometry. Supposing that the head is secured between the two branches of the instrument in the manner indicated by Figure 2. It is evident that learning the

ordinates of the main points of the different parts of the curve included between *aa'* and *bb'* as well as their reciprocal distances from one another will permit one to discover the points through which this profile must pass. Nothing is easier than to obtain with small ruler RR' the length of lines *aa'*, etc. One acquires these lengths by merely touching with small ruler RR' each of the projecting points of the face (a dozen is enough), and, when this ruler is even with each of them, you can then dictate to an aide the two numbers indicated, one being how much the point is elevated above the large ruler, the other being at what distance from zero it finds itself on this same ruler. A piece of paper, preferably graph paper, is now readied. For there is nothing more to do but to set up on a horizontal line a series of parallel lines showing in millimeters their lengths and respective intervals as expressed by the preceding numbers, in order to obtain with the most rigorous precision the points through which must pass the curve that constitutes the profile of the face; by carrying out this procedure, the profile of the entire head, already largely obtained, is now complete. Finally, in order to have in place all the elements necessary for anthropometric research, one needs to mark upon the drawing the position of the ear cavity at the point where two circular arcs traced with a compass intersect each other, arcs whose radii have for spacing the length measured with the cephalometer from the ear cavity to any two points of the face.

To summarize, all these operations which we have just described at length are executed very rapidly, and they are accomplished with an instrument that is extremely easy to carry in a small bag. One quickly obtains, and above all more precisely than what could be made by a good draughtsman, the exact profile of the face and head; and, as has been demonstrated, all the measurements anthropology finds useful can readily be taken as well. By comparing these highly accurate profiles to those that you see an artist create, however skillful you and others might suppose this person to be, you will recognize and perceive the extent to which freehand drawings always deviate from reality.

III. APPLICATIONS OF THE INSTRUMENT TO THE SOLUTION OF DIVERSE PROBLEMS AND TO THE REPRODUCTION IN 3-D OF SOLID FIGURES.

Concerning these aforementioned applications of the pocket cephalometer, my instrument enables one to resolve a great number of interesting geometric problems, such as those, for example, relating to the curve that originates from the section of a solid figure which has been cut through by a plane. Concerning this section, it is easy to see that with the solid having been grasped between the two branches (rulers AC and BD) of the instrument, and the small movable ruler being promenaded over the solid figure in such a way that it constantly remains tangent to it, one acquires, with the help of the cephalometer's scale marks, a system of ordinates that leads, by a very simple graphical construction, to the procurement of the curve formed upon the solid by the plane that intersects it. Hence, one can prove experimentally that the curve created by a plane passing through any section of a cone, for example, is either a circle, an ellipse, a parabola, or a hyperbola, depending on the inclination of this plane.

This instrument therefore allows one to reconstruct graphically by means of the Cartesian coordinate system the curve generated on a solid figure by the intersection of a plane. But it is easy to see that any solid may be regarded as an object constituted by the superposition of an infinite number of horizontal planes. It is obvious, for example, that if you cut up the head into a series of equally spaced horizontal slices, it would then be sufficient to layer all these slices upon one another in the same order of their sectioning in order to restore this head. Now that we have seen that the instrument can produce an exact copy of each of these horizontal slices, nothing will be easier than to

reproduce the solid figure itself. It will suffice, assuming the instrument has been properly fitted upon a movable vertical support, to capture the profile of the figure's sections millimeter by millimeter by transferring and putting them on cardboard strips of 1 millimeter thickness, then cutting these strips according to the contour indicated, and finally to superpose them. It is clear that these layered strips will yield a solid figure which will be an exact reproduction of the model.

Carried out in the manner that I have just described, the operation, very simple in theory, will prove exceedingly slow to perform in practice. In order to render this operation easier, I have invented a second instrument, founded upon the same geometric principles as the preceding, but which allows one to ascertain nearly instantaneously the contours of solid figures. As a result, this second instrument produces the series of horizontal profiles whose superposition enables one to reconstitute the solid figure. It also permits one to more rapidly take the profile of the head and visage than does the pocket cephalometer, but it is a little bit more costly, and mainly less portable.

Figure 4, which shows the instrument applied on the head so as to determine the profile, makes much more understandable the device's fundamental principles. It is composed of three copper frames, each formed of two thin and parallel metal plates that can be tightened with a pressure screw. Between these plates slide quite frictionlessly parallel metallic rods that are perfectly cylindrical; each of these rods is 20 centimeters long by 2 millimeters wide.

Fig. 4

By a mechanical artifice whose description would entail far too much, we have gotten, on the one hand, the rods to remain constantly parallel to themselves, and on the other, not allowed the rods to sag or get entangled with one another whenever one loosens the two frames that keep them together. It was above all this twofold inconvenience involving the rods that long ago made us renounce use of the instrument named *profilemeter*, which moreover only gives the profile of the face, whereas my new instrument furnishes the profile of the entire head, as one can see in Figure 4. To obtain this profile, one need only tighten the screw in order to keep the rods immobile, and then place the frame flat upon a sheet of paper, following the contour of the rods with a pencil. Prior to these last two steps, one should see to it that this sheet of paper is laid upon a piece of cardboard sufficiently thick in order to compensate for the thickness of the frame, and done so in such a way that the metallic rods find themselves entirely even with the paper.

Let's suppose that we now want to adapt the instrument to perform a three-dimensional (3-D) reproduction of a solid figure, the head for example. I have demonstrated above that by layering a sufficient number of horizontal profiles of a solid figure, one is able to reproduce this form. Nothing remains then but to indicate how to operate this instrument. It is very easy to use. The upper frame is first fitted flat upon the end of a graduated vertical shaft, and then can be lowered at pleasure down the shaft toward a solid support mounted at the base. With the head being held steady by means of a headrest similar to those used by photographers, one next takes horizontally (in the Figure 4 drawing, the instrument, having been positioned to obtain the vertical profile of the head, is disposed vertically)

at equal distances of every 2 millimeters, for example, the horizontal profiles of the head. The curves thus acquired are transferred by pencil onto thin cardboard sheets which, when cut out, themselves serve as patterns for cutting up slices of clay, wax or similar substances having exactly the preceding thickness. In superposing in correct order all these layers, each one of which is naturally composed of two reference marks, there is nothing more to do but to smooth out some angles with a chisel or file in order to obtain a copy of the head. With two frames and an assistant, who with pencil transfers onto cardboard an obtained profile while the operator takes another profile, one can proceed most rapidly.

I must point out that, even for a skillful artist who prefers to make copies from nature, the preceding instrument will always prove useful, because it is the only device that enables one to verify whether a derived region is completely conformable to the original. The instrument having been, in fact, applied upon the part being examined must, when one applies it upon the same region of the copy, follow the contours exactly.

As one can with a pantograph enlarge or reduce at will each drawing of the profiles procured by the above method, one sees that one may obtain with great precision a 3-D copy enlarged or reduced from the original.

Outside of these applications to sculpture, this apparatus allows one to easily solve various important geometric problems, particularly making immediately apparent what the curve is on any solid, cylinder, cone, ellipsoid, etc., that has been brought about by the intersection of a plane.

The preceding instrument is, I believe, the first ever that permits one to obtain a life-size 3-D reproduction, which can be reduced or enlarged, of a person's head. The utilization of a lathe to obtain enlarged or reduced copies of statues is not a feasible approach upon the living. Meanwhile, photosculpture is nothing but an unrealizable theoretical concept. As for the device invented forty years ago by the mechanical engineer, Monsieur Sauvage, which is composed of a sort of cylinder filled with knitting needles, into which the person doing the molding would plunge the object, one cannot employ it upon living beings. Not surprisingly, this apparatus, besides being very expensive as well as possessing the limitation of enabling one to only reproduce a single side of the head or any other solid object, has rapidly sunk into oblivion.

* * *

The two instruments that I have described at length--the pocket cephalometer and my 3-D copy invention--appeared at the Universal Exposition in the anthropological sciences section. With their low price putting them well within reach of most people's pocketbook, they will render, I hope, as much service to artists as to museums of anthropology. They constitute a new application of the graphical methods so much in use nowadays among physicians, mathematicians, and physiologists.

Gustave Le Bon