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EFFECT OF TEMPERATURE INEQUALITIES ON THE BALANCE.

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The topic herein presented had its origin in some work preliminary to another investigation, requiring the use of a sensitive balance operated with the greatest possible degree of precision. The balance used is by Sartorius, with 18 cm. beam and sensibility of about 2.3 scale divisions per mgr., pans empty, and so constructed that the sensibility increases slightly with moderate increase of load. The writer was studying this balance with a view to getting acquainted with its peculiarities, determining its constants and learning what degree of precision to expect of it (as should always be done with a new balance about to be used in particular work), and had taken a series of consecutive zero readings by the oscillating pointer method with pans empty, when a marked progressive change in the readings attracted immediate attention and demanded explanation.

The first readings, separated by a few moments only, were as follows:

10.56	10.33
10.56	10.32
10.41	10.27
10.45	10.26
10.37	10.09

Subsequent sets of readings, in which a fair degree of constancy had been secured, gave the probable error of a single pointer reading as less than 0.03 scale division, so that the change observed must have been real and not due simply to errors of observation.

Variations of temperature were naturally looked to as the probable cause. The balance was badly located, with the right end of the case adjacent to an outside wall and the left away from it. At this particular time, the wall was cold, and the temperature of the room was rising, so that such an effect was to be expected. But balances are frequently used in just such locations, and the magnitude of the change, amounting in only a few minutes to what would be equivalent with this balance to over 0.2 mgr. placed upon the right-hand pan, was such as not to be tolerated in precise weighing. It was thought well, therefore, to look into the matter somewhat before entering upon further work.

After experimenting for a time with sensitive thermometers placed inside the case, the writer prepared a thermo-electric arrangement of ten pairs of elements, which was suspended immediately behind the beam with the two sets of junctions in juxtaposition with the two end knife-edges. This apparatus was connected with a sensitive D'Arsonval galvanometer of the wall type, which gave a deflection of twenty scale divisions per degree centigrade, so that the temperature difference between points very near the ends of the beam could be fairly estimated to about one two-hundredth of a degree. The object of this arrangement was to study the effect of known temperature inequalities in the case upon the zero readings of the balance. One set of results must suffice here. In these, the conditions were in a measure controlled by having an electric light mounted outside the case at the left end, and turning it on and off at will. The accompanying figure best illustrates the results, which are tabulated below.

Time P. M.	Galv. Read.	Pointer Read.	Remarks
4:10	2.9	10.12	Light off
4:17	15.1	10.47	Light on
4:20	16.9	10.55	Light on
4:22	17.9	10.69	Light on
4:26	11.0	10.60	Light off
4:34	7.8	10.30	Light off
4:36	6.4	9.97	Light off
4:37	15.0	9.84	Light on
4:39	16.8	10.04	Light on
4:42	18.0	10.21	Light on
4:45	19.0	10.30	Light on
4:48	19.5	10.35	Light on
4:52	20.1	10.32	Light on
4:54	20.5	10.29	Light on
4:58	20.9	10.20	Light on
5:03	11.0	9.84	Light off
5:05	8.8	9.33	Light off
5:07	7.0	9.24	Light off
5:10	6.0	9.01	Light off
5:12	5.3	8.99	Light off
5:17	4.9	8.94	Light off
5:19	4.3	8.99	Light off
5:21	4.1	9.01	Light off

An examination of these curves suggests several things. Note the remarkable promptness of the pointer reading effect when the light is turned on. The second drop in the pointer reading *precedes* the drop in temperature difference, and is gradual instead of sudden, showing that it is due partly to other causes. This does not occur in the first and shorter exposure to radiation. No doubt the other causes operating to bring down the pointer reading are the equalization of temperature in the beam by conduction and the gradual growth of air currents in the case by contact with the warm glass on the left side. The same thing is noticed in the rise of the pointer reading at the end of the series, while the temperature difference is still decreasing. It is to be noted that the whole range of temperature difference is less than one degree.

It is evident that air currents in the case, set up by difference of temperature at the two ends, have an effect opposite to that of expansion in the beam. For. the current is downward at the cooler end, bearing down on the pan; while the corresponding arm is the shorter, which tends to raise the pan. It is difficult to say how much the effect of expansion in the beam may be thus modified by the air currents; but it is likely that with broad pans the modification may be considerable, providing the air currents have had sufficient time to get fairly started.

The statement is made in some laboratory manuals that the difference in length between the two arms of a first-class balance when in adjustment will be found negligible for all but the most precise weighing, for which latter purpose the interchange of object and weights is recommended. This is perhaps quite true, providing the beam is at a uniform temperature; *but the experiments herein described show how marked may be the effect of even slight temperature inequalities.* Moreover, if such inequalities exist, unless they can be kept constant throughout the various operations of the double weighing, with the opening and closing of the case that are necessary in any balance not provided with special reversing apparatus, the interchange method does not remedy the difficulty.

The writer made two double weighings of the same object by the interpolation method, using the same individual weights in both cases, but under different temperature conditions. The first set was made on a warm day, the room being considerably colder than outside; while the second set was made on a cool day, the room being steam heated. The balance had not been adjusted as to arm ratio since its arrival from the makers; and the right arm was still toward the outside wall. The results were as follows:

FIRST SET.

Object on left pan ....19.23112 grams
Object on right pan ....19.23219 grams

SECOND SET.

Object on left pan ....19.23148 grams
Object on right pan ....19.23213 grams

The right arm is obviously the longer in both cases. But if the mean of the first set be taken, it will be found that the residual or departure of each weighing from it is 0.00052, while for the second set the residual is only 0.00032. The explanation of this is, that in the first case the right arm was warmer than the left, thus adding to the inequality, while in the second, it was cooler, subtracting from it. The difference in temperature at the ends of the beam could not have been in either case more than one or two-tenths of a degree, as indicated by the galvanometer.

The beam of the balance here used is of phosphor-bronze, with a centigrade coefficient of expansion, according to the makers, of 0.0000181. A simple calculation, using this figure and the known constants of the balance, shows that a uniform temperature gradient of one degree from one end of the beam to the other, barring air currents, would produce an anomalous deflection of about 1.8 scale divisions, corresponding to well toward a milligram. The thermo-electric apparatus, when used under the best conditions obtainable in the winter with the balance situated as it was, though carefully screened and blanketed, showed temperature gradients of nearly one-fourth of one degree, and much greater ones when no special precautions were taken. The variations observed are therefore not at all surprising.

In conclusion, it may be suggested that sufficient care is seldom taken in conducting balance work to secure freedom from the disturbing influences of temperature gradients, direct radiation and accidental air currents. For successful work, the balance should be centrally located in a quiet, thermostatic room, on a pier if possible, and carefully screened from radiations from heating apparatus, artificial lights and sunlit windows. It is well to blanket the case, and the illumination should come from the front, not from the side. Unless such precautions are taken, it is doubtful if the great precision often claimed for weighing methods can actually be realized. Further, it will be found a source of satisfaction, to anyone endeavoring to get the best results from weighings, to install within the case, as described, a thermo-electric series of simple design, which will give warning of the presence of temperature inequalities, and thus indicate when the best conditions exist. Such a thermopile may be easily made in any laboratory shop from iron and copper wires mounted on an ebonite or wooden frame, and can be located so as to be used during weighing without being in the way.