Designation: E1270 – 88 (Reapproved 2014)

Standard Test Method for
Equal Arm Balances[1]

This standard is issued under the fixed designation E1270; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This test method is designed to test balances whose lever-arm ratio is substantially equal to unity. Although largely superseded by new technologies, equal-arm balances retain a special niche for very high precision weighing of larger samples (usually greater than 1 kg) as well as objects with large buoyancy (such as gas bottles). Balances of this type can range from simple instruments of moderate precision (1:10 000) to extremely high precision devices with precision of 1:10 000 000 or better. A number of accessory devices may be included for assisting in the weighing process. These devices may contribute to errors as well as can the basic lever mechanism. This method is designed to test the entire instrument including the accessories.

1. Scope

1.1 This test method can be used for testing equal-arm balances of any capacity and sensitivity. The testing procedure should enable the user to characterize his instrument sufficiently to determine whether or not it is suitable for the purpose for which it is to be used.

1.2 The characteristics to be examined include:

1.2.1 Sensitivity at all loads,

1.2.2 Lever arm ratio,

1.2.3 Damping ratio (for instruments without accessory dampers),

1.2.4 Period of oscillation,

1.2.5 Precision, and

1.2.6 Linearity and calibration of accessory devices that provide on-scale indication of weight.

1.3 *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E617 Specification for Laboratory Weights and Precision Mass Standards

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *capacity*—maximum load recommended by the manufacturer. Usually, the capacity refers to the maximum load on each pan simultaneously.

3.1.2 *readability*—value of the smallest unit of weight which can be read. This may include the estimation of some fraction of a scale division or, in the case of a digital display, will represent the minimum value of the least significant digit.

3.1.3 *sensitivity*—smallest value of weight which will cause a change of indication which can be determined by the user. This may be independent of the readability because of the choice of the reading device used. For example, a magnifying glass may be used in conjunction with a reading scale to observe a sensitivity not readily determined without the magnifying glass.

3.1.4 *precision*—repeatability of the balance indication with the same load under essentially the same conditions. The more closely the measurements are grouped, the smaller the index of precision will be. The precision should be measured under environmental conditions that represent the conditions under which the balance is normally used.

3.1.5 *accuracy*—degree of agreement of the measurement with the true value of the magnitude of the quantity measured.

3.1.6 *linearity*—characteristic of a direct reading device. If a device is linear, calibration at 2 points (for example, 0 and full-scale) calibrates the device (for example, 2 points determine a straight line); if a device is nonlinear, additional points are needed (perhaps a great many).

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[1] This test method is under the jurisdiction of ASTM Committee E41 on Laboratory Apparatus and is the direct responsibility of Subcommittee E41.06 on Weighing Devices.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.7 *standard weight*—any weight whose mass is given. Since weights are not always available with documented corrections, weights defined by class (see Specification E617) may be used if the class has sufficiently small tolerance limits and there is an understanding that errors perceived as being instrumental could be attributed to incorrectly adjusted weights.

3.1.8 *off-center errors*—differences in indicated weight when a sample is shifted to various positions on the weighing area of the weighing pan. No separate test is described.

3.1.9 *full-scale calibration of an accessory device*—indicated reading at equilibrium of an accessory device when a standard weight equal to the full-scale range of the device isplaced on the sample pan. Usually, some means is provided by the manufacturer to adjust the full-scale to match the weight of the standard.

4. Summary of Test Method

4.1 Throughout this test method, the instrument is to be used in the manner for which it is intended by the manufacturer. All measurements are made with weights whose values are sufficiently well known for the purpose of the user. The nominal value of the weights used will be determined by the capacity and rated sensitivity of the balance as well as by the resolution and range of the accessory reading devices.

5. Significance and Use

5.1 This test method should enable the user of the balance to interpret data determined thereon in terms of accuracy and precision. It should be helpful in using a particular instrument to best advantage. Weaknesses as well as strengths should become apparent. It is not the intention of this test method to compare similar instruments of different manufacture but rather to assist in choosing an instrument which will meet the needs of the user.

6. Apparatus

6.1 *Standard Weights*—Individual or summations of weights equal to approximately ¼, ½, ¾ and the total capacity.

6.2 *Tare Weights*—Weights of the same denominations as the standard weights but not necessarily calibrated.

6.3 *Calibrating Weights*—Balances equipped with accessory devices such as sliding beam weights, chainweights, optical scales or electrical transducers require small standard weights equal to the full-scale reading as well as smaller weights suitable for calibrating intermediate points between the zero and full-scale points of the devices. Summations of small standards can be used for this purpose.

6.4 *Stop Watch:*

6.5 A room-temperature thermometer with a resolution of at least 1°C.

7. Preparation of Apparatus

7.1 Place the instrument in the location at which it is to be tested. If electrically operated, plug in the line cord to the type of socket recommended by the manufacturer.

7.2 Place the standard weights near (or within) the instrument.

7.3 Place the thermometer on the bench in position so that it may be read without being touched.

7.4 Make sure that the instrument and test weights are clean.

7.5 Allow the instrument and weights to sit undisturbed sufficiently long to reach temperature equilibrium with the surrounding area. In the case of a large, high precision instrument in a controlled environment, it may be necessary to allow 24 h for such equilibrium.

7.6 Read the manufacturers instructions carefully. During each step of the test procedure, the instrument should be used in the manner recommended by the manufacturer.

8. Procedure

8.1 *Sensitivity*—The sensitivity can be measured at a number of different loads from zero to the capacity to provide a sensitivity versus load curve, or, it can be measured at the load of particular interest. This test applies to balances which have a null position indicator. Balances which are direct reading in the on-scale range must be calibrated according to 8.8.4, 8.8.5, 8.8.6 or 8.8.7.

8.1.1 Place nominally equal weights on each pan for the selected load.

8.1.2 Observe the indication. If necessary, place small weights on the appropriate sample pan to obtain an indication near zero.

8.1.3 Place a small weight on the left pan sufficient to change the indication about ½ scale of the on-scale range. Record the indication as d_1.

8.1.4 Remove the small weight and place it on the right pan and record the new indication as d_2 (remember that for indicator scales graduated either side of center zero, indications to the left are recorded as negative values).

8.1.5 Compute the sensitivity as follows:

$$S = 2 \times W/(d_1 - d_2) \quad (1)$$

where:

S = sensitivity in mass units/scale division, and
W = mass of small test weight.

Example: d_1 = 5.5 div.
d_2 = −5.3 div.
W = 10 mg
S = 2 × 10/(5.5 − (−5.3)) = 1.85 mg/div.

8.2 *Sensitivity as a Function of Load*—Balance designs vary but in the case of high precision balances, the manufacturer usually tries to provide a nearly level sensitivity at all loads. This is accomplished by the position of the plane determined by the terminal pivots in relation to the central pivot. If this plane is lower than the central pivot, the sensitivity will decrease with increasing load. Conversely, if the plane is higher than the central pivot, the sensitivity will increase with increasing load and can reach a state of instability if the center of gravity goes above the center pivot. Placing all of the pivots in the same plane provides a nearly level sensitivity limited by the elastic properties of the weighbeam. To measure the relationship of sensitivity to load, repeat 8.1 at various loads from zero to the capacity and plot sensitivity as a function of load.

8.3 *Lever Arm Ratio*—Equal arm balances are not usually used as direct-reading instruments. Rather, they are used as comparators using standard weights for reference. For precision measurements such as weight calibration, the measuring technique eliminates errors due to the inequality of arm-lengths. For relative measurements such as quantitative chemical analysis, if the inequality is considered to be in a constant ratio, the results of a number of weighings on the same balance will have a common multiplier (L_1/L_2) and the resulting computations representing, perhaps, fractional components of a compound will be mathematically correct. If there is a need to determine an absolute mass value from a single direct measurement, the lever ratio must be determined.

8.3.1 Observe the rest point with empty weigh pans.

8.3.2 Place approximately equal weights on each pan whose value is near the capacity of the balance.

8.3.3 Observe the new rest point.

8.3.4 Transpose the weights to the opposite pans and observe the rest point.

8.3.5 Measure the sensitivity at this load from 8.1.

8.3.6 Compute the lever ratio as follows:

$$r_L = \frac{M}{M + S_1(d - (d_1 + d_2)/2)} \qquad (2)$$

where:

r_L = lever ratio,
S_1 = sensitivity in (mass units)/(scale division),
d = rest point of empty pans in 8.3.1 (scale divisions),
d_1 = rest point from 8.3.3,
d_2 = rest point from 8.3.4, and
M = mass of test weights (the value on *each* pan).
Example: =
M = 100 g (on each pan)
S_1 = 1.85 mg/div. = 0.00185 g/div.
d = + 1.5 div.
d_1 = + 8.5 div.
d_2 = −2.5 div.
r_L =

$$\frac{100}{100 + 0.00185(1.5 - (8.5 - 2.5)/2)}$$

r_L = 1.0000278.

8.3.7 A ratio greater than 1 indicates that the left lever is longer and if a sample is placed on the left pan and standard weights on the right, the "true'' weight is:

$$W_T = W_I / r_L \qquad (3)$$

where:

W_I = indicated weight.

8.4 *Damping Ratio*—An undamped balance will oscillate around a rest point with decreasing amplitude of oscillation due to air damping on the weight pans and to friction in the bearing system. The ratio of the amplitude of one oscillation to that of the next may be a measure of several characteristics of the balance. Since these cannot easily be separated, this measurement is not especially useful since pivot conditions can be better measured as part of a measurement of precision. In the case of a damped balance, this measurement may be useful insofar as it may be used to characterize the effectiveness of the damping mechanism. Useful damping is that which produces a steady reading in one or two oscillations. Since the damping ratio is usually a function of the load, damper mechanisms are usually set at some compromise value or are adjusted so that they may be optimized for a given load. Release the beam and observe consecutive indications in the same direction. Compute the damping ratio r_D as follows:

$$r_D = d_1 / d_2 \qquad (4)$$

where:

d_1 = first turning point, and
d_2 = second turning point in the same direction.

8.5 *Period of Oscillation*—The time required to make one full oscillation is an indicator of the time required to make a measurement either for a damped or undamped balance. The period is a function of the magnitude of the moving mass and of the sensitivity of the balance. For a given arm length, balances of high sensitivity have longer periods.

8.5.1 For the convenience of the user, high sensitivity balances may have means for magnifying the indication thus allowing the sensitivity to be lowered and the period shortened. However, such an approach must be used with care since such magnification means smaller angles of deflection are measured and the balance becomes more sensitive to the tilting which might occur on a bench or floor of insufficient rigidity.

8.5.2 Place weights of equal value on the pans at or near the load of interest. Release the beam and start the stop watch as the direction of the indicator changes. Count several turning points and stop the watch after *n* periods of oscillation. Calculate the period, *p*:

$$p = t/n \qquad (5)$$

where:

t = total elapsed time, and
n = number of turning points.

8.6 *Precision*—The term 'precision' in weighing usually means repeatability. In quantitative terms, it refers to expected uncertainty of a single reading. The usual method for determining the precision is to compare the results of a series of measurements by some statistical treatment and to compute some value which gives the user an estimate of the potential uncertainty of a single reading. A common technique is to compute the standard deviation (s) of a series of observations. The larger the number of observations the better; but 10 is usually enough. Assuming a normal distribution of data, 3s will represent with a high degree of certainty the maximum anticipated error of a single measurement. One convenient measurement model is a series of double substitutions.

8.6.1 Place a weight, '*A*', considered to be the standard, on the left pan and a tare weight of the same nominal value on the right pan. Observe the balance indication (A_1).

8.6.2 Remove the standard from the left pan and place a test weight '*B*' on the left pan. The tare weight remains on the right pan. Observe the balance indication (B_1).

8.6.3 Add a small weight (S) to the left pan chosen so that the change in indication will be approximately equal to the difference between the indications A_1 and B_1. Observe the indication with this weight on the left pan B_2.

8.6.4 Leaving the weight S in place, remove the weight 'B' from the pan and replace weight 'A'. Observe the indication (A_2).

8.6.5 Compute the difference between weights 'A' and 'B'.

$$D_1 = S \times \frac{(A_1 - B_1 - B_2 + A_2)}{2 \times (B_2 - B_1)} \tag{6}$$

8.6.6 Repeat 8.6.1 – 8.6.5 a convenient number of times (for example, 10) recording D_1, D_2, ... D_n.

8.6.7 Compute the standard deviation, s, as follows: Fig. 1

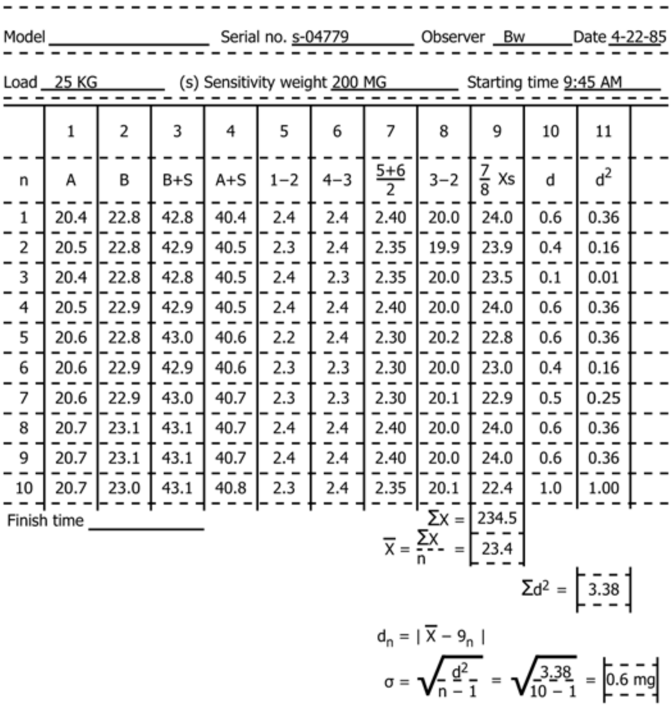
$$s = \sqrt{\frac{\sum d^2}{n - 1}} \tag{7}$$

where:

d = difference of each D from the mean $\bar{X}$,
$\bar{X}$ = $\frac{D_1 + D_2 + \dots D_n}{n}$, and
n = number of double substitutions (8.6.1 – 8.6.5 equals one double substitution). (See Fig. 1.)

8.6.8 The computation of s is useful to the extent that the measurement system is under control, for example, the range of s measured at various times remains within acceptable limits. It is useful to maintain a control chart where the s's are plotted as a function of time. A pattern can then be established so that when a particular computation falls outside of the pattern, the observer may wish to examine the measurement process for some fault.

8.6.9 Although a separate test for off-center errors is not described herein, the test for precision will include errors attributable to this type of error.



Model ____________ Serial no. s-04779 Observer Bw Date 4-22-85

Load 25 KG (s) Sensitivity weight 200 MG Starting time 9:45 AM

	1	2	3	4	5	6	7	8	9	10	11
n	A	B	B+S	A+S	1−2	4−3	$\frac{5+6}{2}$	3−2	$\frac{7}{8}$ Xs	d	d^2
1	20.4	22.8	42.8	40.4	2.4	2.4	2.40	20.0	24.0	0.6	0.36
2	20.5	22.8	42.9	40.5	2.3	2.4	2.35	19.9	23.9	0.4	0.16
3	20.4	22.8	42.8	40.5	2.4	2.3	2.35	20.0	23.5	0.1	0.01
4	20.5	22.9	42.9	40.5	2.4	2.4	2.40	20.0	24.0	0.6	0.36
5	20.6	22.8	43.0	40.6	2.2	2.4	2.30	20.2	22.8	0.6	0.36
6	20.6	22.9	42.9	40.6	2.3	2.3	2.30	20.0	23.0	0.4	0.16
7	20.6	22.9	43.0	40.7	2.3	2.3	2.30	20.1	22.9	0.5	0.25
8	20.7	23.1	43.1	40.7	2.4	2.4	2.40	20.0	24.0	0.6	0.36
9	20.7	23.1	43.1	40.7	2.4	2.4	2.40	20.0	24.0	0.6	0.36
10	20.7	23.0	43.1	40.8	2.3	2.4	2.35	20.1	22.4	1.0	1.00

Finish time ____________

$\Sigma X = \boxed{234.5}$

$\bar{X} = \frac{\Sigma X}{n} = \boxed{23.4}$

$\Sigma d^2 = \boxed{3.38}$

$d_n = | \bar{X} - 9_n |$

$\sigma = \sqrt{\frac{d^2}{n - 1}} = \sqrt{\frac{3.38}{10 - 1}} = \boxed{0.6 \text{ mg}}$

A = Indicated reading of the "A" weight
B = Indicated reading of the "B" weight
s = mass value of the sensitivity weight.
= standard deviation in the same mass units as s

NOTE 1—Numbers in equations refer to data in that particular column.

FIG. 1 Computation Sheet Double Substitution Weighings

8.7 *Accessory Reading Devices*—A number of devices are available to assist the user in making measurements. These are usually designed to eliminate the need for some of the smaller weights used in measuring a sample. For example:

8.7.1 A graduated or notched strip across the top of the weighbeam can accommodate a sliding or rolling weight whose value is chosen so that each graduation or notch represents some weight value.

8.7.2 A chainweight compared to a reading device which acts as a continuously variable weight. This can be calibrated to read directly in mass units.

8.7.3 Mechanically operated weights that may be added to or removed from one of the weighpans.

8.7.4 An optical scale that subdivides the angle of tilt of the beam into small readible graduations which can then be calibrated in mass units.

8.7.5 Electrical transducers such as a linear variable differential transformer that provides an electrical signal which is a function of the angle of beam displacement.

8.7.6 Load cells arranged so that the range of the cell represents some fraction of the capacity of the balance and whose resolution represents the readability.

8.7.7 Force balance systems that provide a restoring force to the weighbeam and whose capacity may represent some fraction of the capacity of the balance.

8.7.8 Magnifying devices such as microscopes or photodetectors which magnify the null point observation. Many of these devices require calibration or adjustment so that they may be used to produce observations in mass units rather than in arbitrary scale divisions or digital units.

8.8 *Device Calibration:*

8.8.1 *Graduated or Notched Beam Strip*—Direct reading capability is dependent upon the accuracy of the graduations and on the adjustment of the moving weight. Place the sliding weight at the zero mark and observe the rest point indication. Move the weight to the maximum indication and place a standard weight equal to the indicated value on the pan opposite the moving weight. For example, if the maximum reading on the beam strip is 10 mg and the weight moves from left to right, place the standard weight 10 mg on the left pan. Observe the new rest point. If the sliding weight is correctly adjusted, the two rest points should be the same. If not, either a readjustment of the sliding weight is required or a calibrating factor computed. Intermediate graduations may be calibrated with smaller standards. Since it may not be practical to change the location of graduations on the beam, it may be useful to plot a correction curve to translate the markings into mass units.

8.8.2 *Chainweight*—The full-scale calibration of a chainweight is determined by the distance from the central pivot of the beam to the point at which the chain is attached to the beam. The chainweight mechanism is designed to measure out a length of chain and adjustment to read directly in mass units is accomplished by changing the distance between the chainweight pivot and the center pivot. Non-linearity in the chain or the indicating scale may lead to inaccurate weighings. In addition, frictional forces in the chain links and suspension may lead to imprecision.

8.8.2.1 Chainweight full scale calibration. Set the chainweight indicator to zero. Observe the rest point. Place a standard weight equal to the maximum reading on the chainweight indicator on the pan opposite the central pivot from the suspension point of the chain. If, for example, the chain is suspended from the right side of the central pivot and the indications increase as the chain lengthens, place the standard weight on the left pan. Observe the null point. It should remain the same as in the previous observation. If the rest point sense is such that the standard weight appears to be heavy, the suspension point for the chain must be moved farther from the center pivot. Note that moving the suspension also affects the zero point. Therefore, the zero indication must be checked and adjusted each time that the suspension point of the chainweight is changed. Several adjustments may be necessary in order to correctly position the chainweight. Intermediate points may be calibrated by means of small standard weights. If necessary, a correction curve can be plotted.

8.8.2.2 *Chainweight Precision*—A variety of methods are available to check the precision but one simple way will give a great deal of information. Place a weight on the pan equal to about one-half the full-scale of the chainweight indicator and set the indicator at the position which gives a null indication on the beam indicator. Without arresting the beam, turn the chain indicator back to zero and gradually increase the indication until a null reading is obtained again, always moving the indicator in the same direction. Observe the indicator reading. Again, without arresting the beam, turn the chainweight indicator to the maximum reading and then return it until a null reading is again obtained with the chain indicator descending in value. Record the chainweight indication. Repeat each indication several times and compute the standard deviation (s). The data may be interpreted as necessary.

8.8.3 *Mechanically Operated Weights*—These mechanisms merely substitute for manual placement of weights on the pan. If the mechanical weights are removed from the same pan on which the sample is placed (substitution weighing), the values of the individual weights and combinations of weights are of primary concern. Generally, weights should not be calibrated on the resident balance because of the limits of precision of the balance itself. Weights may be calibrated by standards laboratories if necessary. Weights used in the substitution mode may be read directly. However, if the weights are applied to the opposite pan from the sample in order to achieve equilibrium, the lever ratio must be considered as well (see 8.3.6).

8.8.4 *Optical Scales*—Graduated reticles read either through a telescope or by means of an optical projection system add convenience because many subdivisions of the scale can be utilized. Frequently, 10 000 scale graduations (including vernier subdivisions) are used. These devices are convenient in minimizing the need for small weights. However, since the angular displacement of the optical scale depends upon the sensitivity of the balance they are best suited for balances designed to maintain sensitivity constant with load. Full scale calibration is done by setting the indication to zero with the weigh pan empty and then placing a standard weight equal to the full scale indication of the optical device on the pan. If the indication does not agree with the weight of the standard, the sensitivity of the weighbeam must be adjusted by raising or lowering its center of gravity. Usually trimming weights are provided on the balance to accomplish this. Always recheck the zero point after each adjustment because it can also be affected by this adjustment. Linearity can be checked using small standard weights to provide a calibration curve for the optical scale.

8.8.5 Electrical transducers such as linear variable differential transformers (LVDT's) are similar in application to optical scales in that they subdivide the angular displacement of the beam into many readible units. Linearity errors may be larger than for optical scales since LVDT's have a force component which may be a non-linear function of the position of the weighbeam. The full-scale calibration and linearity may be checked in the same manner as for optical scales although an electrical adjustment may be provided for adjusting the full-scale calibration rather than means for adjusting the c.g. As in the case of an optical scale, beam sensitivity may be a function of load and if the system does not provide for constant beam load, calibration should be done at the load at which the balance is to be used if direct reading capability is required. If the LVDT is used only as a null-position indicator, the effect of the load on the sensitivity may be of less concern.

8.8.6 A load cell used in combination with a weighbeam behaves differently from a displacement transducer in that the sensitivity may not be load dependent. Load cells typically have a small displacement and, if the center of gravity of the weighbeam is adjusted to neutral equilibrium, there will be no force component due to the mass of the weighbeam. Therefore, that portion of the sample weight which is within the range of the load cell is measured directly by the load cell and the weighbeam merely acts as a force transfer lever. The rest of the sample weight must be counterbalanced by weights on the pan. Calibration for full-scale and linearity is done in the same way as for displacement transducers. Electrical adjustments are usually provided.

8.8.7 Electromagnetic force cells use current in a coil located in a magnetic field to provide a counter-force to that applied to it. A position detector maintains the position of the beam by varying the current in the coil in a servo-loop. Since negligible displacement is required, the sensitivity of the system can be made independent of the load. These devices usually exhibit excellent linearity and low hysteresis so that the precision within the on-scale range can be quite high. As with load cells, this transducer would probably be used for only a fraction of the capacity, the rest being supplied by weights. Full-scale calibration and linearity tests are performed in the same way as for load cells.

8.8.8 Devices for magnifying the beam deflection are usually designed to magnify the null-point rather than to provided on-scale indication. Their function is to permit lowering of the mechanical sensitivity of the weighbeam and thereby shortening the period of oscillation. An additional benefit of lowering the center-of-gravity of the balance is that the balance sensitivity becomes less dependent on the load (such as, effects due to flexing of the beam or misalignment of the three knives are reduced). For very sensitive balances (1 ppm or better) they provide the additional benefit of moving the center of gravity sufficiently below the central pivot that the position of the center-of-gravity becomes less temperature dependent thereby improving the stability of the balance. The principal disadvantage is that the sensitivity of the balance to tilt is increased. No separate calibration is required for these devices. The sensitivity and precision are measured as part of the entire balance.

9. Interpretation of Results

9.1 Information about the capabilities of a particular equal-lever balance is important in determining its usefulness for a particular application. Since these instruments are available in many sizes and capacity/sensitivity ratios, these tests have been designed to be independent of these factors and the user should be able to adapt them to his or her needs.

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