〈1251〉 WEIGHING ON AN ANALYTICAL BALANCE

INTRODUCTION

Weighing is a frequent step in analytical procedures, and the balance is an essential piece of laboratory equipment. The general information described here applies directly to electronic balances used in analytical procedures. Although many portions of the chapter are applicable to all balances, some are applicable only to analytical balances. This chapter should not be considered all-inclusive, and other sources of information (e.g., the US National Institute of Science and Technology and balance manufacturers) may be useful and applicable when analysts perform a weighing operation or implement a weighing procedure. The information given in this chapter is applicable not only to balances used for materials that must be accurately weighed (see *Balances* 〈41〉) but also to balances used in all analytical procedures.

QUALIFICATION

Users should consult *Analytical Instrument Qualification* 〈1058〉, standard operating procedures, and recommendations from manufacturers when they devise qualification plans.

Installation

The balance's performance depends on the conditions of the facility where it is installed. Analysts should consult information provided by the manufacturer before they install a balance.

SUPPORT SURFACE

The balance should be installed on a solid, level, nonmagnetic surface that minimizes the transmission of vibration (e.g., a floor-mounted, granite weigh bench). If a metallic support surface is used, the surface should be grounded in order to prevent the buildup of static electricity.

LOCATION

If possible, the balance should be located in a room that is temperature and humidity controlled. The location should have a clean, consistent electrical power supply. The location should be free of drafts and should not be near ovens, furnaces, air conditioner ducts, or cooling fans from equipment or computers. The balance should be positioned away from outside windows so that direct sunlight does not strike the balance. The balance should not be installed near sources of electromagnetic radiation such as radio-frequency generators, electric motors, or hand-held communication devices (including cordless telephones, cellular telephones, and walkie-talkies). The balance should not be located near magnetic fields induced by laboratory instrumentation or other equipment.

The performance of the balance should be assessed following installation and before use in order to demonstrate adequate performance. In some situations, it may not be possible to position the balance in an optimum environment. Examples of potential facility issues include the following:

1. Air currents sometimes are present in the laboratory.
2. Temperatures in the laboratory vary excessively (check the manufacturer's literature about temperature sensitivity).
3. Humidity is either very low or very high. Either condition may increase the rate at which the sample weight varies because of pickup or loss of water. Low humidity increases the buildup of static electricity.
4. Adjacent operations are causing vibration.
5. Corrosive materials are used nearby or are routinely weighed.
6. The balance is located within a fume hood because it is used to weigh corrosive or hazardous materials.
7. The balance is adjacent to equipment that produces a magnetic field (e.g., a magnetic stirrer).
8. Direct sunlight strikes the balance.

In situations when the balance is located near equipment or systems that induce vibration, drafts, electromagnetic radiation, magnetic fields, or changes in temperature or humidity, the assessment should be conducted with those systems operating in order to duplicate a worst-case scenario.

Operational Qualification

An operational qualification should be performed either by the user or by a qualified third-party vendor after the equipment has been installed.

As a minimum, the power should be turned on and the balance should be allowed to equilibrate according to the manufacturer's instructions (1–24 h, depending on the type of balance) before use. Depending on the balance, analysts should include the following procedures in the operational qualification:

1. Mechanical mobility of all moveable parts
2. Control of stable indication
3. Manually triggered or automatic adjustment by means of built-in weights

4. Operation of ancillary equipment
5. Tare function
6. Initial calibration

Several types of electronic analytical balances use built-in weights for manually triggered or automatic adjustment. This adjustment usually is applied to reduce the drift of the balance over time and to compensate for drifts caused by variations in the ambient temperature.

Calibration normally is performed as part of the operational qualification, but it also can be performed periodically thereafter. Calibration should be performed at the location where the balance is used in normal operation.

Performance Qualification

Table 1 provides a list of the most important balance properties that should be assessed during performance qualification. Depending on the risk of the application and the required weighing process tolerance, some of these tests may be omitted. Tests also can be omitted if there is evidence that the property in question has only minimal effect on the weighing performance. Any procedures used should be consistent with in-house standard operating procedures, applicable for the specific balance, and adequately justified. Performance qualification should be performed periodically as described in standard operating procedures, and the frequency of each of the individual tests can vary depending on the criticality of the property.

The weights that are used to perform the tests should be stored and handled in a manner that minimizes contamination. Before executing the tests, the technician should place the weights in the vicinity of the balance for an appropriate time to reach sufficient thermal equilibrium. If possible, tests should be carried out with a single test weight in order to minimize handling errors, but multiple test weights are permitted.

The tests should be recorded in such a manner that the data can be used to easily track balance performance and to assist in laboratory investigations as needed. Meaningful acceptance criteria can be set depending on the required weighing tolerance, i.e., the maximum allowed deviation permitted by specifications, regulations, etc., of a quantity to be weighed from its target value. Procedures should be in place to address test results that are outside acceptable ranges and to provide assurance that balance cleanliness and environment have not affected the result. Also, a procedure should be in place for removing a balance from operation when observed results fall outside acceptable ranges.

Table 1. Suggested Performance Tests and Acceptance Criteria

Property	Definition	Examples	Acceptance Criteria
Sensitivity	Change in the displayed value divided by the load on the balance, which causes this change.	The test load at or sufficiently close to the capacity of the balance.	NMT 0.05% deviation from 1 (the sensitivity of a correctly adjusted balance), where ⟨41⟩ is applicable. For other uses, respective tolerance requirement divided by 2.
Linearity	Ability of a balance to follow the linear relationship between a load and the indicated weighing value. Nonlinearity usually is expressed as the largest magnitude of any linearity deviation within the test interval.	From 3 to 6 points over the range of the balance.	NMT 0.05% deviation where ⟨41⟩ is applicable. For other uses, respective tolerance requirement divided by 2.
Eccentricity	Deviation in the measurement value caused by eccentric loading—in other words, the asymmetrical placement of the center of gravity of the load relative to the load receiver. Eccentricity usually is expressed as the largest magnitude of any of the deviations between an off-center reading and the center reading for a given test load.	Performed in the center of gravity and the four quadrants (for rectangular platter shapes) or at analogous locations for other platter shapes. Test load usually should be 30% of the capacity of the balance or higher (refer to the manufacturer's manual for any possible upper limit).	NMT 0.05% deviation where ⟨41⟩ is applicable. For other uses, respective tolerance requirement divided by 2.
Repeatability	Ability of a weighing instrument to display identical measurement values for repeated weighings of the same objects under the same conditions, e.g., the same measurement procedure, same operator, same measuring system, same operating conditions, and same location over a short period of time. Repeatability usually is expressed as the standard deviation of multiple weighings.	10 replicate weighings (using a test weight that is a few percent of the nominal capacity of the balance).	Requirement from ⟨41⟩ where applicable. For other uses, user specified requirements will apply.

Sensitivity, linearity, and eccentricity all account for systematic deviations; i.e., they limit the accuracy of the balance (based on the definition of accuracy in *Validation of Compendial Procedures* ⟨1225⟩ and ICH Q2). In the International Vocabulary of Metrology (VIM) and documents of the International Organization for Standardization, this concept is referred to as trueness. Because deviations are largely independent from each other, it is not likely that all deviations occur simultaneously and have the same algebraic sign. Therefore the arithmetic addition of all individual deviations to assess the balance accuracy would constitute a rather conservative approach. A quadratic addition of the individual deviations is a more realistic approach. By allocating 50% of the weighing tolerance budget to the acceptance criteria of the individual properties, e.g., sensitivity, linearity, and eccentricity, analysts ensure adherence to the required weighing tolerance. Therefore, the acceptance criteria for the individual properties that account for the systematic deviations are set to weighing tolerance divided by 2. These properties—or a subset of them—also can be taken to fulfill the accuracy requirement described in ⟨41⟩. In this case the acceptance criteria thus allow a maximum deviation of 0.05% for sensitivity, linearity, and eccentricity. Repeatability preferably is tested with a test weight of a few percent of the balance capacity. At the lower end of its measurement range, the performance of laboratory balances is limited by the finite repeatability, and limitations induced by systematic deviations normally can be neglected. Therefore, the whole weighing tolerance budget can be allocated to the acceptance criterion of the repeatability test.

For the sensitivity and linearity tests as described above, the analyst should use certified weights with an appropriate weight class (e.g., according to International Organization of Legal Metrology R111 or American Society for Testing and Materials E617, available from www.oiml.org and www.astm.org, respectively). [NOTE—If a differential method is used for the linearity test, certified weights may not be required.]

Depending on the acceptance criterion, it may be sufficient to consider only the nominal weight value of the test weights. If the nominal value of the test weight is considered, analysts should ensure that the maximum permissible error does not exceed one-third of the acceptance criterion. Alternatively, if the certified value of the test weight is considered, its calibration uncertainty should not exceed one-third of the acceptance criterion. If more than one weight is used to perform the test, the calibration uncertainties of the weights must be summed and the sum should not exceed one-third of the acceptance criterion. For tests such as eccentricity or repeatability, the use of certified weights is optional, but analysts must ensure that the mass of the weight does not change during the test.

The tests described above also can be included in formal periodic calibration in order to fulfill applicable cGMP requirements.

Balance Checks

A balance check using an external weight helps ensure that the balance meets weighing tolerance requirements. The balance check is performed at appropriate intervals based on applicable standard operating procedures. The frequency of the balance check depends on the risk of the application and the required weighing tolerance. Checks with external weights can be replaced partially using automatic or manually triggered adjustment by means of built-in weights. When analysts perform the balance check with an external weight, the same acceptance criteria may apply as described in the sensitivity test above.

Minimum Weight

The minimum net sample weight, in short, minimum weight, m_{min}, of an analytical balance can be expressed by the equation:

$$m_{min} = k \times s/\text{required weighing tolerance}$$

where k is the coverage factor (usually 2 or larger) and s is the standard deviation (in a mass unit, e.g., in mg) of NLT 10 replicate measurements of a test weight. If the standard deviation obtained is less than $0.41d$, where d is the scale interval, the standard deviation is replaced by $0.41d$. The lower limit of $0.41d$ for the standard deviation results from the rounding error of the digital indication of a weighing instrument. The rounding error that is allocated to a single reading is calculated as $0.29d$. Note that a weighing always consists of two readings, one before and one after placing/removing the sample on/from the pan, with the difference between the two indications being the net sample weight. The two individual rounding errors are usually added quadratically, leading to $0.41d$. Taring the instrument after placing the tare container on the pan does not affect the rounding error as the zero indication is also rounded. The minimum weight describes the lower limit of the balance below which the required weighing tolerance is not adhered to. The equation above takes into account that the performance of analytical balances at the lower end of the measurement range is limited by the finite repeatability.

For materials that must be accurately weighed, ⟨41⟩ stipulates that repeatability is satisfactory if two times the standard deviation of the weighed value, divided by the desired smallest net weight (smallest net weight that the users plan to use on that balance), does not exceed 0.10%. For this criterion the equation above simplifies to:

$$m_{min} = 2000 \times s$$

If the standard deviation obtained is less than $0.41d$, where d is the scale interval, the standard deviation is replaced by $0.41d$.

If not subject to the requirements of ⟨41⟩, the minimum weight value may vary depending on the required weighing tolerance and the specific use of the balance.

To facilitate handling, the test weight that is used for the repeatability test does not need to be at the minimum weight value but can be larger because the standard deviation of repeatability is only a weak function of the test weight value.

In order to satisfy the required weighing tolerance, when samples are weighed the amount of sample mass (i.e., the net weight) must be equal to or larger than the minimum weight. The minimum weight applies to the sample weight, not to the tare or gross weight.

Factors that can influence repeatability while the balance is in use include:

1. The performance of the balance and thus the minimum weight can vary over time because of changing environmental conditions.
2. Different operators may weigh differently on the balance—i.e., the minimum weight determined by different operators may be different.
3. The standard deviation of a finite number of replicate weighings is only an estimation of the true standard deviation, which is unknown.
4. The determination of the minimum weight with a test weight may not be completely representative for the weighing application.
5. The tare vessel also may influence minimum weight because of the interaction of the environment with the surface of the tare vessel.

For these reasons, when possible, weighings should be made at larger values than the minimum weight, i.e., the desired smallest net weight that the users plan to use on that balance should be larger than the minimum weight.

OPERATION OF THE ANALYTICAL BALANCE

Select the appropriate balance for the quantity and performance needed. General chapter ⟨41⟩ provides requirements for balances used for materials that must be accurately weighed. The balance user should check the balance environment (vibration, air currents, and cleanliness) and status of calibration before use.

Receivers

To ensure suitable performance in measuring the weight of a specimen, analysts should consider selection of a proper receiver for the material.

GENERAL CHARACTERISTICS

All receivers must be clean, dry, and inert. The total weight of the receiver plus the specimen must not exceed the maximum capacity of the balance. With a properly maintained and adjusted laboratory balance, weighing uncertainty for small samples, i.e., net weights with a mass not exceeding typically a few percent of the capacity of the balance, essentially is determined by the repeatability. However, repeatability depends on the size and surface area of the weighed object. For this reason large or heavy receivers introduce a deviation from the conditions under which the repeatability was determined without considering the receivers. Therefore, either receivers of a low mass and small surface should be used (especially in cases when specimens of low weight are being measured) or the repeatability test should be performed with the receiver placed on the weighing pan as a preload. Receivers should be constructed from nonmagnetic materials in order to prevent magnetic interference with electronic balance components. Receivers should be used at ambient temperature in order to prevent the formation of air currents within the weighing chamber.

SOLID SAMPLES

Receivers for weighing solid materials include weighing paper, weighing dishes, weighing funnels, or enclosed vessels, including bottles, vials, and flasks. Hygroscopic papers are not recommended for weighing because they may have a detrimental effect on the observed results.

Weighing dishes typically are constructed from a polymer or from aluminum. Antistatic weighing dishes are available for measuring materials that retain static electricity. Weighing funnels typically are constructed from glass or from a polymer. The design of this type of receiver combines attributes of a weighing dish and a transfer funnel, which can simplify the analytical transfer of a weighed powder to a narrow-necked vessel such as a volumetric flask. For solid samples that are volatile or deliquescent, analysts must weigh the material into an enclosed vessel. Where practical, analysts should use an enclosed vessel with a small opening in order to reduce sample weight loss from volatilization or weight gain from the adsorption and absorption of atmospheric water.

LIQUID SAMPLES

Receivers for liquid samples typically are inert, enclosed vessels. For liquid samples that are volatile or deliquescent, analysts should use an enclosed vessel with a small opening, and the enclosure should be replaced rapidly following material transfer. Special precautions should be taken to be certain that the receiver and the enclosure are constructed from a material that is compatible with the liquid sample. The receiver and enclosure must have a seal that is sufficient to prevent leaks from a liquid that is of low viscosity or has low surface tension or a low boiling point.

Types of Weighing

WEIGHING FOR QUANTITATIVE ANALYSIS

The initial step for many quantitative analyses is to accurately weigh a specified amount of a sample. *General Notices, 6.50.20 Solutions* stipulates that solutions for quantitative measures must be prepared using accurately weighed analytes: i.e., analysts must use a balance that meets the criteria in ⟨41⟩. Errors introduced during the weighing of a sample can affect the accuracy of all subsequent analytical measurements.

ADDITION WEIGHING

Addition weighings typically are used for solid samples or liquid samples for which volatility is not an issue. The receiver is placed on the balance. After the balance display stabilizes, the analyst should tare the balance; add the desired amount of material to the receiver; allow the balance display to stabilize; record the weight; and quantitatively transfer the material to an appropriate vessel or, if it cannot be guaranteed that the entire amount has been transferred, weigh the receiver again and note the weight difference.

DISPENSE WEIGHING

Dispense weighing typically is used for weighing emulsions or viscous liquids such as ointments. In these situations it is not practical to weigh the material into a typical receiver. Accordingly, the analyst should tare the balance; place the sample on the balance in a suitable container (e.g., a bottle, tube, transfer pipet, or syringe) that has been wiped clean on the outside; record the weight after the balance display stabilizes; transfer the desired amount of sample to an appropriate receiving vessel, such as a volumetric flask; and place the pipet or syringe back onto the balance. The difference in the two weighings is equal to the weight of the transferred specimen.

GRAVIMETRIC DOSING

Gravimetric dosing typically is used for sample and standard preparations or capsule filling. For such weighing the analyst places the volumetric flask, vial, or capsule shell on the balance; tares the balance after the balance display stabilizes; adds the solid or liquid components into the receiver by means of dosing units; and records the respective weights.

Problem Samples

ELECTRICALLY CHARGED SAMPLES AND RECEIVERS

Dry, finely divided powders may be charged with static electricity that can make the powder either attracted to or repelled by the receiver or the balance, causing inaccurate weight measurements and specimen loss during transfer. A drift in the balance readings should alert the operator to the possibility that the material has a static charge. Commercially available balances with a built-in antistatic device can be used to remedy the problem. Such devices may use piezoelectric components or a very small amount of a radioactive element (typically polonium) to generate a stream of ions that dissipate the static charge when passed over the powder being weighed. Antistatic weigh boats, antistatic guns, and antistatic screens also are commercially available. The static charge depends also on the relative humidity of the laboratory, which in turn depends on atmospheric conditions. Under certain conditions, static charge is caused by the type of clothing worn by the operator and this charge can cause large errors in the weighing. Borosilicate glassware and plastic receivers have a well-known propensity for picking up static charge, especially at low relative humidity. The gloves used to protect the operator also may increase the potential for a static charge problem. Placing the container in a metal holder may help to shield the static charge, and antistatic gloves also can help to alleviate the problem.

VOLATILE SAMPLES

When weighing a liquid that has a low boiling point, analysts must receive the specimen in a vessel with a gas-tight enclosure of small diameter. The analyst then tares the vessel and enclosure, adds the desired amount of sample, and replaces the enclosure. After the balance display stabilizes, the analyst records the specimen weight.

WARM OR COOL SAMPLES

Samples that are warm or cool should be equilibrated in the laboratory, or the weight readings may be erroneous. With regard to warm samples, the apparent weight is smaller than the true weight because of heat convection. For example, a flask that is warmer than ambient air warms up this air, which then flows upward along the flask and reduces the apparent weight of the contents by viscous friction.

HYGROSCOPIC SAMPLES

Hygroscopic materials readily absorb moisture from the atmosphere and steadily gain weight if left exposed. Therefore, hygroscopic samples must be either weighed promptly or placed in a vessel with a gas-tight enclosure. For a gas-tight vessel, analysts should tare the vessel and enclosure, add the desired amount of sample, and replace the enclosure. After the balance display stabilizes, the analyst can record the specimen weight.

ASEPTIC OR BIOHAZARDOUS SAMPLES

The weighing of sterile or biohazardous samples should take place within the confines of a clean bench, biosafety cabinet, isolator, or similar containment device. Air flow within the hood potentially can cause balance instability, so after a balance has been installed under a hood, analysts should perform a rigorous qualification study with suitable weight artifacts (see ⟨41⟩) in order to determine the acceptability of the balance performance in this environment.

WEIGHING CORROSIVE MATERIALS

Many chemicals, such as salts, are corrosive, and materials of this nature should not be spilled on the balance pan or inside the balance housing. Extra care is essential when materials of this nature are weighed. Analysts should consider the use of sealed containers such as weighing bottles or syringes. In the event of a spill, requalification of balance may be necessary, depending on the nature of the spill.

Safety Considerations When Weighing

During a weighing, the analyst may be exposed to high concentrations of a pure substance. The analyst must carefully consider this possibility at all times and should be familiar with the precautions described in the substance's Material Safety Data Sheet before weighing it. Hazardous materials should be handled in an enclosure that has appropriate air filtration. Many toxic—and possibly allergenic—substances present as liquids or finely divided particles. When weighing these substances, analysts should use a mask that covers the nose and mouth to prevent any inhalation of the substance, and they should use gloves to prevent any contact with the skin. [NOTE—The use of gloves is good practice for handling any chemical. If it is necessary to handle the container being weighed, the analyst should wear gloves not only for self-protection but also to prevent moisture and oils from being deposited on the weighed container.]