

Electrostatics and Weighing

Dealing with Static Samples



Electrostatically charged samples or containers can be difficult to weigh. Problems with balance stability or measurement drift can often be caused by static charges. This white paper explains measures that can be taken to prevent electrostatic charges building up, but more importantly what can be done to dissipate these charges once they have been generated. Understanding electrostatic charges and the effects they can have on samples and containers are critical to avoid disruption to weighing processes. XPR analytical balances simplify handling of static samples, to ensure the highest accuracy and most reliable weighing results.

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1 Introduction to Electrostatics

What is static?

Static is the accumulation of electrical charges on the surface of a non-conductive material. The phenomenon of static electricity requires the separation of positive and negative charges. When two different materials are in contact with one another, electrons can move from one material to the other, which leaves a positive charge on one material, and an equal negative charge on the other.

2 What Causes Electrostatic Charges?

Friction is the most common way for electrostatic charges to be generated on an object. Everyone remembers the experiment in physics class, where a glass rod is rubbed with a cloth and will then attract small pieces of paper or lift the hair away from your head. Typical laboratory examples include:

- Drying a glass beaker with a cloth
- Handling a volumetric flask with disposable gloves
- Unpacking a laboratory vessel from a plastic bag
- Filling a vessel with loose materials (bulk)

Charge separations are caused by rubbing, for example, when tare containers are grasped or lifted. This is fostered by materials that have a strong electrical insulation effect, such as PTFE or plastic materials (like polypropylene, polycarbonate or polystyrene), but also glass. In addition, unfavorable external conditions, such as a dry atmosphere, poorly grounded floors, or the use of plastic gloves, can contribute to the formation of charge separation and, thus, to electrostatic charging.

However, charges can also arise without the involvement of friction. Merely separating two different materials, such as lifting a glass flask off of a plastic surface is sufficient to generate a strong static charge.

The Triboelectric Series (Fig. 1) is a list that shows which materials have a greater tendency to become positively charged and which have a greater tendency to become negatively charged. The further apart the respective materials are in the Triboelectric Series, the more easily a static charge will be generated on contact between the two materials.

Positive	Air
	Dry human skin
	Glass
	Human hair
	Nylon
	Wool
	Silk
	Aluminium
	Paper
Neutral	Cotton
	Steel
Negative	Wood
	Hard rubber
	Nickel/Copper
	Brass/Silver
	Gold/Platinum
	Polyester
	Polystyrene
	Polyurethane
	Polyethylene
	Polypropylene
	PVC
	Silicon
	PTFE
	Silicon rubber

Figure 1: Triboelectric Series.

3 What Are the Effects on Weighing and Weighing Accuracy?

Electrostatic charges can cause sample handling difficulties, errors in weighing results, and longer weighing times. The effect on the accuracy and reproducibility of the measured value can be very significant.

The presence of static is often recognizable by:

- Drifting measurement readings
- Non-repeatability of measurement results
- Balance instability (or stabilization time longer than usual)

Drift and non-repeatability of results, and balance instability is usually due to the dissipation of electrostatic charges. These observations are due to the vertical component of the Coulomb force continually changing, which makes it difficult to obtain a precise measurement difficult.

Electrostatic charges also disrupt the weighing process if the sample or opening of the tare container is charged. When this happens, powder can “jump” from the spatula onto the tare container, causing precision working to become an ordeal (as illustrated in Fig. 2). Dry powders are very susceptible to static influences and can be troublesome to weigh. Weighing a small quantity into a large glass or polymer vessel represents the classic use case where an electrostatic charge could significantly increase the error of the weighing result.



Figure 2: “Jumping” powder during the weighing-in step caused by electrostatic charges.

The cause of these issues is a net charging of the weighing sample that, without additional measures, is not reduced or is reduced only slowly. If weighing vessels are charged, polar opposite charges on the metal surfaces of the weighing chamber are attracted to them (see Fig. 3). This attraction between the charged vessel to the weighing pan and the charges on the weighing chamber produce an additional force that the balance measures as supposed extra weight. Typically, under such influences, balances take a long time to stabilize, and the measurement is inaccurate due to the additional disruptive force.

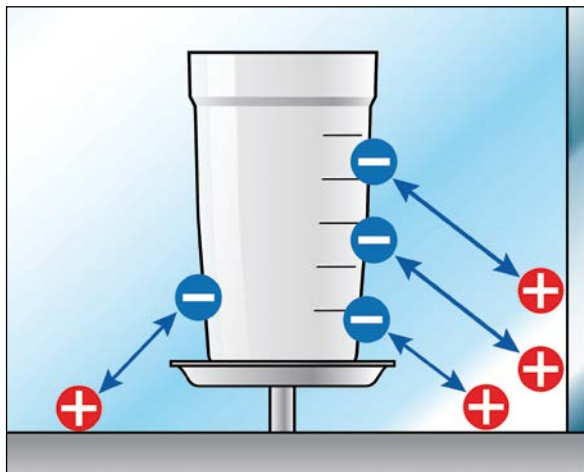


Figure 3: A negative charge on the measuring flask and a positive charge on the balance housing cause a force to be exerted between the balance and the vessel. The vertical component of this force adds to the weight of the flask and influences the weighing result.

The effects on the weighing accuracy could be:

- The reported value could be more or less than the real weight
- Errors in the range of 1–100 mg have been observed

Because the charges generated can be negative or positive, and either attract or repel each other, the real weight may be more or less than the reported value. Errors of a few milligrams to 100 mg have been observed, which is highly significant in terms of percentage error when weighing small samples.

Yet there are cases where the problem is difficult or indeed impossible to notice. For example, it is possible to achieve a stable weight with a net electrostatic force present, without any of the typical indicators that static is affecting the weighing result.

The physics behind it

An electrical charge on the balance or the sample or vessel to be weighed causes an electrostatic force. A formula can be derived to define electrostatic force attraction and repulsion. Coulomb's Law [Formula 1] states that electrical charges exert a mutual force on each other (F_E).

$$F_E = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{Q_1 Q_2}{r^2} \quad \text{or simplified to} \quad F_E = k_e \frac{Q_1 Q_2}{r^2} \quad [1]$$

Where:

- k_e is Coulomb's constant
- Q represents individual charge on two separate objects
- r is the distance between the objects
- ϵ_0 & ϵ_r are absolute and relative dielectric constants

Due to the potential difference, a force acts between the measured object and the balance. The balance measures the vertical component of this force (F_E) and interprets it as a weight corresponding to a mass of Δm , according to equation 2:

$$F_E = g\Delta m \quad [2]$$

in which g is the gravitational constant

By combining formulae 1 and 2, and rearranging so that the mass change is the subject of the equation, this becomes:

$$\Delta m = \frac{1}{g} \left(k_e \frac{Q_1 Q_2}{r^2} \right) \quad [3]$$

Formula 3 describes the influence on the weighing result.

Typical laboratory example:

An analytical balance is used for dosing a defined quantity of powder into a glass flask in order to prepare a solution with a specific concentration. A 100 mL volumetric flask is placed on the weighing pan. Under normal conditions, there is an electrostatic charge on the flask and therefore a complementary charge is induced in the weighing chamber. This results in a net attractive force.

This net force pulls the flask downwards, making it appear heavier than it really is or pushes it upwards, making it appear lighter. Under dry air conditions, or climate controlled environments, typical of an analytical laboratory, charges are more easily generated and lead to greater potential for weighing errors. If the balance displays a stable weight, the user proceeds by taring the balance and manually dosing a powder, which can be a demanding or time-consuming step.

A net force in either direction leads the user to dose too much or too little powder, resulting in incorrect final solution concentrations. Typically, the charges on the tare vessel slowly discharge to the environment over time, which could cause the user to continually add too much powder, leading to even larger weighing errors. The concentration of the resulting solution is thus erroneously high, which may have a significant effect on some analytical measurements, potentially leading to Out-of-Specification (OOS) results, or large amounts of retesting work.

4 How Quickly do Charges Dissipate?

Electrostatic charges dissipate over time:

- Depending on the conditions, charge dissipation can take a few seconds or minutes, or several hours in a controlled dry atmosphere (relative humidity $\leq 20\%$).
- Good insulators (e.g. borosilicate glass or laboratory grade plastics) can make charge dissipation slower.

Charges dissipate fast from poorly insulating materials (good electrical conductors), but this can be very slow with items made from a good insulator (poor electrical conductor). Most laboratory vessels are made of borosilicate glass, which is an excellent electrical insulator. The same is true for almost all laboratory-grade plastics used in the manufacture of laboratory items. Even common window glass (sodium silicate glass) makes a good insulator under dry conditions. These good insulating materials can slow down charge dissipation. Clean glassware taken straight from the laboratory dishwasher carries and holds a large amount of charge.

The time constant of charge dissipation is influenced by the surface conductivity. The higher the surface conductivity of the charged body, the faster the electrostatic charges can drain away. Next to the material's intrinsic properties, the surface conductivity also depends to a great extent on the relative air humidity and the degree of surface contamination.

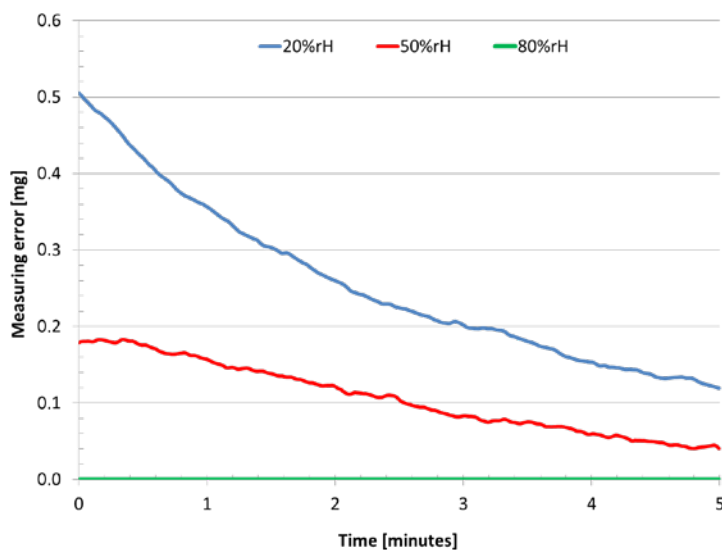


Figure 4: GLASS VESSEL – Electrostatic charge dissipation over time in varying humidity conditions.

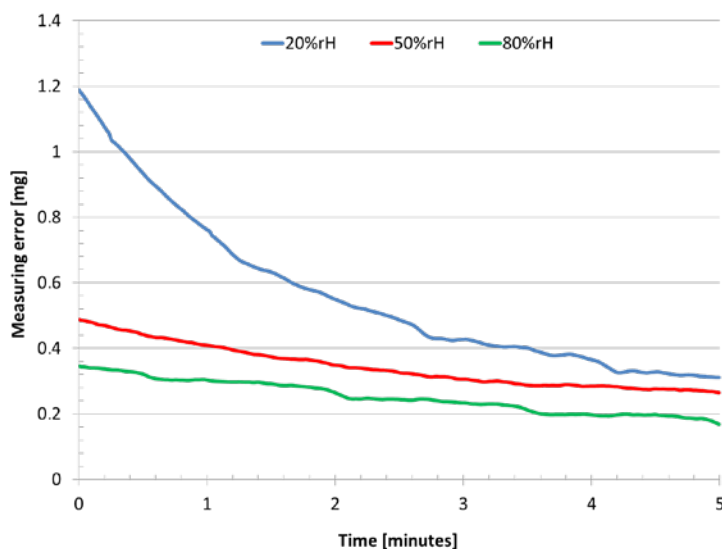


Figure 5: PTFE VESSEL – Electrostatic charge dissipation over time in varying humidity conditions.

Figs. 4 and 5 show the electrostatic charge dissipation over a period of five minutes for a glass vessel compared to a PTFE vessel. Both graphs show larger measurement errors in lower relative air humidity environments (blue lines = 20% RH). In every case, the weighing errors reduce over time, as the charge dissipates. Fig. 4 shows that a glass flask is unable to become charged at 80% relative air humidity (green line). However, for PTFE containers, even when the air humidity is high, significant weighing errors are observed over several minutes (see Fig. 5).

5 What Can Be Done to Prevent or Eliminate Static Charges?

The best way to control electrostatic charges are to try to avoid generating them in the first place!

5.1 Preventing Build-Up of Electrostatic Charges

Tips to avoid generating electrostatic charges whilst weighing in the laboratory:

- Use electrically conductive or anti-static treated materials whenever possible:
 - Plastic and glass vessels can quickly become charged and are therefore non-ideal materials.
 - SmartPrep weighing funnels from METTLER TOLEDO are specifically designed for this purpose.
- Avoid contact between dissimilar materials when handling (according to the Triboelectric Series).
- Avoid unnecessary rubbing of the vessel (especially touching it whilst wearing protective gloves).
 - If possible use weighing tweezers for handling containers.
- Increase air humidity in air-conditioned rooms:
 - Electrostatic charges frequently occur during the winter season in heated (dry) rooms.
 - The optimum relative humidity is 45–60%.
- Make sure that the balance and the weighing pan are always electrically grounded.
 - All METTLER TOLEDO balances fitted with three-pin plugs are automatically grounded
- Avoid wearing electrically insulated footwear. Use grounded shoes and grounding straps instead.

The simplest way to avoid static charges is to use conductive materials, such as those already offered in many plastic laboratory vessels, such as SmartPrep weighing funnels from METTLER TOLEDO (Fig. 6). With these vessels, the disruptive charges drain away via the weighing pan that is grounded, and the charge is eliminated. Unfortunately, it is often not possible for the user to freely select the material of the tare container for many applications.

It also helps to make sure that the user does not substantially contribute to the buildup of electrical charges by wearing insulated footwear or unnecessarily rubbing or holding the vessel with protective gloves. A very dry atmosphere also fosters the charging of weighing samples, especially in winter. A relative humidity of 45–60% can reduce the problem, although this alone often does not resolve the problem altogether.



Figure 6: SmartPrep weighing funnel: a disposable plastic weighing aid with special anti-static properties.

5.2 Reducing the Forces Produced by Static Charges

Tips to avoid generating electrostatic charges whilst weighing in the laboratory:

- Electrically shield the tare container and sample in a metal basket (which acts as a Faraday cage), e.g. use an ErgoClip tare vessel holder from METTLER TOLEDO.
- Use a smaller tare vessel, to reduce surface area and weight, which has a direct relation to the forces generated.
- Ensure that the sample is placed centrally on the weighing pan, and ensure minimum possible protrusion beyond the rim.
- Use a light electrically conductive underlay to increase the distance between the tare vessel and the surface of the weighing area.

5.2.1 Use an ErgoClip (Faraday Cage)

A Faraday cage is an enclosure made of a mesh of conductive material, which is used to block electrostatic and electromagnetic fields. The ErgoClip from METTLER TOLEDO (Fig. 7) is a small metal basket that acts a Faraday cage, and is optimally designed for shielding electrostatic charges. The ErgoClip eliminates the disruptive influence of having a differently charged tare container and balance interior, and has the added advantage that it holds the tare vessel securely in a defined position. A variety of ErgoClips are available, which are easy to install and ideally suited for use with a range of standard laboratory vessels, such as reagent glassware and tubes (e.g. test tubes, PCR tubes and centrifuge tubes).



Figure 7: Weighing with an ErgoClip, a small metal basket, which acts as a tare vessel holder and shields the vessel from electrostatic charges.

5.2.2 Solution for Large Tare Containers

The weight or dimensions of a large tare container can make it impossible to use a metal basket to shield the charges. In these cases, an alternative way to neutralize the disruptive charges on the surface of the vessel must be sought. In some laboratories, anti-static pistols are used. The piezo-crystal creates positive and negative ions when the trigger is pulled, but they are not truly effective in all cases and therefore are not recommended. Ionizers that operate using high voltage are more suitable because they are structurally integrated (see chapter 5.3.2).

5.3 Dissipating Static Charges If They Are Present

Solutions to dissipate electrostatic charges if they are present whilst weighing in the laboratory:

1. Utilize a high-voltage ionizer to discharge samples and tare containers
 - Use an internal ionizer
 - XPR balance has an optional Ionizer module
 - Use an external ionizer, such as a U-electrode
 - A compact ionizer mounted on the side of the balance is suitable for small vessels and sample quantities
 - A U-electrode is more suitable for larger vessels and sample quantities
2. Use radioactive sources (polonium-210, weak x-ray sources, etc.) to ionize the air (subject to country-specific regulations)

A variety of high-voltage ionizer options are offered by METTLER TOLEDO. These are designed to either be integrated inside the balance draft shield (internal ionizers), or positioned directly beside the balance door (external ionizers). All of these anti-static solutions use an alternating current (AC) high-voltage field to produce a “cloud” of both positively and negatively charged ions at the electrodes, which act to neutralize the charges on sample and weighing containers, without creating any disruptive air currents. This is a very effective solution, even though it only works within a specific region around the electrodes.

Note: Ionizers used in conjunction with a fan are generally not recommended. The risk of toxic samples being agitated and blown around the work space cannot be ruled out. Fans also disrupt the measurement result by causing slower stabilization times and less accurate measurement results.

5.3.1 Internal Ionizers

An integrated internal ionizer is an optional accessory on XPR analytical balances from METTLER TOLEDO. It can easily be retrospectively installed, if not originally selected. A small blanking cover panel inside the draft shield can be simply removed and replaced by the ionizer module (see Fig. 8).

The internal ionizer is a neat, effective and efficient solution. By having the ionizer installed inside the draft shield of the balance, and therefore closer to the weighing pan, the discharging of samples and containers is more effective. The ionizer is automatically activated if electrostatic charges are detected within the draft shield by the static detection functionality (StaticDetect™). This method has an efficiency advantage, as the whole electrostatic detection and elimination process occurs automatically without the need for manual intervention by the user. Furthermore, in case the first pass was insufficient to eliminate all the static charge present, no additional time is necessary to open the balance doors to retrieve the sample and pass it repeatedly past the electrode to attempt full discharge. Instead, in one click, the user can simply turn on the ionizer from balance terminal screen, whilst the sample remains on the weighing pan with the door is closed, in the case that further ionization is required.



Figure 8: Ionizer module installed on XPR analytical balance.

5.3.2 External Ionizers

External ionizers, such as a U-electrode or point electrode, are suitable for use with most types of laboratory balance. These types of ionizer should be positioned directly beside the balance door. Activation and deactivation of the ionizer is linked to the draft shield, so that the ionizer is automatically turned on when the door is opened, and turned off when the door is closed. This method has an efficiency advantage, as the ionization of the sample can occur whilst the user is performing the dosing operation, which saves time. As the sample or container is placed into the weighing chamber, they pass by the electrode and are thereby discharged. The selection of a point electrode or a U-electrode typically depends on the size of the container: U-electrodes are used for larger samples and containers as they produce a larger cloud. Such systems are characterized by long life in routine operation.



Figure 9: METTLER TOLEDO XPR microbalance in combination with a point ionizer.

5.3.3 Use of Radioactive Sources

The use of high-voltage ionizers also has some limits. When working in controlled atmospheres, the charge receiver usually lacks oxygen and can therefore not be discharged. Strips of polonium, americium or other weak alpha-radiating materials have proven effective in such atmospheres. Radioactive particle radiation is suitable for eliminating disruptive charges in difficult atmospheres, however, the half-life period of the radiator is so short that it must be replaced after one year and appropriately disposed of as radioactive waste.

5.3.4 Elimination of Charge in Difficult Cases

Using PTFE vessels (or other strong electrical insulators)

When using materials with a very strong electrical insulation effect, additional measures may be required. A grounding strap between the spatula and grounded surface may be helpful. Sometimes even simply wrapping the container with uncoated aluminum foil can help to eliminate the disruptive static effects. If this doesn't work, a multi-electrode high-voltage ionizer, such as a U-electrode from METTLER TOLEDO, should be used. Keeping the sample within the electrode area for longer may also help to ensure discharge (i.e. up to 20 seconds).

Working with dry powders

Problems similar to those with tare containers also occur with test substances. Powdery substances that have just been dried in plastic containers can easily be charged, and exhibit the typical jumping from spatula onto other surfaces phenomenon. In this situation, passing the spatula loaded with sample in front of a high-voltage ionizer has proved to be effective. Powdered samples on the insides of bottle necks or vessel openings can be prevented from jumping by increasing the time the vessel spends in the vicinity of the ionizer electrode.

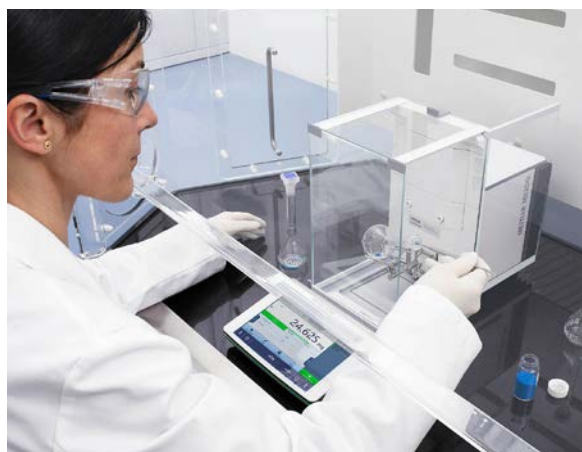


Figure 10: Weighing in a safety cabinet with XPR analytical balance.

Working inside containment devices

Discharging under a flow of air, such as in safety cabinets, is tiring and difficult, as it causes the charged air particles to be pulled rapidly away from the air flow. In this case, it helps to position the sample or container between the electrodes in the direction of the air flow and discharge for a longer period of time.

6 Eliminating Static Charges: XPR Analytical Balance Solution



Figure 11: Eliminating static charges with the XPR analytical balance.




6.1 Automatic Static Detection (StaticDetect™)

StaticDetect™ is a patented innovation to help balance users avoid weighing problems caused by electrostatic charges, which is immune to electromagnetic interference, and is available on XPR analytical balances from METTLER TOLEDO. The principle is the automatic detection of the presence of an electrostatic charge on the tare container and/or sample using a sensor, which also measures the magnitude of the effect on the weighing measurement.

Automatic detection of disturbances due to electrostatic charges makes balance operation easier to manage and ensures that results are more reliable. As the existing weighing cell is used for detection, the balance can not only recognize electrostatic charges on the material to be weighed, but also provide information about the size of the measurement error by taking into account the effective geometry. This markedly increases the assurance that a user is working with accurate and reliable weighing results.

The static detection cycle is performed concurrently with the weighing process. It only takes a few seconds, typically within the balance stabilization time, which avoids any delay in obtaining the weighing result. The user can select a detection threshold to indicate what is acceptable.

The StaticDetect functionality operates successfully in any laboratory environment, including under challenging conditions such as in fume hoods or containment systems. It starts automatically, as soon as sample is placed on the balance and the door is closed. The balance terminal screen displays an icon in the top left corner:

-  indicates that the sample is not affected by static;
-  indicates that sample is affected by static;
-  indicates that the ionizer is on.

If static is detected during a weighing process (red icon displayed), the internal ionizer module will be activated automatically for a duration of 5 seconds, in order to eliminate the static charges on the sample. Further ionization cycle(s) can be initiated manually from the balance terminal and should render the sample completely free from static charges (green icon displayed).

6.2 How Does StaticDetect™ Work?

A concentric electrode, which is galvanically isolated, is integrated beneath the grounded weighing pan. An alternating square wave current, with an amplitude of 60 V and frequency of 1.2 Hz, is applied to the electrode during the detection phase. The positive half-cycle of the square wave signal generates positive charge carriers on the electrode, represented by Fig. 12 (a).

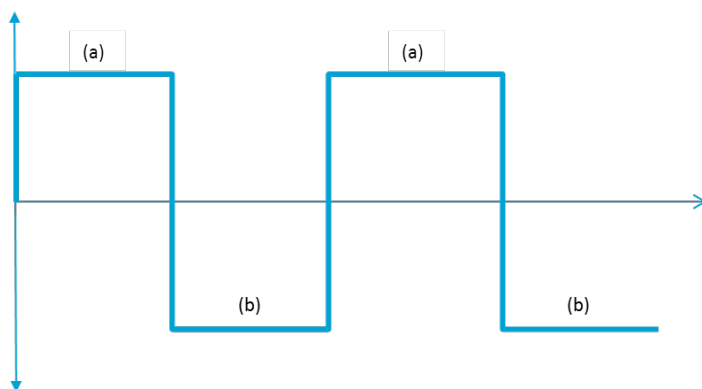


Figure 12: Square-wave alternating current (AC) signal (60 V, 1.2 Hz).

If the weighing sample is free of charge carriers, then no electrostatic forces will be generated, according to Coulombs Law, and therefore the weighing cell will measure the true weight of the sample.

However, if the sample is negatively charged, there will be a momentary attractive force between the negatively charged sample and the positively charged electrode. The weighing cell registers the vertical component of this force, thereby producing a result that exceeds the true mass (as illustrated in Fig. 13).

In the following half-cycle, the electrostatic field changes sign, due to negative charge carriers being generated on the electrode, see Fig. 12 (b). At this point, there is a mutual repulsion between the sample and the electrode, which causes the measured result displayed to be less than the actual mass (as illustrated in Fig. 14).

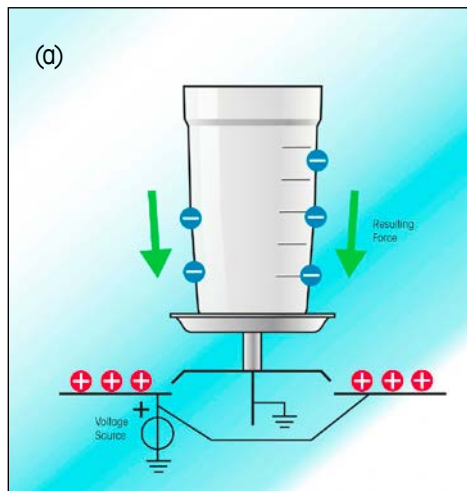


Figure 13: An attractive force acting between the sample and the electrode. The vertical component of this force is added from the actual weight, causing the displayed measurement to be higher than it should be.

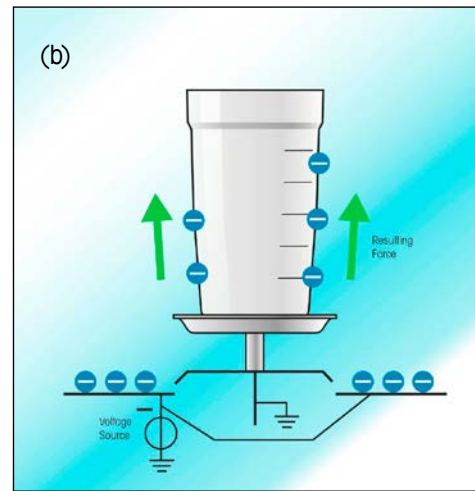


Figure 14: A repulsive force acting between the sample and the electrode. The vertical component of this force is subtracted to the actual weight, causing the displayed measurement to be lower than it should be.

The difference in the measurement result between the two phases of the signal, (a) and (b), is entirely attributable to the electrostatic force (F_E). If the sample is not electrostatically charged (i.e. has no charge carriers), then this difference will be zero. Using this methodology, the sensor can determine the amount by which the electrostatic force is affecting the measurement result, and thus calculate the true weight of the sample.

Of course, the same theory applies if the sample has a positive charge, but simply the attractive and repulsive forces at each phase of the signal are opposite. This method works effectively over a large weighing range. Coulombs Law makes it evident that the mutual force between the two charges also depends on how far apart they are; hence the force is highly contingent on their spatial proximity. Only the measurement technique outlined here can cover this gap.

Watch a short video explaining how StaticDetect™ works here:

► www.mt.com/lab-static

6.3 Alternative Methods

Other methods for detecting whether a body is electrostatically charged do exist. However, they all have the disadvantage of being unable to estimate the extent by which the electrostatic charge influences the weight value.

7 Summary

Balance users need to be aware of the causes and effects of electrostatic charges in relation to weighing. Whenever possible, preventative action should be taken to reduce or eliminate the build-up of static charges, in order to avoid any errors or delays in the weighing results. Various tips and recommendations are provided on how to reduce the effects of static in a weighing environment. In addition, established solutions for deionization of the weighing vessel or sample are described and compared.

The ability to automatically detect and eliminate the presence of electrostatic charges during a weighing process is an important step forward in weighing technology. The latest generation of XPR analytical balances is able to either eliminate any detected electrostatic forces using an ionizer module, or identify and record the magnitude of the effect of these electrostatic forces on the weighing result. This makes handling statically charged samples much easier and more efficient for the balance user, as well as ensuring that weighing results are more accurate and reliable.

8 Further Reading

- Weighing the Right Way Guide, Proper Weighing with Laboratory Balances, METTLER TOLEDO, Doc. No. 720906, January 2015, ► www.mt.com/weighing-guide
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- Reichmuth A, Mettler Toledo; Einflüsse und deren Vermeidung beim Wägen
- Reichmuth A, Mettler Toledo; Weighing small samples on laboratory balances

9 About the Co-Author

Prof. Peter Ryser is Professor of Micro-engineering at the Swiss Federal Institute of Technology in Lausanne. He has more than thirty years of research and teaching experience from various corporate and academic institutions. Previously, a Director at Siemens Building Technologies, he was responsible for R&D, product innovation and patents. Prof. Ryser has a Ph.D. in Applied Physics from the University of Geneva, a Master's degree in Experimental Physics and an MBA.



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