Electrostatic Formulas for Force, Voltage, and Discharge Time on Charged Samples or Surfaces

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- Interpreting basic measurements made with a surface voltmeter
- Calculating the voltage of an object and voltage differences in space and across solids
- Determining whether a spark is likely
- Measuring voltage and surface charge of small objects, or at other than 1″
- Calculating the electric field strength
- Calculating the attractive/repulsive force between surfaces or objects
- Determining the "ohms per square" and the self-discharge time of surfaces or objects
- Formulas for discharge by air ions (or by immersion in a fluid), ion imbalance, charge plate detector

In these formulas, the unit of electric charge is amp seconds (ampsec, which is also called "coulomb"); its symbol is Q. One ampsec is the charge of 6.25×10^{18}electrons or protons (ions). An amp is 6.25×10^{18} electrons/sec. Force is expressed in grams (technically gramweights). Lengths are in cm (although the recommended distance between sensor and sample is 1″ or 2.5 cm). Time is in seconds (sec).

Basic measurements made with a surface voltmeter: The term $V_{displayed}$ refers to the number displayed on a surface voltmeter (electrostatic voltmeter). When the meter is held at the specified distance from a large sheet of metal (provided the sheet diameter is greater than 5x the specified distance), $V_{displayed}$ is the voltage of that sheet, with respect to earth ground, in units of volts. For example, when using the handheld Surface DC Voltmeter Model SVM2 with the sensor disc 2.5 cm from the center of a metal sheet, a reading of "9.400" (kV) means that the sheet is at +9400 volts with respect to ground. If the sensor is brought closer, $V_{displayed}$will be higher than the actual voltage. (If the measurement distance is other than 1 inch, or if the sample surface is small, formulas are given below to correct the reading.)

The surface "voltage" of an electrostatically-charged insulator can also be measured in the same way. However, insulators behave differently from metals (conductors). When a surface voltmeter or any grounded object is brought close to a charged insulator, the proximity will reduce the voltage of the insulator's surface in that region. The voltage is approximately proportional to the distance between the grounded object and the insulator's surface, multiplied by Q/A (the amount of charge per cm^2 on the surface). In addition, the voltage varies from place to place across an insulator. (Compare this to the voltage of a metal sheet, which is always the same everywhere on the sheet.) For this reason, the "voltage" of an insulator is poorly-defined, Instead, either the total charge Q or the charge per unit area Q/A on the surface is usually the parameter measured on a charged insulator. **If the SVM2 surface voltmeter's sensor is held near an insulator with a uniform charge per area (Q/A), then $Q/A = V_{displayed} \times 3.6\times10^{-14}$ (in ampsec/cm^2), and the average voltage of the surface directly under the sensor is $V_{surface} = V_{displayed} \times L/2.5$ cm**. However, the voltage is generally higher at other points on the surface, and the voltage will increase once the surface voltmeter is taken away. "L" is the distance between the sensor and the surface.

Calculation example of Q/A: if the reading on the SVM2 meter is "-23.648" (kV) near a large sheet of rubber, that sheet has excess negative charge on its surface, and the amount of charge per unit area is $-23648 \times 3.6\times10^{-14} = -8.5\times10^{-10}$ ampsec/cm^2. The reading can be used to determine the total charge on the sheet, by multiplying the area of the sheet (in cm^2) by -8.5×10^{-10} ampsec/cm^2. (To calculate total charge accurately, scan the surface and use the average value of $V_{displayed}$, because the amount of charge per area may vary across the surface.) The Q/A equation is valid only if no large metal sheet is nearby (closer than a few inches), and the charged part of the sheet must have a width that is at least 5x the sensor distance (i.e., surface width must be at least 5L for measurement accuracy).

Note that the formula for Q/A does not depend on L (except that sensor distance L should be < 1/5 of the width of the charged surface). Therefore the 1″ spacer is not needed for insulator Q/A measurements. Near a wide (width = W), uniformly-charged insulator sheet, $V_{displayed}$ generally does not depend on L (provided $W > 5 L$). However, near a wide metal sheet held at a constant voltage, $V_{displayed}$ does depend on L, so a 1″ spacer is generally used for measuring metal (or any conductor). **For a wide metal surface of width W with the sensor a distance L away (provided again that $W > 5L$ for accuracy), $V = V_{displayed} \times L/2.5$cm.**This formula is used for measurement distances other than 2.5 cm (1″).

Operating principle of a surface voltmeter, and the measurement of small samples: The Surface DC Voltmeter Model SVM2 has a metal sensor disc on its rear surface. When placed in a charged environment, the disc acts electrically as if it has a diameter of 3.2 cm, even though the physical diameter is actually 2.5 cm. The disc is connected to a amplifier with essentially infinite input resistance. When held near a region of excess positive charge (or positive voltage), electrons leave the amplifier input and are attracted to the sensor disc, This leaves a positive charge at the amplifier, which is displayed ($V_{displayed}$) as a positive number, and is proportional to the amount of charge in the disc (even though $V_{displayed}$ is of opposite polarity of the charge in the disc). The process is similar if all polarities are reversed.

The amount of charge that flows to the sensor disc is $Q_{sensor} = -V_{displayed} \times 3\times10^{-13}$, where Q_{sensor} is in ampsec. **If a charged sample (with charge Q) has a smaller diameter than the actual diameter of the disc, and if the sensor's distance from the sample is $L = 2.5$ cm, then $Q_{sensor} = -0.16\ Q$, so that $Q = V_{displayed} \times 1.87\times10^{-12}$. If the sensor is brought closer so that $L < 0.1$ cm, then $Q_{sensor} = -Q$, so that $Q = V_{displayed} \times 3\times10^{-13}$**. Once Q is known, the first formula in the next paragraph can be used to approximate the average voltage of the sample. A different type of sample is a small piece of metal that is held at a fixed voltage. This sample does not have a fixed value of Q, but its voltage can be estimated. (See "Interpreting voltage…" below.)

Voltage: When a large number of either + or – charges is confined into a relatively small volume, mutual repulsion will make the charges try to escape from the volume. The "voltage" associated with that volume is proportional to the amount of energy that a single charge would acquire if it were allowed to escape and fly away, eventually colliding with earth (ground). Call "D" the diameter or approximate dimension of the confining volume, which is usually a solid object. If neither earth ground nor any significant amount of charge are near the confining volume ("near" means closer than about five diameters, or 5D), then the voltage (in volts) in the volume is about **$V = 1.8\times10^{12}\ Q/D$**, where Q is the charge present in ampsec, and V is negative if Q is negative. This voltage is with respect to earth ground, which is usually defined as zero volts. If some charge of the opposite polarity is brought near the volume, then a single charge that happens to escape from the volume will experience less repulsive force; this effect will reduce the voltage to a number less than that given by the equation. Different areas inside the confining volume may be at slightly different voltages. For example, if the charged "volume" is actually a 1.5 volt battery (which in this example has a lot of static charge on it), the + terminal will be at 1.5 volts higher voltage than the – terminal.

Voltage can also calculated near a uniformly-charged surface, but in this case, only the voltage difference per cm can be unambiguously defined. **If a surface has positive charge per area of Q/A, then the voltage decreases by $5.7\times10^{12} \times Q/A$ for every cm of distance away from the surface**. For example, if a surface contains $+10^{-11}$ ampsec per cm2, and the surface has a voltage of +1000 volts (an arbitrarily-chosen number), the voltage is by definition +1000 on the surface. However, the voltage is 1000 – 57 = 943 volts at distance 1 cm away from the surface, and 2 cm away, it is 886 volts. This voltage "fall off" only follows that formula close to the surface. "Close" means a distance less than the 1/5 the diameter of the surface. If another surface with the same value of Q/A, but negative, is held close to the positive surface, the voltage "fall off" will be doubled to $1.14\times10^{13} \times Q/A$. For example, if two sheets, one with $Q/A = +10^{-11}$ ampsec per cm^2 and the other with $Q/A = -10^{-11}$ ampsec per cm^2 are held 3 cm apart, the voltage difference between them will be $1.14\times10^{13} \times 10^{-11} \times 3$ cm = 342 volts.

A slab of insulator material may have a voltage difference through its thickness. That is, it may have excess + on its front surface and excess – on its rear. The voltage difference can be measured directly by a surface voltmeter. Place metal foil, such as aluminum, on one face of the slab (sheet of insulator) and connect the foil to ground. The foil should be the same size and shape as the slab face. Then measure the voltage of the other face of the slab as though that face were a metal sheet connected to a voltage. The result is the voltage difference through the slab. If it is a + voltage, then the + side is facing the surface voltmeter.

Sparking: If there is a significant voltage difference between a + charged object and a – charged object, and a wire is then positioned so it partially bridges the distance between the objects, **there will be a spark if the voltage difference divided by the open-air distance separating them is greater than 10000 volts per cm**. There may be a spark at greater open-air distance, especially if the wire is sharp. This spark distance also applies if one of the "objects" is earth ground (at zero volts). Even without wires, a charged object can only hold a certain amount of charge before the charges spontaneously fly apart by sparking into the air. **If a sphere with diameter D (centimeters) is charged to voltage V, it will spark if $V > 5000$ D**. (For shapes other than a sphere, use the cube root of the volume in cm^3, for D. This is approximate, and sparking is more likely at sharp edges.) Charged surfaces are likely to spark if Q/A is greater than about 10^{-9} ampsec per cm^2 (on a surface voltmeter, if $V_{displayed} > 28{,}000$ volts). Sparking is more likely if a sharp grounded wire is brought to within 1/5 (or less) of the diameter of the charged surface. The only way to charge an object more is by placing it in a vacuum or embedding it in a good insulator.

For very small spark gaps, the “10000 volts per cm” rule does not apply. At a voltage difference of about 500 volts (or less), it is almost impossible to initiate a spark, even between two pointed wires that are much less than 1/20 cm apart. Effectively, there is a lower limit of a few hundred volts on the voltage that can produce an open-air spark. Therefore, the use of grounded, pointed needles (tinsel) will not discharge a surface lower than a few hundred volts.

Interpreting voltage and surface charge for small samples and/or distance other than 1”: If the surface being measured is a large sheet of insulating material with charge per area of $Q/A = -8.5\times10^{-10}$ ampsec/cm^2 as in the above example with a rubber sheet, the surface voltmeter will read about -24 kV if held 1” from the surface. Surprisingly, the meter will also read about -24 kV if held 2” or even 10” away, as long as the maximum measurement distance is less than 1/5 the width of the charged sheet. (In contrast to this uniformly charged insulator, the reading on a large metal sheet will decrease with distance, to be discussed below). If only a one cm^2 piece of the sheet is cut off and measured, with the meter’s sensor directly over the piece (2.5 cm away), the meter will only read about -0.515 kV, even though the piece still has -8.5×10^{-10} ampsec/cm^2 on its surface. Furthermore, if the meter is then pulled back to 2”, it will read even lower (about -0.144 kV or -144 volts). This effect is caused by the physics of electrostatics and cannot be avoided. However, if the diameter of the sample (or its width, as an approximation) is known, along with the measurement distance L (usually 2.5 cm), it is simple to estimate Q/A for that sample, along with the total charge and the actual voltage of the sample. Assume that the diameter (width) of the sample D is greater than the effective diameter of the sensor disc, so $D > 3.2$ cm. If the sensor is distance L from the sample, then for an insulator sample, $Q/A = V_{\text{displayed}} \times 3.6\times10^{-14} \times f/(f-1)$, where f is the square root of $[1 + D^2/4L^2]$. Q/A is in units of ampsec/cm^2. Here D and L can both be either in cm or inches, and $V_{\text{displayed}}$ is the voltage displayed on the SVM2 surface voltmeter, written in volts (not kilovolts). If the sample is not round, use the square root of the sample’s area to substitute for D.

The Q/A equation above is also valid if the sample is a conductor, but only if the conductor is small (<5 cm diameter) and only if it is not connected to a voltage source. If the sample is a conductor connected to a voltage supply, or if it is > 20 cm diameter or connected to a large piece of metal, then the actual voltage on the sample is more complicated to measure. In this case, charges will move around on the conductor as a the meter is brought close to it. They move in such a way that the voltage is the same everywhere on the conductor. It is **$V = (L/2.5\text{cm}) \times V_{\text{displayed}}$ x the square root of $(1 + 2L^2/D^2)$**. The formula is valid for any value of the sample diameter D, but it requires that $L> 0.35$ cm. (At a sensor-to-sample distance $L< 0.35$ cm, multiply the right side of the previous formula by $\{1.7 – 2L\}$. This makes the effective diameter of the sensor equal to the real diameter if the disc when the sensor is very close to the sample.) L and D are in units of cm.

If a metal sheet is small ($D << L$), the voltage formula simplifies to $V = (1.4\, L^2/D) \times V_{\text{displayed}}$. In contrast, if $D >> L$, the formula above simplifies to $V = (L/2.5\text{cm}) \times V_{\text{displayed}}$. This last formula, for a wide conductor, contains “L”, whereas the Q/A formula for wide insulators does not: $Q/A = V_{\text{displayed}} \times 3.6\times10^{-14}$. The surface voltmeter reading $V_{\text{displayed}}$ near a large metal sheet will increase if L is decreased, but the reading near a large charged insulator does not increase as the measurement distance L is decreased. Therefore, if L = 1”, the meter will correctly read the voltage on a sheet of metal. At L = 2”, it will read about half the voltage, so double the reading. At distances greater than about 10 cm, the actual voltage on the metal is generally a little lower than $V_{\text{displayed}} \times L$, because of the influence of any other conductors that might be nearby. Their effect is not very predictable. (10 cm is the approximate width of the surface voltmeter.)

Because the SVM2 displays a number that is proportional to the charge accumulated on its sensor, the voltage on a conductor can also be measured by direct contact in the same way a standard voltmeter is used, except that when using an SVM2, the input resistance is essentially infinite. A 0.3 pF capacitor is required for this (add three 1 pF capacitors in series). Connect one end of the capacitor to the sensor disc and the other to ground, and press “RESET”. Then connect that end of the capacitor to the sample (a conductor). The display will read the correct voltage, subject to some charge being “loaded down” by the 1/3 pF of the capacitor. Avoid touching any part of the assembly to the black plastic near the disc, which will short the signal. Each capacitor should be rated for at least 1/3 the maximum expected voltage.

Electric Field: If two sheets of metal are a held distance X from each other (as the plates of a capacitor are held) and the voltage difference between the sheets is V, then the average E-field in the space between the sheets is $E = V/X$. One of the “sheets” could be a surface voltmeter, which is usually maintained at zero voltage. Then the other sheet is (presumed to be) at a nonzero voltage. **If the surface voltmeter is held closer than about 10 cm and the metal sheet is wide, the average E-field between the meter and the sheet is slightly less than $E = 0.4 \times V_{\text{displayed}}$**, but the close proximity of the meter causes the E-field to be higher than it would normally be. **If the meter is far from the metal sheet or if the E-field source is a charged insulator (at any distance), the average E-field is $E = 0.2 \times V_{\text{displayed}}$.** This is the E-field in volts per cm (not volts per meter).

An insulator with surface charge per area of Q/A will have a surface E-field of E = 5.7×10^{12} x Q/A. If a large grounded metal sheet is brought near the surface, the E-field in the volume between insulator and the metal doubles to E = 1.14×10^{13} x Q/A. (E is in V/cm.) Also, E = 1.14×10^{13} x Q/A between two insulator surfaces with charge per area of +Q/A and -Q/A.

Force (pressure) of attraction or repulsion between surfaces: If two sheets of an insulating material are each charged, they will repel if the charges are of the same polarity and will attract if opposite. Theoretically, if at least one sheet is uncharged, the sheets will neither attract nor repel. However, if the two are held near but not touching, the conductivity of air will often cause a neutral sheet to assume a polarity that is opposite of the other sheet's polarity. This causes attraction. Sometimes charging is in the other direction, causing repulsion, especially if the sheets first touch each other. These effects may alter the amount of charge on each sheet, but if the final value of Q/A (charge per unit area) is measured, the attractive or repulsive force between the sheets can be calculated. **If two charged sheets are brought close together, the force per area of attraction or repulsion between two sheets is the product of their respective Q/A values multiplied by 5.8×10^{16}**. Note that Q/A is in units of ampsec/cm^2, and force per area is in units of grams/cm^2. Q/A for insulators can be measured using a surface voltmeter, as discussed above ("Basic measurements…"). **If a surface voltmeter is used, it will measure the voltage two large charged insulating sheets (obtaining the readings V_1 and V_2), then the force per area between the surfaces is 7.5×10^{-11} x V_1 x V_2, in units of grams/cm^2. It is attractive if V_1 and $V_2$are of opposite polarities.**

If the sheets are small or if measured a distance L away, and the sheet width is not large compared to L, then with the surface voltmeter's sensor directly over the center of the sheet, if the sheet diameter (or the square root of its area for a non-circular shape) is D, then **Q/A = $V_{displayed}$ x 3.6×10^{-14} x f/(f-1), where f is the square root of [1 + D2/4L2]**, in units of ampsec/cm^2. If one sheet is an ungrounded conductor, use its value of Q/A, which must be measured from a "long" distance away (L > 2D), but uses the same formula. If one sheet is a conductor that is either grounded or connected to a voltage supply, first determine Q/A for that conductor (if grounded, Q/A=0). The value $Q/A_{conductor}$ can be measured using a surface voltmeter at a "long" distance from the conductor (L > 10 cm), or it can be calculated if the conductor's voltage is known. Also measure the insulator sheet: $Q/A_{insulator}$, noting that either or both of $Q/A_{conductor}$ or $Q/A_{insulator}$ could be negative. **The force per area between the insulator and conductor sheet is Force/Area = $Q/A_{insulator}$ x ($Q/A_{conductor}$ – $Q/A_{insulator}$) x 5.8×10^{16}**. If negative, it is an attractive force.

Examples of force calculations: The values of Q/A for two insulators that had just been rubbed together to transfer charge can be measured with a surface voltmeter, and then the force between them can be calculated. However, the Q/A values can also be estimated from a triboelectric table if the type of materials and the frictional energy are known. For example, if a 10×10 cm sheet of teflon (at -190 nano ampsec/wattsec of rubbing friction) is rubbed against a 10×10 cm sheet of nylon (at +30 nano ampsec/wattsec) with 300 grams of rubbing force (the force parallel to the surfaces), over a back and forth distance totaling 10 cm, the work done is [300 grams x 10 cm] x 10^{-4} wattsec/gram cm = 0.3 wattsec. The charge transferred (electrons jump from the nylon to the teflon surface) will be [190 + 30] nano ampsec/wattsec x 0.3 wattsec = 67 nano ampsec, or 6.7×10^{-8} ampsec. This charge will be spread out over the nylon 10×10 cm surface, and the opposite charge of -6.7×10^{-8} ampsec will be spread out over the teflon 10×10 cm surface. Therefore Q/A_{nylon} = 6.7×10^{-8} ampsec/100 cm^2 = 6.7×10^{-10} ampsec/cm^2 and Q/A_{teflon} = -6.7×10^{-10} ampsec/cm^2. The attractive force per area while the sheets are close to each other (or while still together) is 6.7×10^{-10} x -6.7×10^{-10} x 5.8×10^{16} = -0.026 gram/cm^2. The area is 100 cm^2, so the total attractive force between the two sheets is −0.026 gram/cm^2 x 100 cm^2 = -2.6 grams (it is attraction because the sign is negative). The use of the triboelectric table can only give a crude estimate of force because there are many variables that can change the numbers.

Another force calculation can be done using the readings of a surface voltmeter, which is more accurate for determining Q/A. The same charged teflon sheet can be directly measured (it must be isolated from other charged objects and from metal while measuring Q/A). Because the teflon is 10 cm wide, the sensor disc can be held very close to the teflon (such as at L = 0.1 cm), so f in the formula "Q/A = $V_{displayed}$ x 3.6×10^{-14} x f/(f-1)" simplifies to 1. Then Q/A = $V_{displayed}$ x 3.6×10^{-14}, and if $V_{displayed}$ = -18325 volts, then Q/A = -6.7×10^{-10}. This sheet will experience attraction to a 10×10 cm metal sheet which is connected to +4000 volts. Because the voltage is known, the value of Q/A_{metal} can be estimated, without measuring it, by using a formula above. The formula V = 1.8×10^{12} Q/D (with D = 10 cm and V = +4000) predicts a total charge Q of $+2.2\times10^{-8}$ ampsec, spread out over 100 cm^2. (Thus the predicted Q/A_{metal} is $+2.2\times10^{-10}$ ampsec/cm^2). Now that Q/A_{teflon} and Q/A_{metal} are known, the force between the sheets can be calculated, from Force/Area = $Q/A_{insulator}$ x ($Q/A_{conductor}$ – $Q/A_{insulator}$) x 5.8×10^{16}. This is the correct formula if the two sheets are parallel to each other, centered over each other, and close to each other (closer than about 1 cm). The fact that – $Q/A_{insulator}$ appears in the formula is the "image charge" effect, in which a grounded (or large or electrically connected) conductor produces a "reflection" of any nearby charges, much as a mirror would. The reflected charge is of the *opposite* polarity of the real charge, but of the same magnitude. Therefore, grounded metal always attracts charged insulators. Solving, Force/Area =

$(-6.7\times10^{-\mathbf{10}}) \times (+2.2\times10^{-\mathbf{10}} + 6.7\times10^{-\mathbf{10}}) \times 5.8\times10^{16} = -0.036$ gram/cm^2. (Note that the second time $6.7\times10^{-\mathbf{10}}$ appears, it is with a "+" sign, which is two negatives.) The total area is 100 cm^2, so the total force is -3.6 grams (attractive).

Determining surface resistance, ohms per square, and the time required for self-discharge of poor conductors: If charge is deposited onto an object which is touching ground, the charge will eventually leak away, but it may take a long time (days). Extremely good insulators, like many plastics, can lose charge spontaneously, but only through the gradual action of air ions. Without air ions present, plastics will only redistribute surface charge very slowly, even at high humidity. (The conductance of most plastics is unaffected by humidity if there is no condensation; however, the surface of any insulator will suddenly conduct if condensation, or a film of water, is present. This will instantly discharge the surface.) Discharge by air ions is discussed later, but a surface voltmeter can be used to measure both the typical self-discharge half-life of a sample, and the number of ohms per square of that sample.

To measure a sample, cut out a square of the sample 2 to 3 inches (5 to 8 cm) on a side. Make a stick out of plastic to hold the sample by a corner. The stick can be glued or taped to the sample. Apply some charge to the sample by rubbing with another material (see triboelectric table) or by induction (see "Charging a surface" below.) Position the surface voltmeter's sensor over the center of the sample. Then touch one of the four sides of the sample (you must be grounded) or touch grounded foil to that entire edge (one of the four edges). Make contact with the entire 2" to 3" length of side you have chosen, at its edge. Determine the amount of time required for $V_{\text{displayed}}$ to drop to one half of its initial value. This half-life, $T_{1/2}$ is the time required for a square of a surface to self-discharge half way. If a sphere of the same material is differentially charged so that for example the left hemisphere is – and the right is +, the sphere will require roughly the same amount of time ($T_{1/2}$) for the charge to reduce to 1/2. After twice that time interval (i.e., $2T_{1/2}$), the charge will be reduced to 1/4. (After $3T_{1/2}$, it is 1/8.). If there are more + charges than -, this type of charge imbalance cannot be removed just by self-discharge, unless the sample is somehow connected to ground, because of the conservation of charge. **The number of ohms per square is approximately ohms/square = $T_{1/2} \times 10^{13}/L$**, where L is the length of the square's edge, in cm. If $T_{1/2}$ turns out to be under 1 sec (very fast), or over 100 sec (very slow), the measurement should be done in a different way.

Charging a surface: There are certain rules concerning how the half-life measurement must be done. The first step is to charge the surface. The surface must initially not be electrically connected to ground or to any other voltage. If the surface to be tested is a separate piece, like a tile, hold it with an insulating plastic stick or place it on top of a plastic (not cardboard) box. This will be a good insulator. The piece can be charged by the "induction" technique. With this method of charging, a charged object is held near the piece that is to be charged. Then a ground wire or your finger is touched to the surface of the piece and held there so that charges can flow along the (weakly conductive) surface. It's best to allow the charges to flow at least several seconds if the conductivity is fairly weak. Then remove the ground wire (finger). Only after the ground is removed, then remove the charged object from the vicinity of the piece to be tested. The piece will now have the opposite polarity of the charged object. (For the "charged object", you can use plastic that has been rubbed against polyurethane foam–the same material used for packing the SVM2– urethane foam will become + and the plastic will become -.) There is a second charging method besides the "induction" technique: Either the plastic box that is being used as a platform or the sample itself can be charged directly by rubbing with polyurethane foam for negative, or with a latex glove for positive. (see triboelectric table for other charging materials.) Then the piece to be tested is dropped onto the plastic box. (Avoid touching the piece while it is in contact with the charged plastic box. While holding the piece, you will gradually discharge it.) Once either the box beneath the test piece or the test piece itself is charged, use the meter to measure the charge half-life. With this 'ohms per square' measurement, the half-life is measured while one edge of the test piece connected to ground.

Measuring "fast" or "slow" values of $T_{1/2}$: If $T_{1/2}$ < 1 sec, it may be easier to measure ohms per square directly with a high-resistance meter. Otherwise, if the reading drops very quickly so that $T_{1/2}$ is less than one second, then redo the charging step and measure the initial meter reading again. (Call this value V_1.) Then hold your finger or foil on the edge for exactly one second and then remove it from the edge. Record the reading, and call it V_2. Then ground the edge one more time for at least 5 seconds. This final reading is V_3. Then $\mathbf{T_{1/2} = .31 / \log[(V_1) / V_2 - V_3]}$. (Log is base 10.) If the reading instead drops very slowly so that $T_{1/2}$ is over 100 seconds and you don't want to wait that long, then read the meter initially just after you ground the edge (not before). Then measure the amount of time required for the reading to drop by 1%. (For example, from 5.000 to 4.950). Call this time $T_{1\%}$. Then $T_{1/2} = 68T_{1\%}$. Regardless of which method is used to obtain $T_{1/2}$, the number of ohms/square is still $T_{1/2} \times 10^{13}/L$. For example, if L = 10cm, and $T_{1/2} = 5$ sec, then R = 5×10^{12} ohms per square.

Discharge by air ions or fluids: Air is very slightly conductive if ions are present. (See About Air Ions). Generally, both + and – ions are present in air, and the two polarities can co-exist. Each polarity is measured separately, in terms of number of + ions per cc (cubic cm) and number of – ions per cc. Call "N" the lesser of the number of + ions per cc or – ions per cc. **The resistivity of air is approximately Resistivity = $6 \times 10^{18}/N$, in units of ohm cm. If a compact object, like a sphere or cube, is in air or a fluid, the discharge half-life time (in seconds) is approximately $T_{1/2} = 2 \times 10^{-13}$ x resistivity of the air or fluid (in ohm cm). Therefore in air, $T_{1/2} = 1.2 \times 10^5/N$, due to ions**. Discharge by air (or by dipping into a grounded fluid) can remove all charge on a surface, including an overall charge imbalance (self-discharge by an object due to its own conductance can redistribute charges over its surface but cannot "bleed off" a charge imbalance of excess + or − unless the surface is connected to ground.) Dipping a charged insulator in water will immediately remove all surface charge. Discharge by air or fluid also shields the effect of any embedded charge in the insulator from influencing the outside; such imbedded charges will become forever undetectable unless the insulator is cut open. If an ion generator is not used, a typical indoor value of N is 10 to 100 ions/cc. Therefore typical indoor charge half-life is between 20 minutes and a few hours. Ionizers are intended to reduce the half-life to a second or less, but both + and − ions must be distributed properly throughout a work area to achieve this. One method of measuring the discharge time is by using a "charge plate detector" (simply an electrically-isolated metal plate in front of a surface voltmeter–if the plate becomes charged, the voltmeter reads its voltage.) A much faster way is by directly measuring the number of + and the number of − ions/cc using an air ion counter. A surface voltmeter can measure the discharge half-life for both + and − charged surfaces, and it can measure charge imbalance and (by a different method) ion imbalance.

Measuring ion balance and discharge times: As was mentioned, an air ion counter can measure the number of both + and − ions/cc (which can co-exist in air). These measurements can determine both the positive and negative discharge half-life times by using the formula $T_{1/2} = 1.2 \times 10^5/N$, where N is the number of positive ions /cc, for the half-life on a negatively-charged object, and vice-versa. However, a surface voltmeter, if it has with sufficient sensitivity, can also measure the + and − discharge half-lives, along with the "imbalance voltage" (voltage that an AC ionizer creates on surfaces if the number of + and − ions are not equal), and it can measure the actual ion imbalance, which is the difference in number between + and − ions. The discharge half-life can be measured either on an insulator or on a conductor. This is similar to a charge plate detector test, although the charge plate method only measures discharge time on a conductor. (Discharge of an insulator that is charged only on the side closest to the ionizer is similar to conductor discharge time, but an insulator that is charged on both sides will require a longer time to discharge.) For the conductive test of discharge time, a metal sheet at least 2×2" (5×5 cm) can be used. Suspend the metal sheet by holding it at one corner with a plastic stick held to the metal with office tape. Never touch the metal sheet during the test. For an insulator discharge test, use an acrylic sheet, but this can be handheld by one corner because it is already an insulator. The acrylic should be discharged before testing; this is done by dipping it in water and then shaking it to remove most of the water. For both types of sheet, charge them + by rubbing the sheet with a latex glove. Hold the surface voltmeter 1" away and note the voltage. Then introduce it into the ionizing environment and note how much time is required for the voltage to reduce to 1/2, which is the half-life. To charge them -, rub with urethane foam (such as the cushioning material that comes with AlphaLab meters). However, they should be discharged first (dip the acrylic, or touch the metal).

Tinsel (grounded, pointed needles) will ionize the air near a charged insulator and discharge it rapidly almost all the way, but will not discharge a surface lower than a few hundred volts, because sparking from the tinsel "turns off" below about 500 volts.

The "imbalance voltage" can be measured using either the acrylic or metal sheet. Discharge the sheet and "Reset" the meter. Again, hold the sheet 1" from the sensor and make sure the display reads within a few volts of zero. Then introduce the sheet and meter to the ionizing environment. The voltage will generally climb to a few hundred volts (usually +) if there is ion imbalance. The voltage is higher when closer to the ionizer, and it should decrease when gradually pulled away. If there is no sheet in front of the sensor, the display of the SVM2 surface voltmeter may gradually climb in value. The sensor itself never reaches more than about 3 volts, so it never reaches saturation–a level of several hundred volts that would be required to stop additional majority ions from colliding with the sensor. Therefore the sensor voltage climbs steadily if the sensor is not covered by a sheet. Note the change in displayed voltage in one second. The excess current being collected by the sensor is that change (in volts) x 0.3 pico amp, and it is of the same polarity as the ion excess.