

Electrostatic charge on aerosol cans

R. P. WILLIAMS, R. E. REUSSER, and C. R. BRESSON, *Phillips Petroleum Company, Research and Development, Bartlesville, OK 74004*

Received February 19, 1980.

Synopsis

The potential ability of an electrostatic charge on an aerosol can to ignite a flammable gas mixture is discussed in terms of electrical capacitor relationships. Energy of the charge determines the INCENDIARY POTENTIAL of the spark and is given by $E = Q^2/2C$, where Q is the coulombic charge and C is the electrical capacitance of the can. To calculate the maximum potential spark energy the significant parameters to measure are: 1) the coulombic charge on the can; and 2) the minimum capacitance at which the can may discharge. Four CHARGE-MEASURING METHODS under industry study are reviewed with a preference expressed for direct measurement with a coulombmeter. Results of charge measurements on cans of various aerosol products and the minimum capacitance values determined experimentally for several sizes of cans are given.

I. INTRODUCTION

Electrostatic charging of aerosol cans by release of the contents is not a newly discovered phenomenon, but it has taken on added significance since the 1978-1979 change from fluorochlorocarbon to hydrocarbon propellants in aerosol products. Additionally, the propellant change has focused attention on an industry need for a standard method of measuring the static electrification of aerosol cans. As illustrated in Figure 1, a positive (or negative) charge often develops on a can as a result of releasing all or part of its contents by normal spray operation or from puncture by a mechanical malfunction on an aerosol filling line.

Some dry powder-containing products impart relatively large charges to the cans with enough energy to enable a spark discharge to potentially ignite a flammable atmosphere. On the other hand, the electrostatic charge produced by the release of non-powder-containing products is much lower and does not usually reach potentially incendiary energy levels. Fortunately, the likelihood of an ignition is greatest in the case of electrically isolated charged cans which is a condition that does not frequently occur. Chances for ignition are remote during normal use in hand-held spraying since distribution of the charge over the body capacitance lowers the energy correspondingly.

A new investigator in the field of incendiary electrical sparks is confronted by a

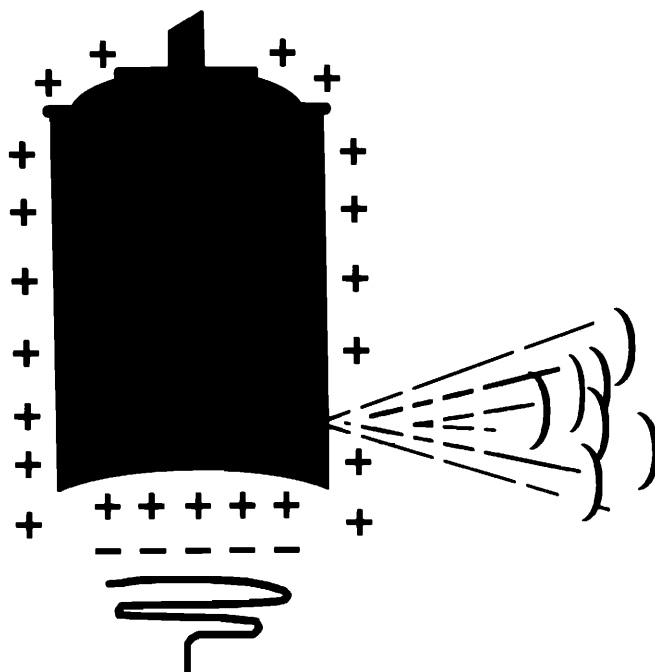


Figure 1. Aerosol can charging.

potpourri of electrical terms such as voltage, charge, capacitance, and energy. However, when more clearly understood, it is seen that energy is the chief factor that determines the ability of a spark discharge to ignite a flammable gas mixture. The amount of spark energy required for ignition reportedly depends upon the gas composition, electrode geometry, and other conditions (1), but for a butane/air mixture the minimum ignition energy has been indicated to be near 0.2 millijoules (2). While 0.2 millijoules is a credible value, further experimentation is warranted to confirm its relevance in the case of spark discharges from can surfaces in clouds of commercial aerosol products.

II. DISCUSSION

A. ELECTRICAL CAPACITOR RELATIONSHIPS

An aerosol can may be considered as one electrode of an electrical capacitor, the other being earth ground or nearby grounded metal. Thus, a brief review of electrical capacitor relationships is helpful to understanding of the factors affecting the energy of an electrostatic charge.

A capacitor is constructed by juxtaposing two conductors to permit attractive interaction by virtue of equal and opposite charges on their surfaces. The common parallel plate type of capacitor is illustrated in Figure 2.

If a battery is connected across the capacitor as shown, electrons are withdrawn from the left hand plate and forced upon the right hand plate, thus, producing excess charges, $+Q$ and $-Q$, on the inner surfaces of the plates. Charge, then, is defined as

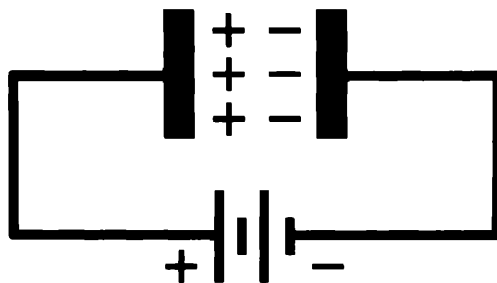


Figure 2. Electrical capacitor relationships.

the quantity of electrification, expressed in units of coulombs, resulting from a surplus or deficit of electrons. The coulombic charge may be either measured directly with a special electrometer (coulombmeter) or calculated by:

$$Q \text{ (coulombs)} = C \text{ (farads)} \times V \text{ (volts)}.$$

Likewise, V , the voltage (electric pressure) and C , the capacitance (charge storage capability) can be measured with suitable instruments or calculated as:

$$V = \frac{Q}{C}$$

$$C = \frac{Q}{V}$$

Normally, the energy of a charge is not directly measurable, but is calculated by:

$$E_{\text{(joules)}} = 1/2 QV = 1/2 CV^2 = \frac{Q^2}{2C}$$

Where: Q = charge in coulombs, V = voltage in volts, C = capacitance in farads. Thus, to calculate the charge energy, two of the three parameters—charge, capacitance, and voltage—must be known.

For further illustration, the charging of a capacitor by a voltage is roughly comparable to the filling of a pressure vessel by a source of gas at a given pressure. The capacitance determines the amount of electrical charge just as the volume determines the amount of gas that the filled vessel will contain.

The capacitance of a parallel plate capacitor is directly proportional to the surface area of the plates and inversely proportional to the distance separating them. Likewise, the smaller an aerosol can, the smaller its capacitance; and the closer to grounded metal, the greater the capacitance. It should be noted that the coulombic charge, once developed, is relatively constant, being independent of changes in the can environment if corona and conductive losses are prevented. Can capacitance, on the other hand, is condition-dependent and variable, and with it vary also the voltage and energy.

The effect of can capacitance on the charge energy may be illustrated by visualizing two cans which differ significantly in size but which bear the same amount of coulombic charge. The charge on the smaller can of lower capacitance is necessarily more dense, and consequently possesses a higher potential energy, and will release

more kinetic energy in the event of a spark discharge. In an aerosol filling room, the energy of a charge on an aerosol can which has been tossed or propelled by puncture through the air should be greatest when the can reaches the greatest distance from the ground or a large surface of grounded metal (position of lowest capacitance). Discharge in this location might be to a small piece of wire or metal projection. It follows that a charge energy which is known to be safe at this position should be safe anywhere else. It may be concluded, then, that in order to estimate the highest energy that a charge on a can may attain by $E = Q^2/2C$, the two following parameters should be known: 1) The coulombic charge on the can; and 2) The minimum capacitance at which the can might discharge.

B. ELECTRIFICATION MEASUREMENT METHODS

Recently, four methods for measuring static electrification of cans have received investigative emphasis in aerosol products industry laboratories. These are listed below and will be discussed briefly.

- | | |
|-----------------------|----------------------------|
| 1. Coulombmeter: | Direct Charge Measurement |
| 2. Faraday Cage: | Induced Charge Measurement |
| 3. Grid Collector: | Charge Transfer |
| 4. Sensing Voltmeter: | Voltage Measurement |

1. *Direct Charge Measurement.* Figure 3 shows an arrangement for performing a direct measurement of the coulombic charge, adapted to measurements on aerosol cans by the DuPont Company.

In this illustration the can is mounted on a plastic block; although it can be mounted on anything, even a metal support, that is insulated from ground. The leads from a

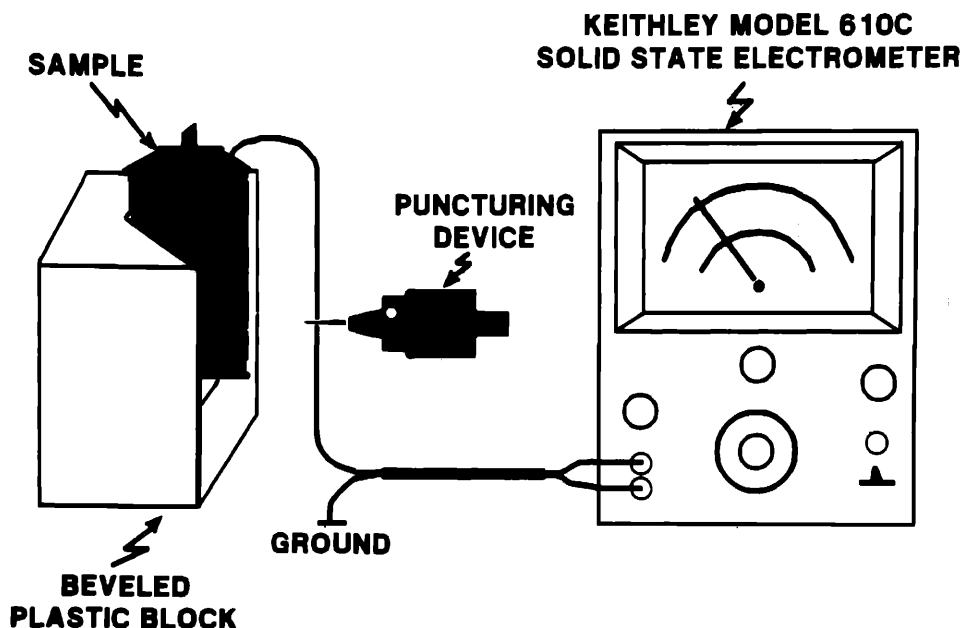


Figure 3. Direct charge measurement.

Keithley electrometer, Model 610 C, are attached to bare metal of the can and to ground. The Keithley electrometer is a high input impedance (10^{14} ohms) instrument, which in the coulombmeter mode permits charge measurement on a capacitor with plus or minus 5 percent accuracy when used carefully. The can is punctured, either with an air-powered drill or a spring-driven spear. The coulombic charge is read on the meter when the can has been emptied. Advantages for this method are: 1) the simplicity of direct charge measurement; 2) the internal electrometer circuitry keeps the can voltage low (a few volts) which prevents charge loss by corona-discharge; 3) the apparatus, excluding the electrometer, is simple and inexpensive to construct; 4) reproducibility and agreement between laboratories are potentially good; 5) the procedure is adaptable to measurement of charge developed by either spray or can-puncture; and 6) can capacitance may also be estimated with the Keithley electrometer. A potential disadvantage is that without modification it may lack ability to measure any charge that resides in the plastic activator, which has been shown by workers at Metal Box, Ltd. to be significant under some conditions (5).

2. *Induced Charge Measurement.* Figures 4, 5, and 6 illustrate the principles of the induced charge measurement method which is related to the Faraday "ice pail" experiment used to demonstrate principles of electric fields and charge inducement. This method was developed by Phillips Petroleum Company (3). If a charged aerosol can is placed inside of a larger can or pail but kept insulated from it as in Figure 4, a capacitor is thereby constructed which exhibits an equal induced opposite charge on the inner surface of the pail.

In Figure 5, the other electrode (or pail) of the can-pail capacitor, designated as capacitance C_x approximately 10 pf, is connected to ground through another capacitor of known, much larger capacitance C_m . In this arrangement a charge equal to that on the can-pail capacitor C_x is induced on the measuring capacitance C_m . The voltage V_m across the known capacitance can be measured and the charge on both capacitors can be calculated by $Q = C_m V_m$. The can-pail capacitance can be measured with a bridge

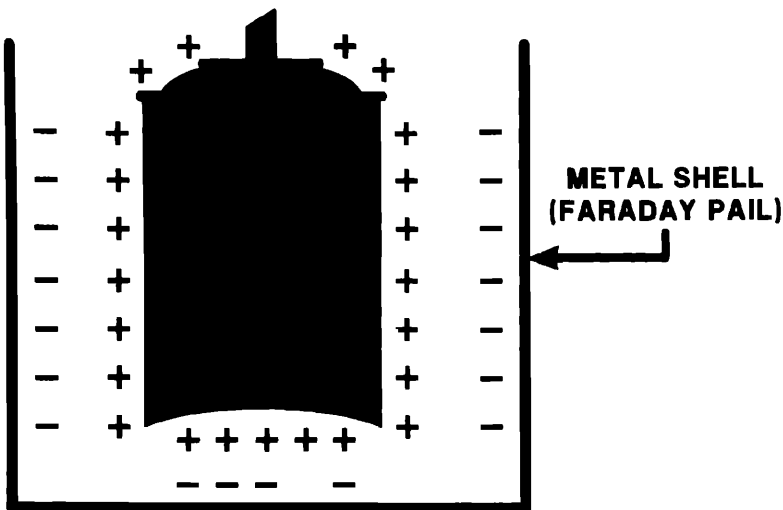


Figure 4. Can-pail capacitor.

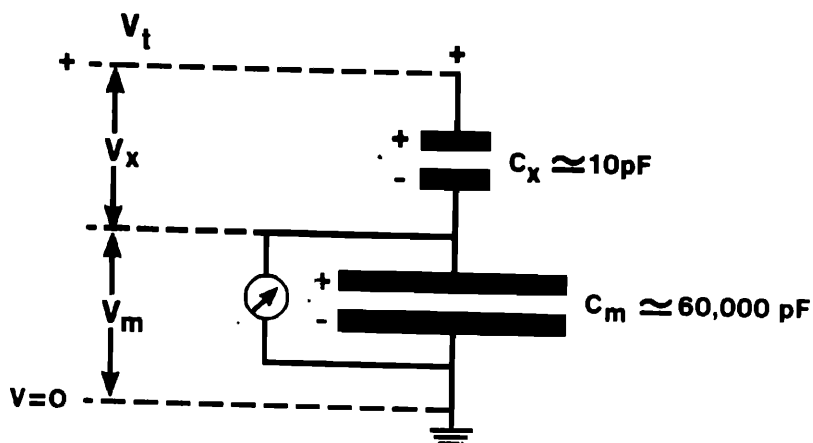


Figure 5. Faraday cage method analysis. C_m is the known capacitance (large compared to C_x); C_x is the capacitance of the aerosol can (measurable); and V_m is the voltage measured across C_m (small compared to V_x). $Q = C_m V_m = C_x V_x$. $E_x = Q^2/2C$.

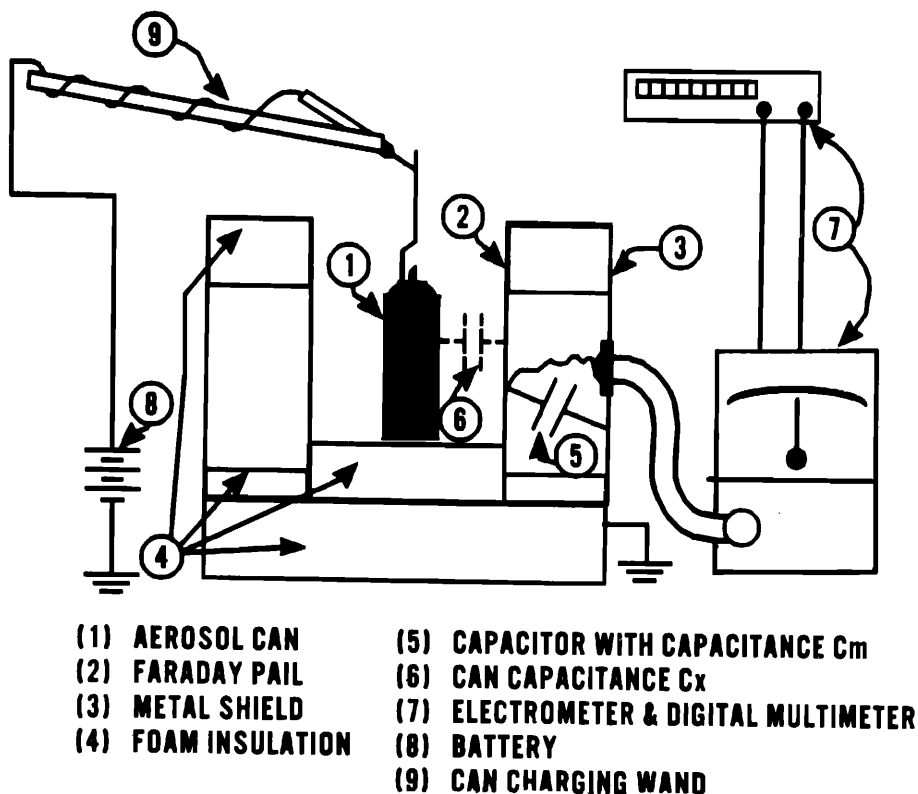


Figure 6. Faraday cage apparatus for aerosol can electrical measurement.

and the energy of the charge on the can in the measurement situation can be calculated as $E = Q^2/2C$.

The apparatus is shown in cross section in Figure 6. The aerosol can is pictured in the Faraday pail on pieces of styrofoam insulation with a stiff wire extending from its top. This wire was used in validation experiments to place a charge of known voltage on the can from a power supply. Validation experiment results showed that charge measurement with accuracy of 0.5% was possible up to 10,000 V. In actual use, the Faraday pail and shield were fitted with a swinging door to allow the product to be released to the outside of the enclosure by spraying or by can puncture.

Advantages for the induced charge measurement method are: 1) the total combined charge on the can and plastic actuator are measured; 2) product may be expelled by spray or can-puncture; and 3) the operating condition of the equipment is easily checked by imparting a charge to the can from a high voltage power supply. The major drawback for the method, at least with the apparatus used to date, was a tendency to lose charge by corona discharge above 25,000 V and by leakage on insulator supports which quickly accumulate conductive aerosol debris. Both faults could likely be corrected by proper equipment design.

3. *Grid-Collector Method.* The apparatus for the grid-collector method of charge measurement is sketched in Figure 7. Workers at the Proctor and Gamble Company and at Metal Box, Ltd. have experimented with this method. A series of screen grids is connected to a known capacitance, which in turn is connected to ground. A voltmeter is connected across the capacitor as shown. Cans of aerosol products are positioned a specified distance from the grid system. The can actuator is depressed with a plastic rod to cause the product to spray into the center of the front grid. As the product is deposited in the grid network the charge carried by the aerosol cloud is transferred to the grids, and thence, is stored in the capacitor.

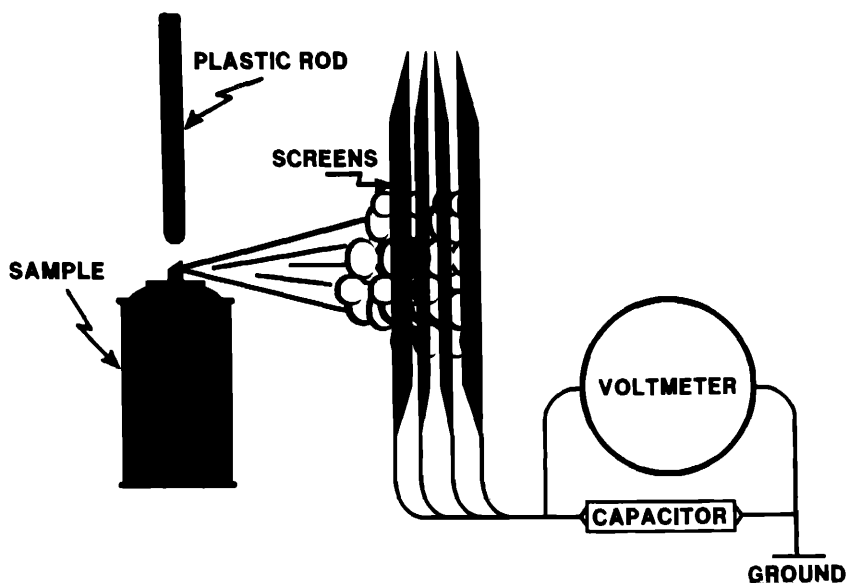


Figure 7. Grid-collector charge measurement.

Voltage developed across the capacitor is measured with the voltmeter and the charge is calculated as $Q = CV$. The coulombic charge collected by the grids should be of equal size and opposite sign to that remaining on the can. Obviously, the greatest potential source of error with this method would be failure to collect all of the charge on the grids because of material being deflected from or passing through the collector. The possibility of such malfunctioning would be minimized by tapering the screen mesh sizes from front to back and by constructing the collector with enough depth to completely contain the expanding aerosol cloud. This method should be capable of measuring the total charge on the can and actuator. Disadvantages are: 1) it may not be easily adapted to can-puncture experiments; 2) frequent cleaning or replacement of the grid system is required for reproducibility; and 3) failure to obtain complete charge transfer is possible.

4. *Voltage Measurements with Sensing Voltmeters.* A commonly-used static measuring device is the sensing voltmeter, consisting of a static sensing head connected to an electrometer. Figure 8 pictures a voltage-measuring arrangement with the device. Such voltmeters are responsive to the electric field that exists in the vicinity of a charged object. If operated in a carefully standardized way these devices give measurements, expressed in volts, which are proportional to the charge, but they do not measure the quantity of charge (coulombs). The instruments are useful for quickly detecting a charge on an object and for obtaining an indication of the charge magnitude. However, a few precautions should be kept in mind when working with a sensing voltmeter. First, the accuracy may be less than desired if it is operated in a casual way because the meter response depends upon the distance between the sensing head and

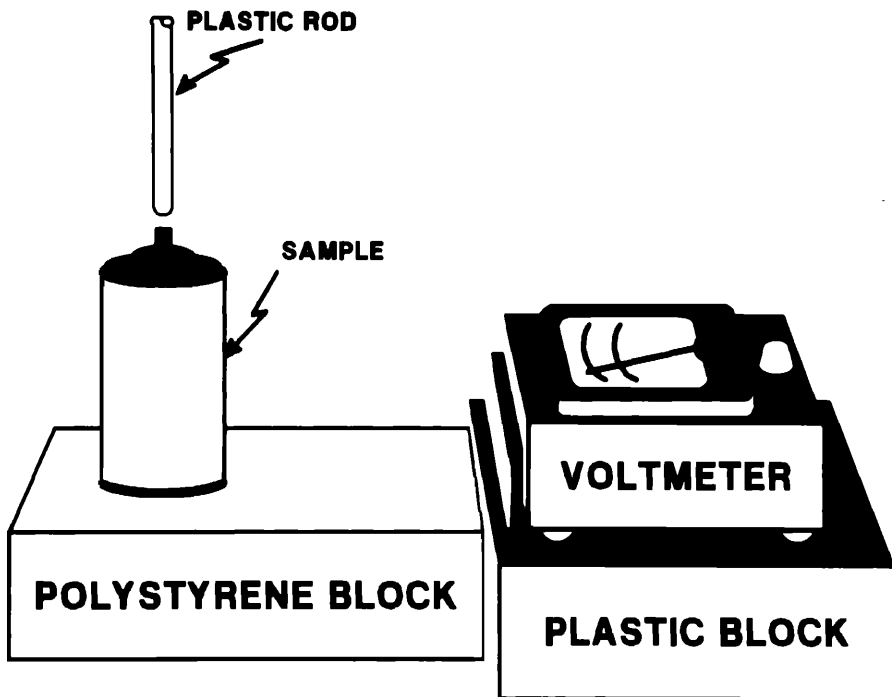


Figure 8. Voltage (electric field) measurement.

the can as well as the geometry of the can. Therefore, the meter should be recalibrated in the environment and with the particular type of can for which it is intended to be used. Second, significant charge loss may occur by corona discharge as a result of the very high voltages on highly charged cans. Thus the can surroundings to several inches should be cleared of metal projections; even then some corona losses may occur at the very high voltages of 100,000 v or more that may develop. Third, the sensing voltmeter alone is not capable of providing enough data to calculate the charge and its energy; for this, the can capacitance must also be determined under the same conditions that the voltage was measured.

C. ESTIMATION OF MINIMUM CAN CAPACITANCE

As already emphasized, the minimum capacitance that a can may transiently possess in an aerosol filling room situation is an important parameter to measure. This minimum capacitance might be expected to approach the self-capacitance; i.e., the capacitance in free space. The self capacitance of a 4.25-in-diameter sphere, with about the same surface area as a 16-oz can, estimated by $C = 4 \pi \epsilon \epsilon_0 r$, is 6.0 pf (picofarads) (4). In Phillips Petroleum Company laboratories the capacitances of suspended cans of various sizes were estimated using the arrangement shown in Figure 9.

The can was hung by a non-conducting polypropylene cord six feet from the floor in a $12 \times 12 \times 12$ -foot laboratory room containing a few randomly placed metal objects. The can was charged with an accurately measured voltage (2000 to 20,000 V) by

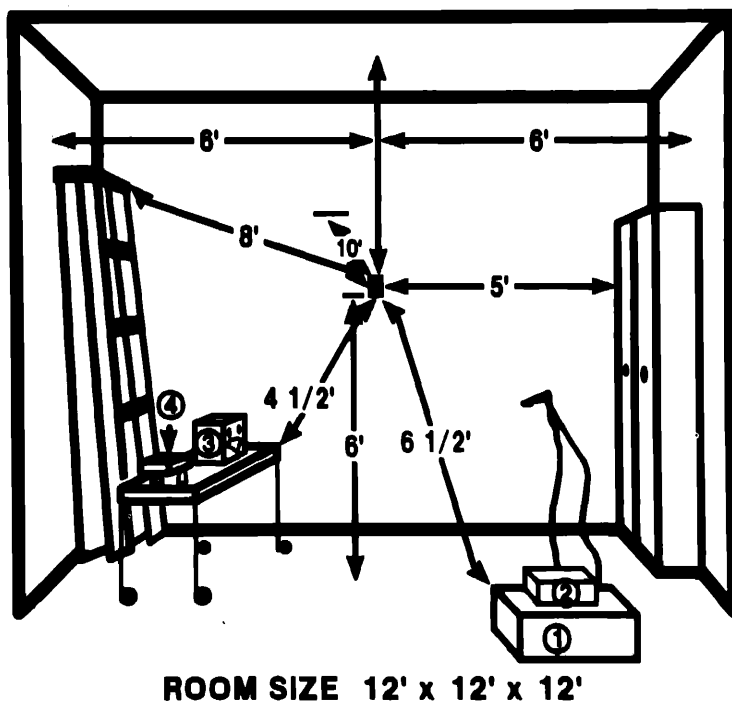


Figure 9. Can capacitance measurement: 1) High voltage power supply; 2) High impedance volt meter; 3) Kiethley electrometer; 4) Digital multimeter.

contacting with a probe from a power supply. The ungrounded lead from a Keithley electrometer was then contacted with the can to measure the charge (coulombs). The capacitances of the suspended cans were then calculated from $C = Q/V$. Average capacitance values from several determinations were 4.0, 4.5, and 5.5 pf for 6-, 8-, and 16-oz cans, respectively. Further calculation, by $Q = \sqrt{2CE}$, shows that for a can capacitance of 4 pf the potentially incendive 0.2-millijoule energy level would be reached at a charge of 4×10^{-8} coulombs. However, it is again cautioned that the relevance of this energy value to that needed to ignite a vapor of formulated aerosol product has not been confirmed and additional work in this regard is recommended.

D. CHARGE DEVELOPMENT WITH COMMERCIAL PRODUCTS

Table I gives data from static electrification studies in the Phillips Petroleum Company laboratories using the direct method of charge measurement in can-puncture tests. The results show that the amount of charge which developed depended both upon the presence and the type of a powder component in the product. Thus, the charge that developed was insignificant when the can contained propellant only. When 11% aluminum chlorohydrate was included with the propellant, the static charge was larger but with energy still well below 0.2 millijoules. However, when 11% talc was incorporated, a charge of high energy, 49 millijoules, developed. This charge would have reached a calculated voltage of 157,000 V on the 4 pf capacitance of the can if it had not been prevented by the relatively high capacitance input of the coulombmeter. The data also show the charge magnitude that various commercial products have been observed to generate on the cans after puncture. Additionally the data show that static quenching agents offer hope for reducing the charge.

III. CONCLUSION

In conclusion, the energy of an electrostatic charge largely determines its potential incendivity. Calculation of the energy requires measurement of two out of three electrical parameters—charge, voltage, and capacitance. Charge and minimum can capacitance are the preferred parameters for measurement in order to calculate the

Table I
Charge Measurement on Punctured Aerosol Cans of Dry Powder-Containing Products

Product	Charge (coulombs)	Voltage (volts)	Energy (millijoules)
A46® Propellant (no powder)	1.2×10^{-9}	300	.0002
A46 + 11% Talc	6.3×10^{-7}	157,500	49.0
A46 + 11% Aluminum Chlorohydrate	1.9×10^{-8}	4,750	.05
Antiperspirant A	6.6×10^{-7}	163,125	53.4
Antiperspirant A + Antistat (0.6%)	9.1×10^{-8}	22,750	1.0
Antiperspirant B	1.8×10^{-7}	45,000	4.2
Antiperspirant B + Antistat (0.5%)	4.6×10^{-8}	11,670	0.27
Cleaner A	2.7×10^{-6}	675,000	912
Cleaner B	1.6×10^{-7}	40,000	3.2
Christmas Decorating Snow	4.4×10^{-7}	110,000	26.6
Antifungal Powder Spray	2.9×10^{-7}	72,500	10.5

greatest energy that a charge on an aerosol can will attain by the equation $E = Q^2/2C$. Of the methods under consideration, the direct method of charge measurement with a Keithley or other high-quality coulombmeter seems preferable for simplicity, precision, and inter-laboratory accuracy. The nominal minimum capacitance of aerosol cans was found to be about 4-5.5 pf; comparative experiments by others are encouraged. Using a can capacitance value of 4 pf, the potentially incendive 0.2 millijoule-energy level is reached at a charge of 4×10^{-8} coulombs. Charge energies greatly exceeding 0.2 are frequently observed to develop on punctured cans of commercial aerosol products in laboratory experiments. Incorporation of optimum amounts of specific antistatic agents offers promise for reducing the charge to non-incendive levels.

IV. ACKNOWLEDGMENT

The assistance of E. Ann Claytor with experimental procedures discussed herein is gratefully acknowledged.

V. REFERENCES

- (1) Benard Lewis and Guenther Von Elbe, *Combustion, Flames, and Explosions of Gases*, Academic Press Inc., New York, (1961) pp. 325-346.
- (2) J. M. C. Roberts and John F. Hughes, *IEEE Transactions on Industry Applications*, Vol. 1A-15, No. 1, 104-108, (January/February 1979).
- (3) R. E. Reusser, M. T. O'Shaughnessy and R. P. Williams, "Measuring In-Plant Electrostatic Charge," *Aerosol Age*, 24 (3), 17-23 (1979).
- (4) F. G. Eichel, "Electrostatics," *Chemical Engineering*, 153-167 (March 13, 1967).
- (5) J. R. Greaves and B. Makin, "A Grid Collection Method for the Measurement of Electrostatic Charge in Aerosol Systems," *Aerosol Age*, 25 (2), 18 (February, 1980).