Digital Coulombmeter Experiments.

This section contains descriptions and explanations of a number of standard experiments and investigations which can be performed using the IPC Digital Coulombmeter. These cover the theory of charge sharing, charging by induction, Faraday's ice pails experiment, charge 'spooning', capacitance investigations and experiments involving CR time constants.

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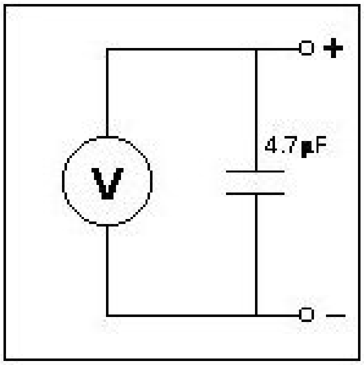
Overview.

The IPC Digital Coulombmeter functions in the same way as a gold leaf electroscope or an electrometer dc amplifier set in the charge measuring mode. The gold leaf electroscope indicates, by deflection of the leaf, the potential difference across the capacitor formed by the top plate and stem, and the case. The electrometer dc amplifier in the charge measuring mode indicates, by deflection on a meter, the potential difference across a capacitor in parallel with the input.

In the IPC Digital Coulombmeter, an integrated high impedance voltmeter with a liquid crystal display is used to measure the potential difference across a capacitor of known capacitance (4.7µF) internally connected to the input terminals as shown in fig. 1. It is a direct-reading instrument which enables quantitative work on electrical charge to be carried out at an early stage of learning and without the need for a separate indicating device; the IPC Digital Coulombmeter has a range 0 to 1999nC.

Figure No1 -

Equivalent circuit of Digital Coulombmeter.



Theory of Charge Sharing.

Consider two capacitors A and B having capacitance Ca and Cb respectively. Initially A has a charge of Qa and B is uncharged as shown in fig. 2. If the two capacitors are connected in parallel as in fig. 3, a charge Qb is transferred to B so that a charge of (Qa-Qb) is left on A.

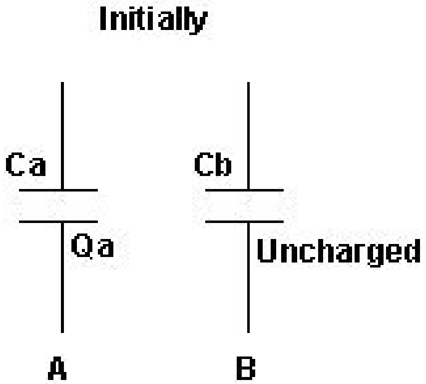


Figure No2

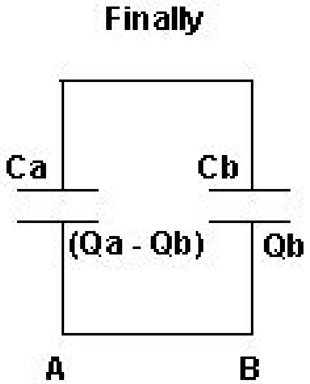


Figure No3

As the potential difference across each capacitor is the same and using charge = capacitance x voltage we can see:

$$\frac{Qb}{Cb} = \frac{Qa - Qb}{Ca} \qquad \text{hence:} \qquad Qb = \frac{Qa \times Cb}{Ca + Cb}$$

It can be seen, therefore, that if Cb is much larger than Ca then most of the charge which is initially on A is transferred to B when the two capacitors are connected together in parallel.

In electrostatics experiments, the capacitance of charged objects is generally low and when they are connected to the coulombmeter, almost all the charge is transferred. The high input capacitance of the coulombmeter (4.7µF) is much greater than that of a conventional electrometer dc amplifier set in the charge measuring mode and enables accurate measurements of charge to be made from external capacitances of up to approximately 0.22µF.

Simple Electrostatics Experiments.

Insert the charge plate supplied into the red (positive) socket of the coulombmeter and connect the black (negative) socket to a good earthing point (such as a metal water tap) using a suitable lead. To enable the coulombmeter to be short-circuited easily between readings to zero it, connect a lead terminated in 4mm plugs to the black socket with the other end left trailing.

Negatively charge a polythene rod by rubbing and hold it about 50mm from the charge plate. The coulombmeter will indicate a negative charge. Remove the rod and the meter reading will fall to zero. If the rod is well charged and brought close to the charge plate, one or two small sparks may be seen (and heard) and charge will be transferred to the charge plate leaving a permanent reading on the meter when the rod is removed. The experiment can be repeated using an acetate rod and, in this case, a positive charge will be transferred to the coulombmeter. With either rod, the quantitative results obtained using the coulombmeter enable the effectiveness of different charging materials and methods to be investigated.

A detailed description of the way in which the charge flows in the above experiments may be desired by older pupils. In this instance, the following explanation may suffice.

When the negatively charged polythene rod is held near the charge plate of the coulombmeter, a charge separation is induced as indicated in fig. 4. Electrons from the charge plate are repelled onto one plate of the internal capacitor leaving the charge plate positively charged. These electrons in turn repel an equal number of electrons from the other plate to earth. This leaves a charge of -Q on one plate of the capacitor and +Q on the other plate. The coulombmeter will indicate the value -Q. A negative sign is shown because the capacitor plate connected to the positive socket of the coulombmeter has become negatively charged.

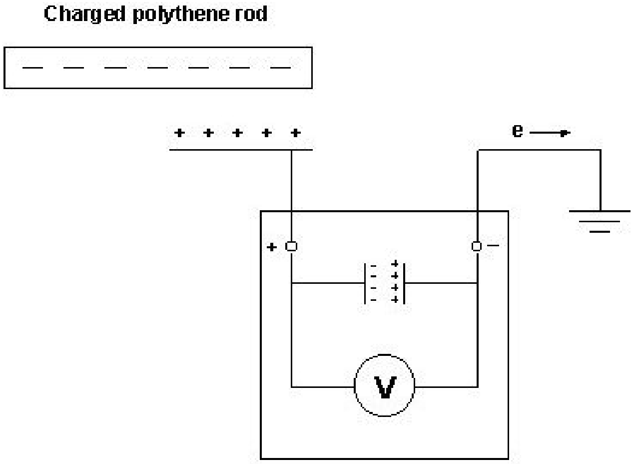


Figure No4 –

Simple electrostatics experiment.

If the polythene rod is removed, electron flow occurs in the opposite direction to return all parts of the circuit to the uncharged state.

When the rod is well charged and brought close to the charge plate so that sparks occur, then negative charge is transferred from the rod to the charge plate and the internal capacitor. By counting the number of sparks and noting the final reading on the coulombmeter when the rod is taken well away from it, the charge transferred by each spark can be calculated.

Charging the coulombmeter by induction.

Hold a charged rod near the charge plate as in fig. 5, in which a positively charged rod is shown. This will induce a charge separation on the internal capacitor of the coulombmeter in the same manner as indicated previously in fig. 4.

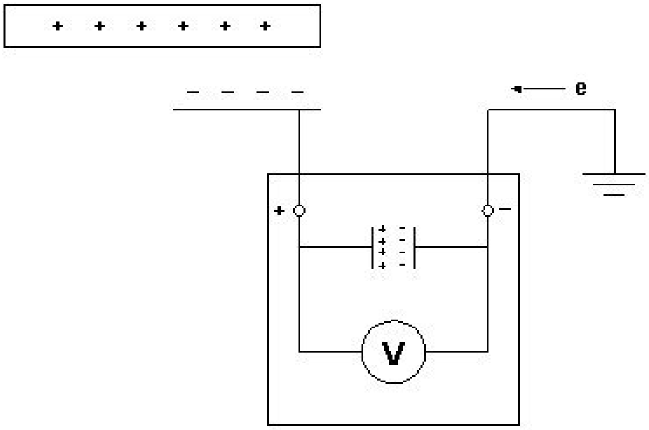


Figure No5 - Charging by induction.

Use the flying lead to short-circuit the input sockets of the coulombmeter and zero the meter reading as in fig. 6. Take away the short-circuit connection as in fig. 7 and the coulombmeter reading will remain zero.

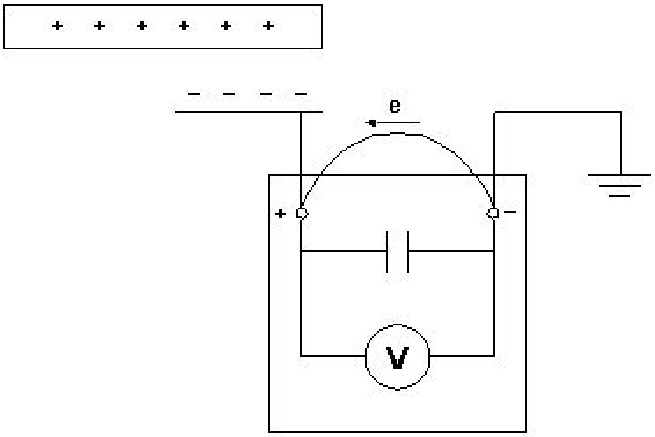
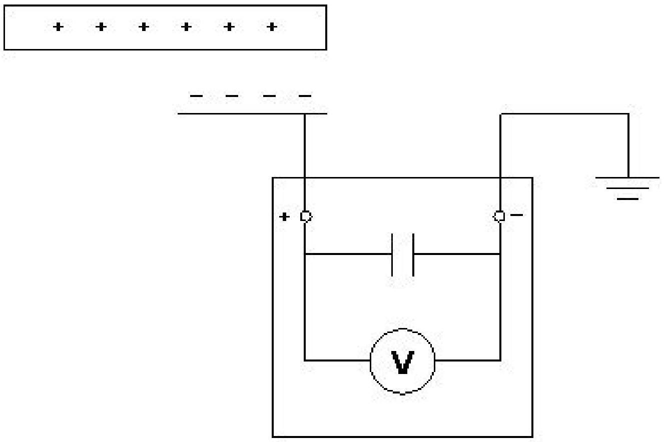


Figure No6 – Short circuit.

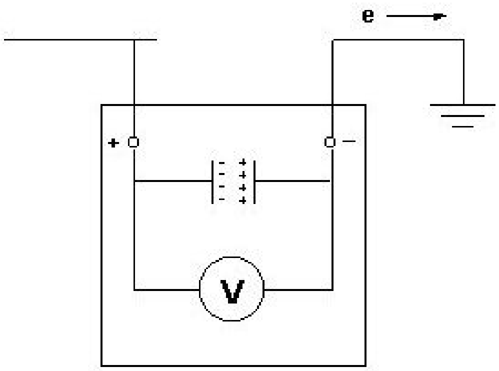
Figure No7 – Short circuit removed.



Remove the rod. Most of the charge on the charge plate will be induced onto one plate of the internal capacitor of the coulombmeter since the capacitance of the charge plate is much lower than that of the coulombmeter.

An equal and opposite charge Q is attracted from earth so that the coulombmeter indicates the induced charge -Q on the positive plate as shown in fig. 8.

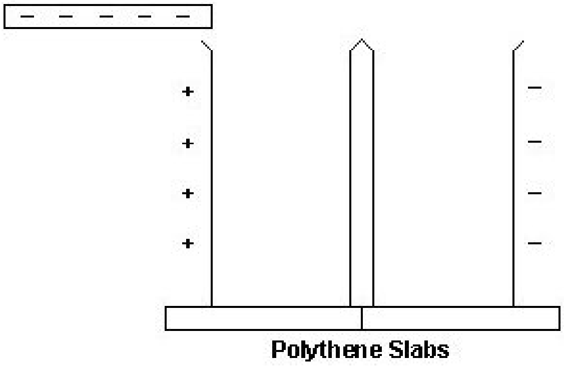
Figure No8 – Charge induced from earth.



Faradays Ice Pails Experiment.

Place two small metal cans (ice pails) in contact on insulating slabs and hold a charged rod near one of them to induce charge separation. In fig. 9. a negatively charged polythene rod is shown repelling electrons from the left-hand can to the right-hand can.

Figure No9 – Ice pails 1.



Next, move one of the insulating slabs to separate the cans as shown in fig. 10. Remove the charged rod so that the charge on each can is only free to move over the surface of the can that it is on, as in fig. 11.

Figure No10 – Ice pails 2.

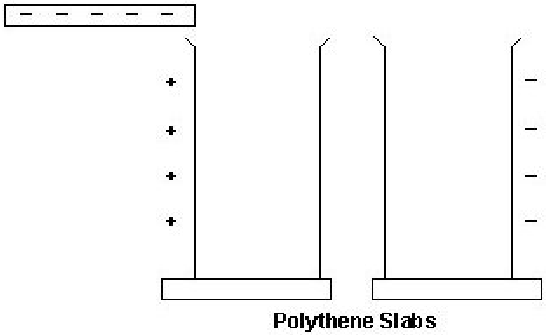
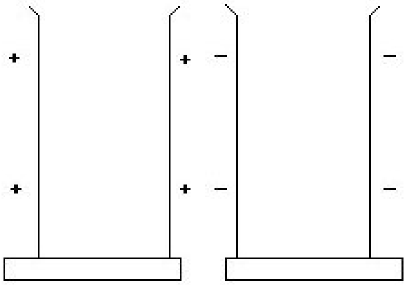


Figure No11 – Ice pails 3.



Determine the polarity of the charge by touching each can in turn with the charge plate of the coulombmeter. When touching the first can, the induced charge is measured by the coulombmeter. On touching the second can the reading of the coulombmeter will return to zero showing that the charge on the first can was equal and opposite to the charge on the second can.

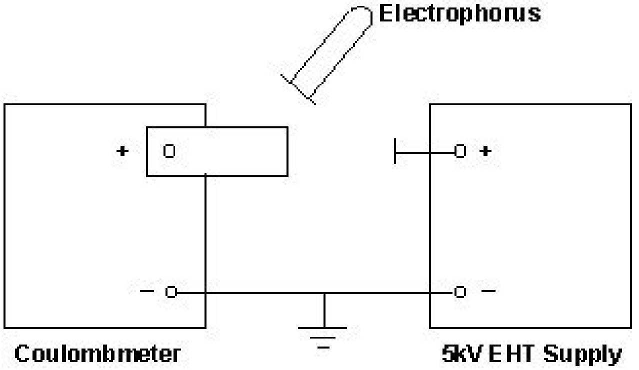
Alternatively, the reading may be zeroed by short-circuiting the sockets of the coulombmeter after touching the first can. This enables the polarity and magnitude of the charge on each can to be determined.

As in all electrostatics work, but in this experiment in particular, it is important to ensure that all insulators used are clean and dry. If this is not so, the small charges that exist on the cans will quickly discharge to earth.

'Spooning' Charge.

Set up the circuit shown in fig. 12 with a small conductor such as a 4mm plug without insulation inserted in the positive socket of the 5kV EHT power supply. If available, a 50MΩ current limiting resistor should be connected in series with the small conductor.

Figure No12 – Charge spooning.



Short across the sockets of the coulombmeter to zero the reading. With the EHT supply set to approximately 4kV, 'spoon' charge from the positive socket of the EHT supply to the coulombmeter charge plate using an electrophorus. It will be seen that an equal quantity of charge is transferred in each operation.

More charge can be transferred by filling the spoon fuller, i.e. by increasing the output voltage of the EHT supply or using a larger 'spoon'. Conversely, less charge can be transferred by decreasing the EHT output voltage or using a smaller 'spoon'.

The capacitance of the electrophorus can be calculated from the readings taken.

Typically, with the EHT supply set to 5kV, a charge of approximately 10nC will be induced onto the electrophorus.

using: Quantity of charge = capacitance x voltage gives:

$$\text{Capacitance of electrophorus:- } \frac{10\text{nC}}{5\text{kV}} = 2\text{pF}$$

Investigating the Parallel Plate Capacitor.

Set up the apparatus as shown in fig. 13. Connect the negative sockets of the 5kV EHT supply, the coulombmeter and the lower plate of the capacitor to a good earthing point.

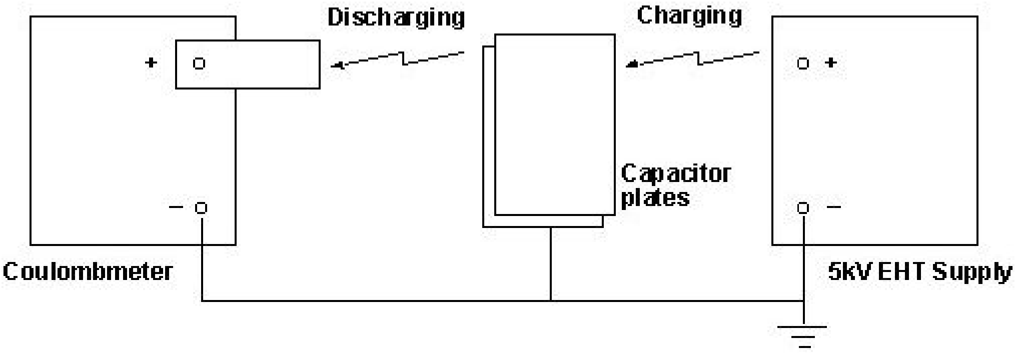


Figure No13 – Parallel plate capacitor.

Charge the capacitor by connecting the upper plate to the positive socket of the EHT supply set to approximately 1kV. Zero the coulombmeter reading and then measure the charge on the capacitor by discharging it into the coulombmeter.

For a capacitor with parallel plates 0.3m x 0.3m, separated by a 1mm air space, the charge transferred is 800nC, hence:

$$\text{Capacitance:- } \frac{800\text{nC}}{1\text{kV}} = 800\text{pF}$$

The permittivity, ε_o, of the medium separating the plates can be calculated from the formula:

$$\varepsilon_o = \frac{C \times d}{A}$$

where:

C is the capacitance of the capacitor = 800pF
D is the separation of the plates = 0.001mε
A is the effective plate area = 0.3m square

so: Ɛo = 8.9 x 10^{-12} Farads per metre

In this experiment, as before, it is important that the insulating spacers of the parallel plate capacitor are clean and dry. Dirty and/or damp insulators can cause the capacitor to discharge as soon as it is connected to the EHT supply. This effect can be demonstrated by performing the experiment with clean, dry insulators and then repeating the experiment after breathing heavily on the insulators in situ.

In addition, the relationship between capacitance and effective plate area can be investigated. Alter the effective plate area by arranging only partial overlap of the plates, keeping the same plate separation. Plot a graph of charge on the capacitor against effective plate area to show how the relationship between the two varies.

The separation of the plates may be altered by increasing the number of insulating spacers between them. Plotting a graph of capacitance against plate separation will verify that the two are inversely proportional to one another.

Measuring Large Capacitances.

The charge on capacitors having capacitances up to 0.22µF can be measured accurately using the coulombmeter. The unknown capacitor can be charged from a dry cell or other suitable dc power supply and then discharged into the coulombmeter using the circuit arrangement of fig. 14. The unknown capacitance can then be calculated by dividing the charge measured on the coulombmeter by the voltage of the charging power supply.

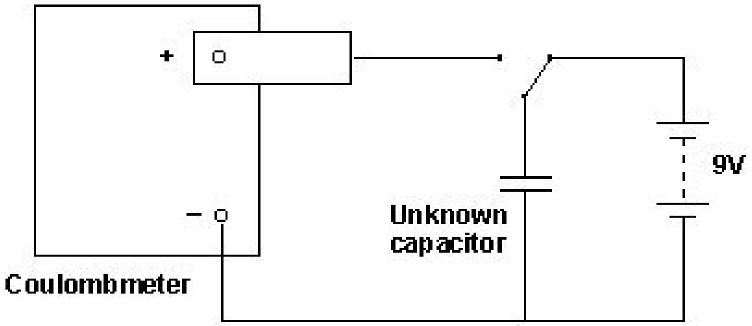


Figure No14 – Measuring large capacitances.

Measuring the capacitance of the coulombmeter by charge sharing.

If a discharged capacitor is connected to a charged coulombmeter then the charge on the meter internal capacitor will be shared with the external capacitor. This enables the capacitance of the coulombmeter to be calculated.

Using the circuit of fig. 15, charge the coulombmeter with, for example, a charged rod as described earlier. Discharge the external capacitor by shorting across its terminals. Note the coulombmeter reading, Q1. Connect the external capacitor to the coulombmeter and record the new meter reading, Q2.

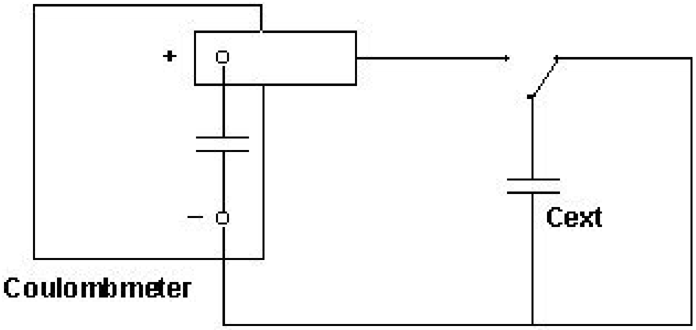


Figure No15 – Coulombmeter capacitance measurement.

Then, the charge on the external capacitor = Q1 - Q2 and the charge on the coulombmeter capacitor = Q2.

The potential difference across both capacitors is the same, so:

$$\frac{Q2}{Cint} = \frac{Q1 - Q2}{Cext} \qquad \text{hence:} \quad Cint = \frac{Cext \times Q2}{1 - Q2}$$

where:

Cint = internal capacitance of the coulombmeter
Cext = external capacitance

The external capacitor should have a capacitance of between 1 and 10µF. Generally, the values of electrolytic capacitors are known only within a wide tolerance range and therefore this type are unsuitable for this experiment. However, any plastic-insulated type capacitor would suffice.

In a typical experiment, using an external capacitance of 2.2µF, charge readings were obtained as follows:

Q1 = 249nC and Q2 = 169nC

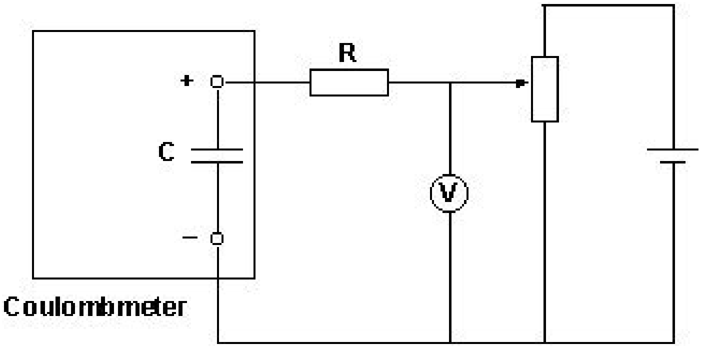
so:

$$Cint = \frac{169}{249 - 169} \times 2.2uF \qquad \text{therefore} \quad Cint = 4.6uF$$

Experiments with CR time constants.

The internal capacitor of the coulombmeter may be used with an external resistor to plot graphs showing the exponential change of charge with time for a CR network. The circuit shown in fig. 16 can be used to measure the charge on the coulombmeter capacitor at any instant. The value of the resistor, R, should be between 2 and 10MΩ and the potential difference applied to the CR network should be approximately 0.3V.

Figure No16 – CR network.



The coulombmeter capacitor can be discharged through the resistor using the circuit of fig. 17. A graph of the charge on the coulombmeter capacitor against time can be plotted as in fig. 18 and the time constant can be determined by drawing a tangent to the curve at the point where the capacitor just starts to discharge. Where this tangent crosses the time axis gives the value of the time constant, CR, of the circuit. From a knowledge of the value of the resistor, R, the capacitance of the internal capacitor of the coulombmeter can be calculated.

Figure No17 – Coulombmeter discharge circuit.

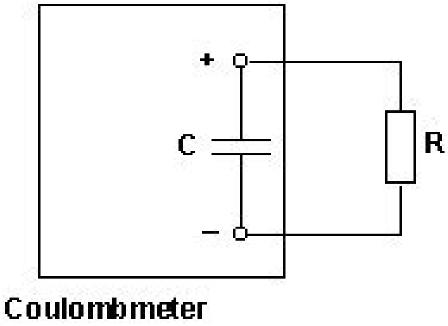


Figure No18 – CR plot.