Dielectric Constant Measurement Trainer

Nvis 6111

Learning Material

Ver 1.2

An ISO 9001: 2008 company

Designed & Manufactured in India by :

Nvis Technologies Pvt. Ltd.

141-A, Electronic Complex, Pardesipura, Indore - 452 010 India

Tel.: 91-731-4211500, E-mail: info@nvistech.com, Website : www.NvisTech.com

Nvis 6111 Dielectric Constant Measurement Trainer

CERTIFICATE OF COMPLIANCE

INTERNATIONAL CERTIFICATION SERVICES PVT. LTD.

This is to certify that the

QUALITY MANAGEMENT SYSTEM of

NVIS TECHNOLOGIES PVT. LTD.

141-A, Electronic Complex, Pardesipura, Indore - 452 010, Madhya Pradesh, India.

has been assessed and registered as complying with the requirements of the following International Standard:

ISO 9001:2015

The Quality Management System applicable to:

Scope : Design And Manufacture Of Didactic Products And Clean Technologies Products Such As Solar Solutions.

Registration No.	**: RQ91/7763**
Registered Date	**: 17th June, 2012**
Reassessment Date	**: 28th June, 2018**
Issue Date	**: 30th June, 2018**
Expiry Date	**: 16th June, 2021**

JAS-ANZ

www.jas-anz.org/register

RED
Invalid After
12/06/2019
Unless
Hologram
Pasted

GREEN
Invalid After
12/06/2020
Unless
Hologram
Pasted

Managing Director

International Certification Services

Accredited by Joint Accreditation System of Australia and New Zealand

Validity of this certificate is based on periodic audits of the management system defined by the above scope and is contingent upon prompt, written notification of significant changes to the management system and/or its components thereof shall be immediately communicated to ICS.
Further clarifications regarding the scope of this certificate and the applicability of ISO 9001:2015 requirements may be obtained at www.icsasian.com

22/23, Goodwill Premises, Swastik Estate, 178 CST Road, Kalina, Santacruz (E), Mumbai – 400 098, Maharashtra, India. Tel.: 022-42200900

Dielectric Constant Measurement Trainer

Nvis 6111

Table of Contents

Nvis 6111 Dielectric Constant Measurement Trainer

Introduction

Nvis 6111 Dielectric Constant Measurement Trainer is very precise to measure the Dielectric Constants of different solid materials like Teflon, Glass, Bakelite, Paper, Nylon etc. By this trainer we can easily measure the Dielectric Constant of any solid materials, for this inbuilt RF Signal generator and LCD is provide.

Dielectrics are things that do not conduct electricity well, if at all. A dielectric is the electrically insulating material between the metallic plates of a capacitor. An effective dielectric typically contains polar molecules that reorient in external electric field. This dielectric polarization increases the capacitor's capacitance.

Dry air is a great example of dielectric materials. Different materials have Dielectric Constants at room temperature, For example, Dielectric of air is about 1, paper is 3, and rubber is 7. The dielectric constant is the ratio of the electrical conductivity when a dielectric material is placed to that of the conductivity in free space. Nvis 6111 uses this relation for calculating dielectric constant.

Nvis 6111 Dielectric Constant Measurement Trainer

Features

- Very easy to operate
- Provided with Variable and Test capacitor
- Variable capacitor with high accuracy measurement
- LCD display

Technical Specifications

Display	:	LCD
Variable capacitor	:	20-290 pF
Test Sample	:	Teflon, Glass & Bakelite
Main Supply	:	230 V $\pm$10%, 50 Hz

Safety Instructions

Read the following safety instructions carefully before operating the instrument. To avoid any personal injury or damage to the instrument or any product connected to the instrument.

Do not operate the instrument if suspect any damage to it.

The instrument should be serviced by qualified personnel only.

For your safety:

Use proper Mains cord	:	Use only the mains cord designed for this instrument. Ensure that the mains cord is suitable for your country.
Ground the Instrument	:	This instrument is grounded through the protective earth conductor of the mains cord. To avoid electric shock, the grounding conductor must be connected to the earth ground. Before making connections to the input terminals, ensure that the instrument is properly grounded.
Use in proper Atmosphere	:	Please refer to operating conditions given in the manual.

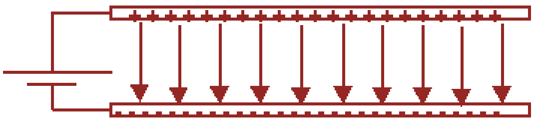
1. **Do not operate in wet / damp conditions.**
2. **Do not operate in an explosive atmosphere.**
3. **Keep the product dust free, clean and dry.**

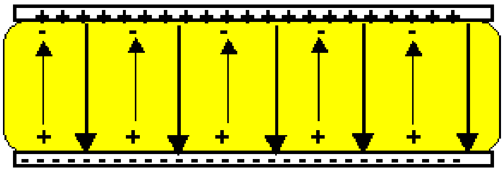
Theory

If the electric field between the plates becomes too strong, the air between them can no longer insulate the charges from sparking, discharging, between the plates. In order to keep this from happening, a dielectric is often inserted between the plates to reduce the strength of the electric field, without having to reduce the voltage being placed across the plates.

Dielectric

An effective dielectric typically contains polar molecules that reorient in external electric field. This dielectric polarization increases the capacitor's capacitance. Generalizing this, any insulating substance can be called a dielectric. While the term "insulator" refers to a low degree of electrical conduction, the term "dielectric" is typically used to describe materials with a high density. Generalizing further, dielectrics, the study of dielectric properties, is concerned with the storage and dissipation of electric and magnetic energy in materials.





Dielectric is a poor conductor of electricity, but an efficient supporter of electrostatic fields. If the flow of current between opposite electric charge poles is kept to a minimum while the electrostatic lines of flux are not impeded or interrupted, an electrostatic field can store energy. This property is useful in capacitor s, especially at radio frequencies. Dielectric materials are also used in the construction of radio-frequency transmission lines.

In practice, most dielectric materials are solid. Examples include porcelain (ceramic), mica, glass, plastics, and the oxides of various metals. Some liquids and gases can serve as good dielectric materials. Dry air is an excellent dielectric, and is used in variable capacitors and some types of transmission lines. Distilled water is a fair dielectric. A vacuum is an exceptionally efficient dielectric.

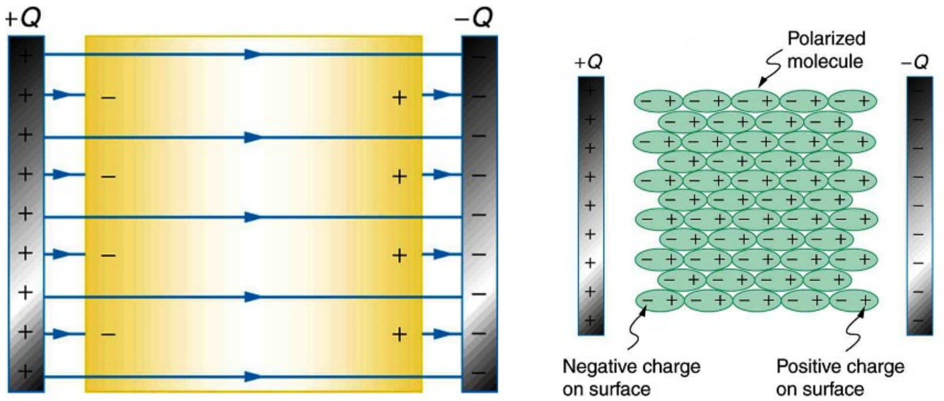
An important property of a dielectric is its ability to support an electrostatic field while dissipating minimal energy in the form of heat. The lower the dielectric loss (the proportion of energy lost as heat), the more effective is a dielectric material. Another consideration is the dielectric constant, the extent to which a substance concentrates the electrostatic lines of flux. Substances with a low dielectric constant include a perfect vacuum, dry air, and most pure, dry gases such as helium and nitrogen. Materials with moderate dielectric constants include ceramics, distilled water, paper, mica, polyethylene, and glass. Metal oxides, in general, have high dielectric constants.

The prime asset of high-dielectric-constant substances, such as aluminum oxide, is the fact that they make possible the manufacture of high-value capacitors with small physical volume. But these materials are generally not able to withstand electrostatic fields as intense as low-dielectric-constant substances such as air. If the voltage across a dielectric material becomes too great -- that is, if the electrostatic field becomes too intense -- the material will suddenly begin to conduct current. This phenomenon is called dielectric breakdown. In components that use gases or liquids as the dielectric medium, this condition reverses itself if the voltage decreases below the critical point. But in components containing solid dielectrics, dielectric breakdown usually results in permanent damage.

The Dielectric Constant

How effective a dielectric is at allowing a capacitor to store more charges depends on the material the dielectric is made from? Every material has a dielectric constant κ . This is the ratio of the field without the dielectric (E_o) to the net field (E) with the dielectric:

$$\kappa = E_o/E$$



E is always less than or equal to E_o, so the dielectric constant is greater than or equal to 1. The larger the dielectric constant, the more charge can be stored. Completely filling the space between capacitor plates with a dielectric increases the capacitance by a factor of the dielectric constant:

$$C = \kappa \, C_o,$$

Where C_o is the capacitance with no dielectric between the plates

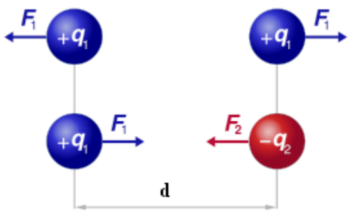
For a parallel-plate capacitor containing a dielectric that completely fills the space between the plates, the capacitance is given by:

$$C = \kappa \, \varepsilon_o \, A / d$$

The capacitance is maximized if the dielectric constant is maximized, and the capacitor plates have large area and are placed as close together as possible. If a metal was used for the dielectric instead of an insulator the field inside the metal would be zero, corresponding to an infinite dielectric constant. The dielectric usually fills the entire space between the capacitor plates, however, and if a metal did that it would short out the capacitor - that's why insulators are used instead.

Material	Dielectric constant	Dielectric Strength (KV/mm)
Vacuum	1.00000	-
Air (dry)	1.00059	3
Polystyrene	2.6	24
Paper	3.6	16
Water	80	-

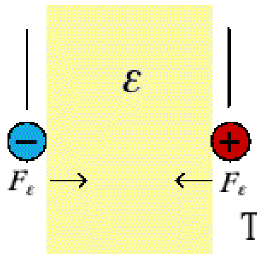
Dielectrics have the strange property of making space seem bigger or smaller than it looks. The dielectric constant value tells you how much smaller or bigger the space gets. It shows itself in two ways.



$$F = \frac{e^2}{4\pi\varepsilon_0 r^2}$$

Force between charges

First, when you put some dielectric between two electric charges it reduces the force acting between them, just as if you'd moved them apart.

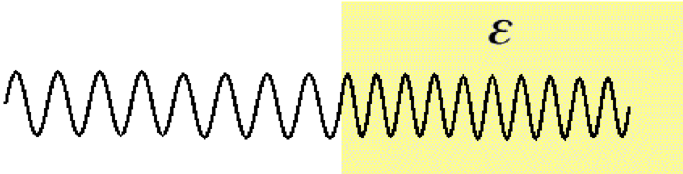


$$F_\varepsilon = \frac{1}{\varepsilon} \times F \equiv \frac{e^2}{4\pi\varepsilon_0 (\sqrt{\varepsilon} \times r)^2}$$

The dielectric 'warps the distance' to $\sqrt{\varepsilon} \times r$.

Where ε is the dielectric constant value some times called the relative permittivity

Secondly, the dielectric constant of a material affects how electromagnetic signals (light, radio waves, millimeter-waves, etc.) move through the material. A high value of dielectric constant makes the distance inside the material look bigger. This means that light travels more slowly. It also 'scrunches up' the waves to behave as if the signal had a shorter wavelength.



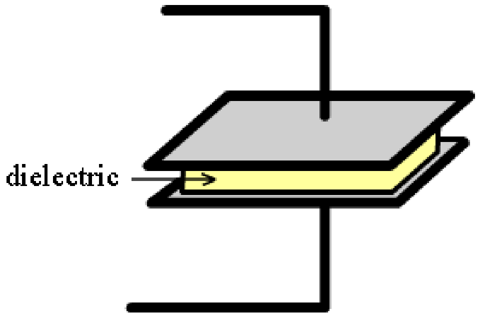
When the wave enters the dielectric both its wavelength and its velocity reduce by the factor $\sqrt{\varepsilon}$

For electromagnetic waves, just like the forces between charges, the dielectric warps the space to make it look a different size.

Dielectric Materials

Materials which are electrical insulators or in which an electric field can be sustained with a minimal dissipation of power, dielectrics are employed as insulation for wires, cables, and electrical equipment, as polarizable media for capacitors, in apparatus used for the propagation or reflection of electromagnetic waves, and for a variety of artifacts, such as rectifiers and semiconductor devices, piezoelectric transducers, dielectric amplifiers, and memory elements. The term dielectric, though it may be used for all phases of matter, is usually applied to solids and liquids.

The ideal dielectric material does not exhibit electrical conductivity when an electric field is applied. In practice, all dielectrics do have some conductivity, which generally increases with increase in temperature and applied field. If the applied field is increased to some critical magnitude, the material abruptly becomes conducting, a large current flows (often accompanied by a visible spark), and local destruction occurs to an extent dependent upon the amount of energy which the source supplies to the low-conductivity path. Temperature instability can occur because of the heat generated through conductivity or dielectric losses, causing thermal breakdown. Breakdown can be brought about by a variety of different causes, sometimes by a number of them acting simultaneously. Nevertheless, under carefully specified and controlled experimental conditions, it is possible to measure a critical field which is dependent only on the inherent insulating properties of the material itself in those conditions. This field is called the intrinsic electric strength of the dielectric. Many of the traditional industrial dielectric materials are still in common use, and they compete well in some applications with newer materials regarding their electrical and mechanical properties, reliability, and cost. For example, oil-impregnated paper is still used for high-voltage cables. However, synthetic polymers such as polyethylene, polypropylene, polystyrene, polytetrafluoroethylene, polyvinyl chloride, poly methyl methacrylate, polyamide, and polyimide have become important, as has polycarbonate because it can be fabricated into very thin films. Generally, polymers have crystalline and amorphous regions, increasing crystalline causing increased density, hardness, and resistance to chemical attack, but often producing brittleness. Many commercial plastics are amorphous copolymers, and often additives are incorporated in polymers to achieve certain characteristics or to improve their workability.



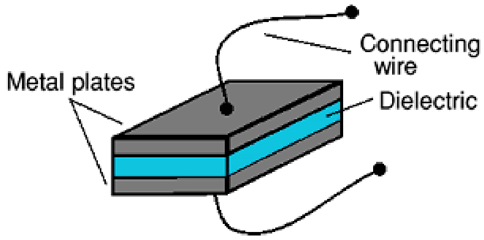
A dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic fields. If the flow of current between opposite electric charge poles is kept to a minimum while the electrostatic lines of flux are not impeded or interrupted, an electrostatic field can store energy. This property is useful in capacitor s, especially at radio frequencies. Dielectric materials are also used in the construction of radio-frequency transmission lines. In practice, most dielectric materials are solid. Examples include porcelain (ceramic), mica, glass, plastics, and the oxides of various metals. Some liquids and gases can serve as good dielectric materials. Dry air is an excellent dielectric, and is used in variable capacitors and some types of transmission lines. Distilled water is a fair dielectric. A vacuum is an exceptionally efficient dielectric.

An important property of a dielectric is its ability to support an electrostatic field while dissipating minimal energy in the form of heat. The lower the s (the proportion of energy lost as heat), the more effective is a dielectric material. Another consideration is the dielectric constant, the extent to which a substance concentrates the electrostatic lines of flux. Substances with a low dielectric constant include a perfect vacuum, dry air, and most pure, dry gases such as helium and nitrogen. Materials with moderate dielectric constants include ceramics, distilled water, paper, mica, polyethylene, and glass. Metal oxides, in general, have high dielectric constants.

The prime asset of high-dielectric-constant substances, such as aluminum oxide, is the fact that they make possible the manufacture of high-value capacitors with small physical volume. But these materials are generally not able to withstand electrostatic fields as intense as low-dielectric-constant substances such as air. If the voltage across a dielectric material becomes too great -- that is, if the electrostatic field becomes too intense -- the material will suddenly begin to conduct current. This phenomenon is called dielectric breakdown. In components that use gases or liquids as the dielectric medium, this condition reverses itself if the voltage decreases below the critical point. But in components containing solid dielectrics, dielectric breakdown usually results in permanent damage.

Dielectric Capacitor

A dielectric capacitor consists of two metal sheets placed on either side of a layer of dielectric material. Dielectrics are materials like glass or plastics (polymers) which are insulators. The behavior of a dielectric is determined by its dielectric constant value.



Dielectric capacitor

Most text books quote the formula shown here to link the value of a capacitor to its plate area (the size of the plate surfaces facing each other), the distance between the plates, and the dielectric constant of the material used. Alas, this simple formula is only approximately correct! Capacitors are designed in a number of different ways.

C = Capacitance

$$C = \frac{\varepsilon A}{d}$$

A = Area of plates

d = Plate spacing (Thickness of dielectric)

ε = Dielectric Constant

Dielectrics in capacitors serve three purposes

1. To keep the conducting plates from coming in contact, allowing for smaller plate separations and therefore higher capacitances;
2. To increase the effective capacitance by reducing the electric field strength, which means you get the same charge at a lower voltage; and
3. To reduce the possibility of shorting out by sparking (more formally known as dielectric breakdown) during operation at high voltage.

Standard Dielectric of some materials

S. No.	Materials	Minimum	Maximum
1	Bakelite	3	22
2	Teflon	2.0	2.8
3	Glass	3	10
4	Paper	1.5	3
5	Rubber	2.5	4.6
6	Polyethylene	2	4

Source: http://www.clippercontrols.com/pages/Dielectric-Constant-Values.html

http://www.csgnetwork.com/dieconstantstable.html

Dielectric measurements

Measurements of the dielectric properties of a material, which are characterized by its complex relative permittivity ε_r, all materials except ferroelectrics this quantity does not depend on applied field: the general behavior is linear, and so voltage of any convenient magnitude can be used for measurement.

Bridge methods

The most commonly used apparatus for measuring ε_r is the alternating-current (ac) bridge. These bridges are readily available in the operating range $10–10^6$ Hz, and sometimes outside it; ultra low-frequency bridges can go as low as 10^{-3} Hz. Most specimen holders for solids are essentially parallel-plate capacitors with the specimen filling all the space between the plates; for liquids, a test cell with cylindrical electrodes is usually employed. The bridges most commonly used are of the Wheatstone type, the most versatile for dielectric measurements being the Schering Bridge.

Resonance methods

Resonance methods, useful for frequencies greater than 1 MHz, involve the injection of voltage or current by one of several methods into an *LC* (inductance-capacitance) resonant circuit. Measurements over a range of frequencies may be made by using coils with different inductance values, but ultimately the inductance required becomes impractically small, and in the range 10^8-10^9 Hz reentrant cavities are often used. These are hybrid devices in which the plates holding the specimen still form a lumped capacitor, but the inductance and capacitances are distributed along a coaxial line. At higher frequencies, the wavelength is comparable to the dimensions of the apparatus, and transmission methods in coaxial lines and waveguides must be used.

Transmission methods

Coaxial lines are used in the frequency range 300 MHz–3 GHz, and waveguides in the range 3–30 GHz. The transmission characteristics are determined by the complex permittivity of the material filling the line or guide. Many different measurement techniques have been devised, but all derive values of the complex relative permittivity ε_r from its relationship to the complex propagation factor γ. In practice, traveling waves are rarely used as the basis of measurement, except for high-loss materials. Usually, reflections from terminations set up standing waves, the amplitude of which in the case of a liquid-filled line can be measured by a suitable probe. The ratios of the field magnitudes at adjacent maxima, and the distance between them, give the information required.

Sub millimeter measurements

Dielectric measurements are difficult to carry out in the frequency range 30–300 GHz, for which λ_0 is in the range 1 cm–1 mm, but for λ_0 less than 1 mm, methods related to infrared spectroscopy are used. Broadband continuous spectra result from Fourier transform spectroscopy, which in its simplest form is equivalent to normal infrared spectroscopy, with the specimen in one of the two passive arms of the interferometer, between the beam divider and either the source or the detector. In the more sophisticated dispersive Fourier transform spectroscopy, the specimen is in one of the active arms, that is, between the beam divider and either mirror. Discrete-point spectra also may be obtained by the use of a Mach-Zehnder interferometer and a laser source. By using interferometric techniques, the frequency range can be extended up to about 5 THz.

Time-domain methods

If a constant direct-current (dc) voltage is suddenly applied to a dielectric specimen, in principle the charging current is related through the Fourier integral transformation to the steady-state ac current which would flow if the applied voltage were sinusoidal at any particular frequency. If the dc voltage is suddenly removed, a similar relationship holds between the discharge current and ac current. Thus the variation of complex permittivity with frequency can in principle be derived from a transient signal in the time domain. Because of various limitations, the method is not capable of giving results of accuracy at all frequencies comparable to those obtainable from a single frequency measurement. Nevertheless, with the aid of computer analysis, the response over a large frequency range can be obtained much more quickly than would be possible by using point-by-point measurement methods.

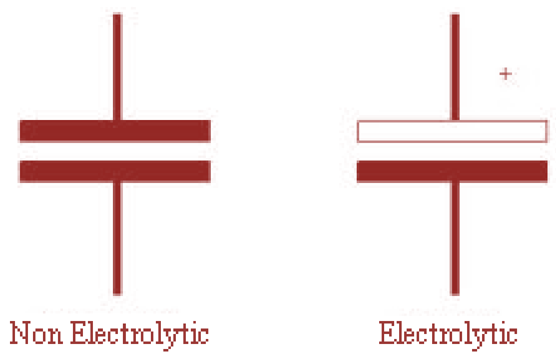
Capacitor

A capacitor is a passive electronic component that stores energy in the form of an electrostatic field. In its simplest form, a capacitor consists of two conducting plates separated by an insulating material called the Dielectric. The capacitance is directly proportional to the surface areas of the plates, and is inversely proportional to the separation between the plates. Capacitance also depends on the dielectric constant of the substance separating the plates. The standard unit of capacitance is the Farad, abbreviated F. This is a large unit; more common units are the microfarad, abbreviated µF (1 µF =10-6F) and the Pico farad, abbreviated pF (1 pF = 10-12 F).

Capacitors can be fabricated onto integrated circuit (IC) chips. They are commonly used in conjunction with transistors in dynamic random access memory (DRAM). The capacitors help maintain the contents of memory. Because of their tiny physical size, these components have low capacitance. They must be recharged thousands of times per second or the DRAM will lose its data.

Large capacitors are used in the power supplies of electronic equipment of all types, including computers and their peripherals. In these systems, the capacitors smooth out the rectified utility AC, providing pure, battery-like DC. The capacitor is constructed with two electrode plates facing each other, but separated by an insulator. When DC voltage is applied to the capacitor, an electric charge is stored on each electrode. While the capacitor is charging up, current flows. The current will stop flowing when the capacitor has fully charged. The value of a capacitor (the capacitance), is designated in units called the Farad (F). The capacitance of a capacitor is generally very small, so units such as the microfarad (10^{-6}F), nanofarad (10^{-9}F), and picofarad (10^{-12}F) are used.

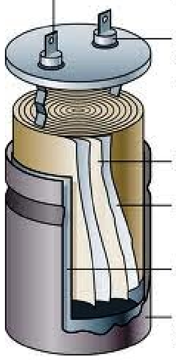
Recently, a new capacitor with very high capacitance has been developed. The Electric Double Layer capacitor has capacitance designated in Farad units. These are known as "Super Capacitors." Capacitors are short term charge-stores, a bit like an electrical spring. They are used widely in electronic circuits. It consists of two metal plates separated by a layer of insulating material called a dielectric. The symbol for a capacitor is shown below:



There are two types of capacitor, electrolytic and non-electrolytic.

- Electrolytic capacitors hold much more charge;
- Electrolytic capacitors have to be connected with the correct polarity, otherwise they can explode.

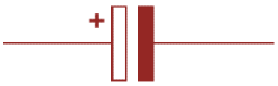
If we pump electrons onto the negative plate, electrons are repelled from the negative plate. Since positives do not move, a positive charge is induced. The higher the potential difference, the more charge is crowded onto the negative plate and the more electrons repelled from the positive plate. Therefore charge is stored. The plates have a certain capacitance.



Capacitance

Capacitance (symbol C) is a measure of a capacitor's ability to store charge. A large capacitance means that more charge can be stored. However 1F is very large, so prefixes (multipliers) are used to show the smaller values:

- µ (micro) means 10^{-6} (millionth), so 1000000µF = 1F
- n (nano) means 10^{-9} (thousand-millionth), so 1000nF = 1µF
- p (pico) means 10^{-12} (million-millionth), so 1000pF = 1nF



Polarized capacitor symbol

Unpolarized capacitor symbol

Capacitance is defined as the charge required to cause unit potential difference in a conductor.

Or

1 Farad is the capacitance of a conductor, which has potential difference of 1 volt when it carries a charge of 1 coulomb.

So we can write from this definition:

$$\text{Capacitance (F)} = \frac{Charge\ \ (C)}{Voltage\ \ (V)}$$

Capacitance is measured in units called farads (F).

Charge and Energy Stored

The amount of charge (symbol Q) stored by a capacitor is given by:

Charge, $Q = C \times V$

Where: Q = charge in coulombs (C)

C = capacitance in farads (F)

V = voltage in volts (V)

When they store charge, capacitors are also storing energy:

Energy, $E = \frac{1}{2}QV = \frac{1}{2}CV^2$ where E = energy in joules (J).

Note that capacitors return their stored energy to the circuit. They do not 'use up' electrical energy by converting it to heat as a resistor does. The energy stored by a capacitor is much smaller than the energy stored by a battery so they cannot be used as a practical source of energy for most purposes.

Capacitive Reactance X_C

Capacitive reactance (symbol X_C) is a measure of a capacitor's opposition to AC (alternating current). Like resistance it is measured in ohms (Ω), but reactance is more complex than resistance because its value depends on the frequency (f) of the electrical signal passing through the capacitor as well as on the capacitance, C.

Capacitive reactance, $\mathbf{X_C = 1/2\pi fC}$

Where: X_C = reactance in ohms (Ω)

f = frequency in hertz (Hz)

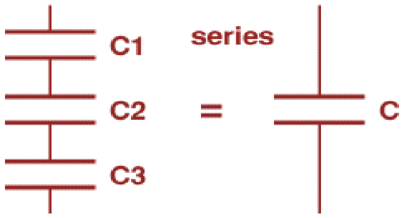
C = capacitance in farads (F)

The reactance X_C is large at low frequencies and small at high frequencies. For steady DC which is zero frequency, X_C is infinite (total opposition), hence the rule that capacitors pass AC but block DC.

For example a 1µF capacitor has a reactance of 3.2kΩ for a 50Hz signal, but when the frequency is higher at 10 kHz its reactance is only 16Ω.

Note: the symbol X_C is used to distinguish capacitative reactance from inductive reactance X_L which is a property of inductors. The distinction is important because X_L increases with frequency (the opposite of X_C) and if both X_L and X_C are present in a circuit the combined reactance (X) is the difference between them capacitors in Series**:**

In series combination the distance between the plate's increases, so the total capacitance is reduced when the capacitors are connected in series. The net capacitance is less than the lowest capacitance present in the series circuit. The result is exactly the same as the resistances in parallel. Combined capacitance (C) of capacitors when they are connected in series:

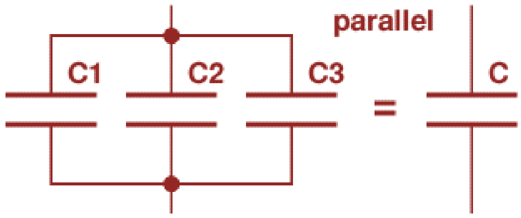


$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$$

Capacitors in Parallel

When capacitors are connected in parallel their value is added up. The reason is that the capacity is increased due to larger plate surface area. The formula for parallel capacitor is same as the resistance in series.

Combined capacitance (C) of capacitors when they are connected in parallel:



$$C = C_1 + C_2 + C_3 + ...$$

Two or more capacitors are rarely deliberately connected in series in real circuits, but it can be useful to connect capacitors in parallel to obtain a very large capacitance, for example to smooth a power supply.

Charging a capacitor

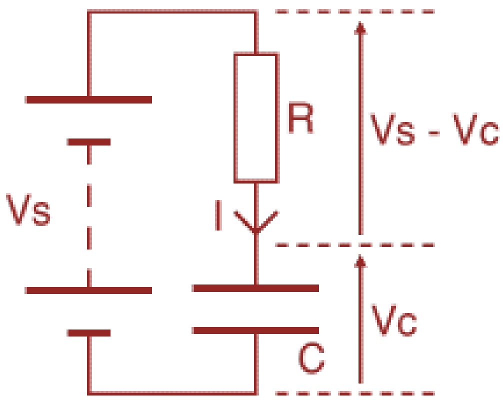
The capacitor (C) in the circuit diagram is being charged from a supply voltage (V_S) with the current passing through a resistor (R). The voltage across the capacitor (V_C) is initially zero but it increases as the capacitor charges. The capacitor is fully charged when $V_C = V_S$. The charging current (I) is determined by the voltage across the resistor ($V_S - V_C$):

Charging current, $I = (V_S - V_C) / R$ (note that V_C is increasing)

At first $V_C = 0V$ so the initial current, $I_0 = V_S / R$

V_C increases as soon as charge (Q) starts to build up ($V_C = Q/C$), this reduces the voltage across the resistor and therefore reduces the charging current. This means that the rate of charging becomes progressively slower.

Time constant = R × C



Where:

Time constant is in seconds (s)

R = resistance in ohms (Ω)

C = capacitance in farads (F)

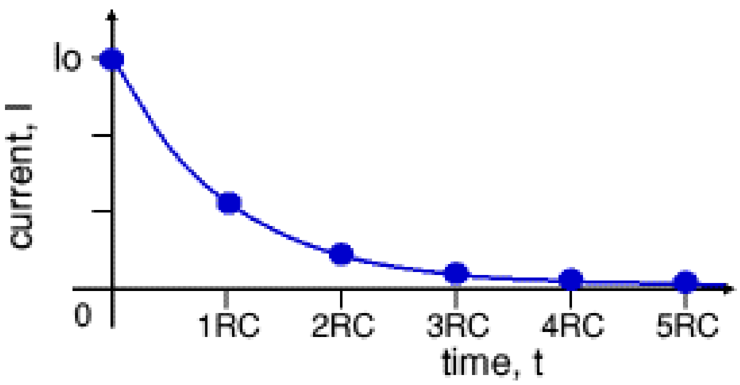
For Example

If R = 47 kΩ and C = 22 µF, then the time constant, RC = 47 kΩ × 22 µF = 1.034 s.

If R = 33 kΩ and C = 1 µF, then the time constant, RC = 33 kΩ × 1 µF = 33ms.

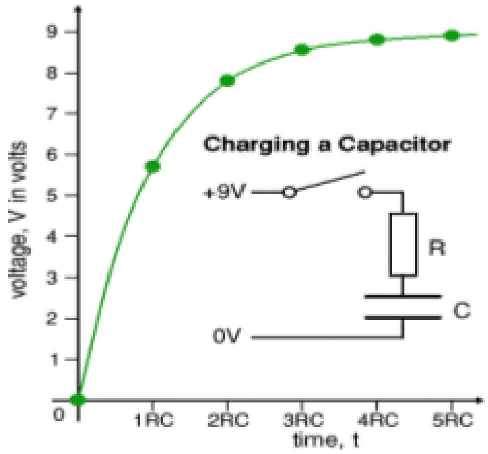
A large time constant means the capacitor charges slowly. Note that the time constant is a property of the **circuit** containing the capacitance and resistance; it is not a property of a capacitor alone. The time constant is the time taken for the charging (or discharging) current (I) to fall to $^1/e$ of its initial value (I_0). 'e' is the base of natural logarithms, an important number in mathematics (like π). e = 2.71828 (to 6 significant figures) so we can roughly say that the time constant is the time taken for the current to fall to $^1/_3$ of its initial value.

After each time constant the current falls by $^1/e$ (about $^1/_3$). After 5 time constants (5RC) the current has fallen to less than 1% of its initial value and we can reasonably say that the capacitor is **fully charged**, but in fact the capacitor takes for ever to charge fully!



Graphs showing the current and voltage for a capacitor charging

The bellow graph shows how the voltage (V) increases as the capacitor charges. At first the voltage changes rapidly because the current is large; but as the current decreases, the charge builds up more slowly and the voltage increases more slowly.



Time	Voltage	Charge
0RC	0.0V	0%
1RC	5.7V	63%
2RC	7.8V	86%
3RC	8.6V	95%
4RC	8.8V	98%
5RC	8.9V	99%

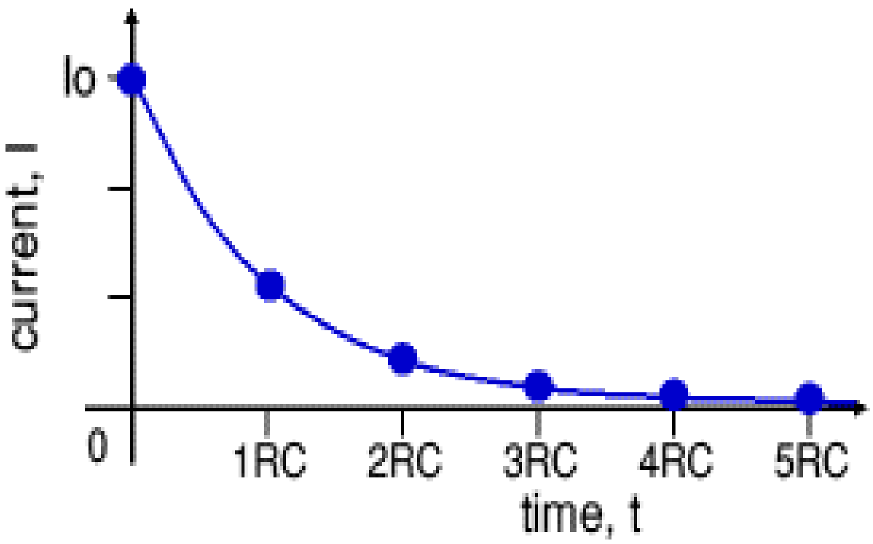
After 5 time constants (5RC) the capacitor is almost fully charged with its voltage almost equal to the supply voltage. We can reasonably say that the capacitor is fully charged after 5RC, although really charging continues for ever (or until the circuit is changed).

Discharging a capacitor

The graph shows how the current (I) decreases as the capacitor discharges. The initial current (I_0) is determined by the initial voltage across the capacitor (V_0) and resistance (R):

Initial current,

$$I_0 = \frac{V_0}{R}$$



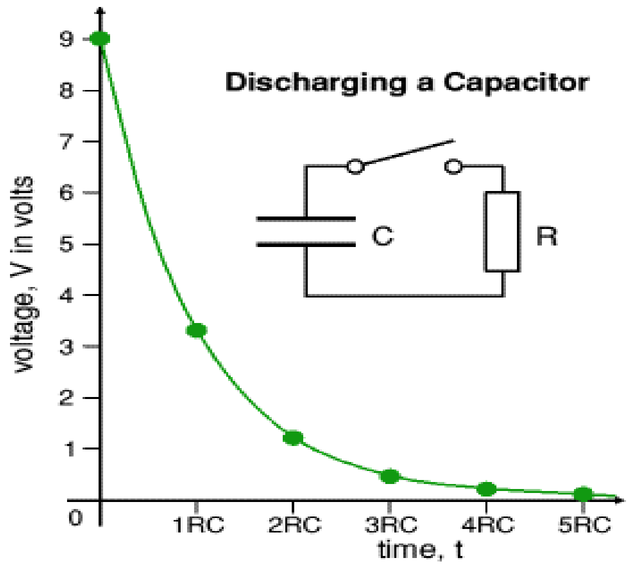
Graphs showing the current and voltage for a capacitor discharging

Note that the current graphs are the same shape for both charging and discharging a capacitor. This type of graph is an example of exponential decay.

The below graph shows how the voltage (V) decreases with capacitor discharge

At first the current is large because the voltage is large, so charge is lost quickly and the voltage decreases rapidly. As charge is lost the voltage is reduced making the current smaller so the rate of discharging becomes progressively slower.

After 5 time constants (5RC) the voltage across the capacitor is almost zero and we can reasonably say that the capacitor is fully discharged, although really discharging continues for ever (or until the circuit is changed).



Time	Voltage	Charge
0RC	9.0V	100%
1RC	3.3V	37%
2RC	1.2V	14%
3RC	0.4V	5%
4RC	0.2V	2%
5RC	0.1V	1%

Electrical Resonance

Electrical resonance occurs in an electric circuit at a particular resonance frequency when the impedance between the input and output of the circuit is at a minimum (or when the transfer function is at a maximum). Often this happens when the impedance between the input and output of the circuit is almost zero and when the transfer function is close to one.

Resonant circuits exhibit ringing and can generate higher voltages and currents than are fed into them. They are widely used in wireless transmission for both transmission and reception.

Resonance with capacitors and inductors

Resonance of a circuit involving capacitors and inductors occurs because the collapsing magnetic field of the inductor generates an electric current in its windings that charges the capacitor, and then the discharging capacitor provides an electric current that builds the magnetic field in the inductor, and the process is repeated continually. An analogy is a mechanical pendulum. In some cases, resonance occurs when the inductive reactance and the capacitive reactance of the circuit are of equal magnitude, causing electrical energy to oscillate between the magnetic field of the inductor and the electric field of the capacitor.

At resonance, the series impedance of the two elements is at a minimum and the parallel impedance is at maximum. Resonance is used for tuning and filtering, because it occurs at a particular frequency for given values of inductance and capacitance. It can be detrimental to the operation of communications circuits by causing unwanted sustained and transient oscillations that may cause noise, signal distortion, and damage to circuit elements.

Parallel resonance or near-to-resonance circuits can be used to prevent the waste of electrical energy, which would otherwise occur while the inductor built its field or the capacitor charged and discharged. As an example, asynchronous motors waste inductive current while synchronous ones waste capacitive current. The use of the two types in parallel makes the inductor feed the capacitor, and vice versa, maintaining the same resonant current in the circuit, and converting all the current into useful work.

Since the inductive reactance and the capacitive reactance are of equal magnitude,

$$\omega L = 1/\omega C,$$

so:

$$\omega = \frac{1}{\sqrt{LC}}$$

Where $\omega = 2\pi f$, in which f is the resonance frequency in hertz, L is the inductance in henries, and C is the capacitance in farads when standard SI units are used.

The quality of the resonance (how long it will ring when excited) is determined by its Q factor, which is a function of resistance.

Resonance Frequency

In physics, resonance is the tendency of a system to oscillate at larger amplitude at some frequencies than at others. These are known as the system's resonant frequencies (or resonance frequencies). At these frequencies, even small periodic driving forces can produce large amplitude vibrations, because the system stores vibration energy. When damping is small, the resonant frequency is approximately equal to the natural frequency of the system, which is the frequency of free vibrations. Resonance phenomena occur with all types of vibrations or waves: there is mechanical resonance, acoustic resonance, electromagnetic resonance, nuclear magnetic resonance (NMR), electron spin resonance (ESR) and resonance of quantum wave functions. Resonant systems can be used to generate vibrations of a specific frequency (e.g. musical instruments), or pick out specific frequencies from a complex vibration containing many frequencies.

Experiment

Object : Measurement of Dielectric Constant of different materials

Items Required

1. Solid Samples
2. Mains Cord
3. Patch Cord

Procedure

1. Connect the Mains Cord to the trainer & switch 'On' the rocker switch.
2. Now rotate the variable resistance knob fully in clockwise direction.
3. Connect variable capacitor to RF output on the trainer.
4. Change the value of capacitance for which maximum value of current is obtained that is the condition of resonance.
5. Note the value of capacitance. Let it be $\mathbf{C_1}$.
6. Place the dielectric sample between the plates of test capacitor such that the dielectric sample just touches both the plats with the help of adjusting screw.
7. Now connect the Test Capacitor with dielectric sample with the help of patch cords across the Test Capacitor (marked) on the trainer.
8. Now reduce the value of variable capacitor to obtain the condition of resonance.
9. Note the value of capacitance. Let it be $\mathbf{C_2}$.
10. Subtract $C_1$and C_2 to determine the value of test capacitance that is **C** here.
11. Now carefully remove the dielectric material from the test capacitor without changing the distance between the plates.
12. Now determine the distance between both the plates.
    Note: Take the help of vernier caliper for better result.
13. Determine the value of area of any one plate of test capacitor that is A by using the formula (Length x Breath)
14. Now calculate the value of Dielectric Constant of given material by following formula

$$C = \kappa\, \varepsilon_o A / d$$

Or

$$K = \frac{C \cdot d}{\varepsilon_0 A}$$

    Where,
    K = Dielectric Constant
    A = Area of plate
    d = Distance between two plates
    C = Capacitance
    ε_0 = Permittivity of free space its value is $\varepsilon_0 = 8.854\times10^{-12}$ F m^{-1}

15. Repeat the whole experiment for determining the dielectric constant of different material.

Sample Results

Experiment

Objective : Measurement of Dielectric Constant of different materials

Formula used

$$K = \frac{C.d}{\varepsilon_0 A}$$

Where,

K = Dielectric Constant

A = Area of plate

d = Distance between two plates

C = Capacitance

ε0 = Permittivity of free space its value is $\varepsilon_0 = 8.854\times10^{-12}$ F m^{-1}

Calculations for Glass

Length of plate = 134mm

Breath of plate = 61mm

Area of plate = Length x Breath = 134 x 61 = 8174 mm2= 8174 x 10-6m

Distance between both plates = 2.8mm = 2.8 x 10-3m

Capacitance = C1-C2

Note: Determine C1 & C2 as mention in procedure

Value of capacitance of test capacitor = 235pF-135pF

= 100pF = 100 x 10-12F

$$K = \frac{100 \times 10^{-12} \times 2.8 \times 10^{-3}}{8.85 \times 10^{-12} \times 8174 \times 10^{-6}}$$

= 3.87

Calculations for Bakelite

Length of plate = 134mm

Breath of plate = 61mm

Area of plate = Length x Breath = 8174mm2 = 8174 x 10-6m

Distance between both plates = 6.5mm = 6.5 x 10-3m

Capacitance = C1-C2

Note: Determine C1, C2 as mention in procedure

Value of capacitance of test capacitor = 240pF –190pF

= 50pF = 50 x 10-12F

$$K = \frac{50 \times 10^{-12} \times 6.5 \times 10^{-3}}{8.85 \times 10^{-12} \times 8174 \times 10^{-6}}$$

= 4.49

Calculations for Teflon

Length of plate = 134mm

Breath of plate = 61mm

Area of plate = Length x Breath = 8174mm2 =8174 x 10-6m

Distance between both plates = 3.1mm =3.1 x 10-3m

Capacitance = C1-C2

Note: Determine C1, C2 as mention in procedure

Value of capacitance of test capacitor = 235pF- 80pF

= 55pF = 55 x 10-12F

$$K = \frac{55 \times 10^{-12} \times 3.1 \times 10^{-3}}{8.85 \times 10^{-12} \times 8174 \times 10^{-6}}$$

= 2.35

Glossary

1. **Coefficient of thermal expansion :** Either volumetric or linear this describes the expansion that occurs with a change in temperature. Volumetric describes the volume change whereas linear describes the change in dimensions.
2. **Dielectric :** (1) Any insulating medium, which intervenes between two conductors and permits electrostatic attraction and repulsion to take place across it.

   (2) A material having the property that energy required to establish an electric field is recoverable in whole or in part, as electric energy.
3. **Dielectric absorption :** That property of an imperfect dielectric whereby there is an accumulation of electric charges within the body of the material when it is placed in an electric field.
4. **Dielectric Constant :** The relative permittivity of a material. Indicates the ability of a material to store electrical energy when a voltage is applied to it.
5. **Dissipation Factor :** The dissipation factor is a measure of the loss of power that takes place in virtually all dielectric materials, usually in the form of heat. It is expressed as the ratio of the resistive (loss) component of the current to the capacitive component of current, and is equal to the tangent of the loss angle.
6. **Dielectric loss angle :** The difference between 90º and the dielectric phase angle.
7. **Dielectric loss :** The time rate at which electric energy is transformed into heat in a dielectric when it is subjected to a changing electric field.
8. **Dielectric phase angle :** The angular difference in phase between the sinusoidal alternating potential difference applied to a dielectric and the component of the resulting alternating current having the same period as the potential difference.
9. **Dielectric power factor :** The cosine of the dielectric phase angle.
10. **Dielectric strength :** The voltage which an insulating material can withstand before breakdown occurs, usually expressed as a voltage gradient.
11. **Dielectric test :** Tests which consist of the application of a voltage higher than that of the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacing under normal conditions.
12. **Electrolyte :** A current-conducting solution between the electrodes of a capacitor used to replenish the dielectric in an aluminum electrolytic capacitor.
13. **Loss Factor :** This is the product of the Dielectric Loss and the Dielectric Constant of a dielectric material.
14. **Piezoelectric :** When mechanical pressure is applied to one of these materials, the crystalline structure produces a voltage proportional to the pressure. Conversely, when an electric field is applied, the structure changes shape producing dimensional changes in the material. The amount of deformation is proportional to the applied electric field and the d33 coefficient of the material.
15. **Porosity :** The proportion of the non-solid volume to the total volume of material.
16. **Super capacitors :** Super capacitors also called ultra capacitors or Electric double layer capacitors (EDLC) are capacitors made up of 2 metal plates with a carbon dielectric material and a conductive electrolyte.

Frequently Asked Questions

Q1. What is dielectric?

Ans. A dielectric is an insulating (or very poorly conducting) material.

Q2. What is the unit for the dielectric constant?

Ans. The Dielectric Constant of a medium does not have a unit because it is a ratio.

Q3. What is the effect of temperature on dielectric constant of a dielectric?

Ans. Dielectric materials have permanent dipoles. As temperature increases, the molecules in the dielectric have more thermal energy and therefore, the amplitude of random motion is greater. This means that the molecules are less closely aligned with each other (even in the presence of an electric field). Hence, the dielectric constant reduces.

Q4. Is Relative dielectric constant is dimensionless?

Ans. Yes it is. Any quantity which is ratio of two physical quantities having same unit is dimensionless. Dielectric constant is ratio of permittivity of medium to the permittivity of free space. As Permittivity of medium and permittivity of free space both have same units (F/m ie Farad/meter) dielectric constant becomes dimensionless quantity.

Q5. What is a dielectric constant?

Ans. The dielectric constant of a particular dielectric is the measure of the dielectric's unit capacitance. It describes the ratio of the capacitance of a dielectric-filled capacitor to a capacitor of the same size with a vacuum between the plates. It is denoted by K.

Q6. What is the dielectric constant of a conductor?

Ans. The dielectric constant of a conductor is infinity. This is because the dielectric constant is the ratio of applied field and the reduced value of field. Since electric field inside a conductor is zero therefore dielectric constant of a conductor is infinity.

Q7. What is electric dipole?

Ans. An electric dipole is two charged objects, with equal but opposite electric charges, that are separated by a distance.

Q8. What is electric dipole moment?

Ans. The electric dipole moment is a measure of the separation of positive and negative electrical charges in a system of charges, that is, a measure of the charge system's overall polarity. The SI units are Coulomb-meter (C m).

Q9. What is electric polarisation?

Ans. When a dielectric substance is placed between two oppositely charge plates then each atom or molecule of the substance behave as a dipole and the substance is said to be polarized and this phenomenon is called electric polarization.

Q10. What is the effect of electric field on dielectric materials?

Ans. An applied electric field will polarize the material by orienting the dipole moments of polar molecules.

Q11. Is vacuum a Dielectric?

Ans. Vacuum cannot be considered as a dielectric. "A dielectric is defined as an insulating material which can be polarized by applying electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material, but only slightly shift from their average equilibrium positions causing dielectric polarization." Nothing like that will happen in the case of vacuum. But in theory, if necessary, vacuum can be considered as a dielectric medium of dielectric constant unity.

Q12. Why water has more dielectric constant than mica?

Ans. This is because water has a much greater dipole moment. On the other hand mica does not possess permanent dipole moment.

Q13. What is the Difference between dielectric and insulator?

Ans The difference between dielectric and insulator lies in its field of application. Dielectrics are used to store the electric charges, while insulators are used to block the flow of electric charges (they more or less act like a wall).

While all dielectrics are insulators (they don't allow the flow of electric charges through them) all insulators aren't dielectric because they can't store charges unlike dielectrics.

Q14 Why are dielectrics used between the plates of a capacitor?

Ans. To avoid that the plates touch each other The better the dielectric, the closer the plates can be, thus making the electrostatic field on the opposite plates more intense, which allows for more electrons displaced via the charging circuit to the positive plate and more incomplete atoms (positive charges) left on the negative plate. Remember: Being the dielectric an isolator, there is NEVER current through the capacitor.

Q15. What is dielectric constant of water?

Ans. The dielectric constant is the ratio of the permittivity of a substance to the permittivity of free space. Water does indeed have a very high dielectric constant of 80.10 at 20 °C this is because the water molecule has a dipole moment and so water can be polarized.

Q16. What is the major difference between conductor and dielectric?

Ans. A conductor is a material which allows electronic flow through it with some finite (though usually very small) resistance as opposed to a dielectric, the other name for an insulator that provides ideally infinite resistance to current flow at all temperatures.

Warranty

- We Warranty the product against all manufacturing defects for 12 months from the date of sale by us or through our dealers.
- The Warranty does not cover perishable item like cathode ray tubes, crystals, batteries, photocells etc.
- The Warranty will become void, if
    - The product is not operated as per instruction given in the learning material..
    - The agreed payment terms and other conditions of sale are not followed.
    - The customer resells the instrument to another party.
    - Any attempt is made to service and modify the instrument.
- The non-working of the product is to be communicated to us immediately giving full details of the complaints and defects noticed specifically mentioning the type, serial number of the product and date of purchase etc.
- The repair work will be carried out, provided the product is dispatched securely packed and insured. The transportation charges shall be borne by the customer.

Note: Glass Beaker is not covered in the warranty.

List of Accessories

1.	Bakelite Sheet	1 No.
2.	Glass Sheet .	1 No.
3.	Teflon Sheet	1 No.
4.	2mm Patch Cord 12”	4 Nos.
5.	Mains Cord	1 No.

References

- http://www.morganelectroceramics.com/resources/glossary-of-terms/
- http://dev.physicslab.org/Document.aspx?doctype=3&filename=DCcircuits_CapacitorsDielectrics.xml
- http://technologyghost.blogspot.in/2010/03/most-likely-viva-voce-questions-vtu.html
- http://uqu.edu.sa/files2/tiny_mce/plugins/filemanager/files/4281690/Practical%20Physics.pdf
- http://whatis.techtarget.com/definition/dielectric-material http://encyclopedia2.thefreedictionary.com/Dielectric+Measurements