Capacitors
Capacitors

• A **capacitor** is a device that stores electric charge.

• A capacitor consists of two conductors separated by an insulator.

• Capacitors have many applications:
  – Computer RAM memory and keyboards.
  – Electronic flashes for cameras.
  – Electric power surge protectors.
  – Radios and electronic circuits.
Types of Capacitors

Parallel-Plate Capacitor

Cylindrical Capacitor

A cylindrical capacitor is a parallel-plate capacitor that has been rolled up with an insulating layer between the plates.
The stored charge $Q$ is proportional to the potential difference $V$ between the plates. The capacitance $C$ is the constant of proportionality, measured in Farads. 

**Farad** = **Coulomb** / **Volt**
Parallel-Plate Capacitor

- A simple parallel-plate capacitor consists of two conducting plates of area $A$ separated by a distance $d$.
- Charge $+Q$ is placed on one plate and $-Q$ on the other plate.
- An electric field $E$ is created between the plates.
What is a capacitor?

• Electronic component
• Two conducting surfaces separated by an insulating material
• Stores charge
• Uses
  – Time delays
  – Filters
  – Tuned circuits
Capacitor construction

- Two metal plates
- Separated by insulating material
- ‘Sandwich’ construction
- ‘Swiss roll’ structure
- Capacitance set by...

\[ C = \varepsilon \frac{A}{d} \]
Defining capacitance

- ‘Good’ capacitors store a lot of charge…
- …when only a small voltage is applied
- Capacitance is charge stored per volt
- Capacitance is measured in farads F
  - Big unit so nF, mF and µF are used

\[ C = \frac{Q}{V} \]
Graphical representation

Equating to the equation of a straight line

\[ C = \frac{Q}{V} \]

\[ Q = CV \]

\[ y = mx \]
Energy stored by a capacitor

- By general definition $E=QV$
  - product of charge and voltage
- By graphical consideration...

$$E = \frac{1}{2} QV$$
Other expressions for energy

- By substitution of $Q=CV$

\[
E = \frac{1}{2} QV
\]

\[
E = \frac{1}{2} CV^2
\]

\[
E = \frac{1}{2} \frac{Q^2}{C}
\]
Charging a capacitor

- **Current** flow
- Initially
  - High
- Finally
  - Zero
- Exponential model
- Charging factors
  - Capacitance
  - Resistance
Discharging a capacitor

- **Current** flow
- Initially
  - High
  - Opposite to charging
- Finally
  - Zero
- Exponential model
- Discharging factors
  - Capacitance
  - Resistance

\[ I(t) \]
Discharging a Capacitor

• Initially, the rate of discharge is high because the potential difference across the plates is large.
• As the potential difference falls, so too does the current flowing
• Think pressure

As water level falls, rate of flow decreases
At some time $t$, with charge $Q$ on the capacitor, the current that flows in an interval $\Delta t$ is:

$$I = \frac{\Delta Q}{\Delta t}$$

And $I = \frac{V}{R}$

But since $V = \frac{Q}{C}$, we can say that

$$I = \frac{Q}{RC}$$

So the discharge current is proportional to the charge still on the plates.
• For a changing current, the drop in charge, $\Delta Q$ is given by:

\[ \Delta Q = -I \Delta t \] (minus because charge large at $t = 0$ and falls as $t$ increases)

• So $\Delta Q = -Q \Delta t / RC$ (because $I = Q / RC$)

• Or $-\Delta Q / Q = \Delta t / RC$
Voltage and charge characteristics

\[ V = V_0 (1 - e^{-t/RC}) \]

\[ Q = Q_0 e^{-t/RC} \]
Dielectrics

• A **dielectric** is an insulating material (*e.g.* paper, plastic, glass).

• A dielectric placed between the conductors of a capacitor increases its capacitance by a factor $\kappa$, called the **dielectric constant**.

\[ C = \kappa C_o \quad (C_o = \text{capacitance without dielectric}) \]

\[ C = \kappa \frac{\varepsilon_0 A}{d} = \varepsilon \frac{A}{d} \]

• For a parallel-plate capacitor:

\[ \varepsilon = \kappa \varepsilon_o = \text{permittivity} \text{ of the material.} \]
Properties of Dielectric Materials

- **Dielectric strength** is the maximum electric field that a dielectric can withstand without becoming a conductor.
- Dielectric materials
  - increase capacitance.
  - increase electric breakdown potential of capacitors.
  - provide mechanical support.

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric Constant $\kappa$</th>
<th>Dielectric Strength (V/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>air</td>
<td>1.0006</td>
<td>$3 \times 10^6$</td>
</tr>
<tr>
<td>paper</td>
<td>3.7</td>
<td>$15 \times 10^6$</td>
</tr>
<tr>
<td>mica</td>
<td>7</td>
<td>$150 \times 10^6$</td>
</tr>
<tr>
<td>strontium titanate</td>
<td>300</td>
<td>$8 \times 10^6$</td>
</tr>
</tbody>
</table>
A charge \( Q \) is initially placed on a parallel-plate capacitor with an air gap between the electrodes, then the capacitor is electrically isolated.

A sheet of paper is then inserted between the capacitor plates.

What happens to:

a) the capacitance?
b) the charge on the capacitor?
c) the potential difference between the plates?
d) the energy stored in the capacitor?
Capacitors in Parallel:

\[ Q = Q_1 + Q_2 + Q_3 \]
\[ = C_1 V + C_2 V + C_3 V \]
\[ = (C_1 + C_2 + C_3)V \]
\[ = C_{eq} V \]

Capacitors in Parallel:

\[ C_{eq} = C_1 + C_2 + C_3 + \ldots \]
Capacitors in Series

\[ V = V_1 + V_2 + V_3 \]

\[ = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \]

\[ = Q \left( \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) \]

\[ = \frac{Q}{C_{eq}} \]

For \( n \) capacitors in series:

\[ \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots \]
What is the effective capacitance $C_{ab}$ between points a and b?
Time constant

- Product of
  - Capacitance of the capacitor being charged
  - Resistance of the charging circuit
  - CR
- Symbol $\tau$ 'Tau'
- Unit seconds

$$CR = \frac{Q}{V} \times \frac{V}{Q \div t}$$

$$CR = t$$
When $t$ equals $\tau$ during discharge

- At $t = \tau$, the capacitor has fallen to 37% of its original value.
- By a similar analysis, $\tau$ can be considered to be the time taken for the capacitor to reach 63% of full charge.

\[
Q = Q_0 e^{-t/RC}
\]
\[
Q = Q_0 e^{-RC/RC}
\]
\[
Q = Q_0 e^{-1}
\]
\[
Q = Q_0 \times 0.37
\]
Graphical determination of tau

- V at 37%
- Q at 37%
- Compared to initial maximum discharge

\[ t = \tau \]

\[ t = RC \]

\[ C = \frac{t}{R} \]
Logarithmic discharge analysis

- Mathematical consideration of discharge
- Exponential relationship
- Taking natural logs equates expression to ‘y=mx+c’
- Gradient is \(-1/\text{Tau}\)

\[
V = V_0 e^{\frac{-t}{RC}}
\]

\[
\frac{V}{V_0} = e^{\frac{-t}{RC}}
\]

\[
\ln V - \ln V_0 = -\frac{t}{RC}
\]

\[
\ln V = -\frac{1}{RC} t + \ln V_0
\]
Logarithmic discharge graph

Gradient term is the $-1/\tau$
www.search for...

• Capacitors
1. WHAT IS RESISTOR?

2. TYPES OF RESISTOR.

3. CONNECTION OF RESISTOR.

4. RESISTOR COLOUR CODE

5. RESISTOR POWER RATING
A RESISTOR IS A PASSIVE TWO-TERMINAL ELECTRICAL COMPONENT THAT IMPLEMENTS ELECTRICAL RESISTANCE AS A CIRCUIT ELEMENT.

THE RATIO OF THE VOLTAGE APPLIED ACROSS A RESISTOR'S TERMINALS TO THE INTENSITY OF CURRENT THROUGH THE CIRCUIT IS CALLED RESISTANCE.

THIS RELATION IS REPRESENTED BY OHM'S LAW:

\[ V = I R \]
UNIT & SYMBOL

➢ THE OHM (SYMBOL: Ω) IS THE SI UNIT OF ELECTRICAL RESISTANCE, NAMED AFTER GEORG SIMON OHM.

➢ AN OHM IS EQUIVALENT TO A VOLT PER AMPERE

➢ OTHER DERIVED UNITS ARE MILLI OHM (1 MΩ = 10\(^{-3}\) Ω), KILO OHM (1 KΩ = 10\(^{3}\) Ω), AND MEGA OHM (1 MΩ = 10\(^{6}\) Ω).

FIXED RESISTOR

VARIABLE RESISTOR
TYPES OF RESISTOR
TYPES OF RESISTOR

RESISTOR

FIXED RESISTOR

VARIABLE RESISTOR
<table>
<thead>
<tr>
<th>FIXED RESISTOR</th>
<th>VARIABLE RESISTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ CARBON COMPOSITE RESISTOR</td>
<td>➢ RHEOSTAT</td>
</tr>
<tr>
<td>➢ FILM RESISTOR</td>
<td>➢ POTENTIOMETER</td>
</tr>
<tr>
<td>➢ WIRE WOUND RESISTOR</td>
<td>➢ THERMISTOR</td>
</tr>
<tr>
<td>➢ RESISTANCE WIRE</td>
<td>➢ HUMISTOR</td>
</tr>
<tr>
<td></td>
<td>➢ VARISTOR</td>
</tr>
<tr>
<td></td>
<td>➢ PHOTORESISTOR</td>
</tr>
</tbody>
</table>
CARBON COMPOSITE RESISTOR

- LOW INDUCTANCE
- IDEAL FOR HIGH FREQUENCY APPLICATIONS
- VERY CHEAP TO MAKE
- HAVE VERY LARGE TOLERANCES
Film Resistor

- The resistive value of the resistor is controlled by increasing the desired thickness of the deposited film.

- Resistance up to 10MΩ can be obtained.

- Have tolerance 1% or less
WIRE WOUND RESISTOR

- MADE BY WINDING A THIN METAL ALLOY WIRE ONTO AN INSULATING CERAMIC FORMER IN THE FORM OF A SPIRAL HELIX

- AVAILABLE IN VERY LOW OHMIC AND HIGH PRECISION VALUES (FROM 0.01 TO 100KΩ)
RHEOSTAT

- RHEOSTAT IS A ADJUSTABLE RESISTOR USED IN APPLICATIONS THAT REQUIRE ADJUSTMENT OF CURRENT OR VARYING OF RESISTANCE IN AN ELECTRIC CIRCUIT

- A SPECIAL TYPE OF RHEOSTAT IS THE POTENTIOMETER
A POTENTIOMETER IS, A POT, IN ELECTRONICS TECHNOLOGY IS A THREE-TERMINAL RESISTOR WITH A SLIDING CONTACT THAT FORMS AN ADJUSTABLE VOLTAGE DIVIDER.

POTENTIOMETERS ARE COMMONLY USED TO CONTROL ELECTRICAL DEVICES SUCH AS VOLUME CONTROLS, JOYSTICKS ETC.
A THERMISTOR IS A TYPE OF RESISTOR WHOSE RESISTANCE VARIES SIGNIFICANTLY WITH TEMPERATURE

THERMISTORS CAN BE USED AS CURRENT-LIMITING DEVICES FOR CIRCUIT PROTECTION, AS REPLACEMENTS FOR FUSES
A HUMISTOR IS A TYPE OF RESISTOR WHOSE RESISTANCE VARIES SIGNIFICANTLY WITH HUMIDITY

A HUMIDITY SENSOR MEASURES THE HUMIDITY LEVEL BY MEASURING THE CHANGE IN THE RESISTANCE OF AN ELEMENT
VARISTOR

A VARISTOR (OR VOLTAGE DEPENDENT RESISTOR) FUNCTION IS TO CONDUCT SIGNIFICANTLY INCREASED CURRENT WHEN VOLTAGE IS EXCESSIVE.

HIGH VOLTAGE VARISTOR
PHOTORESISTOR

➢ A PHOTORESISTOR OR LIGHT DEPENDENT RESISTOR (LDR) EXHIBITS PHOTOCONDUCTIVITY.

➢ PHOTORESISTORS IN MANY CONSUMER ITEMS SUCH AS STREET LIGHTS, CLOCK RADIOS, ALARM DEVICES ETC.
CONNECTION OF RESISTORS
SERIES CONNECTION

- In series connection, the current remains constant.
  (i.e. \( I = I_1 = I_2 = \ldots = I_n \))

- In series connection, voltage adds up.
  (i.e. \( V = V_1 + V_2 + \ldots + V_n \))

\[ R_{eq} = R_1 + R_2 + \ldots + R_n \]
In parallel connection, the voltage remains constant.
(i.e. $V = V_1 = V_2 = \ldots = V_n$)

In parallel connection, current adds up.
(i.e. $I = I_1 + I_2 + \ldots + I_n$)

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$
RESISTOR COLOUR CODE
**EXAMPLE:**

**FIND THE RESISTANCE OF THE GIVEN RESISTOR?**

**RESISTOR VALUE** = \( XY \times Z \pm \text{TOLERANCE} \)

A 22Ω Resistor
22 × 1 Ohms with a tolerance rating of ±5%
## COLOUR CODE TABLE

<table>
<thead>
<tr>
<th>COLOUR</th>
<th>DIGIT</th>
<th>MULTIPLIER</th>
<th>TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACK</td>
<td>0</td>
<td>$10^0$</td>
<td>-</td>
</tr>
<tr>
<td>BROWN</td>
<td>1</td>
<td>$10^1$</td>
<td>± 1%</td>
</tr>
<tr>
<td>RED</td>
<td>2</td>
<td>$10^2$</td>
<td>± 2%</td>
</tr>
<tr>
<td>ORANGE</td>
<td>3</td>
<td>$10^3$</td>
<td>-</td>
</tr>
<tr>
<td>YELLOW</td>
<td>4</td>
<td>$10^4$</td>
<td>-</td>
</tr>
<tr>
<td>GREEN</td>
<td>5</td>
<td>$10^5$</td>
<td>± 0.5%</td>
</tr>
<tr>
<td>BLUE</td>
<td>6</td>
<td>$10^6$</td>
<td>± 0.25%</td>
</tr>
<tr>
<td>VIOLET</td>
<td>7</td>
<td>$10^7$</td>
<td>± 0.1%</td>
</tr>
<tr>
<td>GREY</td>
<td>8</td>
<td>$10^8$</td>
<td>-</td>
</tr>
<tr>
<td>WHITE</td>
<td>9</td>
<td>$10^9$</td>
<td>-</td>
</tr>
<tr>
<td>GOLD</td>
<td>-</td>
<td>$10^{-1}$</td>
<td>± 5%</td>
</tr>
<tr>
<td>SILVER</td>
<td>-</td>
<td>$10^{-2}$</td>
<td>± 10%</td>
</tr>
<tr>
<td>NONE</td>
<td>-</td>
<td>-</td>
<td>± 15%</td>
</tr>
</tbody>
</table>
POWER       RATING
THE POWER RATING OF RESISTORS CAN BE CALCULATED USING THE FORMULA:

\[
\text{Power (P)} = V \times I = I^2 R = \frac{V^2}{R}
\]

THE LARGER THE POWER RATING, THE GREATER THE PHYSICAL SIZE OF THE RESISTOR.

WHEN USED IN AC CIRCUITS THE AC IMPEDANCE OF A RESISTOR IS EQUAL TO ITS DC RESISTANCE.