Capacitors and Dielectrics

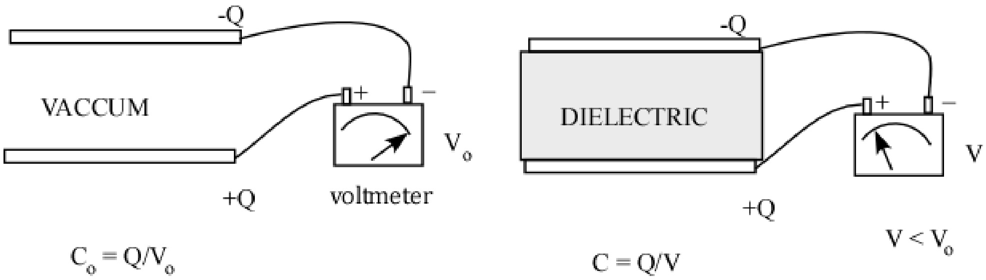
Dielectric - A non-conducting material (glass, paper, rubber….)

Placing a dielectric material between the plates of a capacitor serves three functions:

1. Maintains a small separation between the plates
2. Increases the maximum operating voltage between the plates.
3. Increases the capacitance

In order to prove why the maximum operating voltage and capacitance increases we must look at an atomic description of the dielectric. For now we will show that the capacitance increases by looking at an experimental result:

Experiment



Since $V < V_o$, then $C > C_o$
Since Q is the same:

$$C_oV_o = CV$$

$$\frac{C}{C_o} = \frac{V_o}{V} = K$$

$$\boxed{K = \frac{C}{C_o}}$$ Dielectric Constant

Since C > C_o , then K > 1

$$\boxed{\begin{array}{l} C = kC_o \\ V = \dfrac{V_o}{k} \end{array}}$$

k_{vacuum} = 1 (vacuum)
k = 1.00059 (air)
k_{glass} = 5-10

Material	***Dielectric Constant k***	***Dielectric Strength (V/m)***
Air	1.00054	3
Paper	3.5	16
Pyrex glass	4.7	14

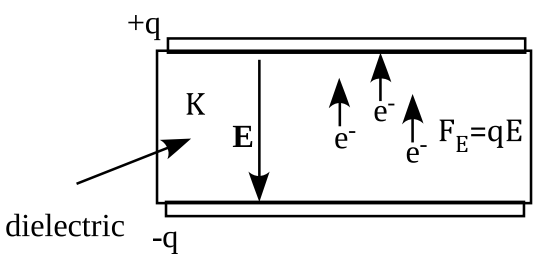
A real dielectric is not a perfect insulator and thus you will always have some leakage current between the plates of the capacitor.

For a parallel-plate capacitor:

$$C = kC_o$$
$$C = \frac{k\varepsilon_o A}{d}$$

From this equation it appears that C can be made as large as possible by decreasing d and thus be able to store a very large amount of charge or equivalently a very large amount of energy.

Is there a limit on how much charge (energy) a capacitor can store? YES!!



As charge 'q' is added to the capacitor plates, the E-field will increase until the dielectric becomes a conductor (dielectric breakdown). Any excess charge will conduct through the dielectric and the capacitor will be damaged. This is why capacitors have a maximum operating voltage.

Dielectric Breakdown – when a material becomes ionized by large E-fields and becomes a conductor.

Dielectric Strength – the maximum E-field that a material can sustain without becoming a conductor.

Breakdown Voltage – Maximum potential that a material can sustain without becoming a conductor.

Table 26.1 Approximate Dielectric Constants and Dielectric Strengths of Various Materials at Room Temperature

Material	Dielectric Constant κ	Dielectric Strength[a] (10^6 V/m)
Air (dry)	1.000 59	3
Bakelite	4.9	24
Fused quartz	3.78	8
Mylar	3.2	7
Neoprene rubber	6.7	12
Nylon	3.4	14
Paper	3.7	16
Paraffin-impregnated paper	3.5	11
Polystyrene	2.56	24
Polyvinyl chloride	3.4	40
Porcelain	6	12
Pyrex glass	5.6	14
Silicone oil	2.5	15
Strontium titanate	233	8
Teflon	2.1	60
Vacuum	1.000 00	—
Water	80	—

[a]The dielectric strength equals the maximum electric field that can exist in a dielectric without electrical breakdown. These values depend strongly on the presence of impurities and flaws in the materials.