Dielectrics - insulator - charges do not flow freely

Force between plates (E-field)
increased due to induced charges

dipoles line up ... get induced surface charge
Again $E$ at plates increased slightly
(less than if had placed conductor)

But inside dielectric

$E$ is reduced

So, can reduce $E$
between plates by filling with dielectric

So $|E'| = \frac{V}{K E_0}$

Reduced by $K$ = dielectric constant $K > 1$

Water $K = 80.4$
Air $K = 1.00054$
Vacuum $K \equiv 1$
Oil $K = 4.5$
Fields are affected by medium
effect is medium-dependent

\[ E = \frac{J}{\varepsilon_0} \]
\[ dV = -E \cdot dS \]
\[ |\Delta V| = V_{\text{between plates}} = \frac{V \cdot d}{\varepsilon_0} = \frac{Q}{A \varepsilon_0} \]

Earlier, we had no dielectric

\[ Q = CV \quad C \text{ was } \frac{\varepsilon_0 A}{d} \]

Now

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

 capacitor is increased!

For a pt charge imbedded in dielectric

\[ E \to \frac{1}{4\pi \varepsilon_0} \frac{Q}{r^2} \]

This is all I will say.

Critical importance to biology + chemistry

This is something you must deal w/ in real-world
real solutions, real gasses, real cells, real exps.

This is the source of all sorts of optical effects!
Current and Circuits

Use \( v \) in place of \( \Delta v \), conventional way to simplify notation.

\[ E \] for uniform wire

\[ E = \frac{V}{L} \]

Charge flows

(Actually electrons, but convention is \( \uparrow \))

Direction of \( + \) charge flows is \( + \)

\( + \)

\( \times \) section of wire

\[ \frac{dq}{dt} = \text{current } i \]

\( i \) is \( + \) in direction of \( + \) charge flow

If \( \text{no other source} \)

If little conductor section is isolated then charge flows until field due to induced charges cancels initial imposed field.

If \( \text{not isolated but part of a circuit} \) -- charge goes around and around.

\[ \text{Current units: } 1 \text{ Ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}} \]
Charge is not continuously accelerated

\[ \text{get a steady state equilibrium between } i \text{ and lattice atoms} \]

Little collisions w/ atoms in the conductor lattice
Transfer energy from charges to the lattice
Moving (vibration + heat)

For given material get certain \( i \) for given \( V \)

\[ V = iR \]

\[ 1 \text{ Volt} = 1 \text{ Ampere} \]

\( R \) is resistance

Math: All materials have resistance except something called a "superconductor"

Except when explicitly said in problem - assume
Metal Conductors - Wires to have high/low resistance

\[ \text{Symbol for resistor} \]

\[ \text{Circuit Diagram} \]

\[ \text{wire w/ no resistance} \]
\[ \Delta V = V = iR \]

\( V \) is said to be the "potential drop across the resistor."

Useful analogy for circuits:

\[
\text{pipe width} \quad \text{or} \quad \text{slats to slow flow}
\]

\[ \frac{W}{q} = V \text{ across resistor} \]

\[ W = qV \]

\[ \frac{dW}{dt} = \frac{dq}{dt} V \Rightarrow P = iV \]

Power = (Current \times Voltage)

\( P = \text{power dissipated across resistor} \)

Also, \( V = iR \)

\[ P = i^2 R \]
**Combinations of Resistors**

\[
\begin{align*}
V_1 &= iR_1 \\
V_2 &= iR_2 \\
V_3 &= iR_3
\end{align*}
\implies i
\]

\[
V = V_1 + V_2 + V_3 = i(R_1 + R_2 + R_3)
\]

Resistors in series: \( R = R_1 + R_2 + R_3 \)

![Resistor diagram]

\[
i = i_1 + i_2
\]

\[
\begin{align*}
V &= iR \\
V &= V_1 = i_1R_1 \\
V &= V_2 = i_2R_2
\end{align*}
\]

\[
\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}
\]

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}
\]

**Resistors in Parallel**

**Batteries and EMF**

Batteries + Generators: able to maintain

\( \equiv \) Seats of electromagnetic force

![Battery diagram]