V – potential <u>difference</u> "across or between" Volt = $\frac{J}{C}$ = $\frac{PE}{\text{charge}}$

- in some sense we should be writing things like $\Delta V = IR$ but since every voltage is a ΔV, why bother with Δ?
- when we talk about "the voltage" at a point, that voltage is a ΔV to "ground"
- "ground" can be any point we select – it need not follow the technical definition of connected to a metal stake driven into the ground water.
- scopes measure voltages relative to ground – cannot easily be used for voltage across

I – current "through" Amp = $\frac{C}{s}$ [typical: mA]

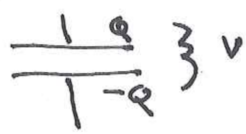
Note: "charge" is absolutely conserved

- current density $J = I/\text{Area}$ – intensive

Kirchhoffs Laws: (1) current in = current out
(2) voltage around loop = 0

R – resistance – ohm's law: $V = IR$ $\Omega = \frac{V}{A}$ [typical kΩ]

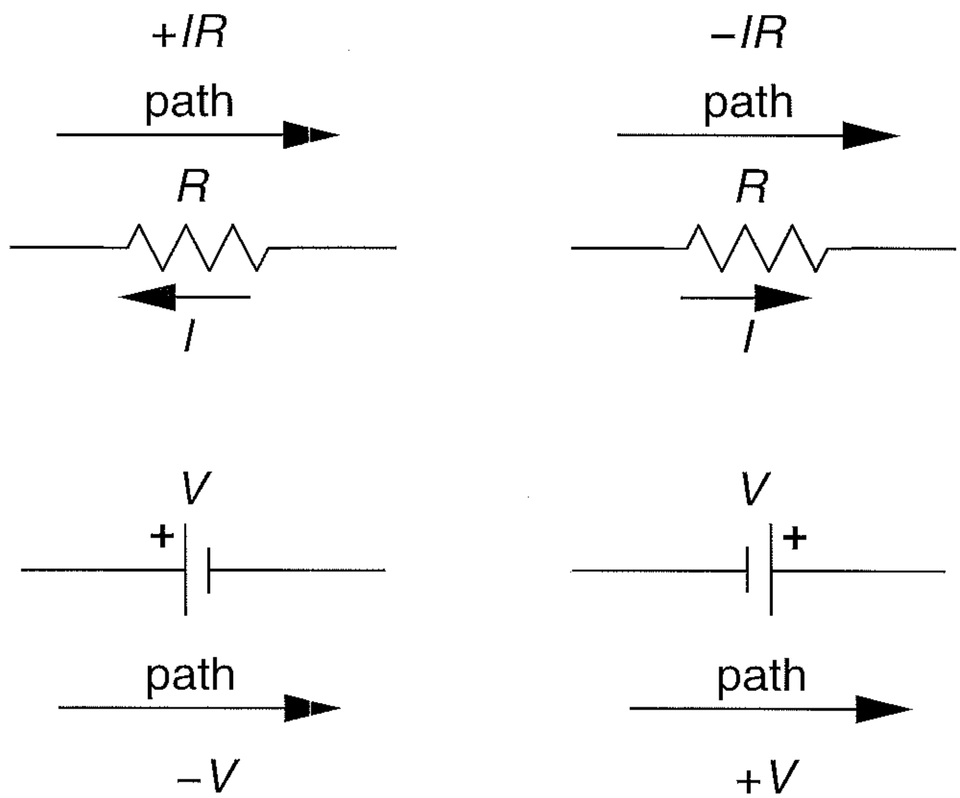
- Note: Ohm's Law is an approximation of nature
- R depends on the material & its geometry "resistivity" is the intensive quantity
- in this class wires are assumed to have $R = 0$ therefore every piece of a wire is at the same voltage.

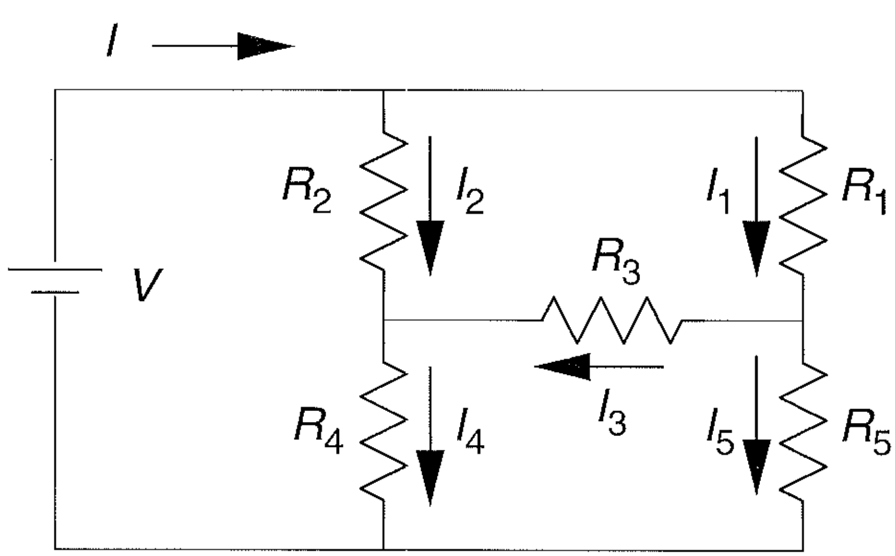
C – capacitance aka condensors  $Q = CV$ $F = \frac{C}{V}$ [μF]

- note: we can have a current "through" a capacitor with current in = current out & Q increasing but no electron is going thru the gap

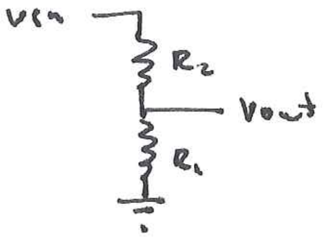
L – inductors – aka coils, chokes $H = \frac{V}{A/s}$ [mH]

 $V = L\frac{dI}{dt}$


+IR
path
R
I
−IR
path
R
I
V
+
path
−V
V
+
path
+V


I
V
R2
I2
I1
R1
R3
I3
R4
I4
I5
R5

The most important example: voltage divider

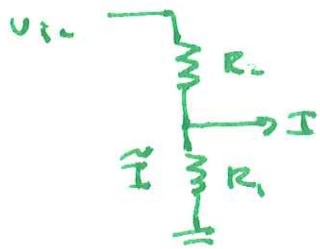


$$V_{in} = (R_1 + R_2) I \rightarrow I = \frac{V_{in}}{R_1 + R_2}$$

$$V_{out} = R_1 I = \frac{R_1}{R_1 + R_2} V_{in}$$

Q: the above assumed current thru R_2 = current thru R_1

what if some current is drawn out —



$$V_{in} = (\tilde{I} + I) R_2 + \tilde{I} R_1$$

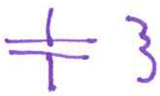
$$\frac{V_{in} - I R_2}{R_1 + R_2} = \tilde{I}$$

voltage divider

$$V_{out} = \tilde{I} R_1 = \frac{R_1}{R_1 + R_2} V_{in} - \underbrace{\frac{R_2 R_1}{R_1 + R_2}}_{R_1 \| R_2} I$$

This is a general result → Thevenin's Thm

Case of sinusoidal "AC" sources



$$V = V_0 \cos(\omega t) \qquad V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$Q = CV = C V_0 \cos(\omega t)$$

$$I = \dot{Q} = - \underbrace{C \omega V_0}_{\text{amplitude} = C \omega V_0} \sin(\omega t)$$

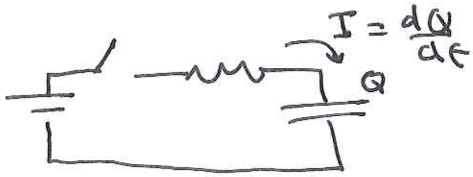
$$\rightarrow I_0 \underbrace{\frac{1}{C\omega}}_{X_C} = V_0$$

$$I = I_0 \cos(\omega t)$$

$$V = L \frac{dI}{dt} = - \underbrace{L I_0 \omega}_{\text{amplitude} = L I_0 \omega} \sin(\omega t)$$

$$V_0 = \underbrace{(L\omega)}_{X_L} I_0$$

Switched DC sources —



$$V = RI + \frac{Q}{C} = R\frac{dQ}{dt} + \frac{Q}{C}$$

1st order, linear, inhomogeneous

Seek homogeneous solution + particular solution

homo: $0 = R\frac{dQ}{dt} + \frac{Q}{C}$

$\frac{dQ}{dt} = \frac{-1}{RC}Q$ ← this is a separable DiffEq but it should be obvious solution is expo:

$$Q = A e^{-t/RC}$$

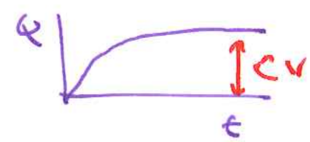
any constant

"time constant" $\tau = RC$

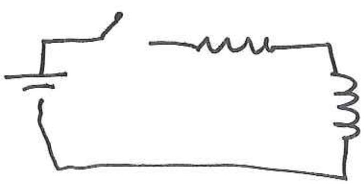
particular: $I = 0$; $Q = CV$

General: $Q = CV + Ae^{-t/\tau}$

BC: $Q(t=0) = 0 \rightarrow Q = CV(1 - e^{-t/\tau})$



$$I = \frac{dQ}{dt} = \frac{V}{R}e^{-t/\tau}$$



$$V = IR + L\frac{dI}{dt}$$

time constant $\tau = L/R$

homo: $\frac{dI}{dt} = \frac{-R}{L}I$; $I = Ae^{-\frac{R}{L}t}$

Particular: $\frac{dI}{dt} = 0$ & $I = \frac{V}{R}$

General: $I = \frac{V}{R} + Ae^{-t/\tau}$

BC: $I(t=0) = 0$ $\quad I = \frac{V}{R}(1 - e^{-t/\tau})$