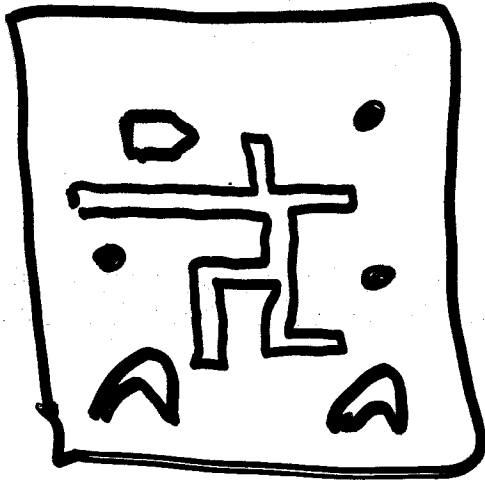


# 2-D Simulator



Robots  
- Good  
- Evil  
- Prey

Food  
Rewards  
Obstacles

etc.

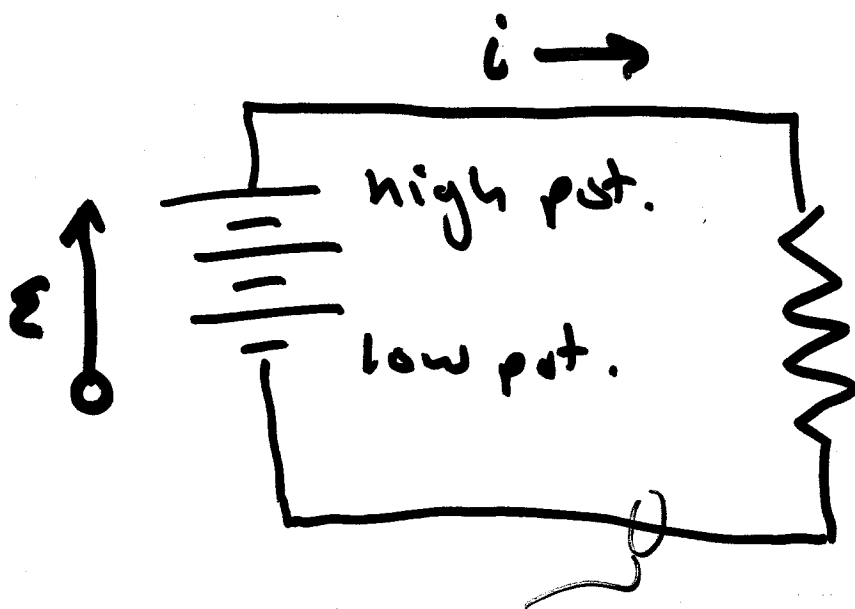
- LOTS OF FREEDOM IN DESIGN OF WORLD
- OCCUPANTS
- SENSORS
- ENVIRONMENT
- COMPLEXITY OF BEHAVIOR
- START SIMPLE
- MATLAB (SANT?)
- PUBLIC PRESENTATION
- WRITE UP

## SIMULATOR PHASE II

- o simpler logic
- o more realistic physical modeling
- o model your Tute bot.

# EMF & circuits

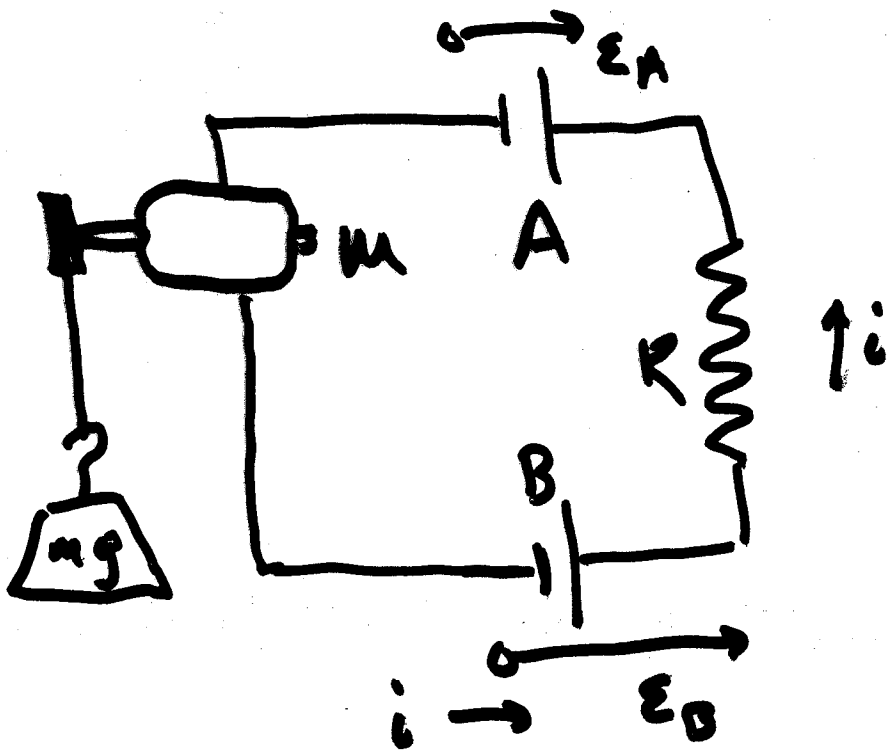
Battery or other seat of emf maintains electric potential difference between 2 points. (this p.d. moves electrons).



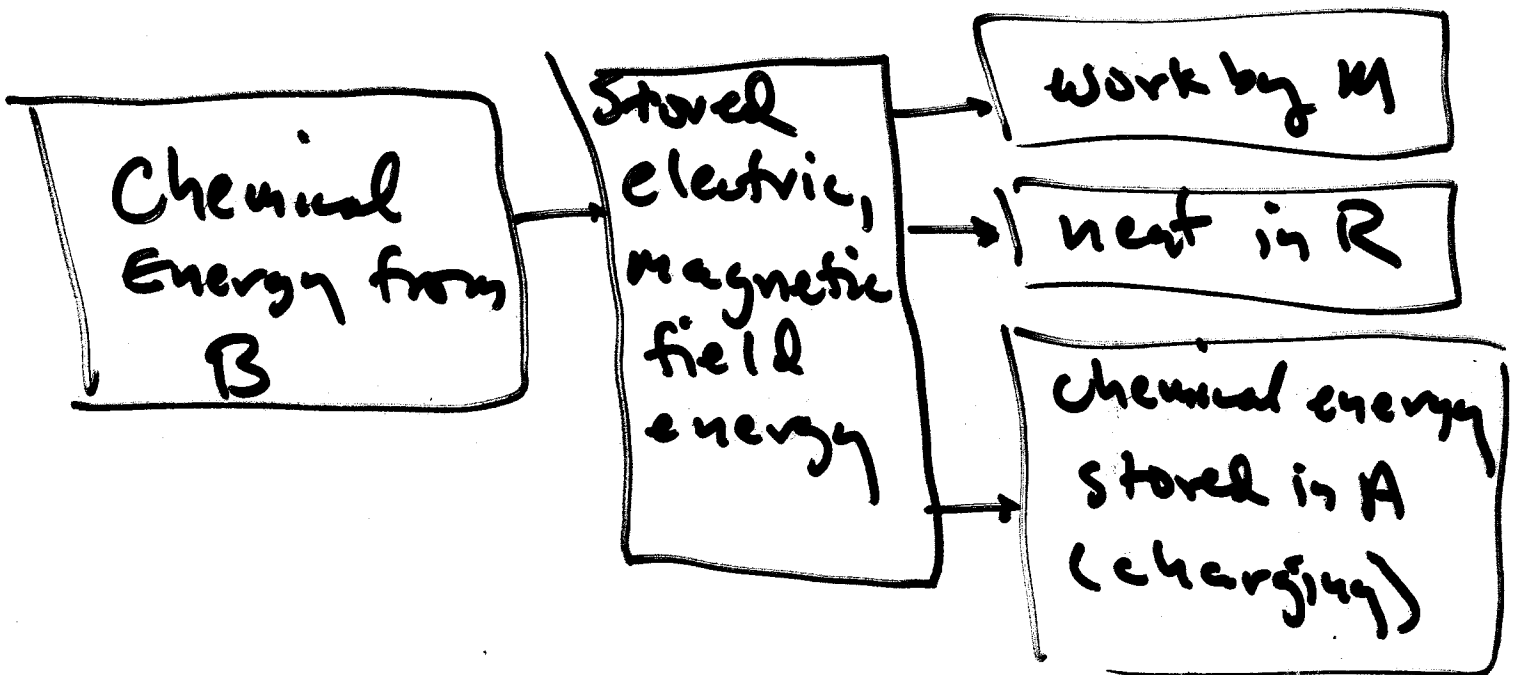
positive charge carriers determine direction of current. (convention)

$dq$  charge passes thru here in time  $dt$ . seat does  $dW$  work to push them up to higher potential.

$$\text{emf } \mathcal{E} \equiv \frac{dW}{dq} = \frac{\text{joule}}{\text{coulomb}} = \underline{\underline{\text{volt}}}$$



o opposing batteries : B wins ( $\epsilon_B > \epsilon_A$ )



a "Reversible" reaction, unlike loss of energy through heating

joule  $\equiv$  1 newton-meter ; unit of work.

newton  $\equiv$   $\frac{\text{kg} \cdot \text{m}}{\text{sec}^2}$  ; unit of force

$$F = m a \quad (\text{Newton's Law})$$
$$\text{nt} = \text{kg} \frac{\text{m}}{\text{sec}^2}$$

coulomb  $\triangleq$  charge through wire in 1 second if current is 1 ampere  
 $q = it.$

$e \triangleq 1.60206 \times 10^{-19}$  coul  
the elementary charge.

# Current Calculation

Joule heating:  $i^2 R dt$  in time  $dt$   
caused by

charge :  $i dt = dq$  in time  $dt$ .

$dq$  moves thru the seat, so...  
def. of emf

$$dW = \mathcal{E} dq = \mathcal{E} i dt$$

this work = Joule heating by conservation  
of energy, so

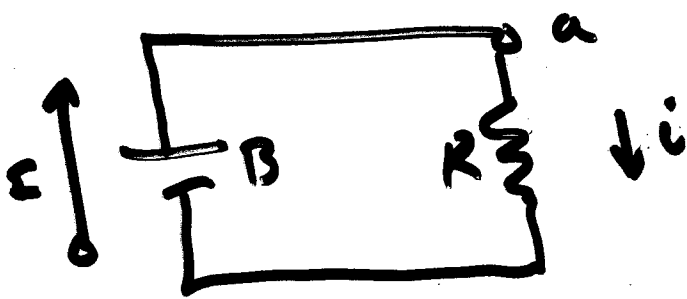
$$\mathcal{E} i dt = i^2 R dt$$

$$\mathcal{E} i = i^2 R$$

$$\mathcal{E} = i R$$

$$i = \frac{\mathcal{E}}{R}$$

This relation  $i = \frac{\mathcal{E}}{R}$  is a consequence of fact that the algebraic sum of changes in potential encountered in complete traversal of a circuit must be zero.



$V = iR$   
 thru  $R$ ,  $-iR$   
 (ohm's law)  
 $R$  measured in  
 ohms.

Negative sign tells  
 at higher pot.

Traversing  $B$  from bottom to top, increase  $+\mathcal{E}$ .

So if initial potential is  $V_a$ ,

$$V_a - iR + \mathcal{E} = V_a$$

$$-iR + \mathcal{E} = 0$$

energy argument, potential argument.

Kirchoff's 2<sup>nd</sup> Law: "Loop Theorem"

Sum of potential changes around  
a circuit = 0.

$R = \frac{V}{i}$ . Resistors turn current  
into voltage and vice versa.

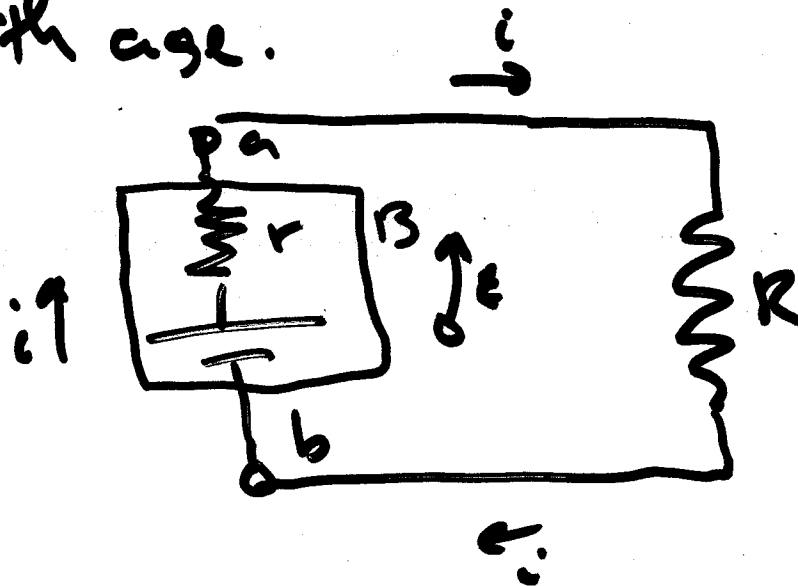
Traverse  $R$  in direction of current, change  
in potential is  $-iR$ . In opposite  
direction is  $+iR$ .

Traverse emf seat in direction of emf,  
change in potential is  $+E$ . In opposite  
direction is  $-E$ .



# E.G. #1.

Batteries (and all cut seats) have internal resistance. In batts, it grows with age.



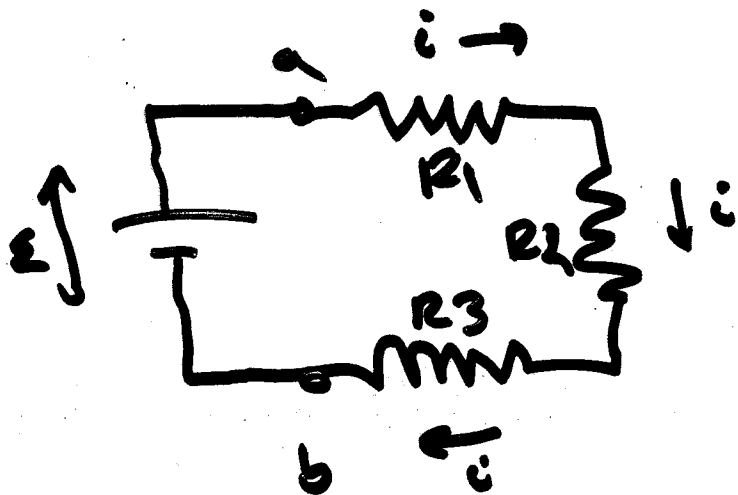
Start at b, go clockwise:

$$V_b + \epsilon - ir - iR = V_b$$

$$+ \epsilon - ir - iR = 0$$

$$i = \frac{\epsilon}{R+r}$$

## Eq #2 Resistors in Series.



clockwise from a:

$$-iR_1 - iR_2 - iR_3 + \epsilon = 0$$

$$i = \frac{\epsilon}{R_1 + R_2 + R_3}$$

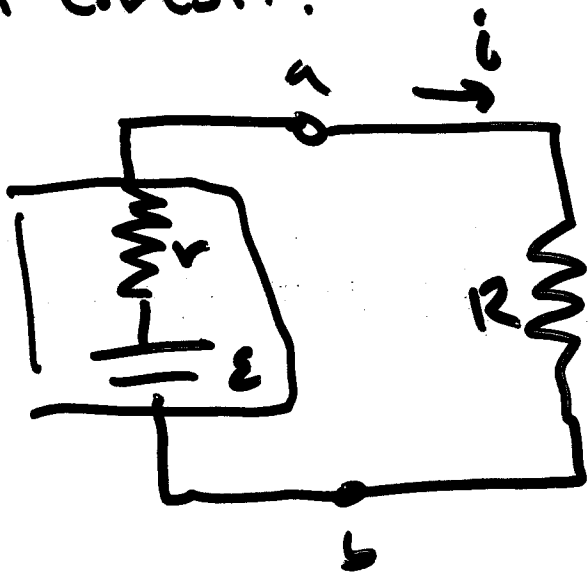
so equivalent resistance

$$R = R_1 + R_2 + R_3.$$

(they add!)

# POTENTIAL DIFFERENCE

How compute the pot. diff. of 2 points in a circuit?



What is  $V_{ab}$   
 $= V_a - V_b$   
for  $\mathcal{E}, r, R$ ?

$$V_b + iR = V_a \quad V_{ab} = V_a - V_b = +iR$$

a is more positive  
potential diff. =  $iR$ .

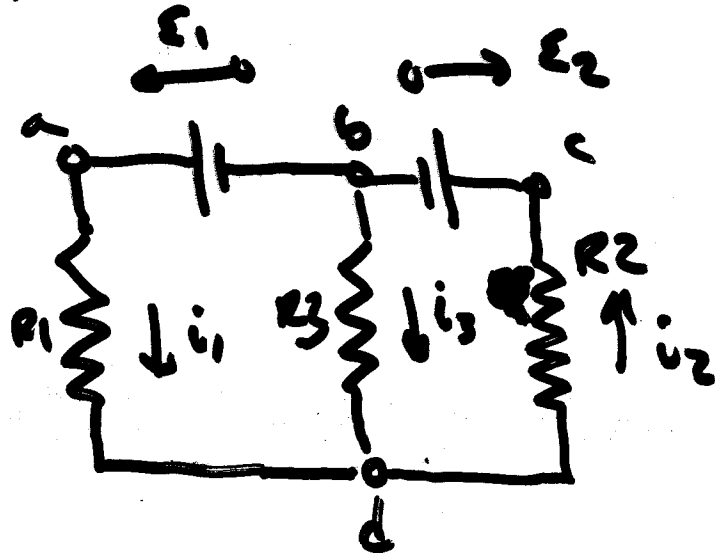
We computed  $i$  before  $i = \frac{\mathcal{E}}{R+r}$

$$\text{So } V_{ab} = \mathcal{E} \frac{R}{R+r}$$

So pot. diff. is algebraic  $\sum$  of  
pot. changes from a to b.

(partial loop theorem). All paths yield same result. 19

# MULTI-LOOP CIRCUITS



b & d are junctions connected by 3 branches. (bad, bd, bcd).

given  $\mathcal{E}$ s and  $R$ s, what are  $i$ s?

label  $i$ , directions arbitrarily chosen.  
( $i_3$ ?!)

Charge does not accumulate or drain from d. so if +  $i$ s come into d, -  $i$ s leave it,

$$i_1 + i_3 - i_2 = 0$$

(1)

Junction theorem: Kirchoff's 1<sup>st</sup> Law

$\sum$  of currents at any junction = 0  
(charge conservation)

- apply this rule at b, get some eqn.  
So if we want to solve for 3  $i$ 's, need 2 more eqns.
- we have several loops with  $\neq$  currents, so can use loop theorem:

left:  $\mathcal{E}_1 - i_1 R_1 + i_3 R_3 = 0$  (2)

right:  $-i_3 R_3 - i_2 R_2 - \mathcal{E}_2 = 0$  (3)

another: no new relationships

So solve (1), (2), (3).

e.g.  $i_1 = \frac{\mathcal{E}_1 (R_2 + R_3) - \mathcal{E}_2 R_3}{R_1 R_2 + R_2 R_3 + R_1 R_3}$

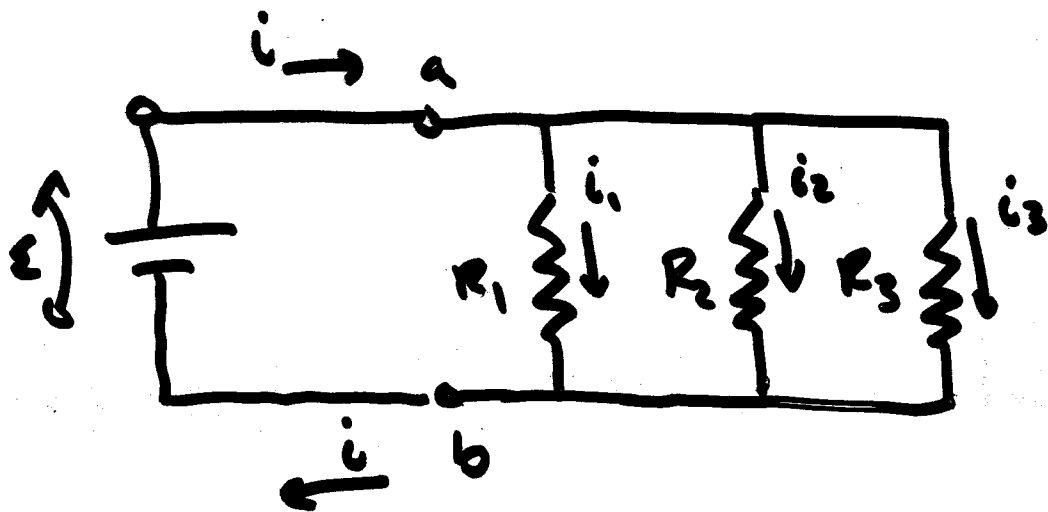
ck special  
cases like  
 $R_3 = 0$

$i_3 =$  always  $-$

11

E.G.

## RESISTORS IN PARALLEL



What is equivalent resistance  $R$  of  $R_1, R_2, R_3$ ?  
( $>$ ?  $<$ ?)

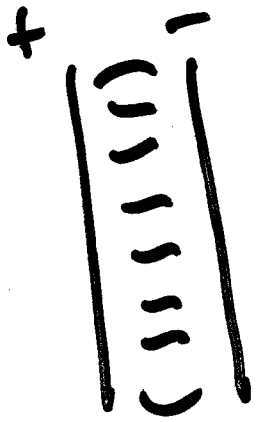
Let  $V$  be the potential diff. between  $a, b$ . Then

$$i_1 = \frac{V}{R_1}, \quad i_2 = \frac{V}{R_2}, \quad i_3 = \frac{V}{R_3}$$

Junction theorem at  $a$ :

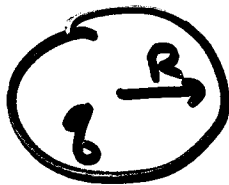
$$\textcircled{1} \quad i = i_1 + i_2 + i_3 = V \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

$$\textcircled{2} \quad i = \frac{V}{R} \quad \text{or} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



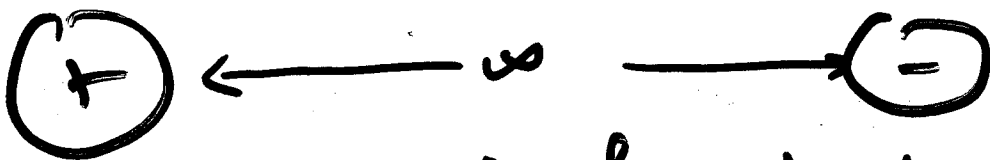
# CAPACITANCE

## CHARGED CONDUCTING SPHERE

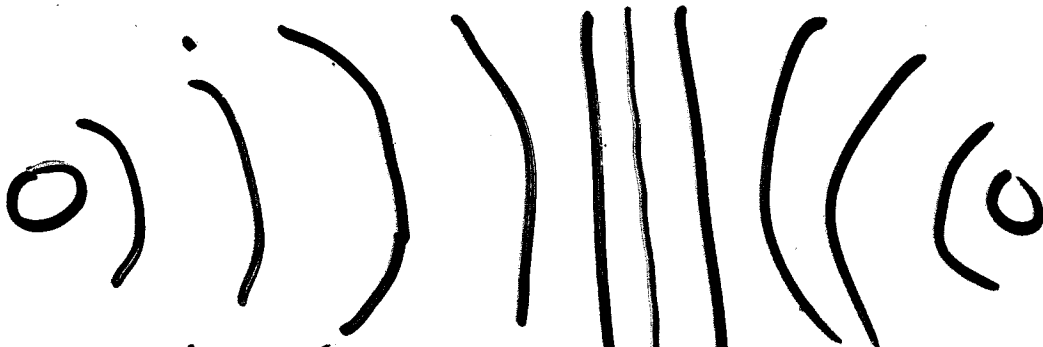


has a potential:

$$V_+ = \frac{1}{4\pi\epsilon_0} \frac{q}{R}$$



Twice the potential difference



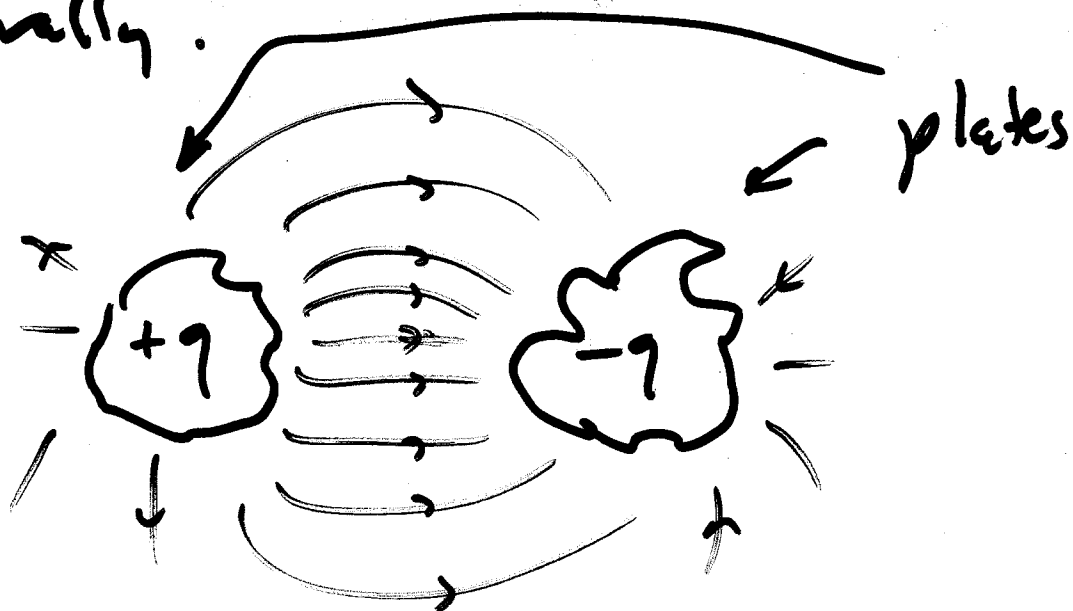
spheres get bigger,  
closer...

At 0 distance  
no difference

$$C = \frac{q}{V}$$

C: farad =  $\frac{\text{coul}}{\text{volt}}$ .  
uf  
mf in practice

generally.



A capacitor.

Practically, one type is foil:



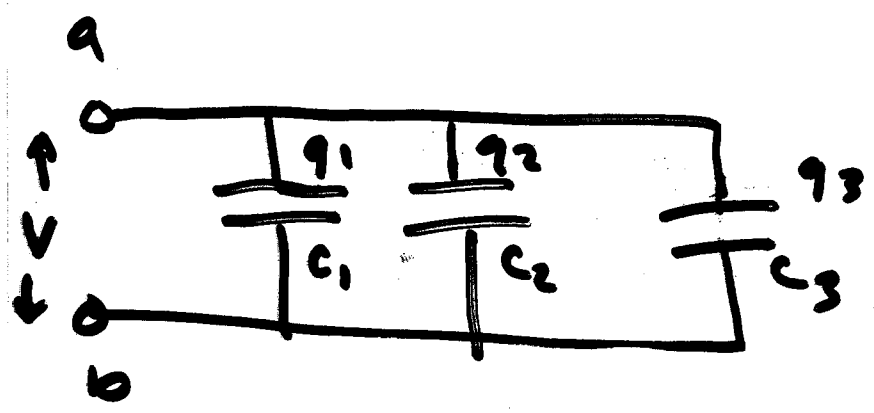
- insulator
- positive
- negative



# CAPACITORS in Practice

$$C = \frac{q}{V} \quad q = CV \quad \text{or} \quad \frac{dq}{dt} = C \frac{dV}{dt} = i$$

## E.G. Capacitors in Parallel



pot. difference same for all: all upper plates connected to a, lower to b.

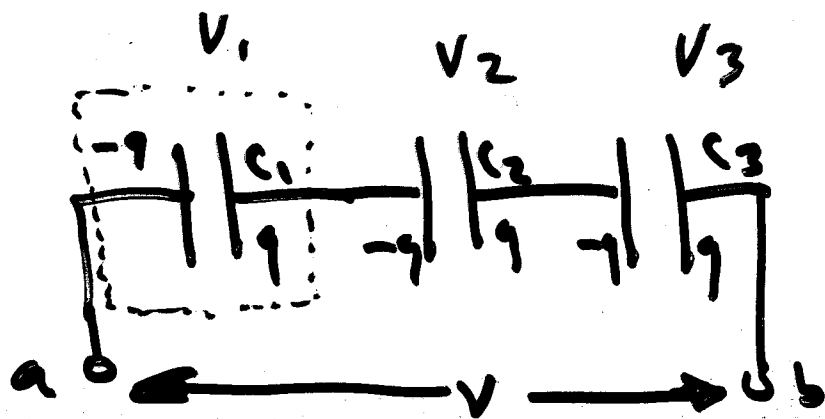
$$q_1 = C_1 V \quad q_2 = C_2 V \quad q_3 = C_3 V$$

$$q = q_1 + q_2 + q_3 = (C_1 + C_2 + C_3) V$$

$$C = \frac{q}{V} = C_1 + C_2 + C_3$$

(like series resistors)

## E.g. Capacitors in Series



$q$  must be same on all plates. Initially no charge, battery just moves it around. Charge can't leave the  area.

$$V_1 = \frac{q}{C_1} \quad V_2 = \frac{q}{C_2} \quad V_3 = \frac{q}{C_3}$$

$$V = V_1 + V_2 + V_3 \quad (\text{series})$$

$$= q \left( \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right)$$

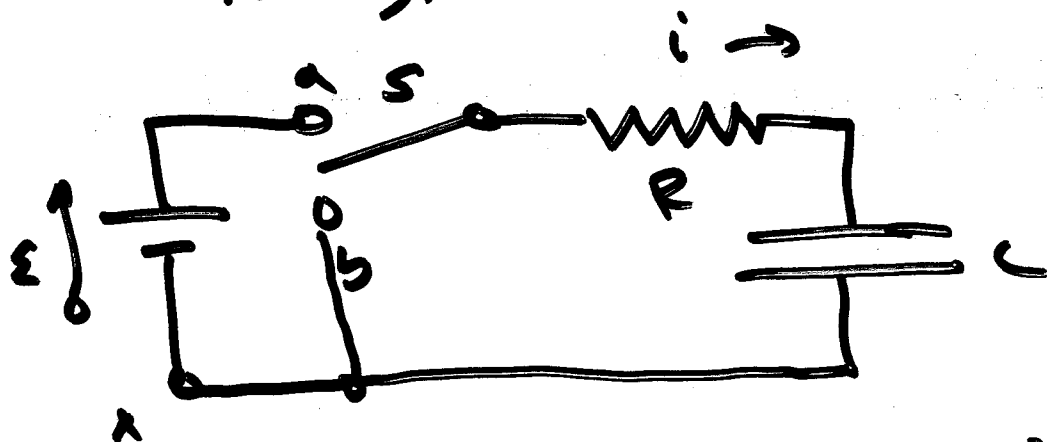
$$C = \frac{q}{V} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

again...  
like || resistors.

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

# RC circuits

Capacitors  $\Rightarrow$  time-varying currents!  
(physics is energy storage in electric field).



throw S to a: then what?

Work is Joule heat + charging C.

$$\mathcal{E} dq = i^2 R dt + d\left(\frac{q^2}{2C}\right)$$

$$\mathcal{E} dq = i^2 R + \frac{q}{C} dq$$

$$\mathcal{E} \frac{dq}{dt} = i^2 R + \frac{q}{C} \frac{dq}{dt} \quad \frac{dq}{dt} = i, \text{ so}$$

$$\mathcal{E} = iR + \frac{q}{C}$$

or from loop theorem

$$\varepsilon = iR + \frac{q}{C} \quad ; \quad i = \frac{dq}{dt}$$

so

$$\varepsilon = R \frac{dq}{dt} + \frac{q}{C} \quad \text{dif. eq.}$$

Just a slight generalization of

$$\dot{x} + ax = 0$$

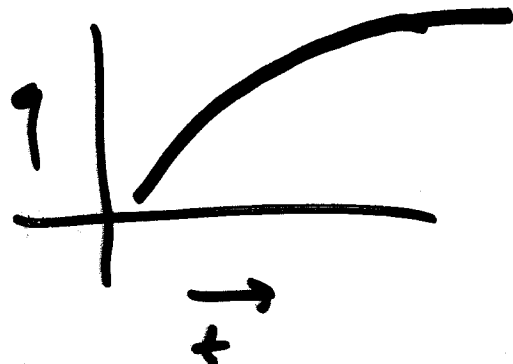
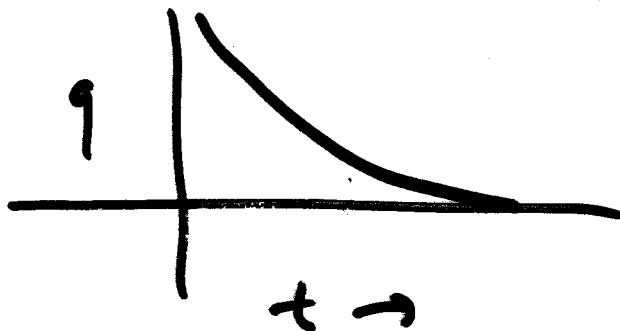
$$\dot{x} = -ax$$

$$-ae^{-at} = -ae^{-at}$$

the secret.

$$\boxed{\text{if } x = e^{-at}}$$

Solutions to 1<sup>st</sup> order linear ordinary des are of form  $e^{-kt}$



\* CHECK

$$\varepsilon = R \frac{dq}{dt} + \frac{q}{C}$$

$$\text{claim } q = C\varepsilon(1 - e^{-t/RC})$$

$$\frac{dq}{dt} = i = -\frac{C\varepsilon}{RC} e^{-t/RC}$$

$$\text{recall } \varepsilon = R \frac{dq}{dt} + \frac{q}{C}$$

$$\varepsilon = R \frac{\varepsilon}{R} e^{-t/RC} + \frac{C\varepsilon(1 - e^{-t/RC})}{C}$$

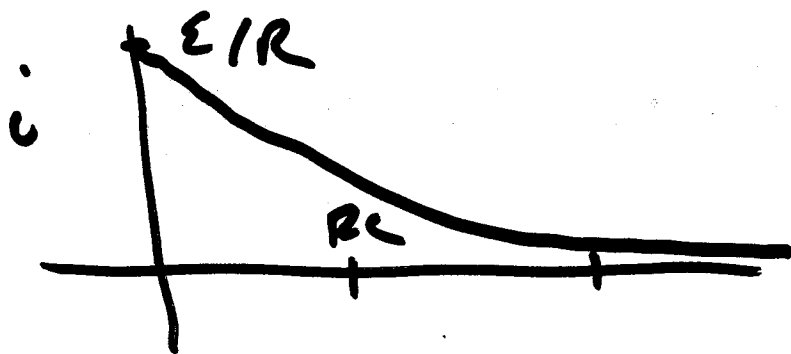
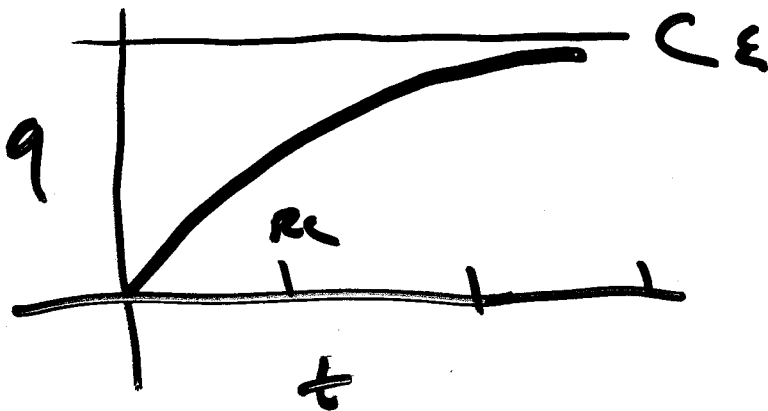
$$\varepsilon = \varepsilon e^{-t/RC} + \varepsilon(1 - e^{-t/RC}) = \varepsilon \quad \square$$

So the general soln (can be guessed)

is

$$q = C\varepsilon(1 - e^{-t/RC})$$

(can be checked).  
\*



What happens  
when we  
throw the  
switch!

$RC$  has dimensions of time: the  
capacitance time constant.

Time it takes to charge to  $(1 - e^{-1}) = 63\%$ .

Now throw switch to b. after  $t \gg RC$



Loop theorem:

$$iR + \frac{q}{C} = 0$$

$$i = \frac{dq}{dt}, \text{ so dif. eq. is } R \frac{dq}{dt} + \frac{q}{C} = 0$$

soln is  $q = q_0 e^{-\frac{t}{RC}}$  with  $q_0$  the initial charge =  $C\varepsilon$ .

$$\text{Current during discharge } i = \frac{dq}{dt} =$$

$$= -\frac{q_0}{RC} e^{-\frac{t}{RC}}$$

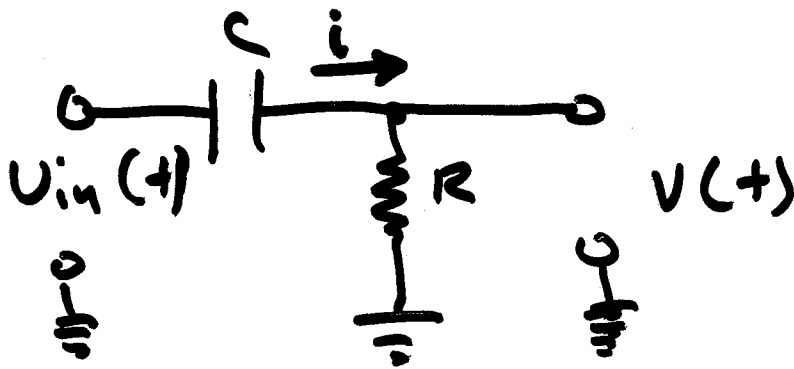
so current is reversed from direction in picture. Since  $q_0 = C\varepsilon$

$$i = -\frac{\varepsilon}{R} e^{-\frac{t}{RC}}$$

so initially current is  $-\frac{\varepsilon}{R}$  which makes sense since Cap is charged to full pot. diff  $\frac{\varepsilon}{11}$ .

E.G.

# A Differentiator



Ground.  
what to  
measure  
V's wrt.

Voltage across C is  $V_{in} - V$ .

$$I = C \frac{dV}{dt} \quad (\text{capacitance}). \text{ definition}$$

$$i = C \frac{d\varepsilon}{dt}$$

$$I = C \frac{d}{dt} (V_{in} - V)$$

$$I = \frac{V}{R} \text{ also}$$

if choose  $\frac{dV}{dt} \ll \frac{dV_{in}}{dt}$

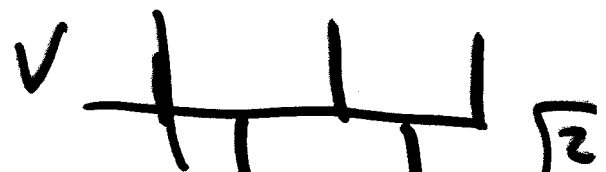
Make RC small.  
If R too small  
you load the input

$$C \frac{dV_{in}}{dt} \approx \frac{V}{R}$$

$$V(t) = RC \frac{dV_{in}}{dt}$$

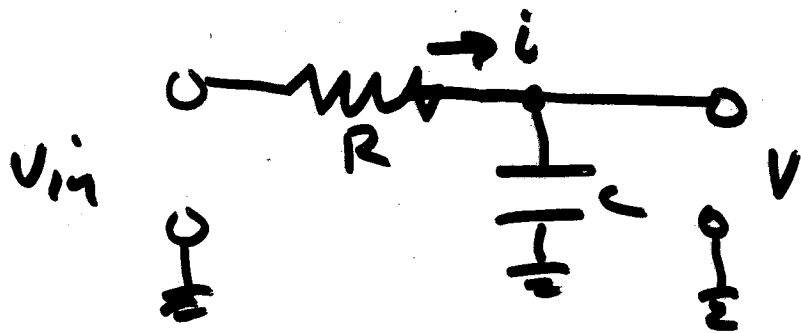


aha!





# E.G. An INTEGRATOR



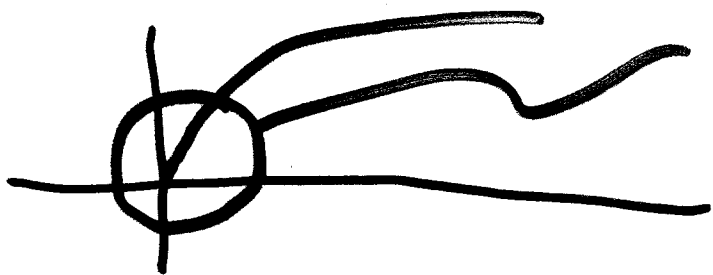
Voltage across  $R = V_{in} - V$ , so

$$I = \frac{V_{in} - V}{R} \quad \text{if } V \ll V_{in} \text{ (with large } RC \text{)}$$

$$C \frac{dV}{dt} \cong \frac{V_{in}}{R} \cong I$$

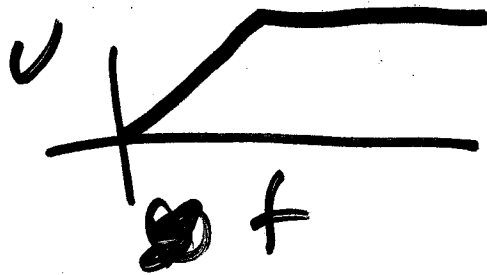
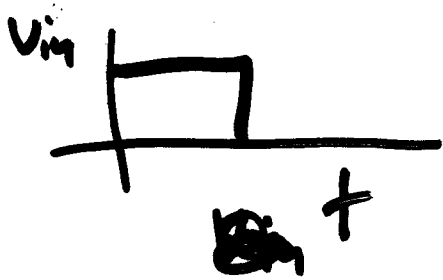
$$V(t) = \frac{1}{RC} \int_0^t V_{in}(t) dt + \text{const.}$$

Note:  $V \ll V_{in} \cong I \propto V_{in}$ . we'd have perfect integrator if we had a current source. A large voltage across a large  $R$  approximates a current source.

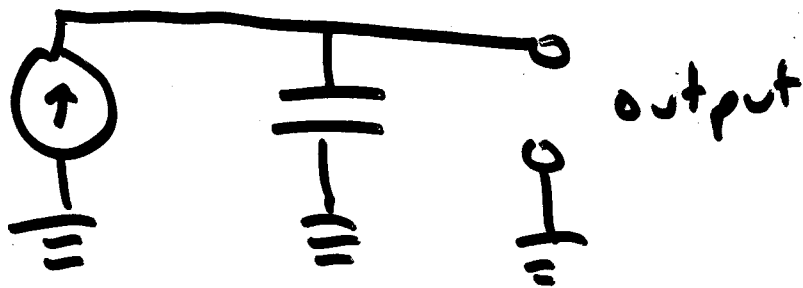


Actually picks off the start of exp. charging curve.

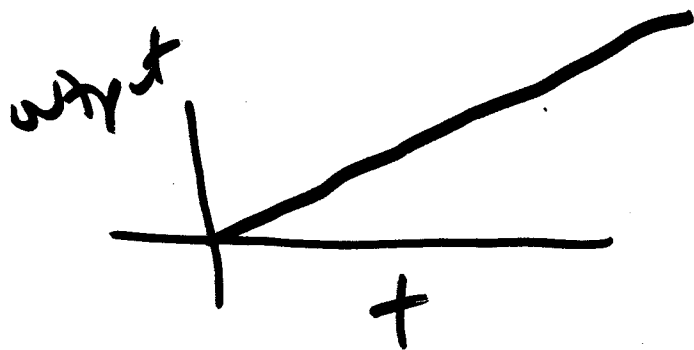
# Integrator (cont.)



Ramp Generator: Charge a capacitor with constant current.



$$I = C \frac{dV}{dt} \Rightarrow V(t) = \left(\frac{I}{C}\right) t$$



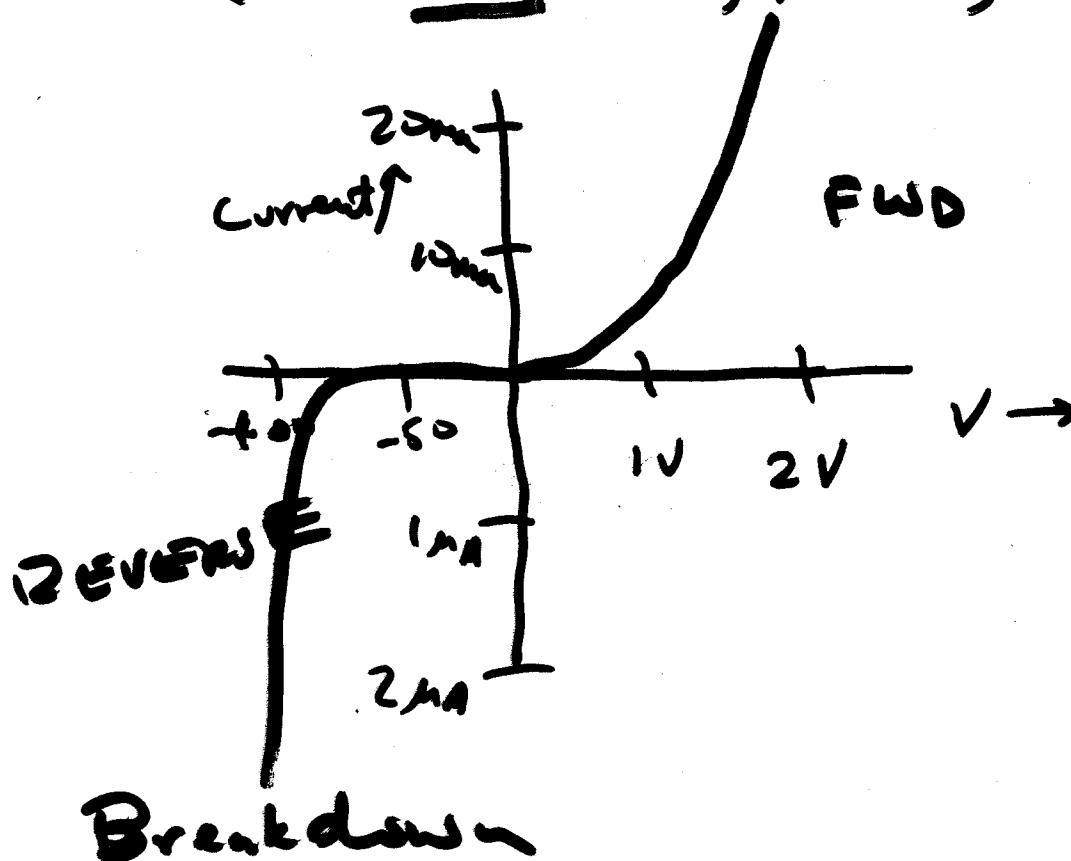
# Diodes

R, C are linear circuit elements. (Double signal, double the response.)

Also they are 2-terminal, passive (no power).



Diode is non-linear, passive, 2-terminal



Diodes



- Anode (arrow) points in dir. of forward current flow.
- Approximates 1-way conductor.
- voltage drop of  $.5 - .8 \text{ V}$ .
- BUT no resistance in terms of Ohm's Law.

E.G. Rectification  
(AC  $\rightarrow$  DC)

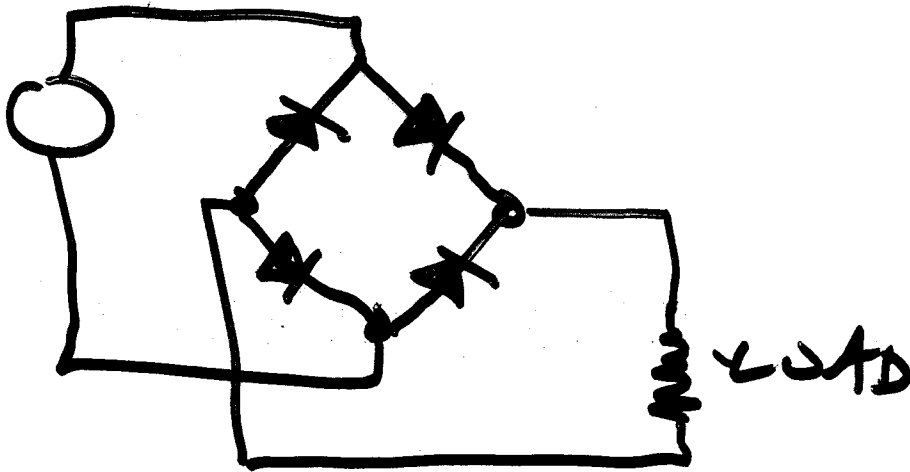


Ideally

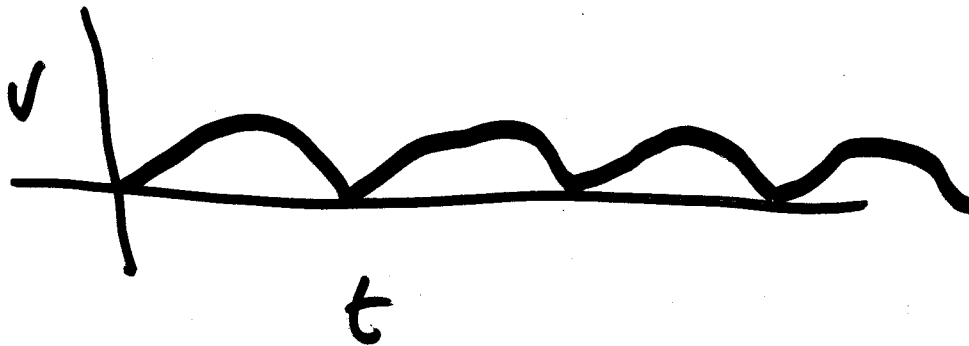
Half-wave:



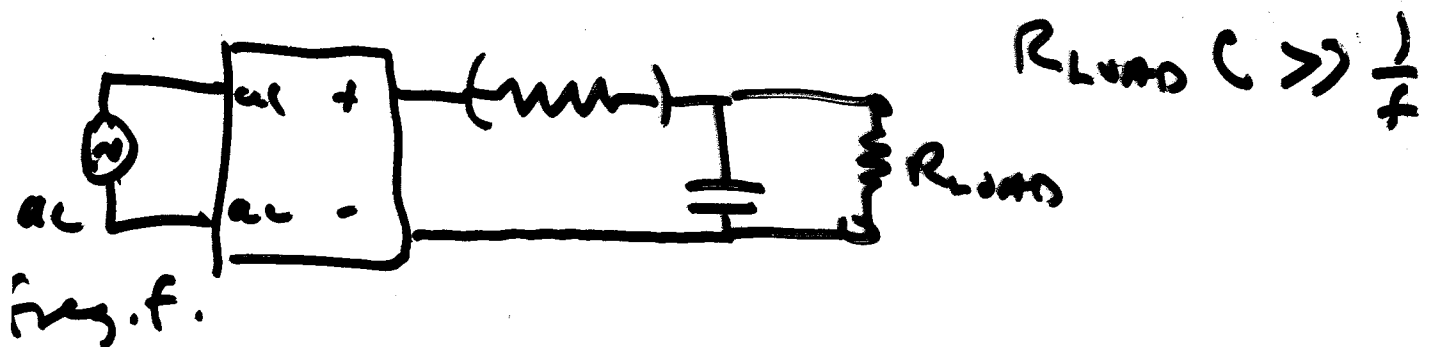
# Full Wave Rectifier:



2 Diodes in series = Twice the voltage drop. Bad for low-voltage supplies.

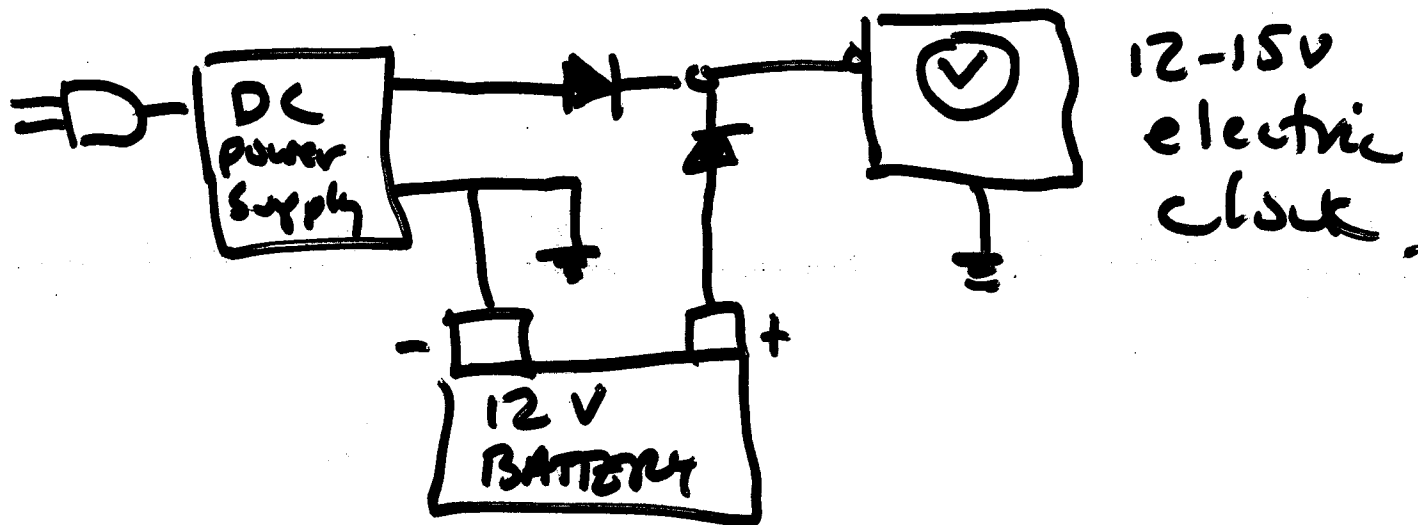


Mega-Cap: FILTERING.  
 er... How smooth this out?



## E.G. Diode Gate

Pass Higher of 2 voltages



## E.G. Diode Clamp

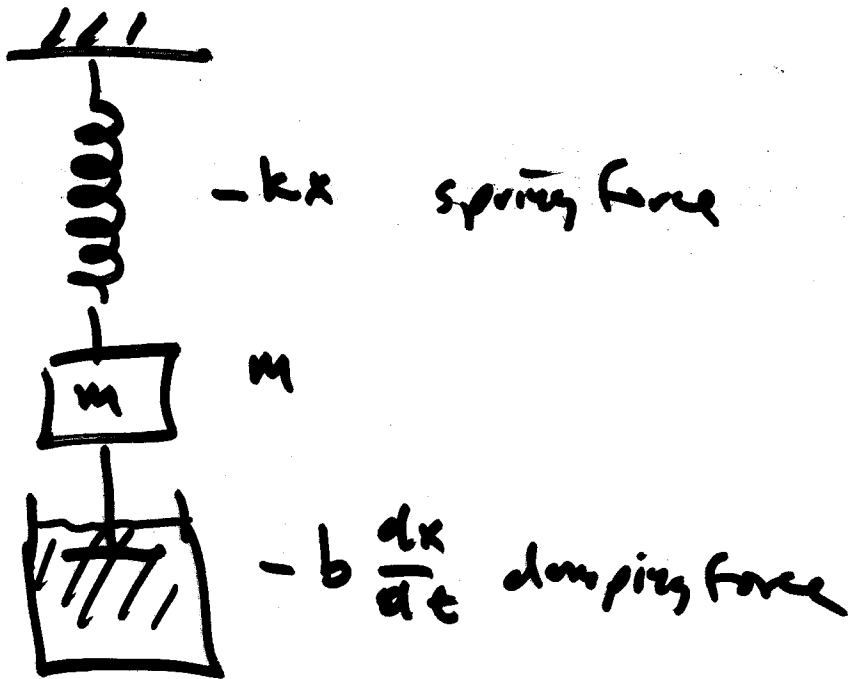
Limit voltage in a signal to  $\approx 5.6$  V, with no effect on lesser (including negative) voltages. (Protect CMOS from static)

$\approx 10k$



# Damped Harmonic Oscillator

- 2nd-order system
- very basic approx. to all systems.



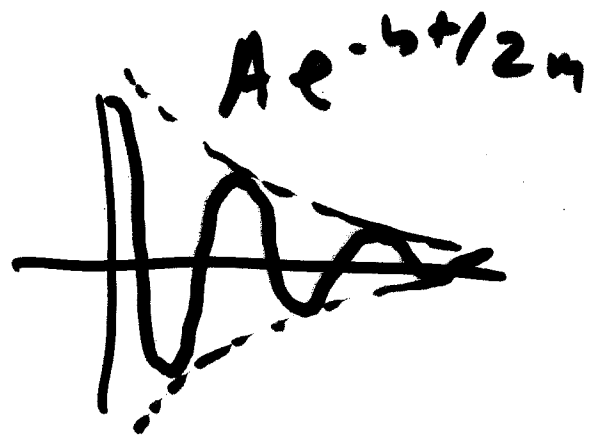
$$F = ma$$

$$-kx - b \frac{dx}{dt} = m \frac{d^2x}{dt^2}$$

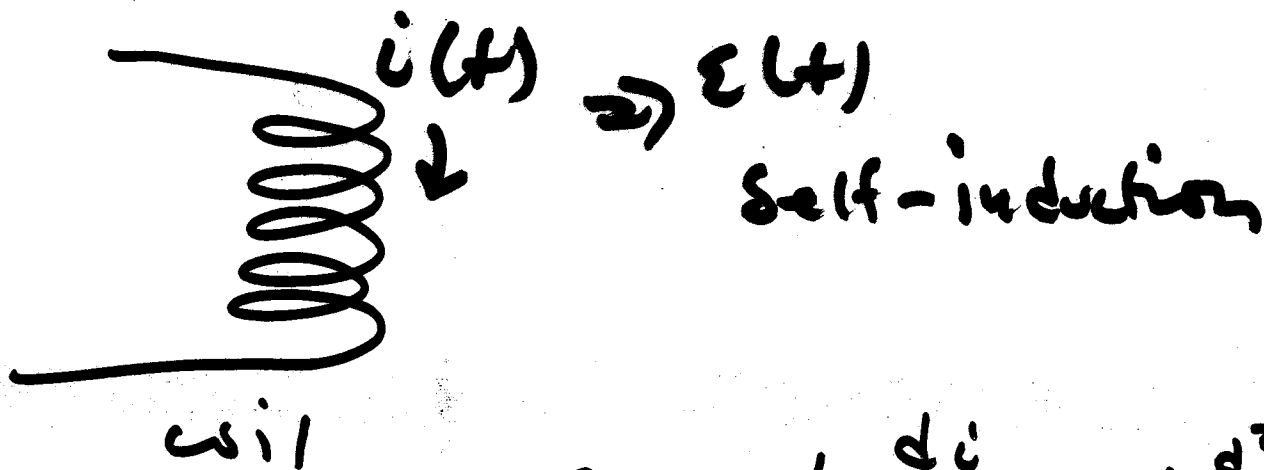
$$m \frac{d^2x}{dt^2} + b \frac{dx}{dt} + kx = 0$$

$$x = A e^{-bt/2m} \cos(\omega' t + \delta)$$

$$\omega' = \sqrt{\frac{k}{m} - \left(\frac{b}{2m}\right)^2}$$

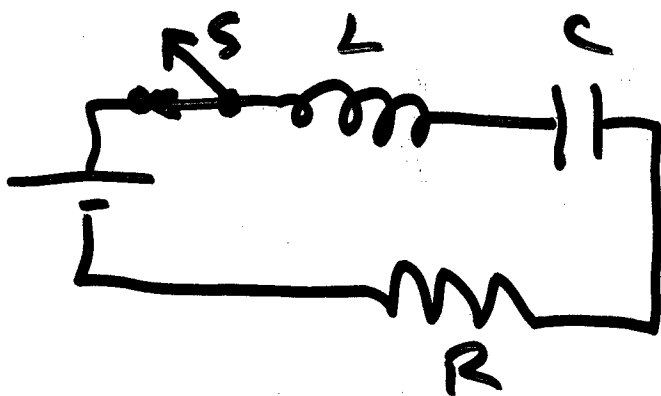


# INDUCTANCE



Self-induction

$$\epsilon = -L \frac{di}{dt} = -L \frac{d^2q}{dt^2}$$



$$L \frac{d^2q}{dt^2} + R \frac{dq}{dt} + \frac{1}{C} q = 0$$

$$m \frac{d^2x}{dt^2} + b \frac{dx}{dt} + kx = 0$$

} !

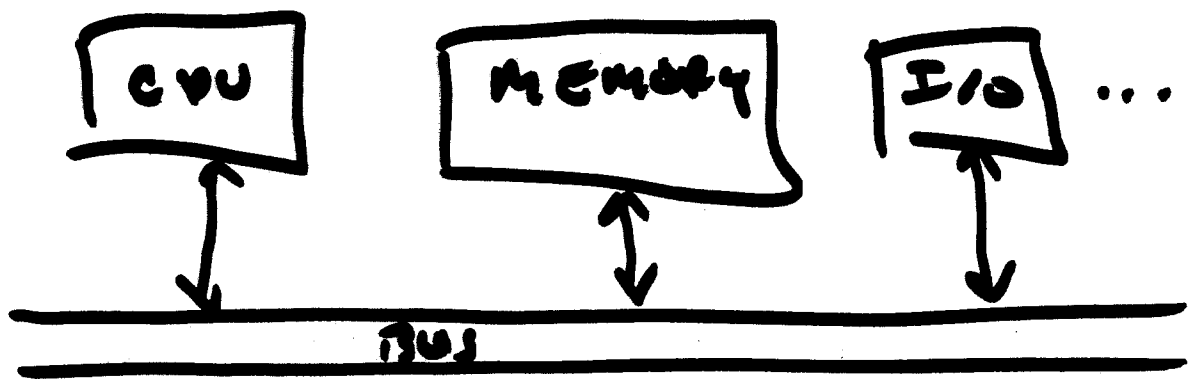
$\Rightarrow$  Analog Computers, controllers, ...



# Microcomputers 101 (J&F ch. 3)

IC hides many realities. It is a multi-tasking OS. But not a bad idea to learn bare-bones hardware concepts. (CSC 254?).

$\mu$  controllers come with useful capabilities for interfacing: serial lines, A/D, timers, pulse counters. Replaces multi-card system.



compare to RW's MC684C11  
p. 51

CPU clock:

XTAL

Instruction timing 2 - 40 cycles  
(1 - 20.5  $\mu$ sec.)

instr. fetch  
decode  
fetch operands  
execute } Bus

Bus is 16 bits wide so  $2^{16}$ , 64K  
locations. (8-bit bytes).

Fig 3.5 shows how bus is configured  
RAM, how address + data live on it.

ports look like memory to CPU  
(locations).

to outside, ports are lines to take  
signals.

Memory: RAM, ROM, PROM, EEPROM  
EPROM

$\mu$  Controller versions exist with all memory  
types...

13