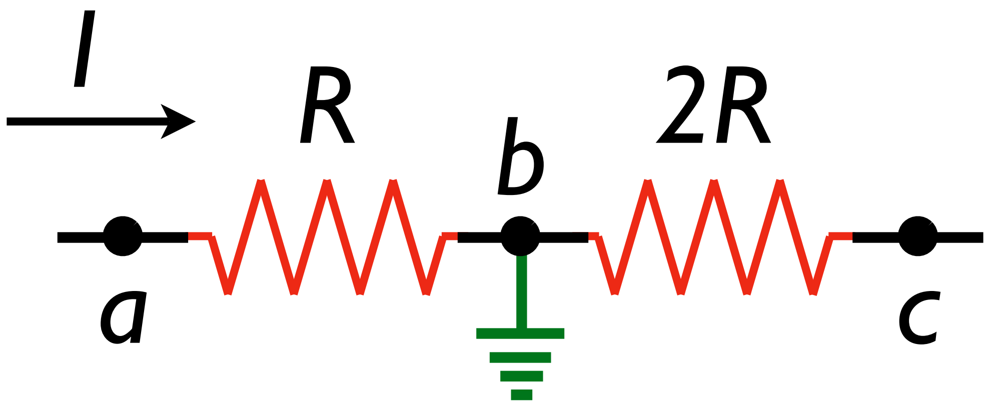
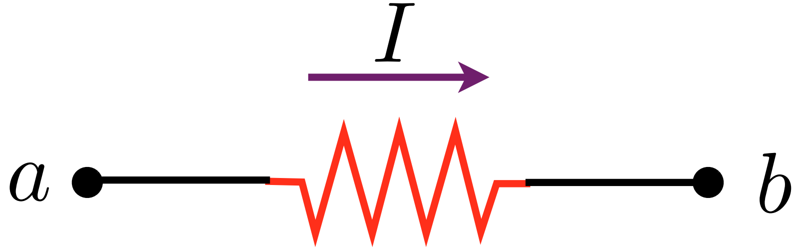
today: dc circuits

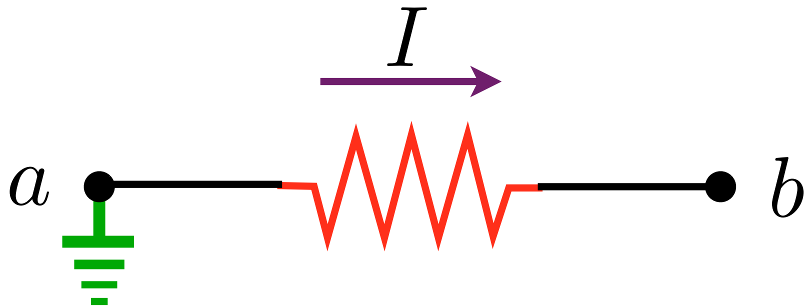

I
R
2R
b
a
c

(a)



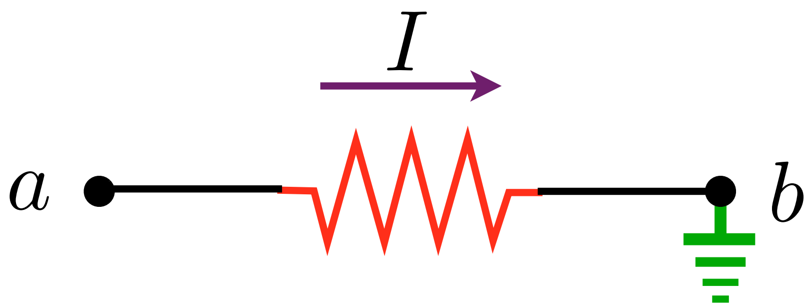
$$\Delta V = V_b - V_a = -IR$$

(b)



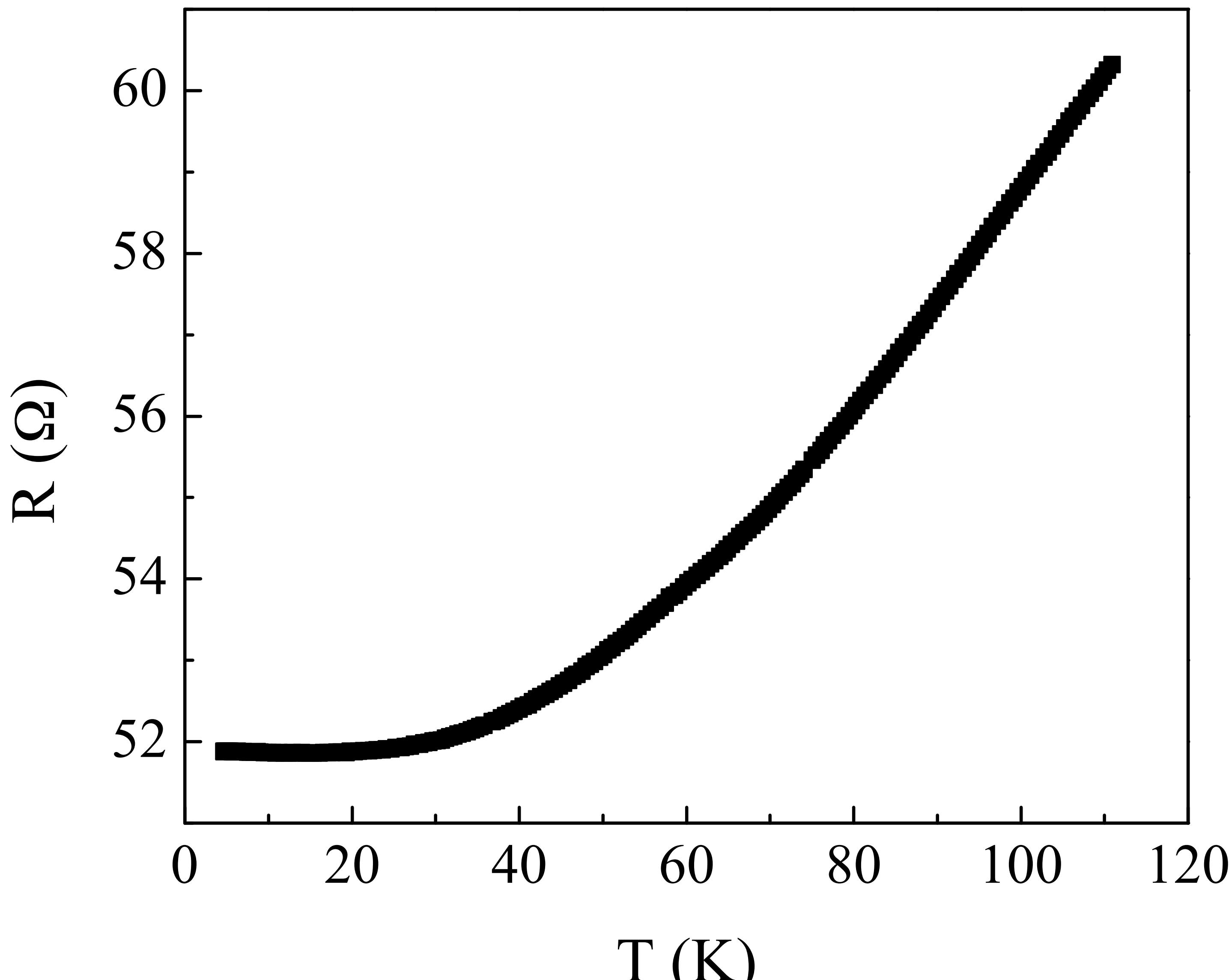
$$V_a = 0 \quad V_b = -IR$$

(c)



$$V_a = +IR \quad V_b = 0$$

resistance of a Cobalt slab versus temperature



why does R go down as we cool it?

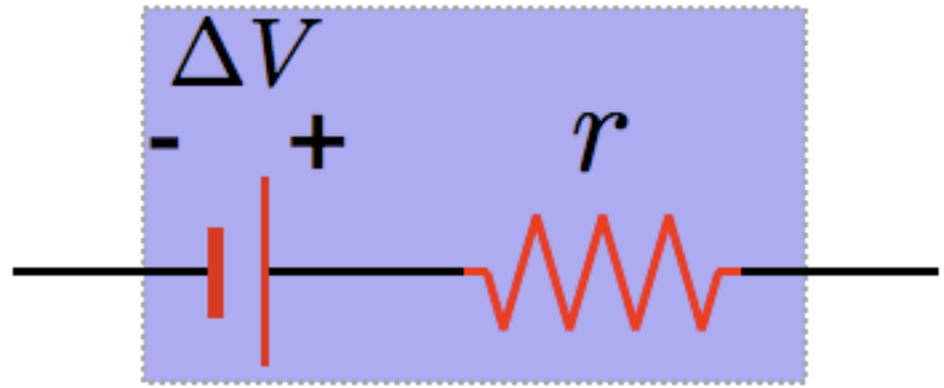
(measured in my lab)

Power

- energy is dissipated in a resistor
- why? how?
- how much?

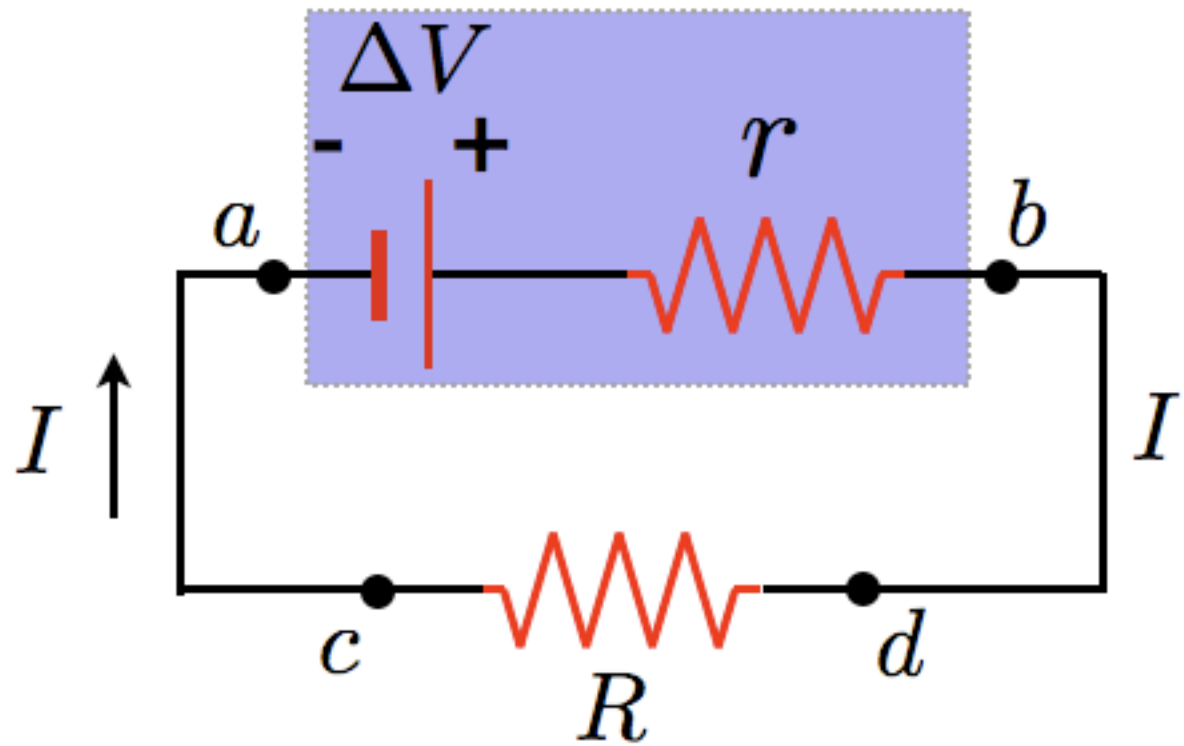
real battery = ideal battery + R

=



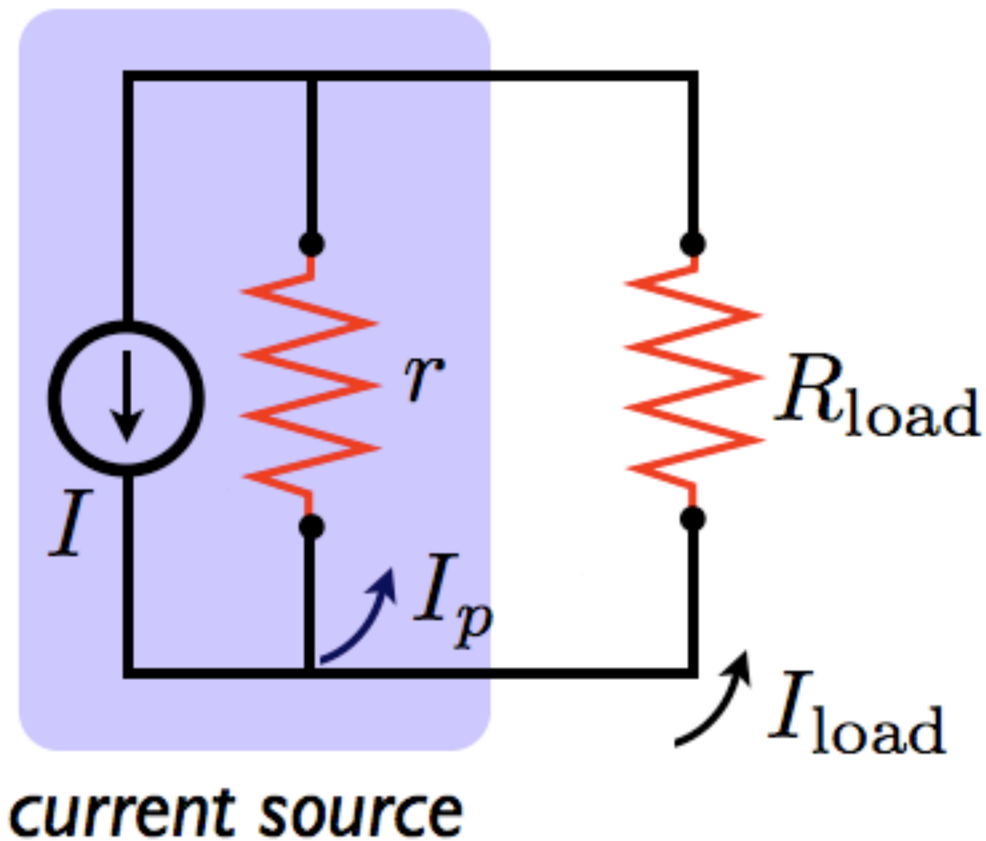
actual circuit has a parasitic r

b)



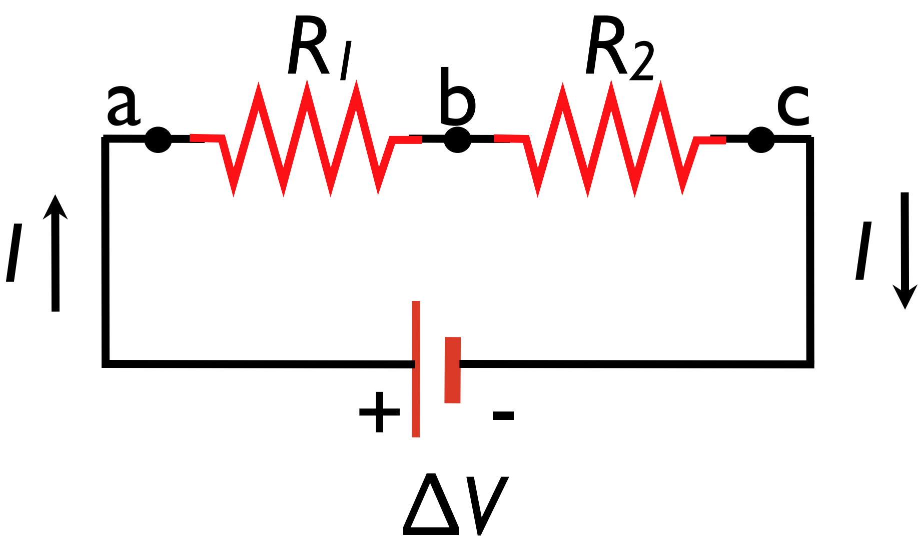
R in series with output
("steals" V)

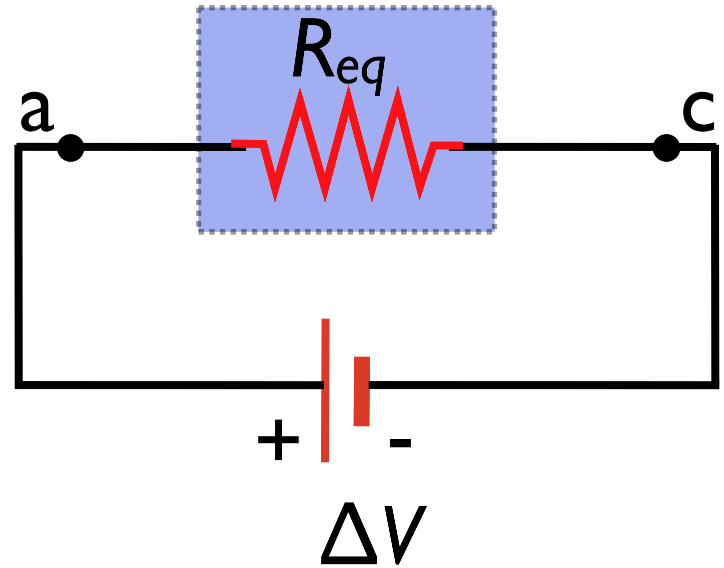
real current sources



R in parallel with output
("steals" I)

series resistors: conservation of energy





Two Resistors in Series:

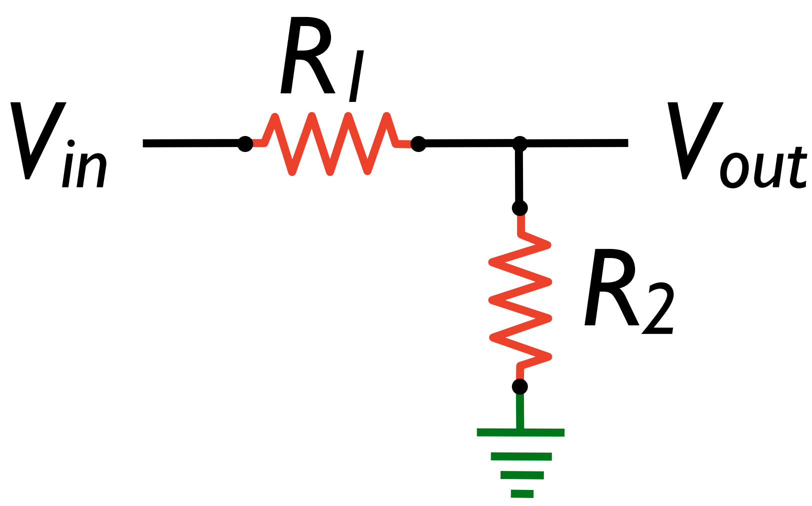
$$R_{\text{eq}} = R_1 + R_2$$

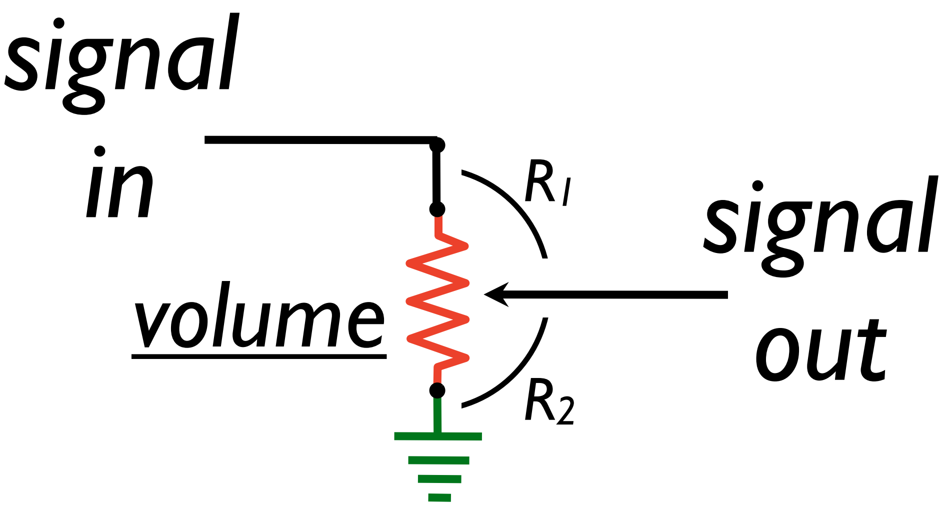
Three or More Resistors in Series:

$$R_{\text{eq}} = R_1 + R_2 + R_3 + \ldots$$

The current through resistors in series is the same.

voltage divider

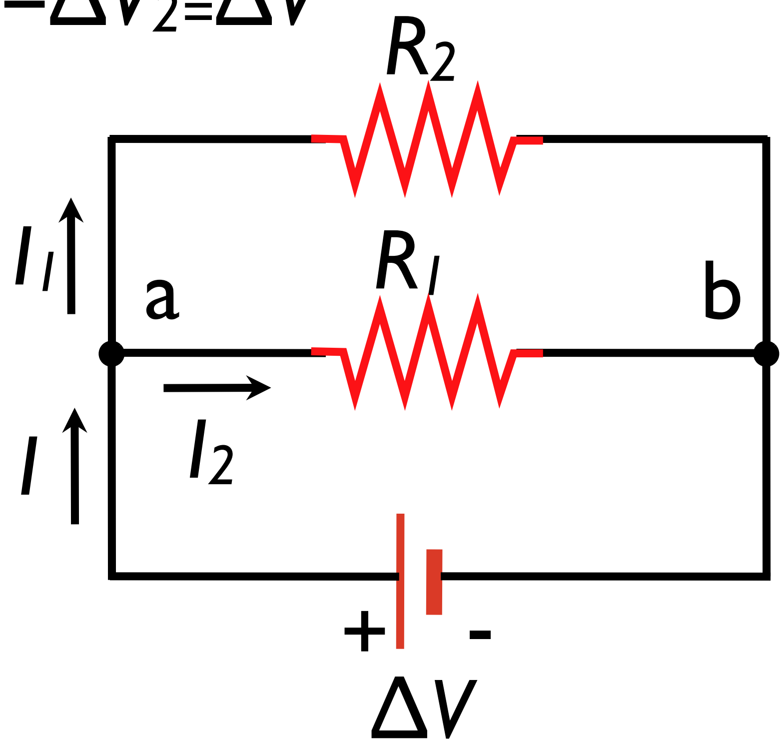




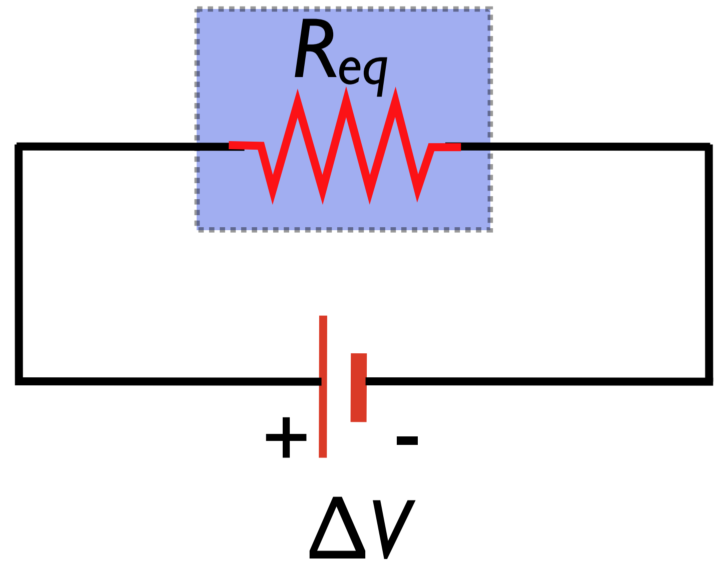
$$V_{out} = \frac{R_2}{R_1+R_2} V_{in}$$

parallel resistors: conservation of charge

$\Delta V_1 = \Delta V_2 = \Delta V$



$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



Two Resistors in Parallel:

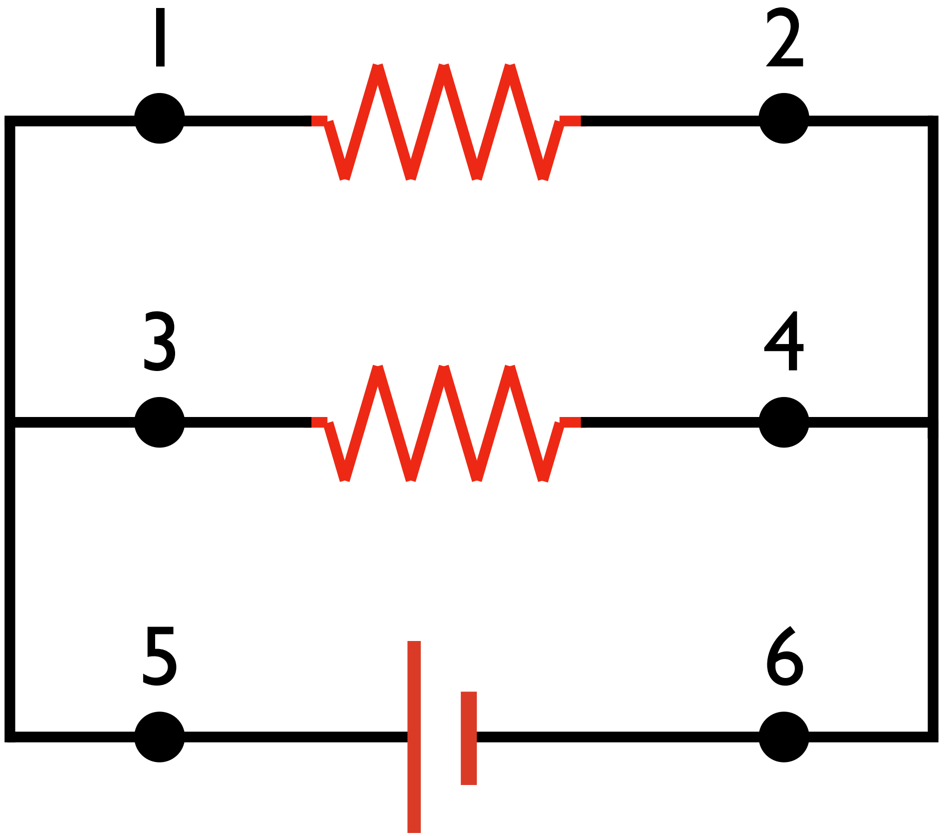
$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Three or More Resistors in Parallel:

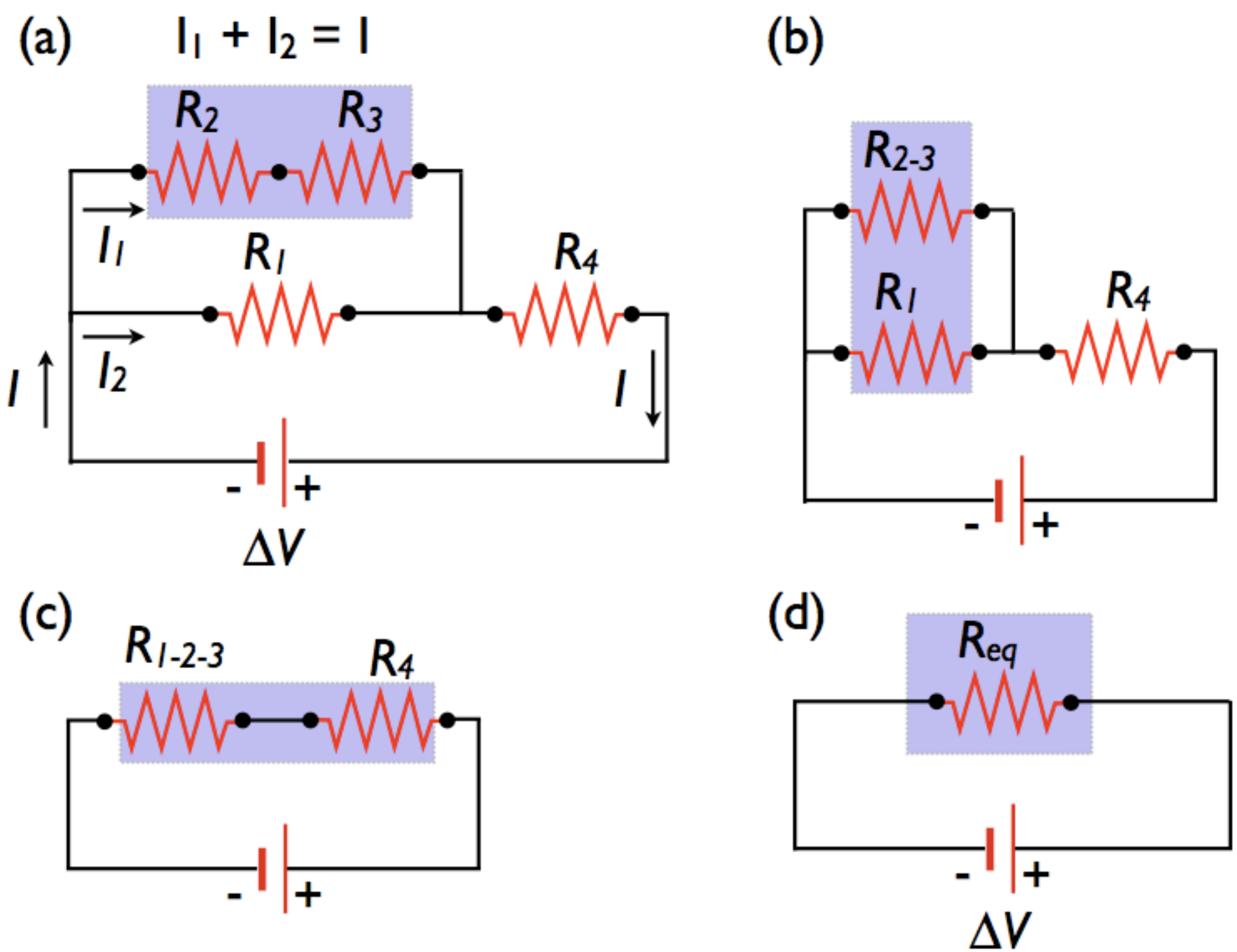
$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

current divider

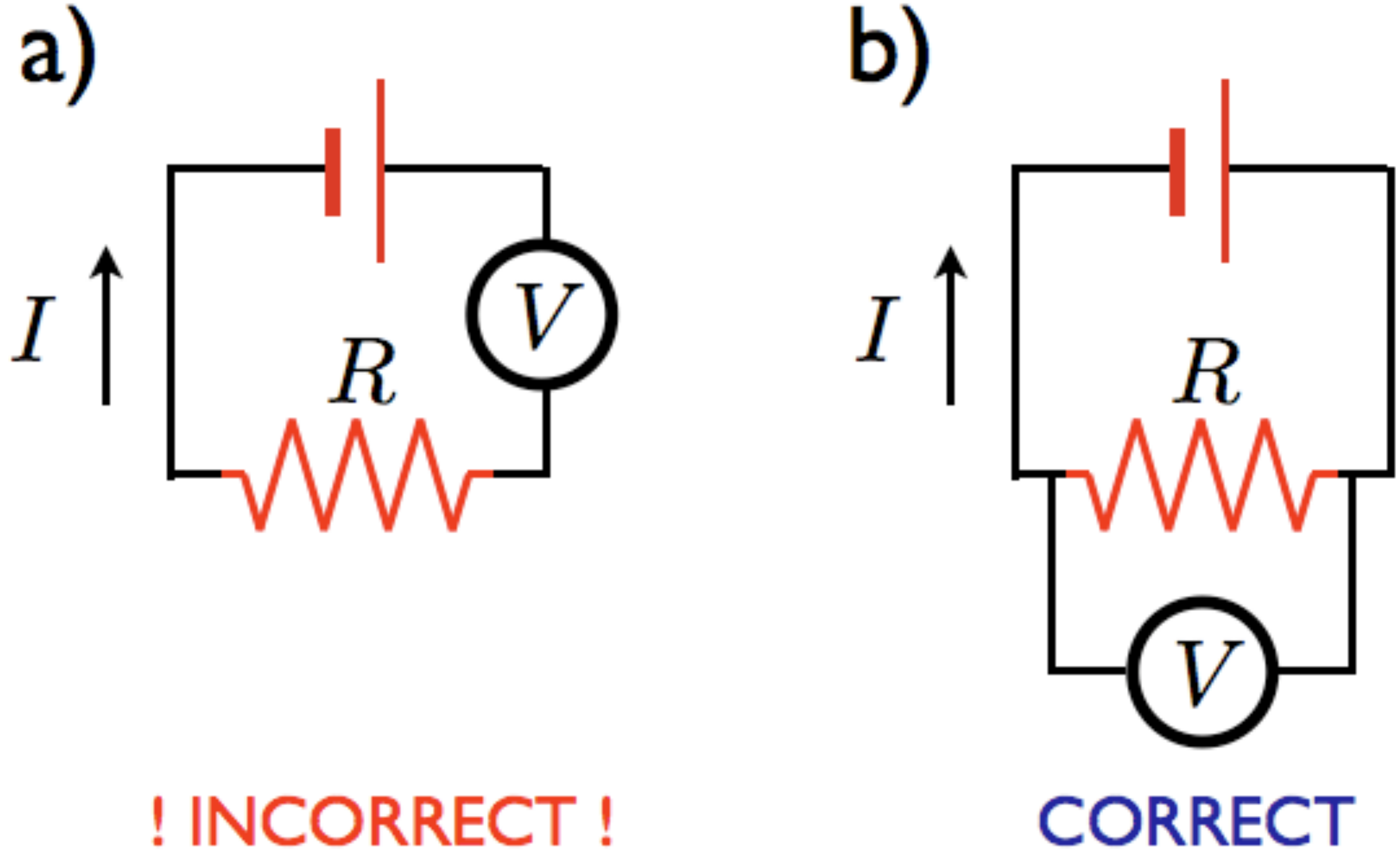
rank the currents



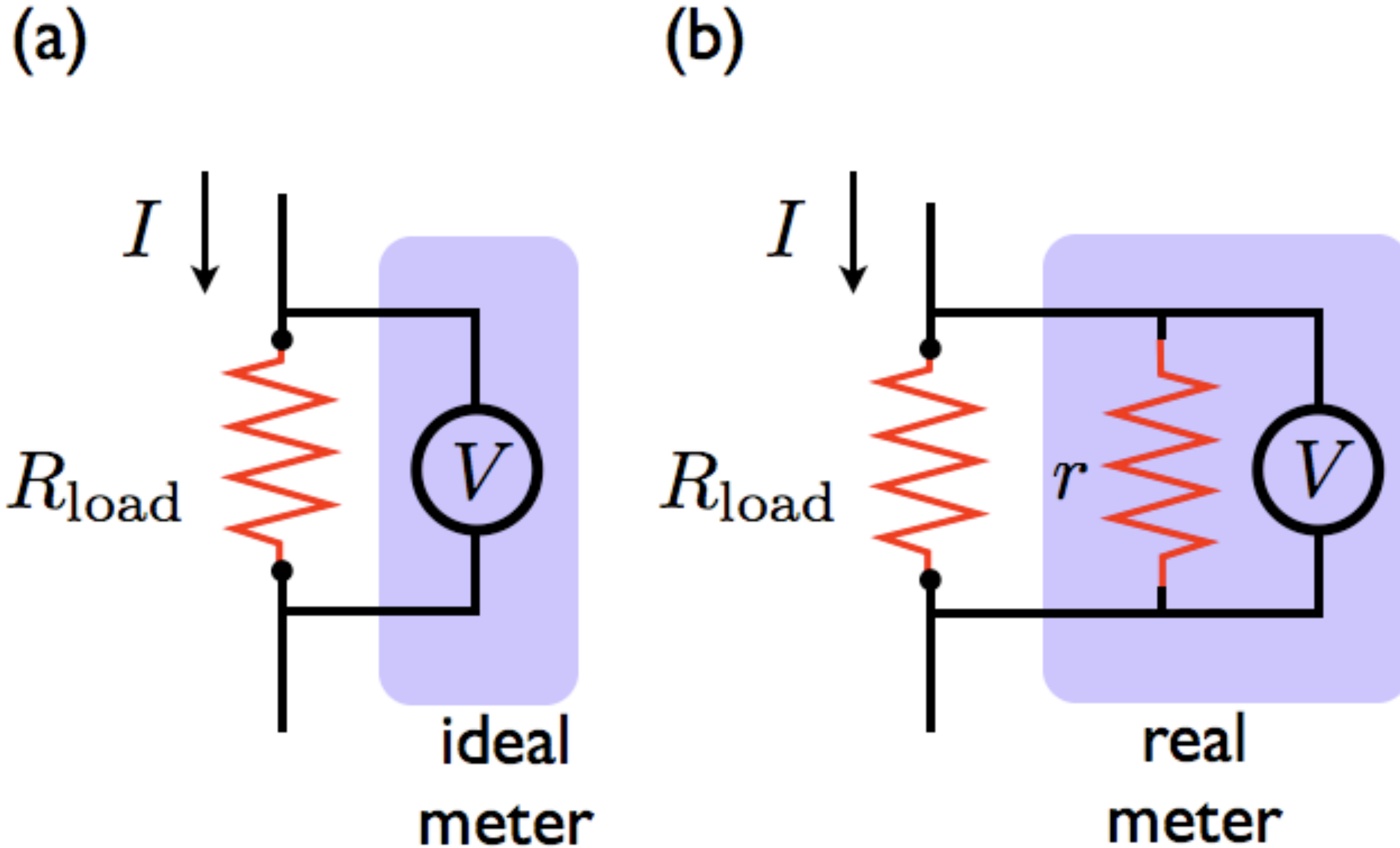
more complex arrangements



measuring voltage

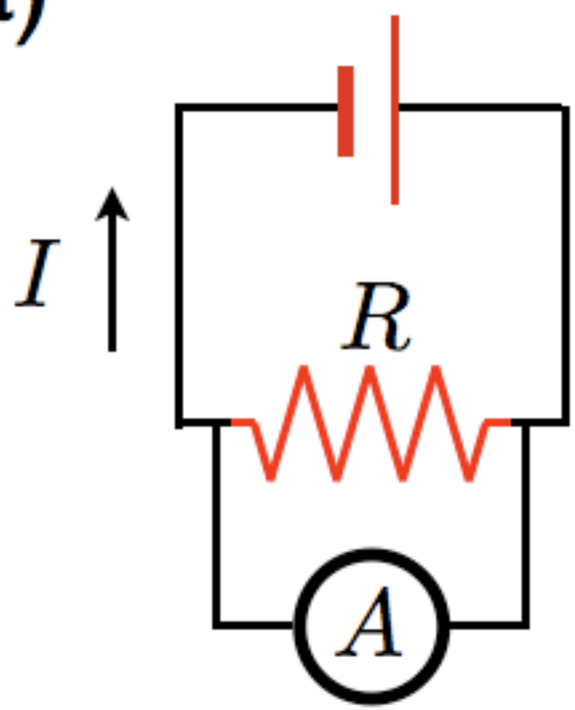


real voltmeters



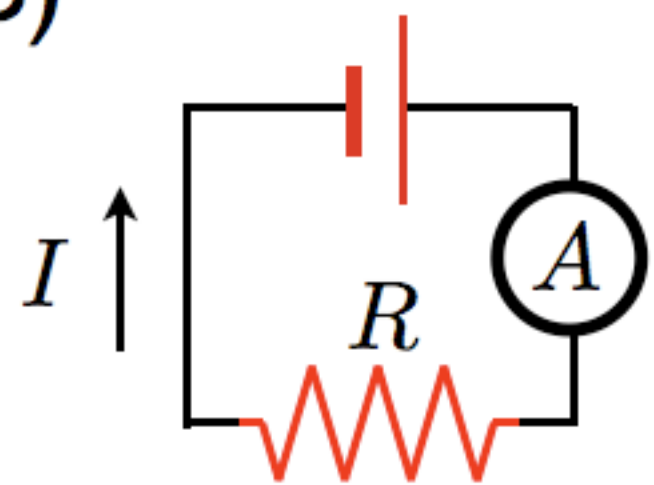
measuring current

a)



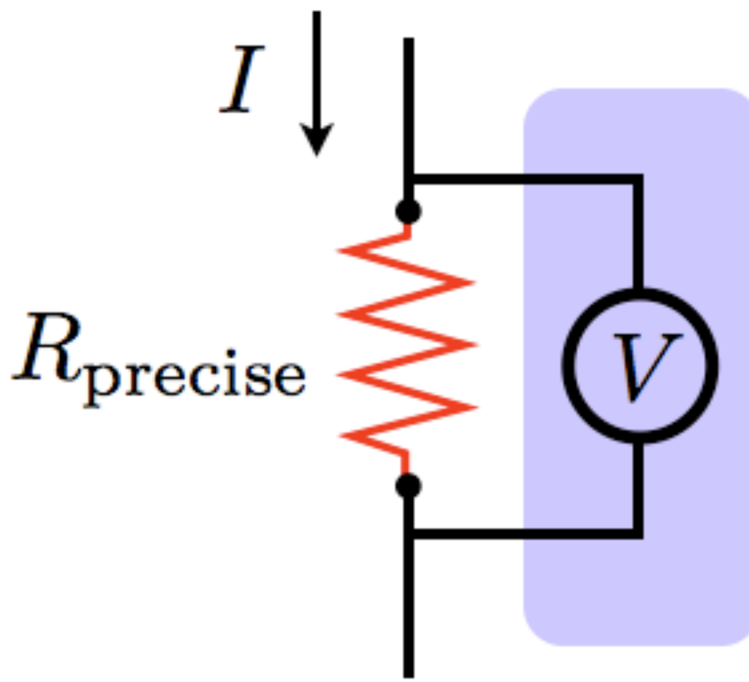
! INCORRECT !

b)

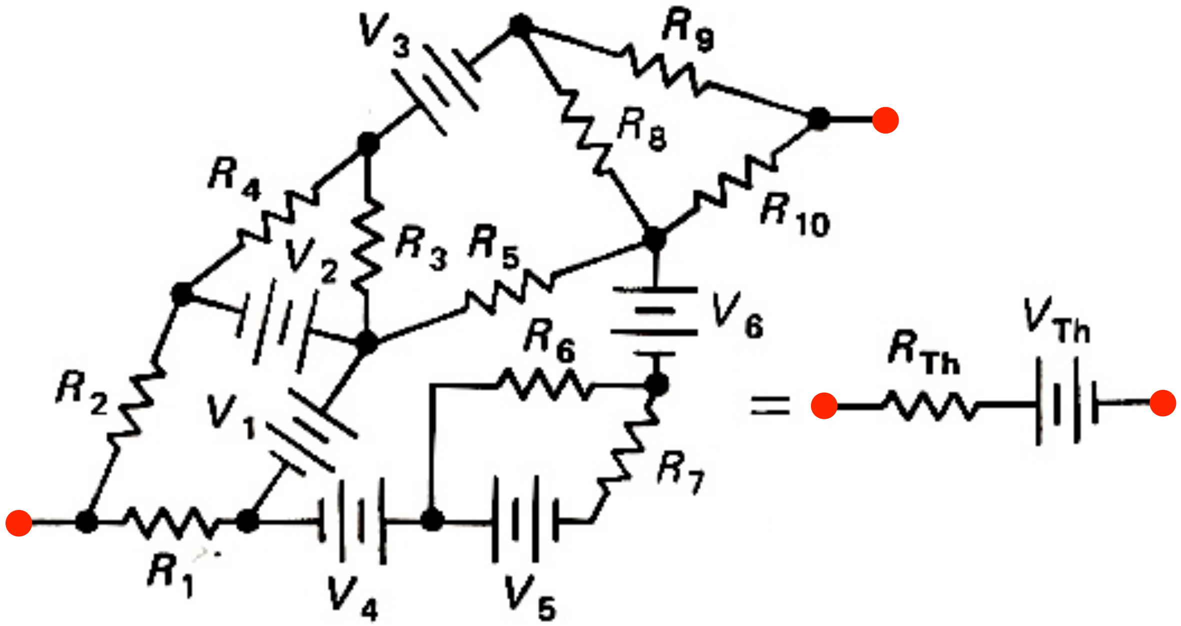


CORRECT

a simple ammeter



Thévenin equivalents



V_{th} = V (open circuit)

$$R_{th} = \frac{V \text{ (open circuit)}}{I \text{ (closed circuit)}}$$

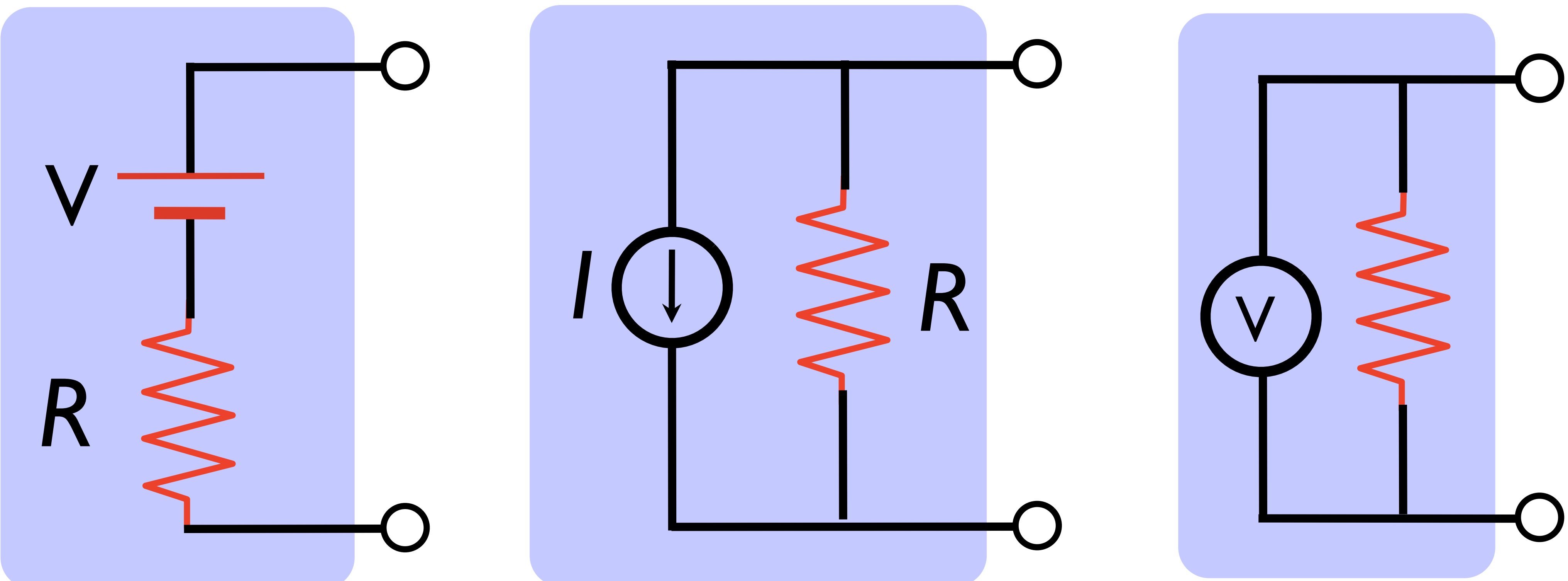
any weird combinations of R's and V's
is equivalent
to a
SINGLE R and V

(or a single I source
in parallel with R)

so what?

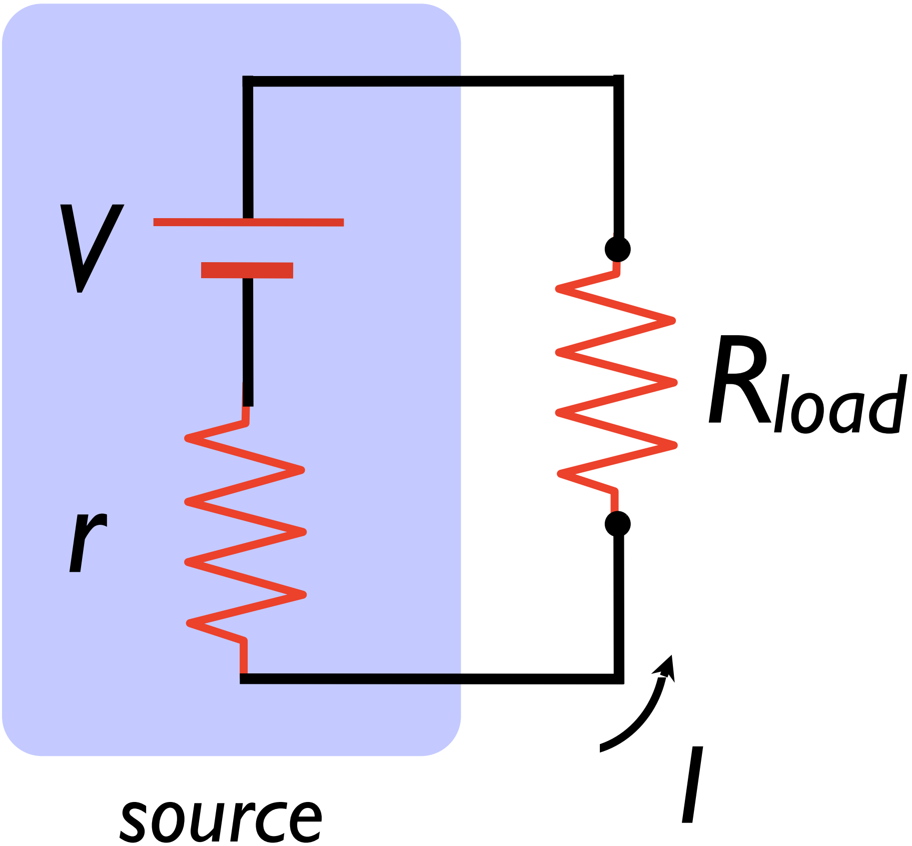
real sources =
ideal sources + R

real meter =
ideal meter with R



what about
ammeter?

V source loading



like a battery

$$\Delta V_{load} = V - Ir$$

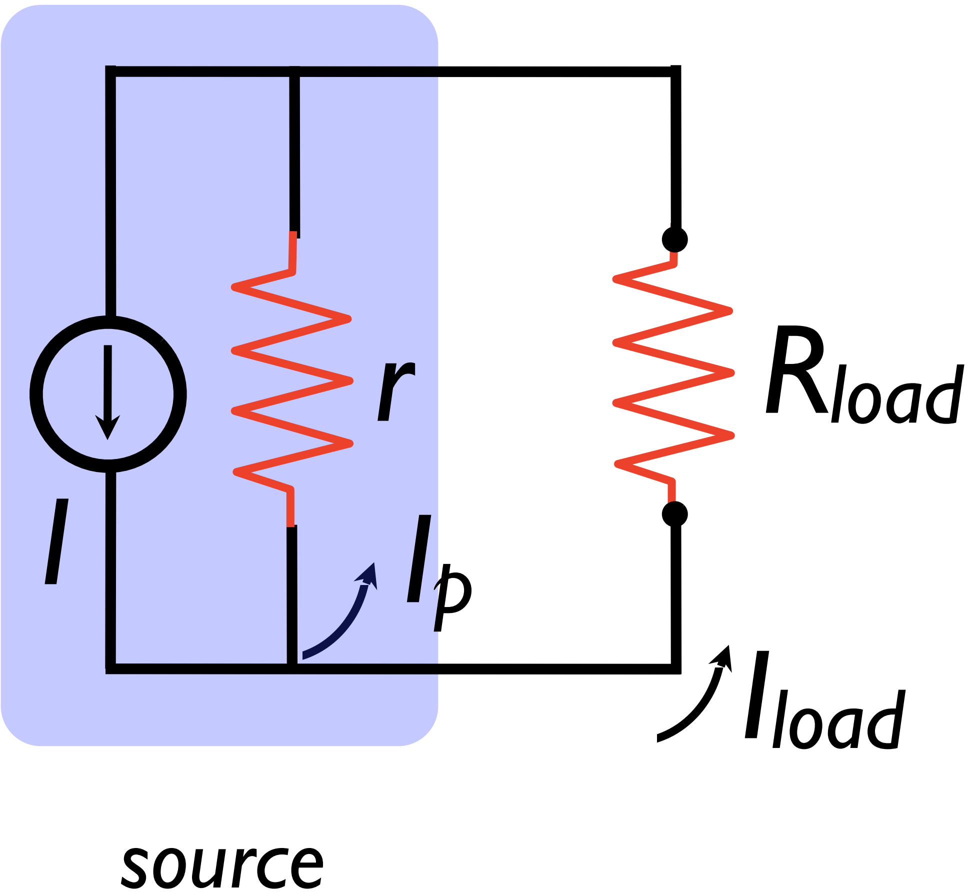
for $r \ll R_{load}$,

$$\Delta V_{load} \approx V$$

V source wants R **high**

one easy solution:
large resistor in parallel with load

I source loading



$$I_{load} = I \frac{r}{r+R}$$

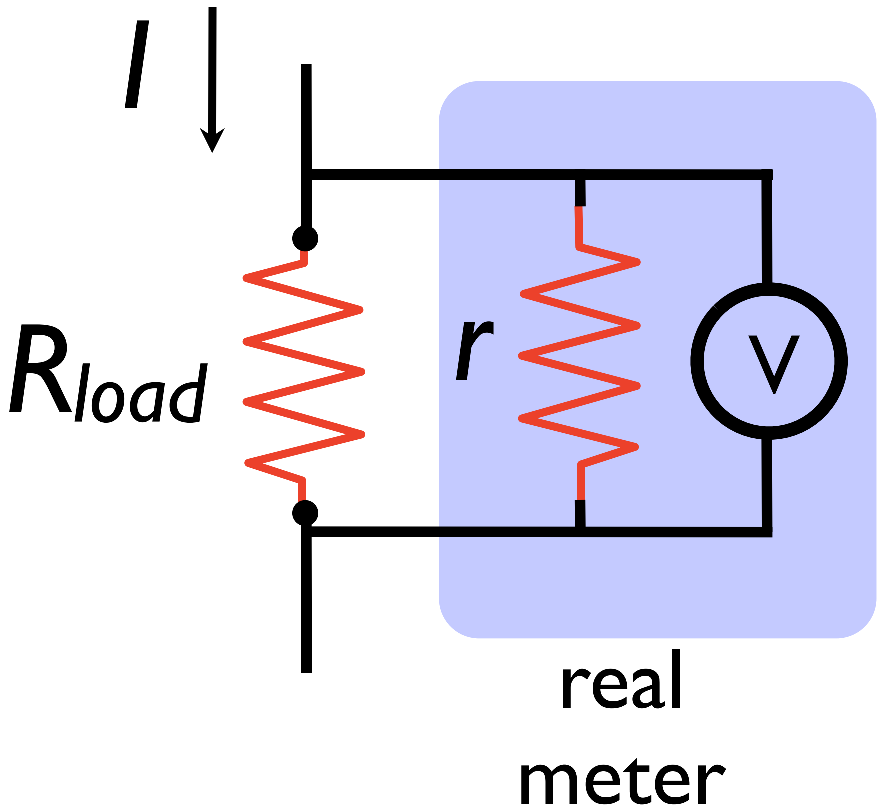
for $R_{load} \ll r$,

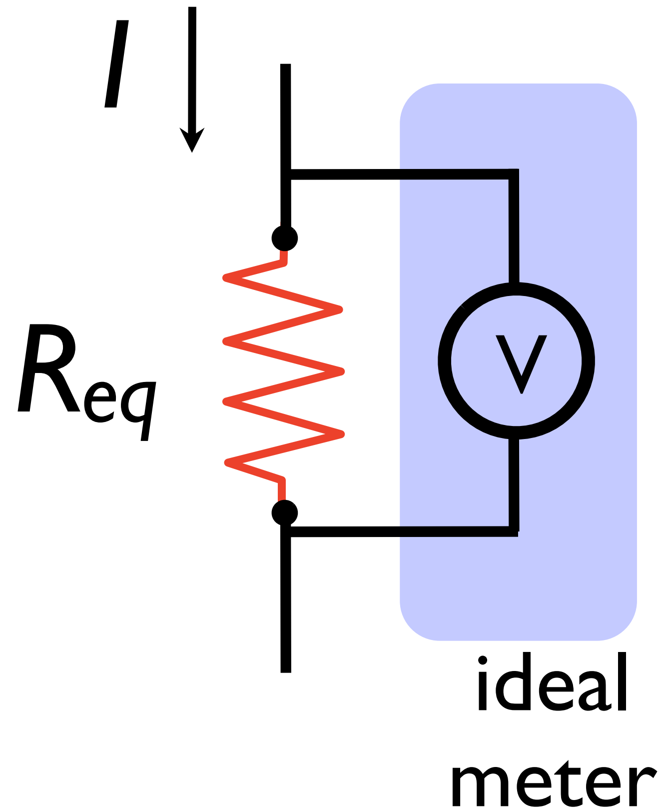
$$I_{load} \approx I$$

I source wants R **low**

sourcing currents at high R_{load} is hard

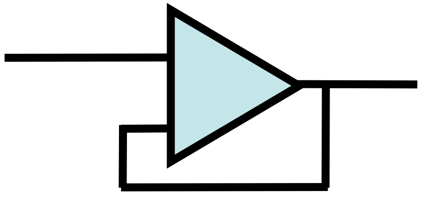
measuring the meter





$$\Delta V_{load} = IR_{eq} = \frac{R}{1+R/r} I \qquad R_{load} \ll r,\ \Delta V_{load} \approx IR$$

summary



voltmeter wants R **low**!
can use a buffer/follower

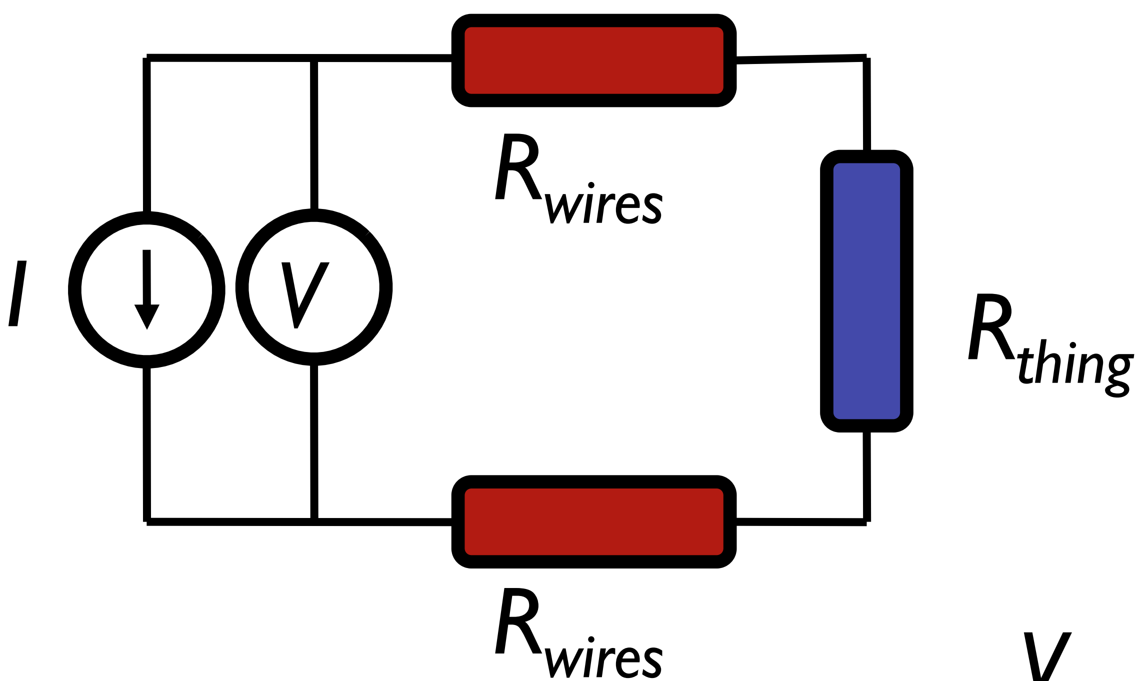
I source wants R **low**
transformer pre-amp
consider sourcing V

V source wants R **high**
large series + parallel resistors
present large R

Sourcing current

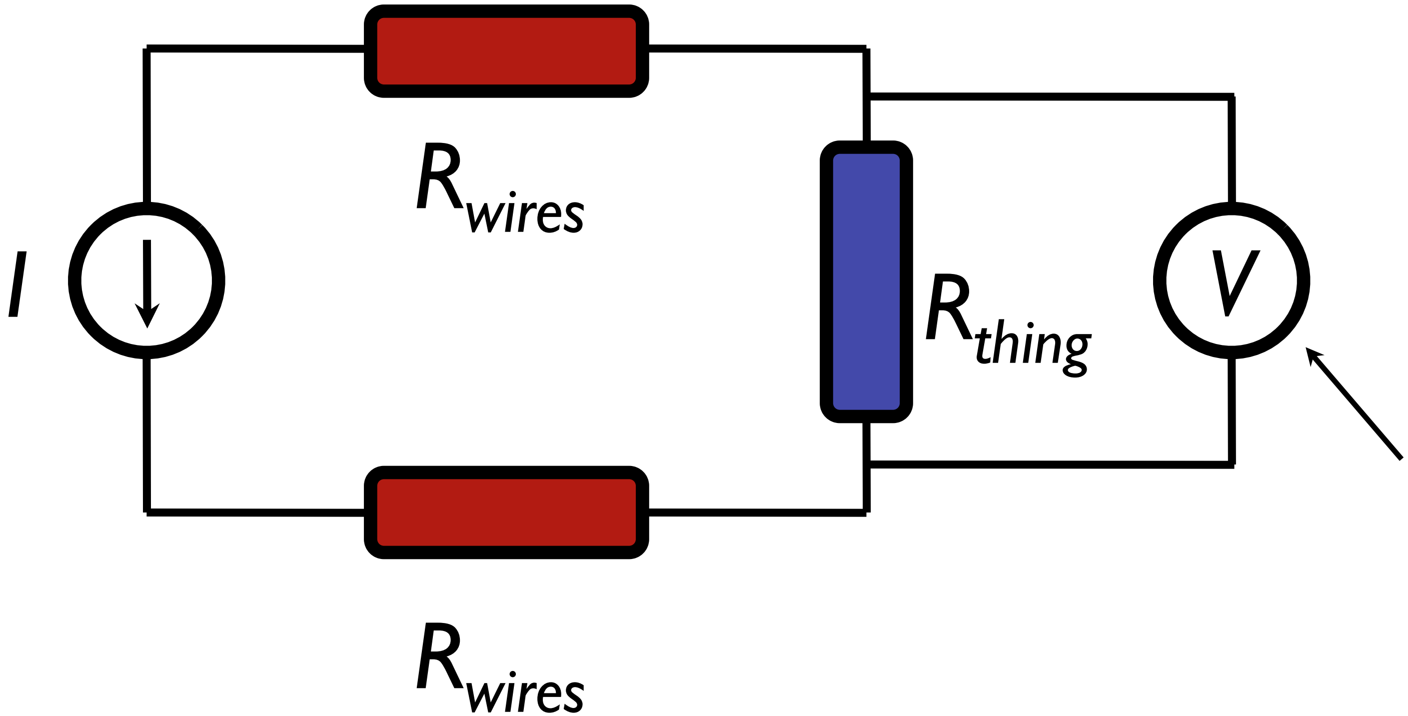
This is what a hand meter does.

Why is it no good?



$$V_{meter} = I(R_{thing} + 2R_{wires})$$

Sourcing current, properly

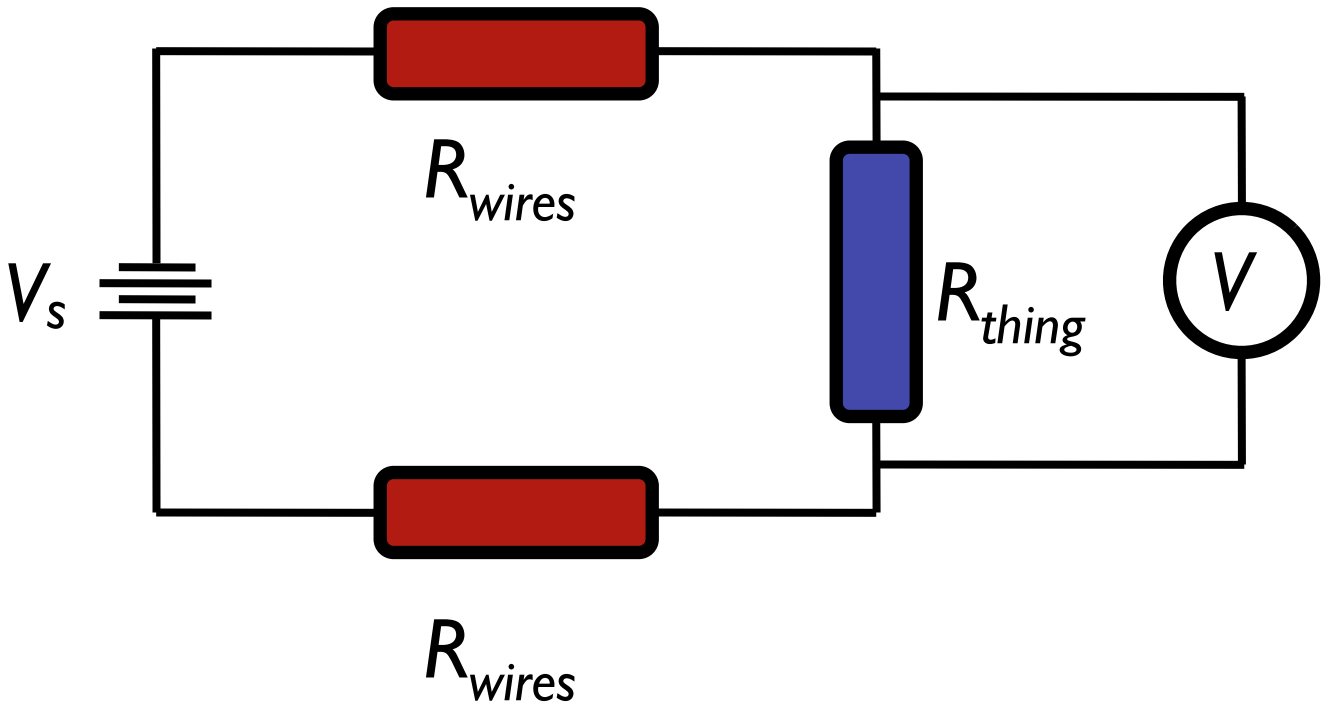


$R_{thing} \ll R_{internal}$

or add buffer

No problem.
You just need four wires.

Sourcing voltage

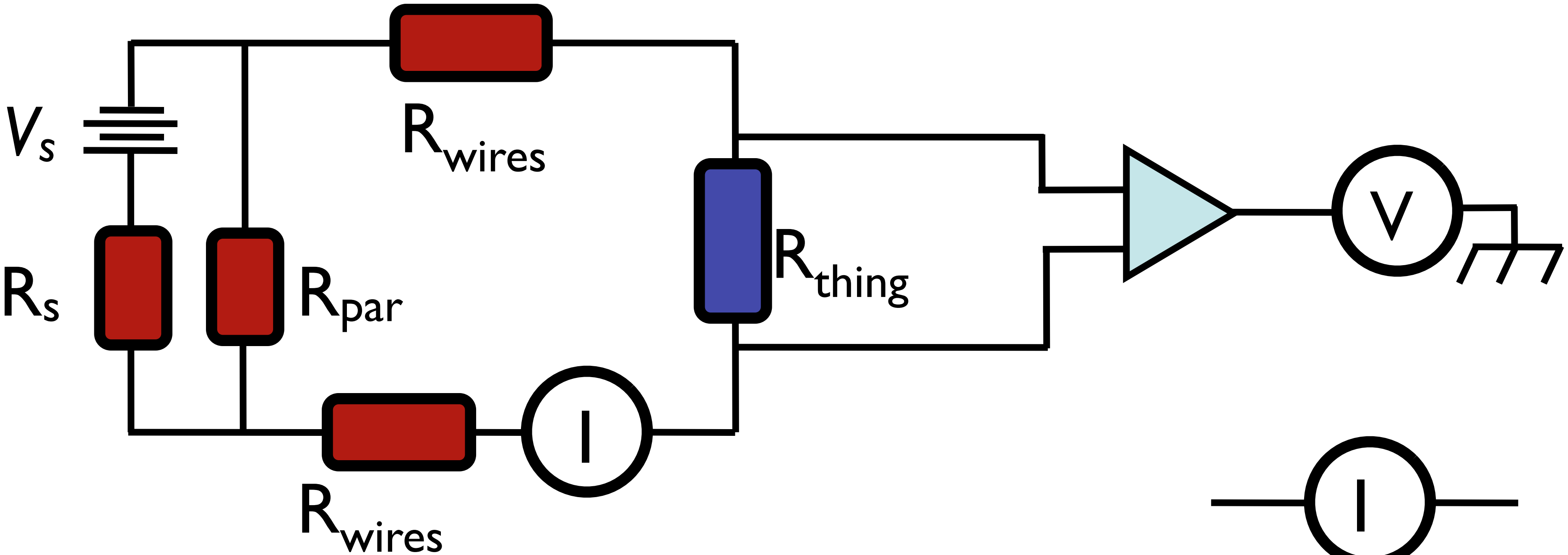


Still have to measure voltage on device

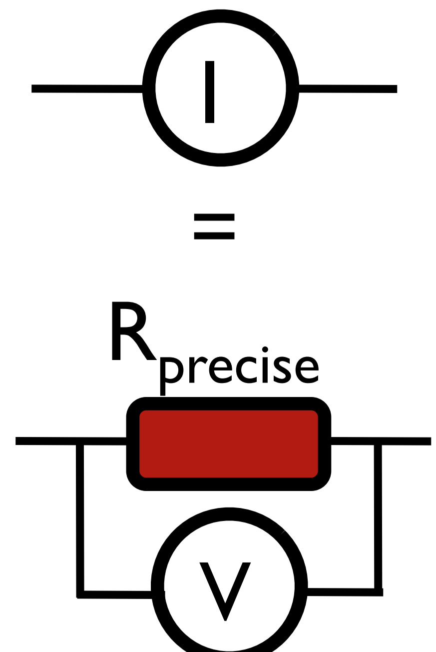
the wires still use up some of V

What about current?

Sourcing voltage II

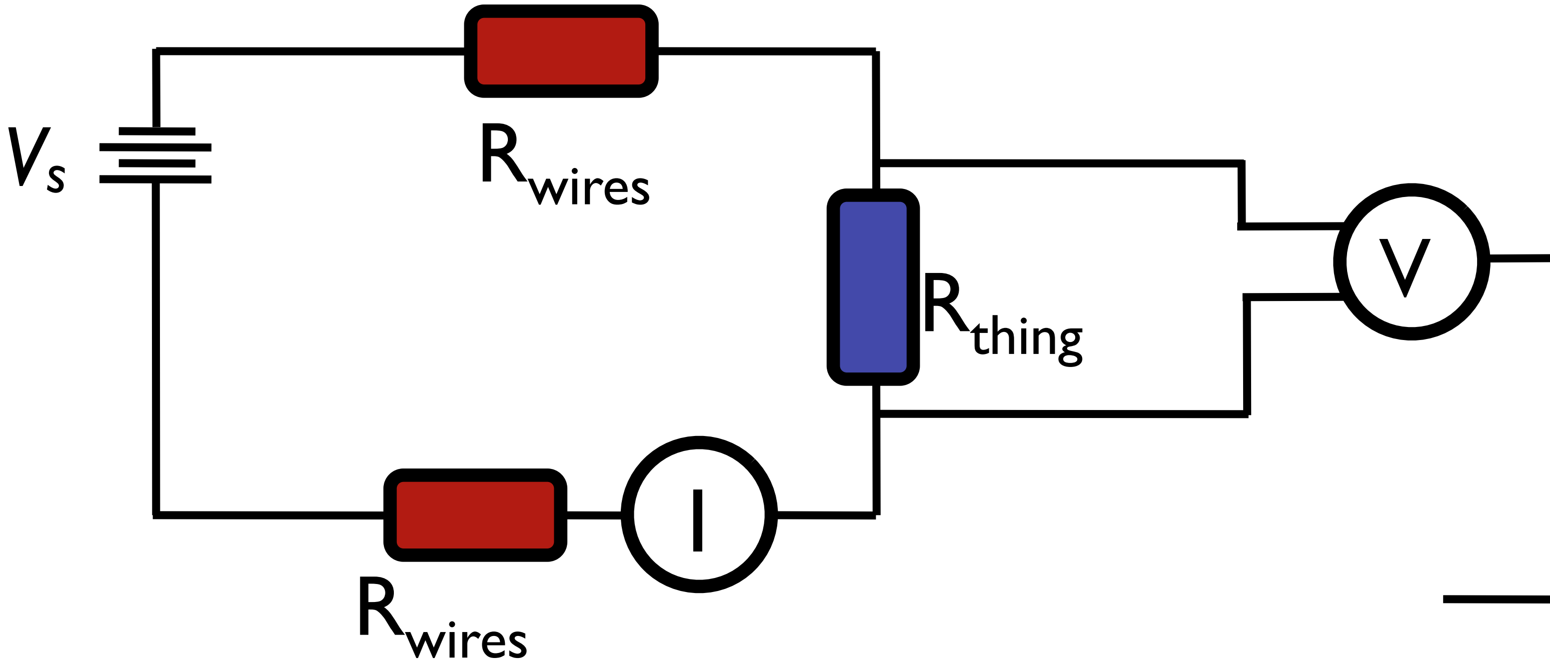


$R = \Delta V / I$

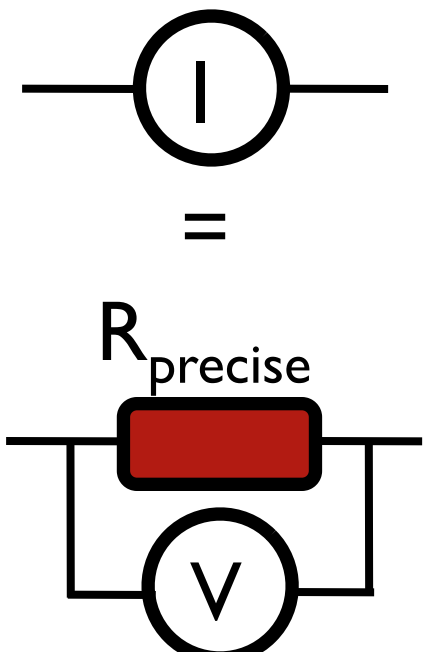


Note we need 4 wires again
current meter - not hard
still problems?

Sourcing voltage properly



$R = \Delta V / I$



Note we need 4 wires again

current meter - not hard

still problems?

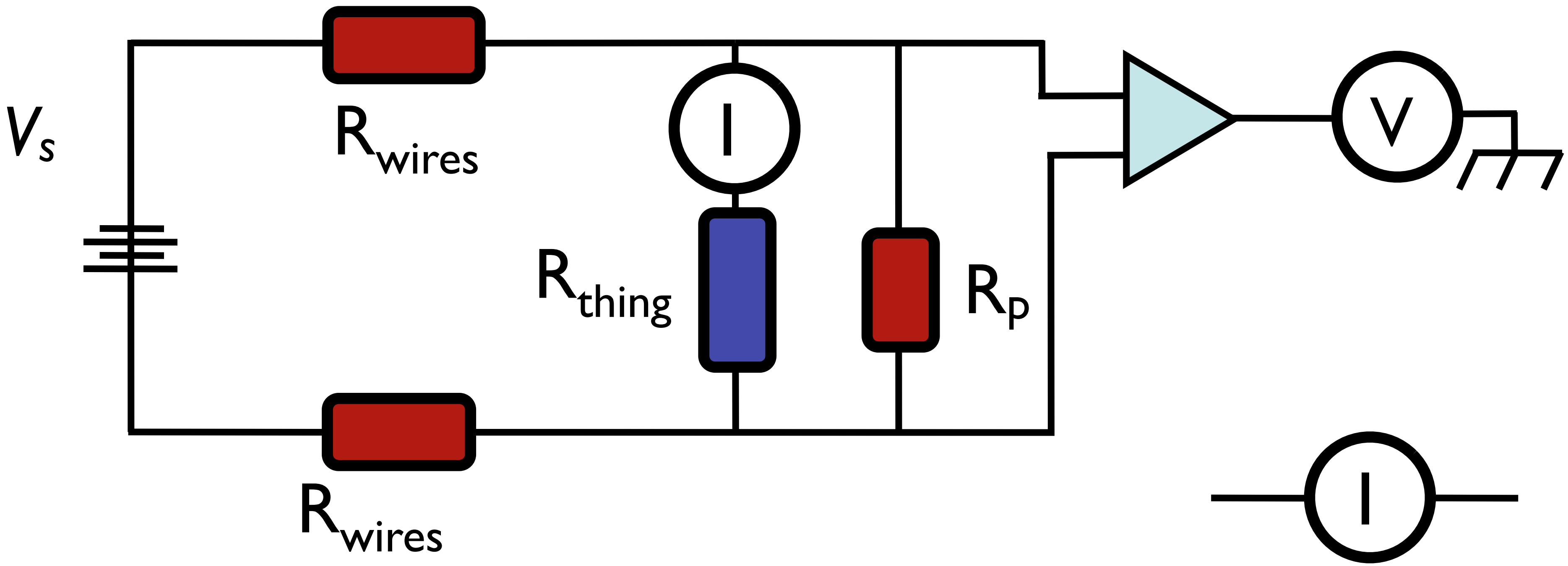
source/meter resistances

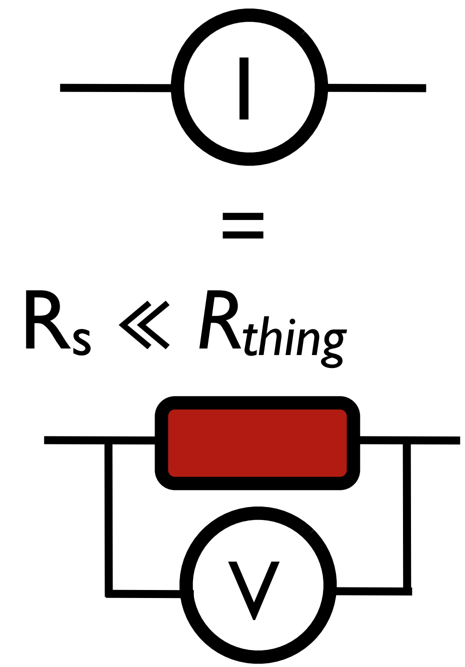
voltmeter wants R low
but V source wants R high

need buffer/amp on V meter
resistor in parallel with source

if V source is problem, R is too low
consider sourcing I

what if I want to measure a *really* high R?





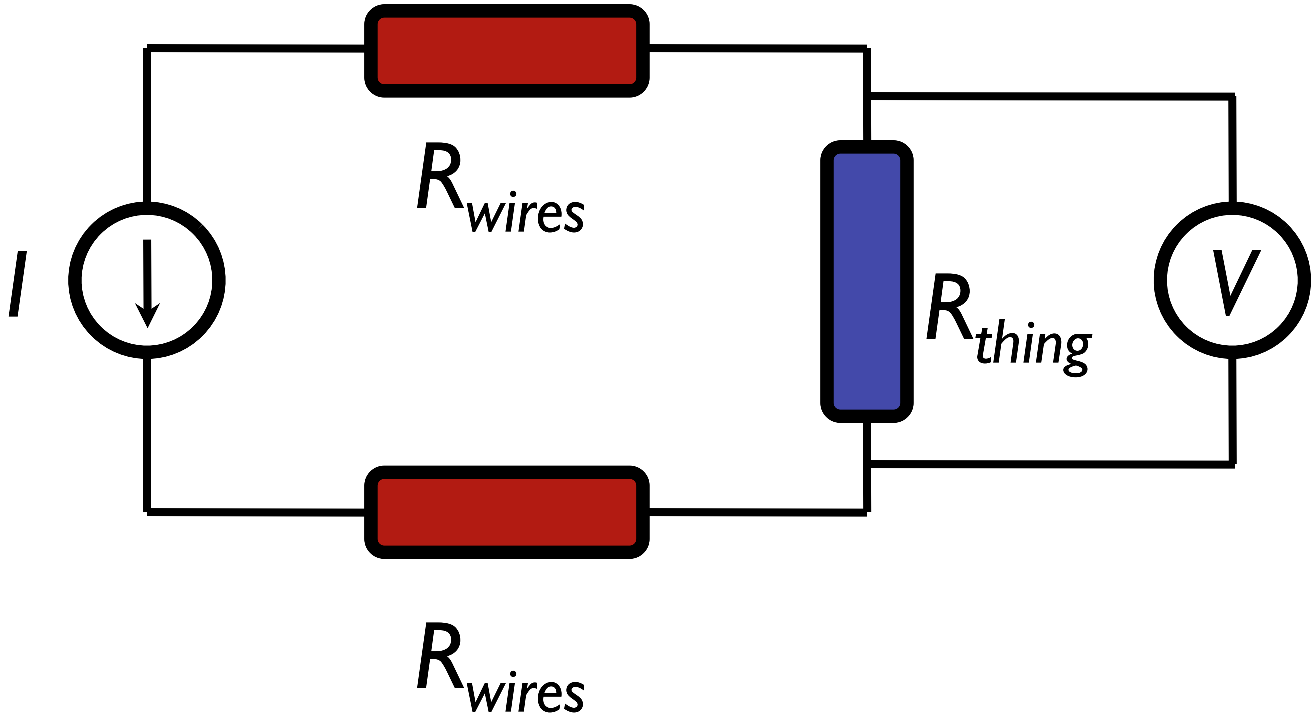
source *voltage*

R_p has same voltage as R_{thing}

R_s has same current

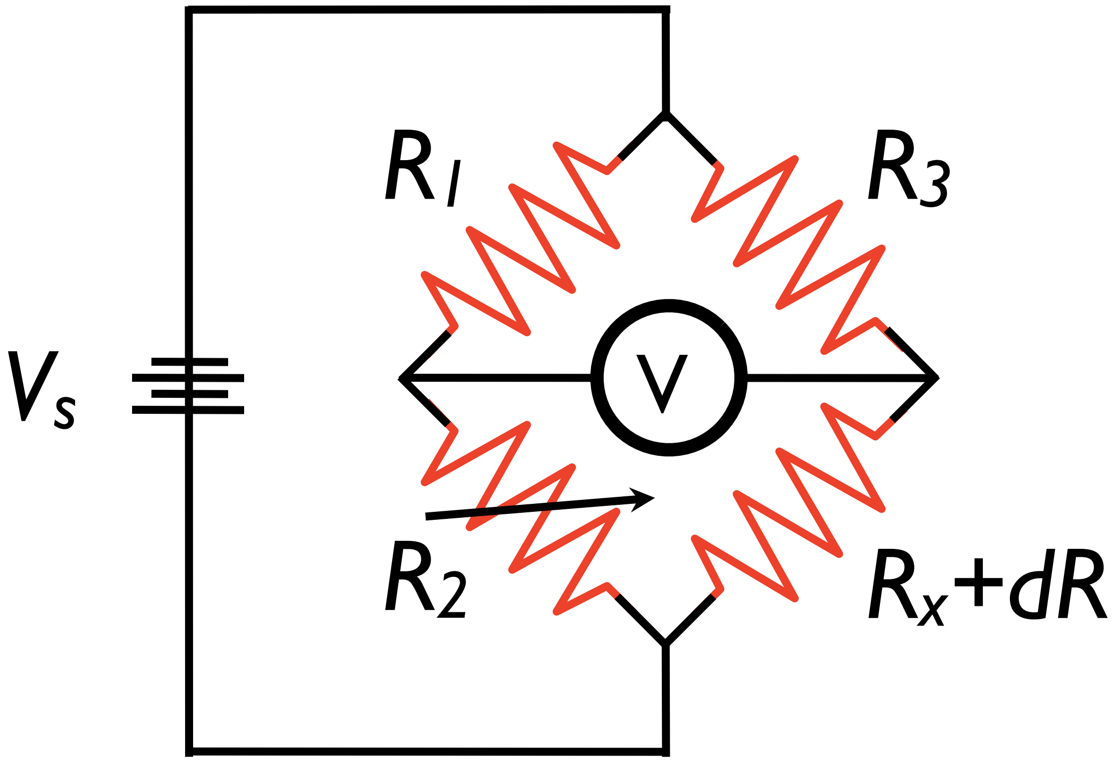
have done $>10^{10}$ Ohm

what if I want to measure a *really* *low* R?



this works just fine ...
so long as your V meter is good
v. good amp / part of a bridge

what if I want to measure a small change in R?



balance bridge to *V=0*
detect small changes from null

R_2 =

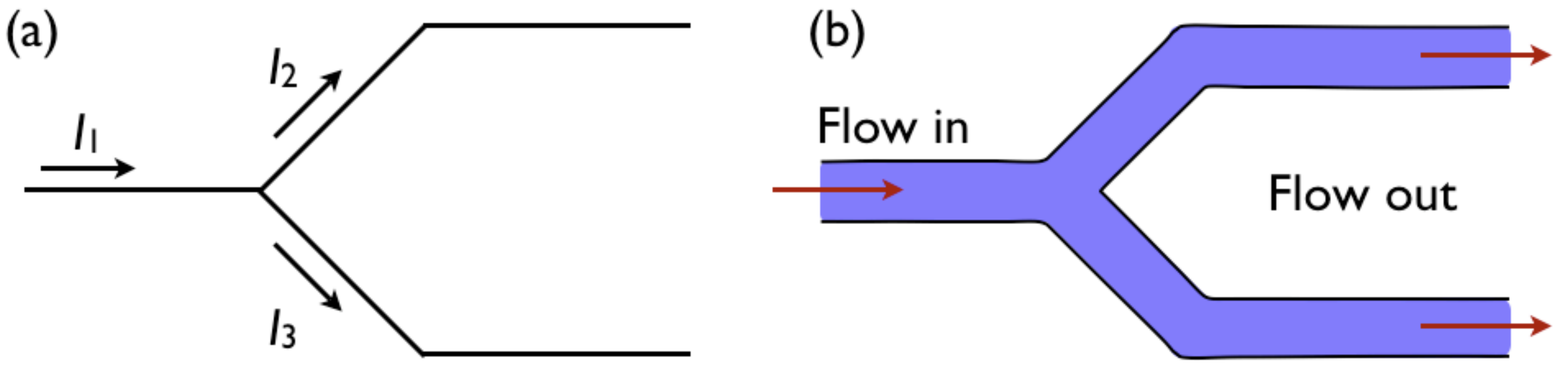
$\approx R_3$

make R_1-R_3 about the same
trimming resistor on R_2 = dR

$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_s$$

$$R_x = \frac{R_3 R_2}{R_1}$$

Rules for analyzing more complicated circuits


(a)
I_1
I_2
I_3
(b)
Flow in
Flow out

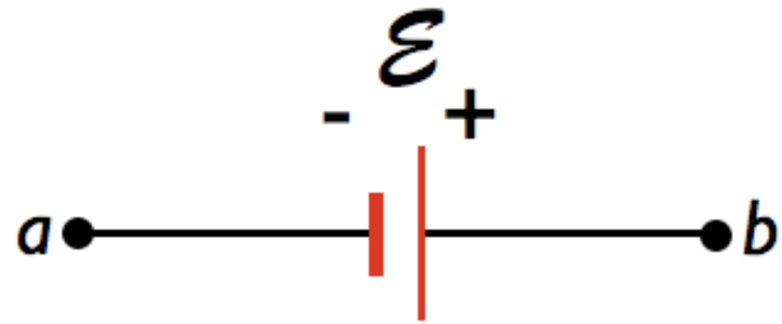
(a)

$$\Delta V = V_b - V_a = -IR$$

(b)

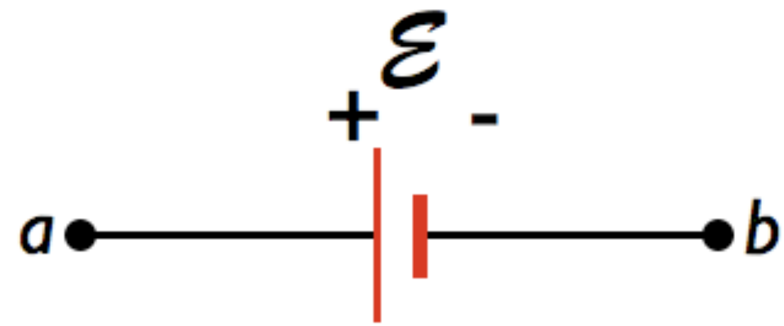
$$\Delta V = V_b - V_a = +IR$$

(c)



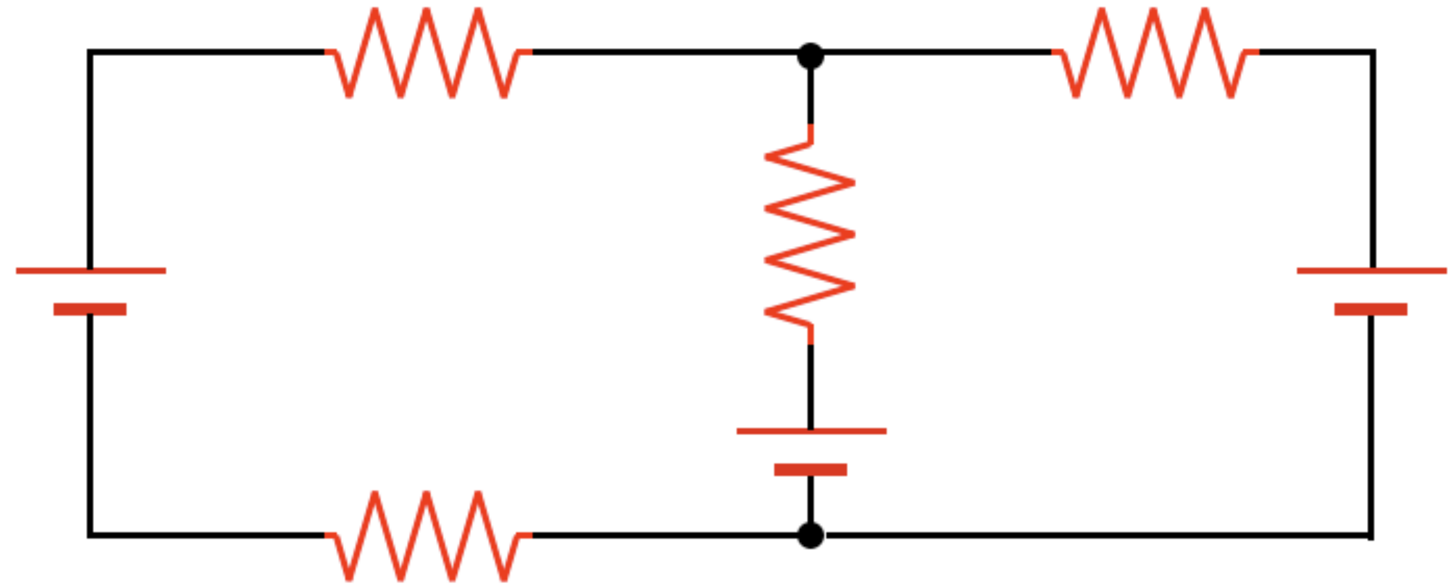
$$\Delta V = V_b - V_a = +\mathcal{E}$$

(d)

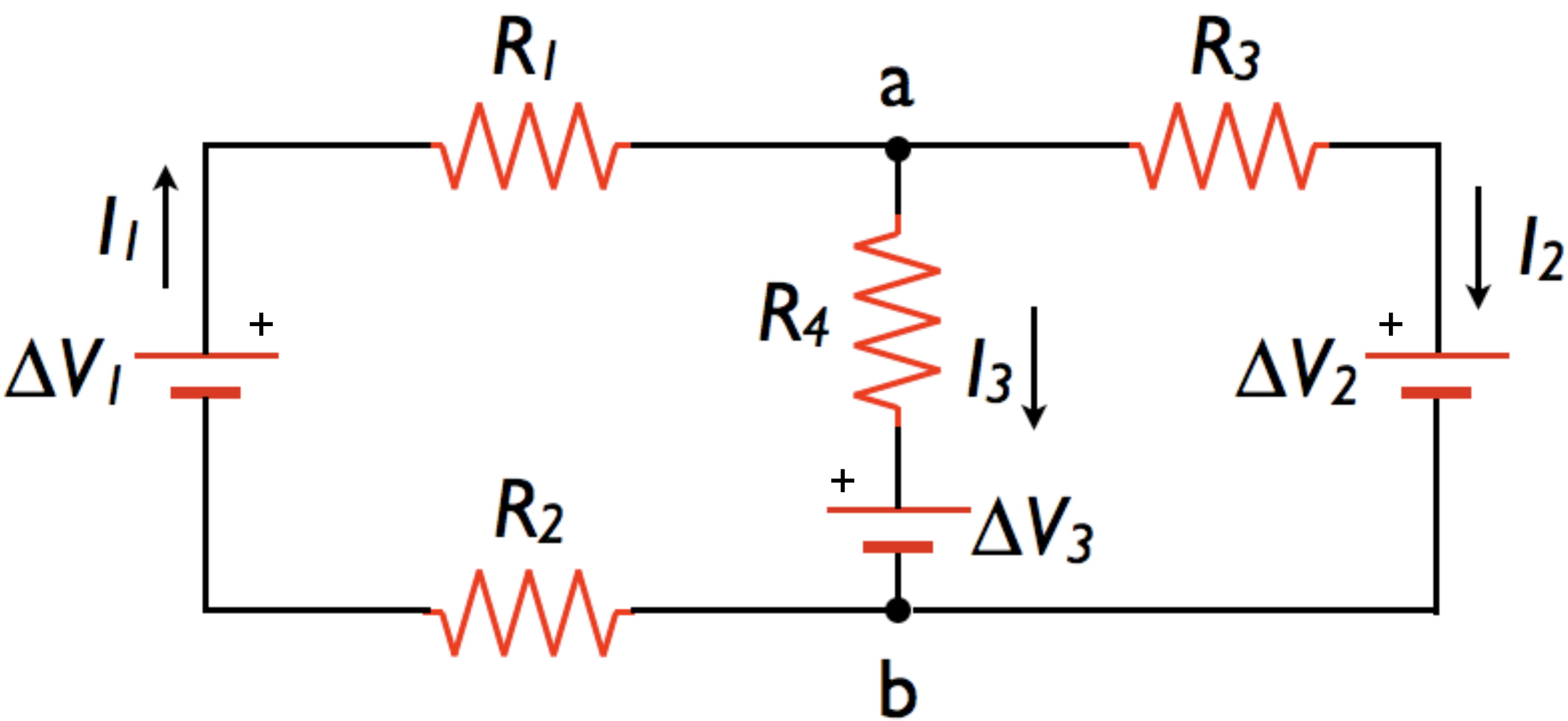


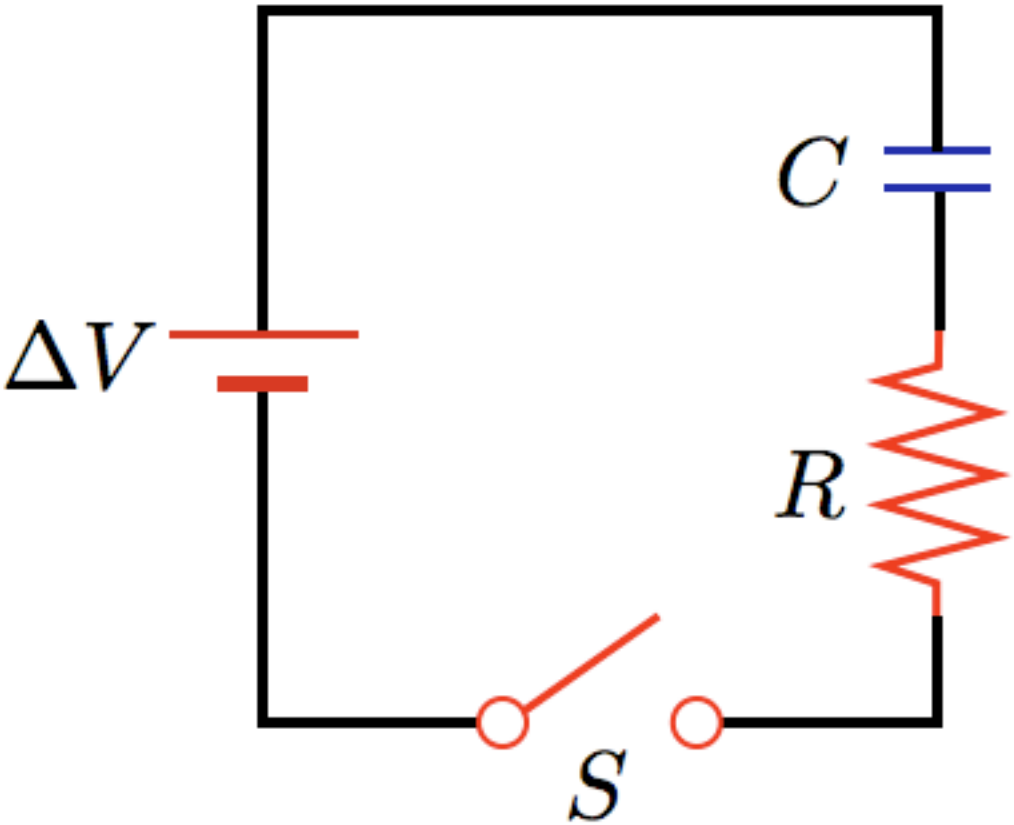
$$\Delta V = V_b - V_a = -\mathcal{E}$$

(a)

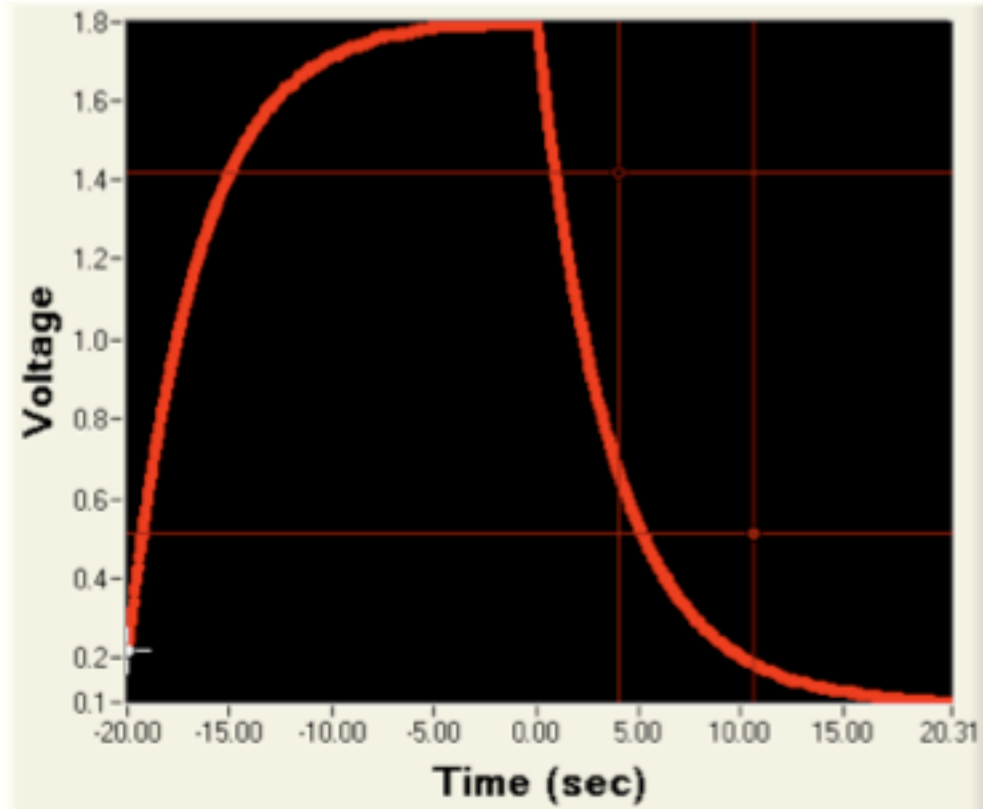


(b)




C
ΔV
R
S

(a)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.1
Voltage
-20.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
20.31
Time (sec)

(b)