The Plan

- complex combos of capacitors
- dielectrics, quickly
- current & resistance
- HW3 hints
- time permitting, bits on dc circuits

Exam 1

- During lab period ... but only 60-90min
  - electric forces & fields
  - electrical potential & energy
  - current & resistance
  - NO RELATIVITY
- study quick quizzes, example probs
- our HW and quizzes (and old ones)
- problems in notes
- choice of problems / partial credit

relax.
it will be ok.

1. It takes 3×10^6 J of energy to fully recharge a 9 V battery. How many electrons must be moved across the $\Delta V = 9$ V potential difference to fully recharge the battery? One electron has a charge of $-e$, given above.

$$PE = qV = neV$$

$$n = PE/eV$$

2. An electron initially at rest is accelerated through a potential difference of 1 V, and gains kinetic energy KE_e. A proton, also initially at rest, is accelerated through a potential difference of -1 V, and gains kinetic energy KE_p. Is the electron's kinetic energy larger, smaller, or the same compared to the protons? Justify your answer. Note that the proton mass m_p is about 1000 times the electron mass m_e.

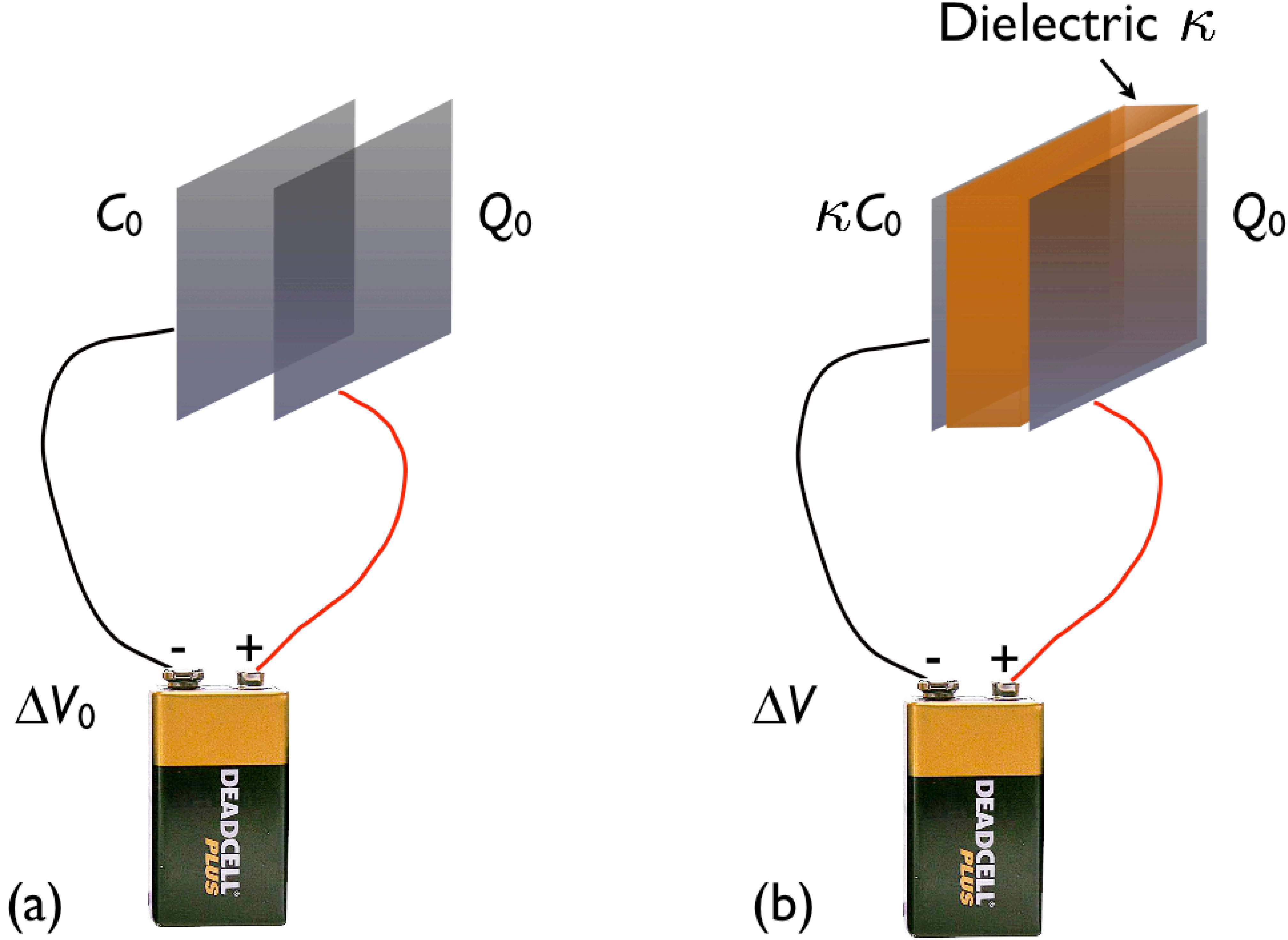
same charge, same potential diff = same PE change

same PE change = same KE

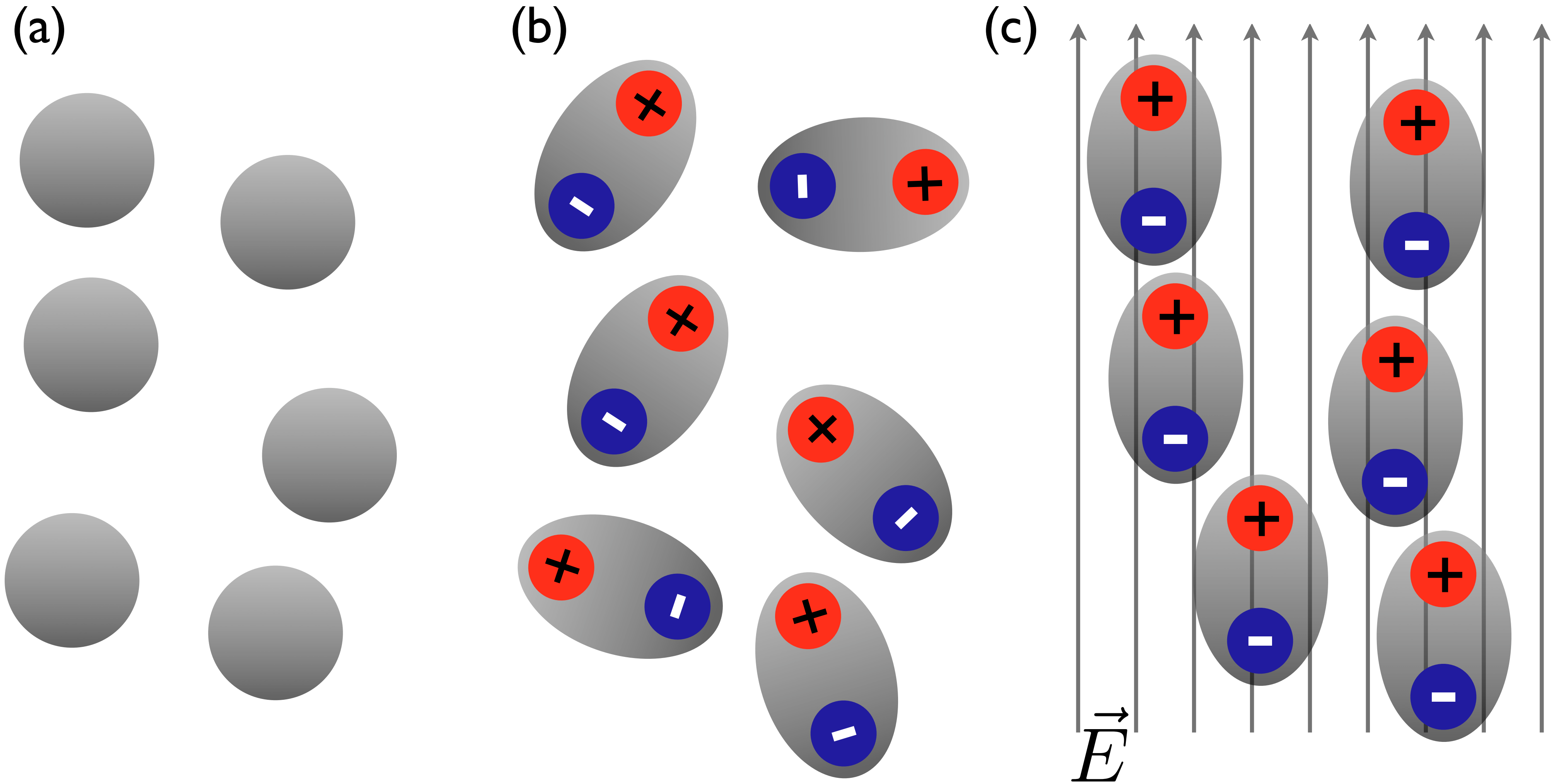
velocity will be different, since m is

3. A "free" electron and a "free" proton are placed in an identical electric field. Which of the following statements are true? *Check all that apply.*

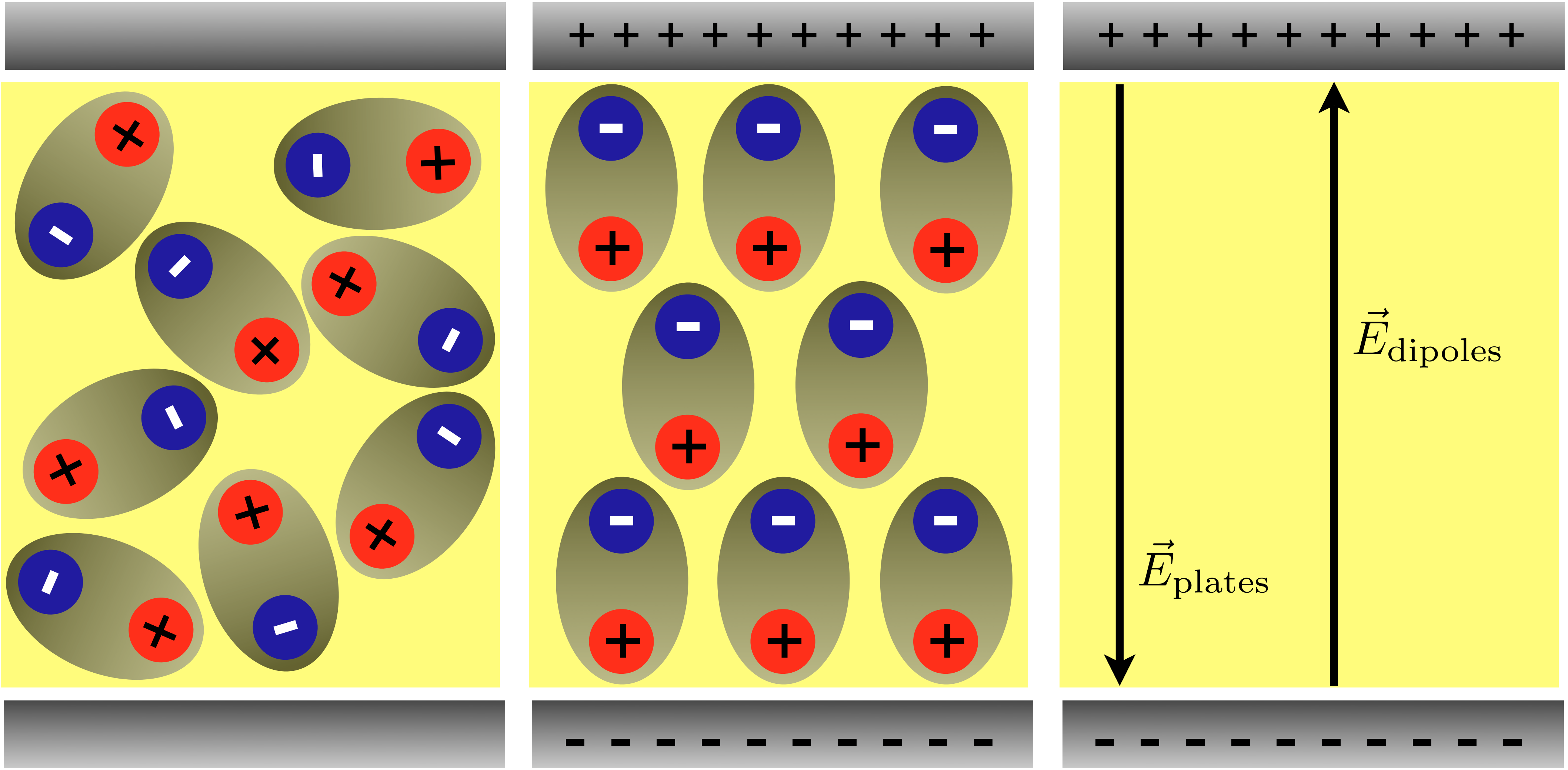
- ☐ Each particle is acted on by the same electric force and has the same acceleration.
- ☐ The electric force on the proton is greater in magnitude than the force on the electron, but in the opposite direction.
- X The electric force on the proton is equal in magnitude to the force on the electron, but in the opposite direction.
- X The magnitude of the acceleration of the electron is greater than that of the proton.
- ☐ Both particles have the same acceleration.

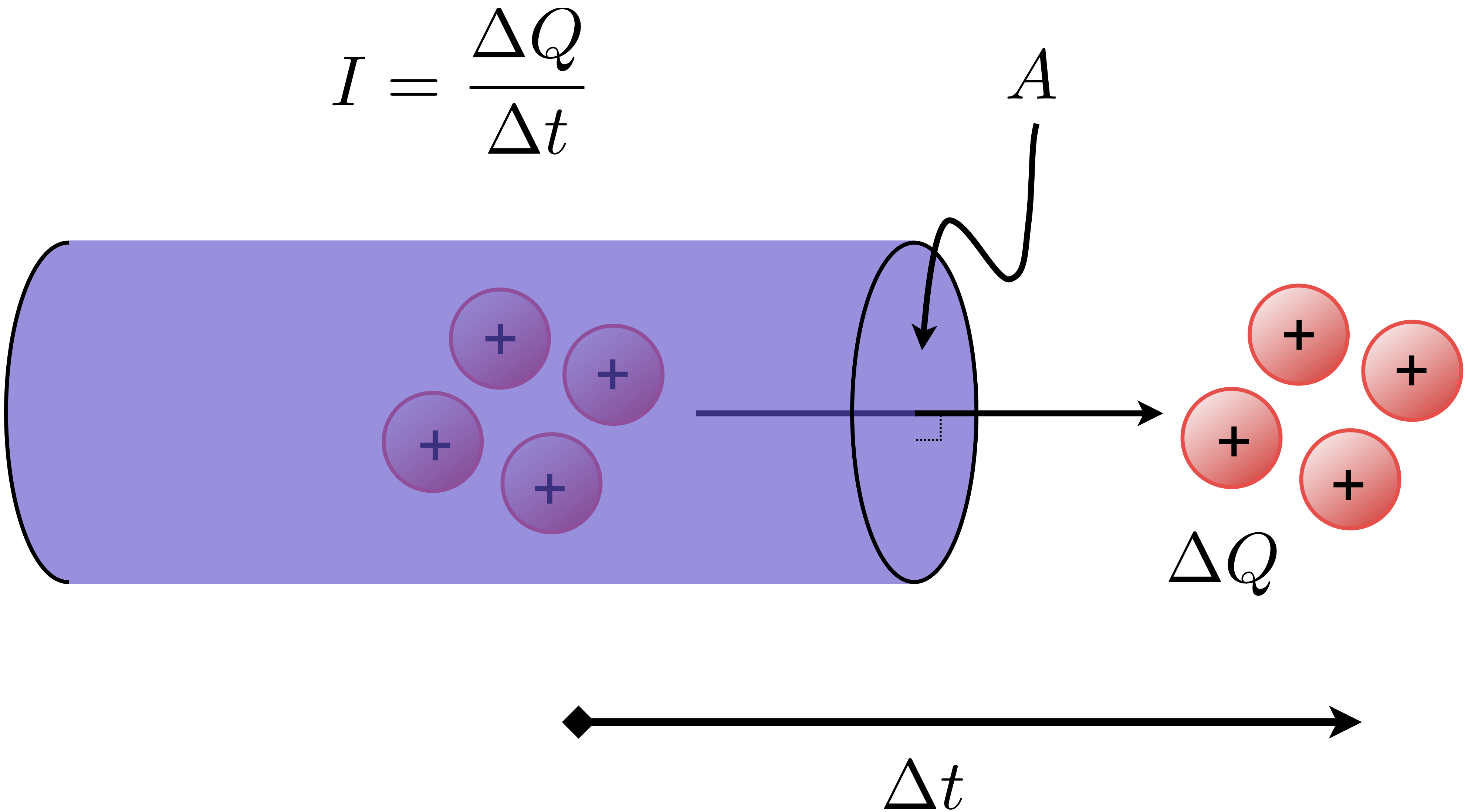


Dielectric κ
C_0
Q_0
κC_0
Q_0
-
+
ΔV_0
DEADCELL
PLUS
-
+
ΔV
DEADCELL
PLUS
(a)
(b)

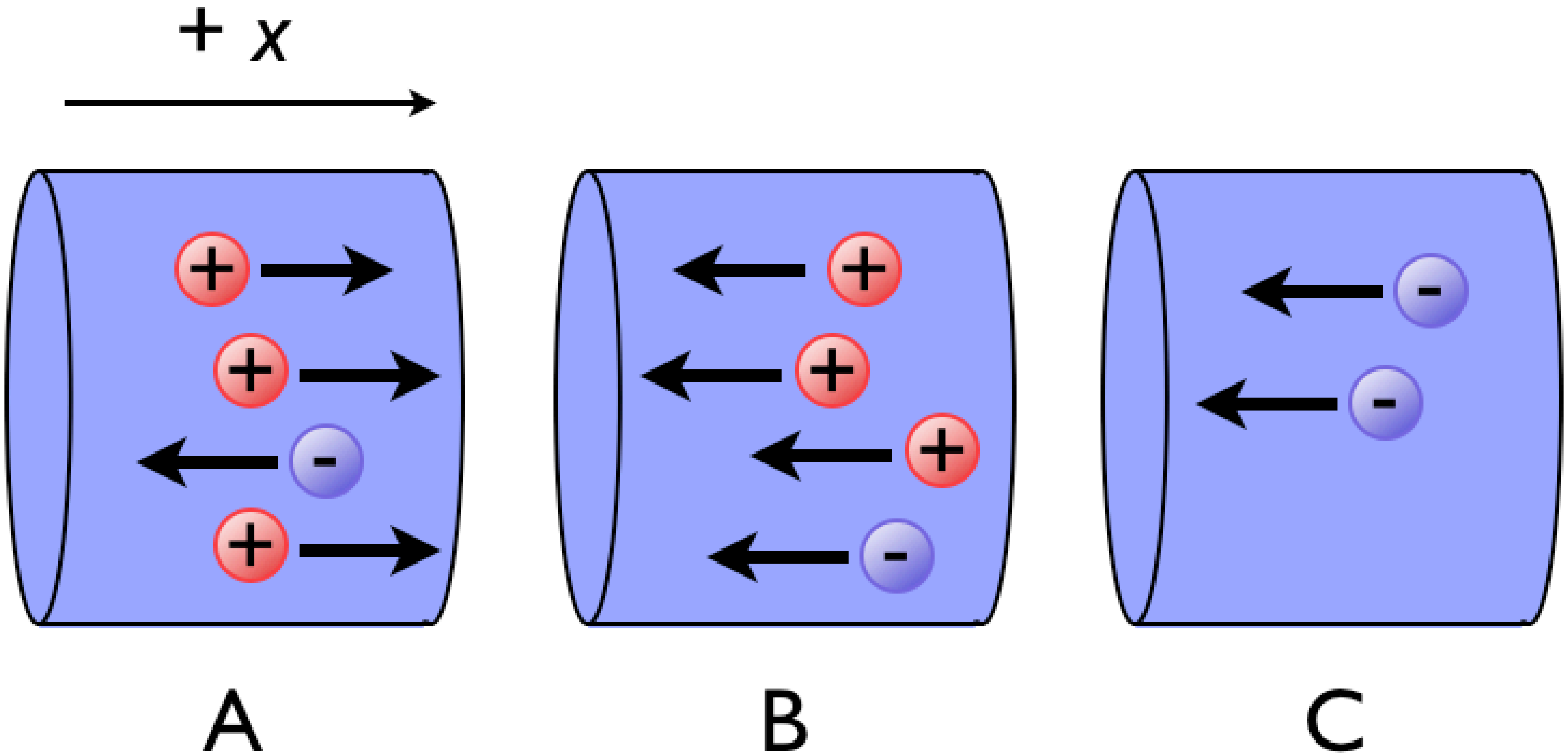


(a)
(b)
(c)
$\vec{E}$


$\vec{E}_{\text{dipoles}}$
$\vec{E}_{\text{plates}}$

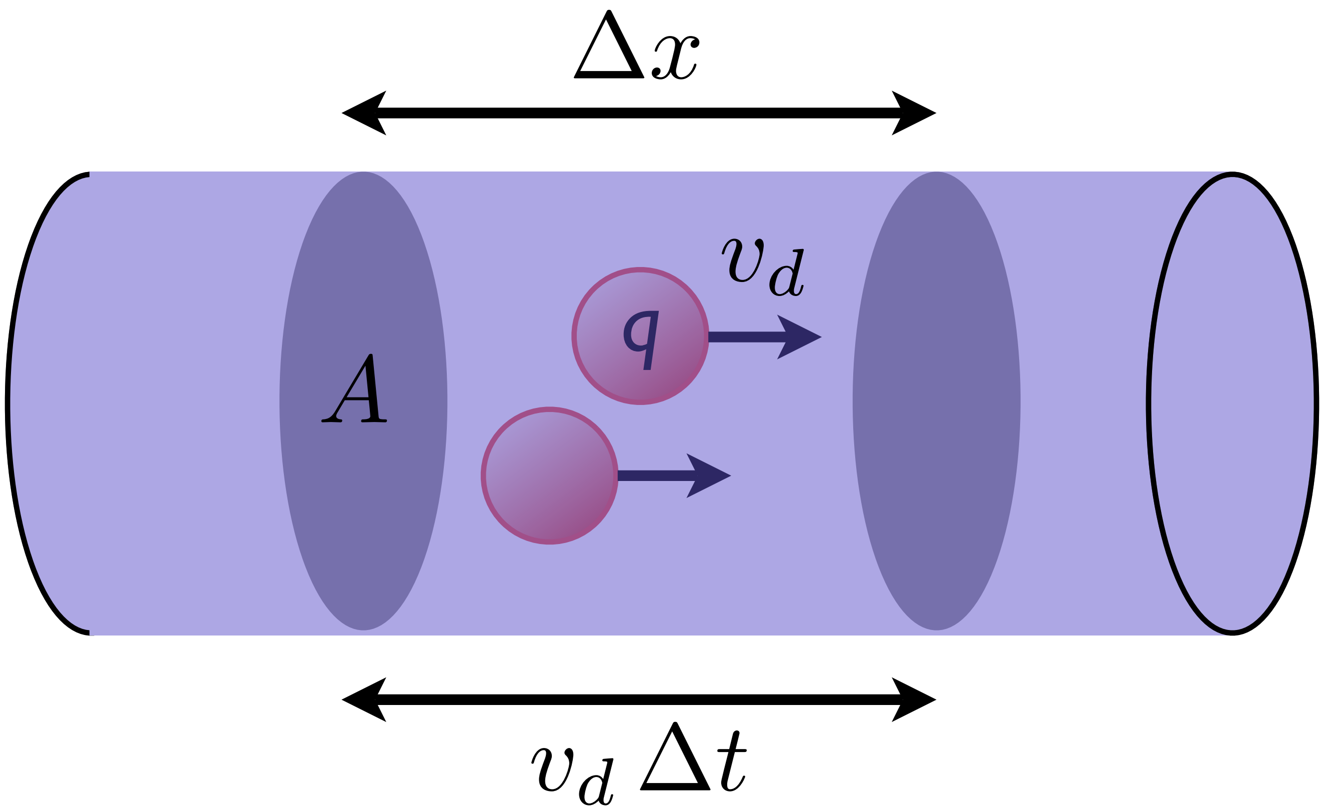


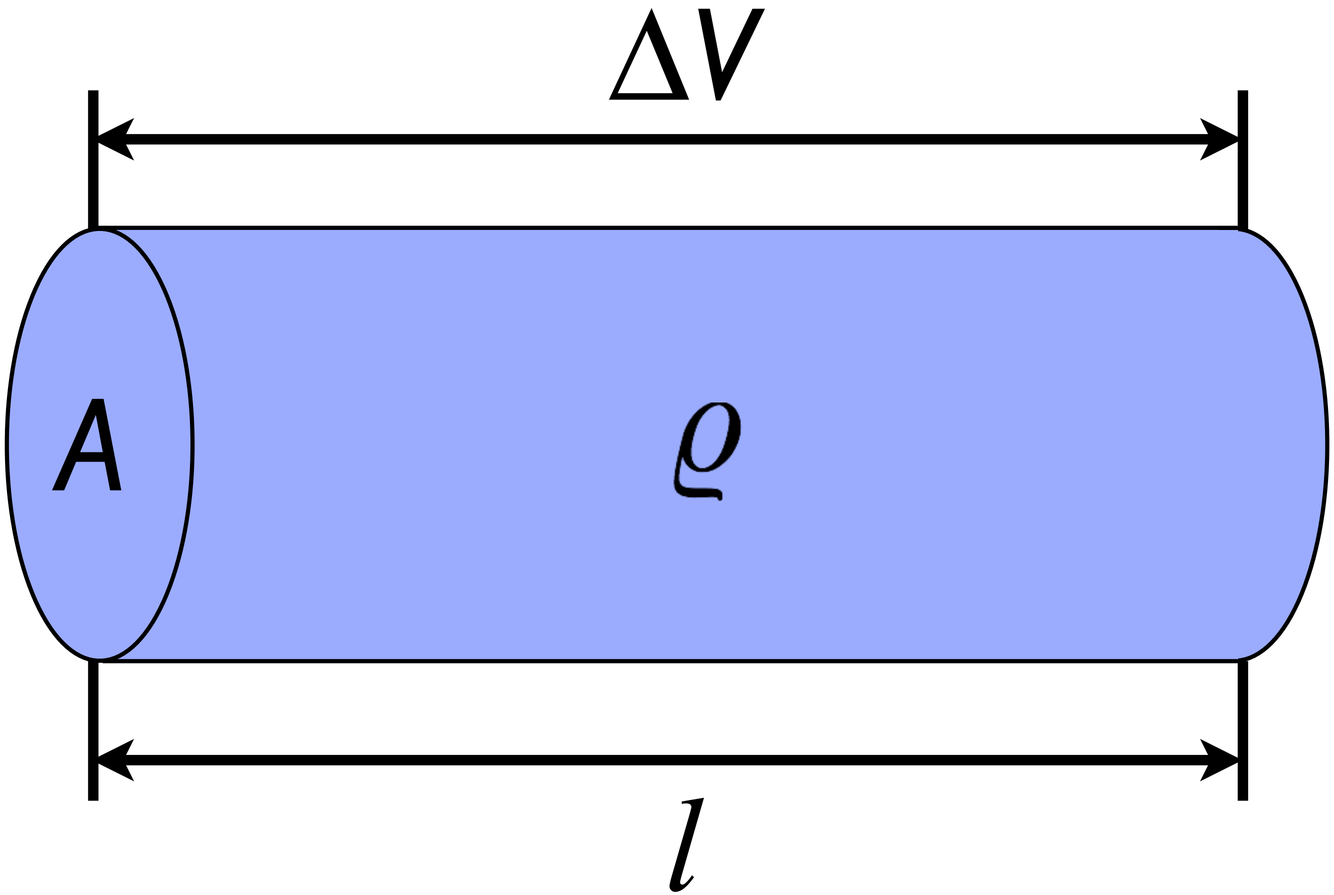
$I = \frac{\Delta Q}{\Delta t}$
A
ΔQ
Δt



+ x
+
+
-
+
+
+
+
-
-
-
A
B
C

not so funny now.

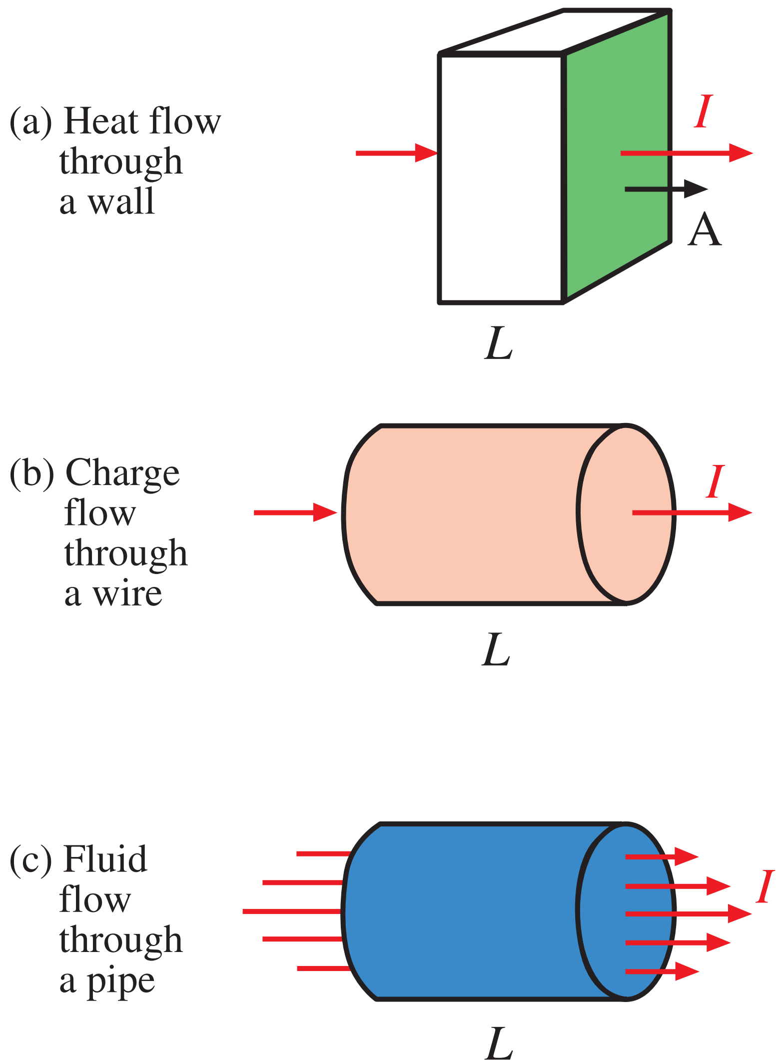

Δx
v_d
q
A
$v_d \, \Delta t$



$$R = \frac{\varrho l}{A} = \frac{\Delta V}{I}$$

I = Cause/Resistance

I is the current, or flow rate, describes different scenes:



Resistance R has the same form in most cases,

$$R = \rho L/A$$

Transport what?	Heat	Electric charges	Displacement of a molecule in a fluid	Volume of fluid
Current form (items/second)	$I = -\Delta T/R$	$I = -\Delta V/R$	$v_{av} \equiv I = -\Delta P/R$	$I = -\Delta P/R$
Current units	J/s or W	C/s or amperes	m/s	m^3/s
Resistance form	$R = \rho L/A$	$R = \rho L/A$	$R = \rho L/A$	$R = \rho L/A^2$
Detail of ρ (resistivity)	ρ = 1/heat conductivity	ρ = electrical resistivity	$\rho = 6\eta\pi$	$\rho = 8\eta\pi$

battery = pump

voltage = pressure

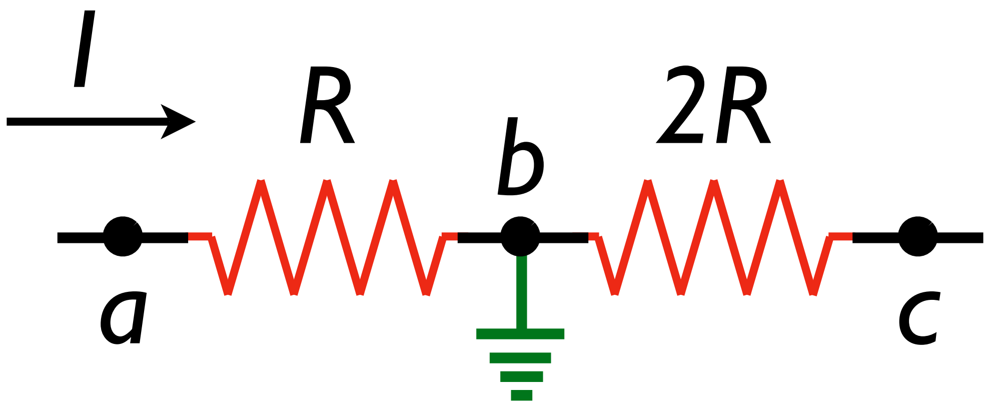
current = flow

resistor = constriction

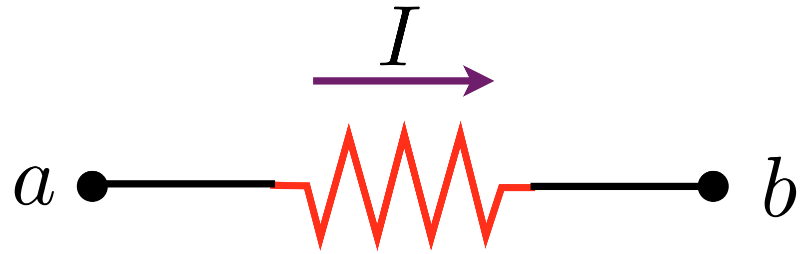
capacitor = diaphragm / flexible reservoir

diode = check valve

inductor = paddle wheel

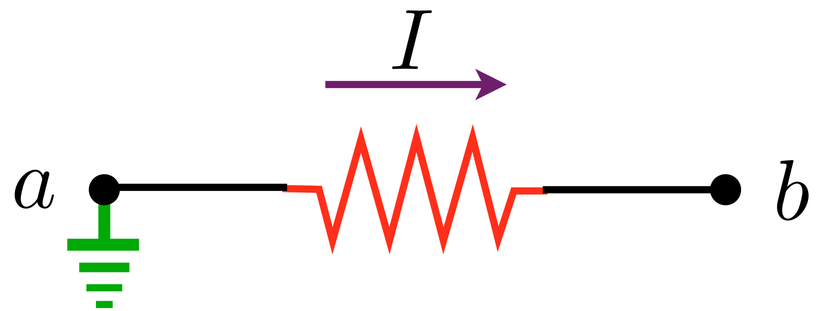

I
R
2R
a
b
c

(a)



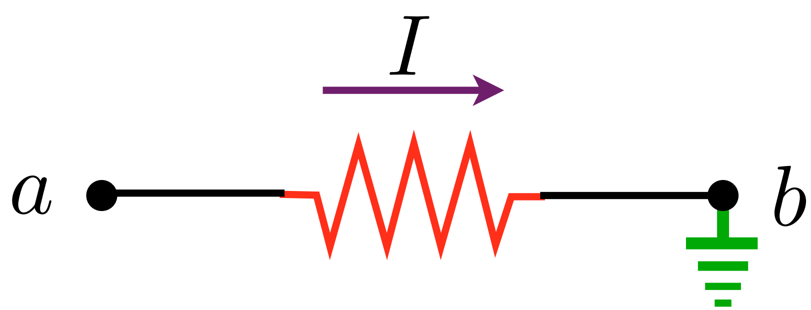
$$\Delta V = V_b - V_a = -IR$$

(b)

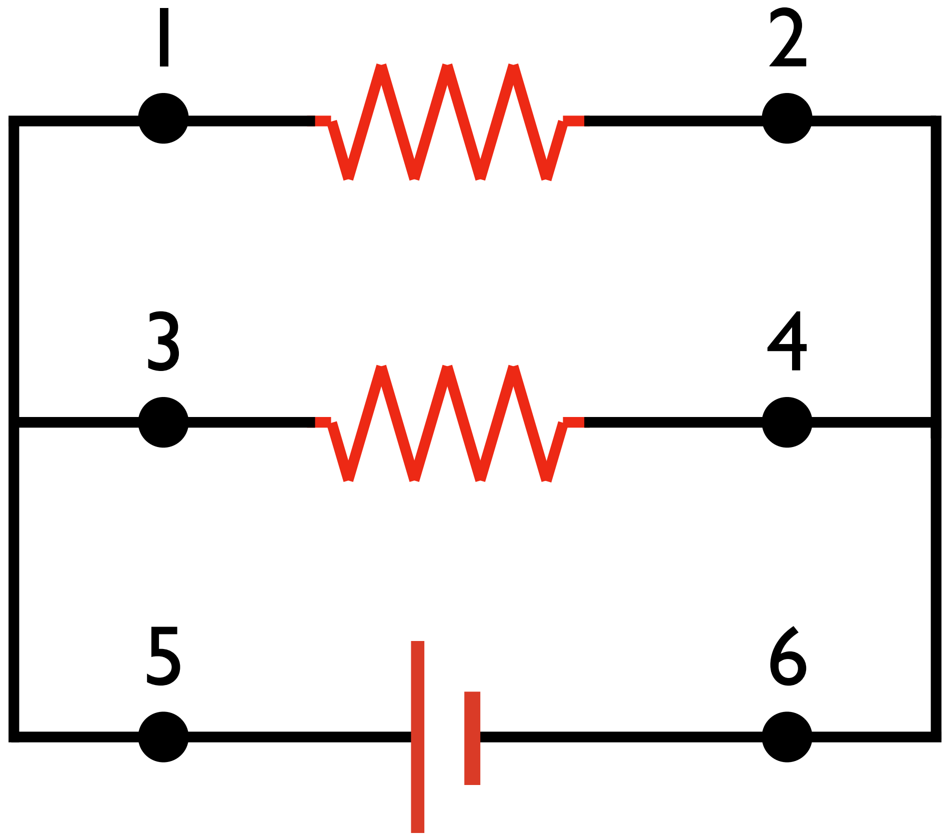


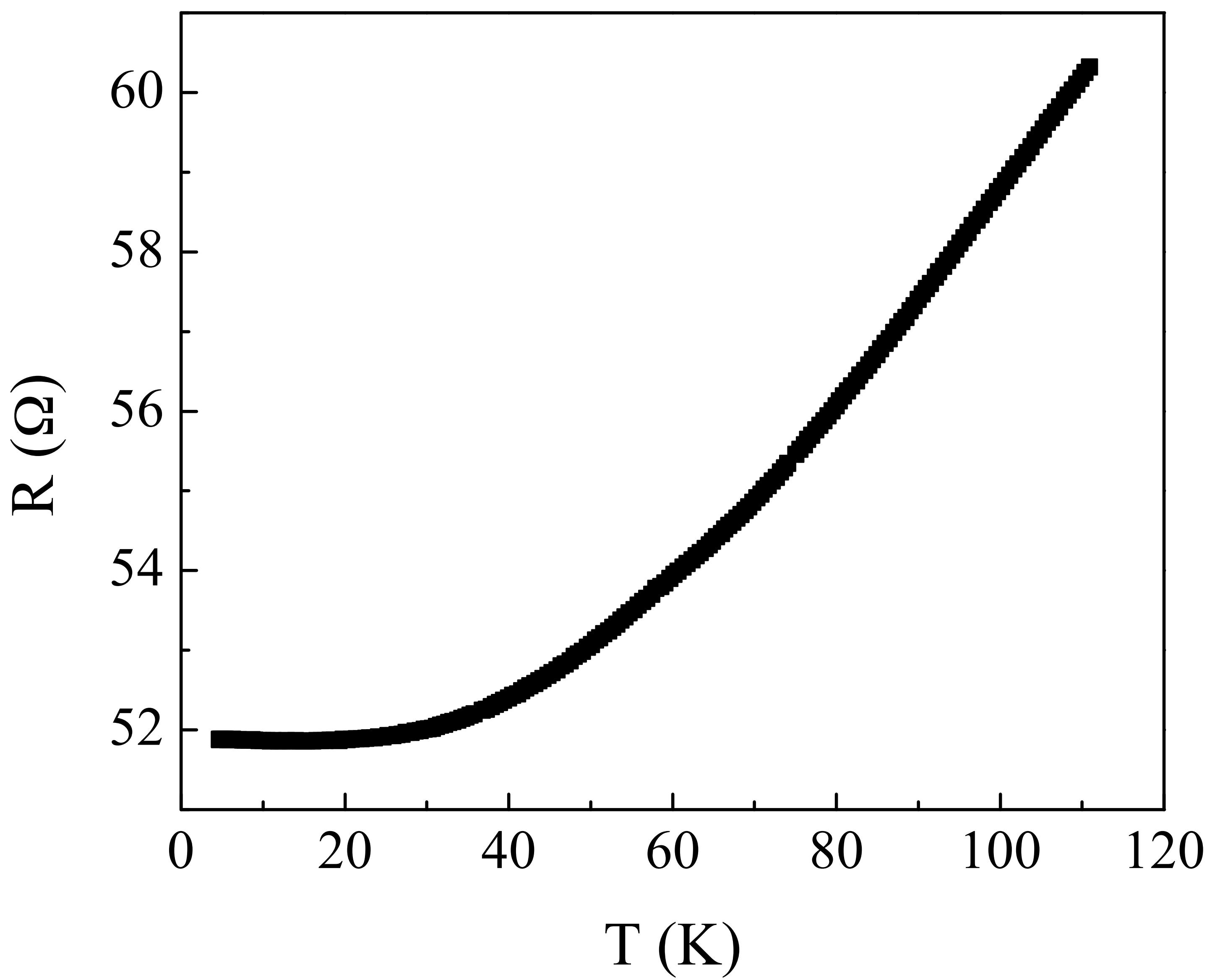
$$V_a = 0 \quad V_b = -IR$$

(c)

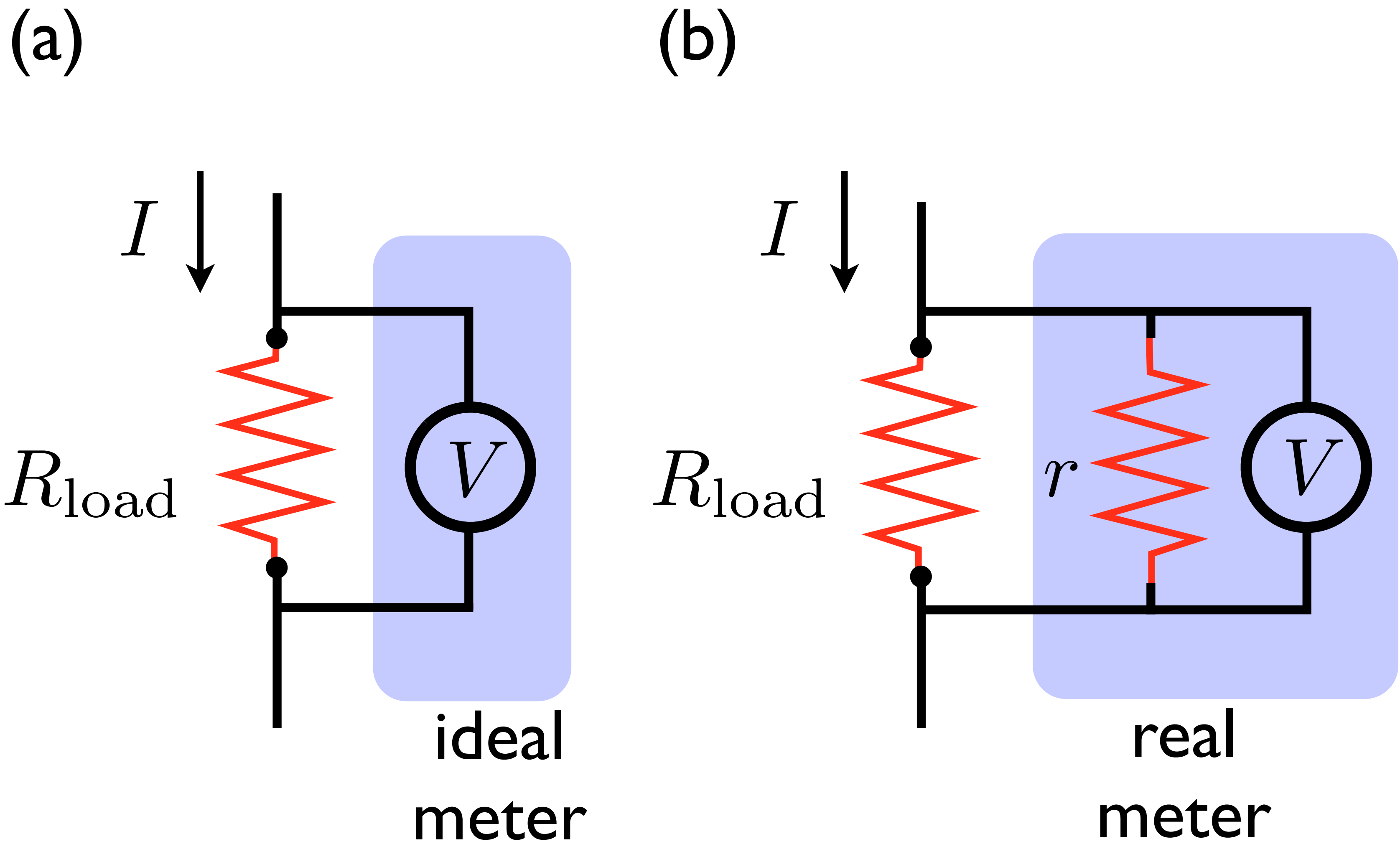


$$V_a = +IR \quad V_b = 0$$

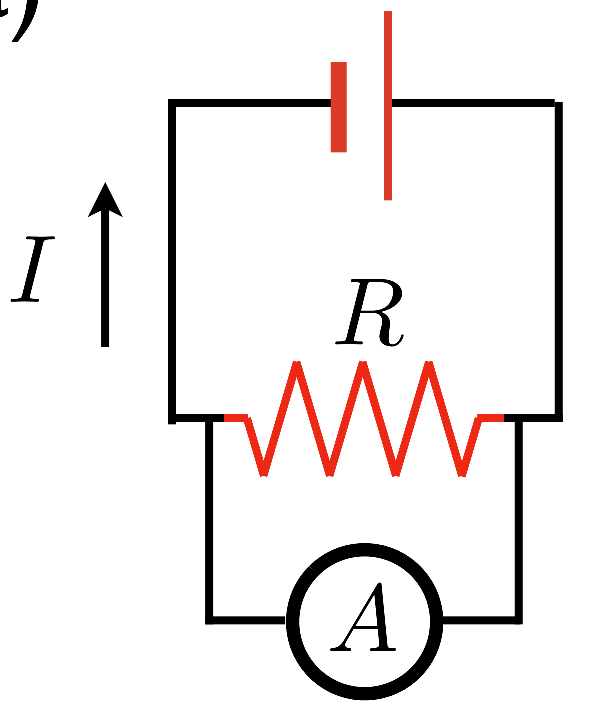

1
2
3
4
5
6



R (Ω)
60
58
56
54
52
0
20
40
60
80
100
120
T (K)

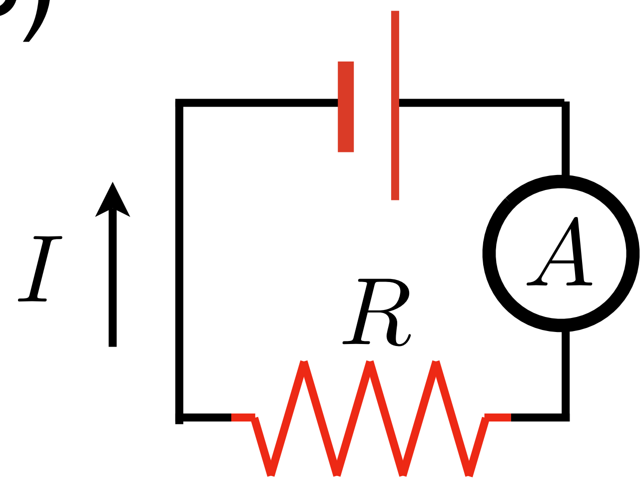

(a)
(b)
I
I
R_load
R_load
r
V
V
ideal meter
real meter

a)

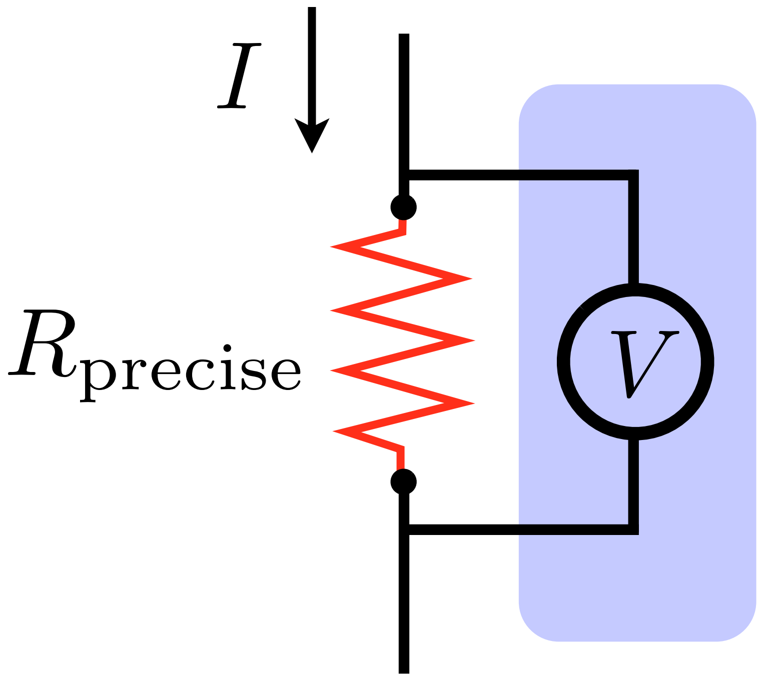


! INCORRECT !

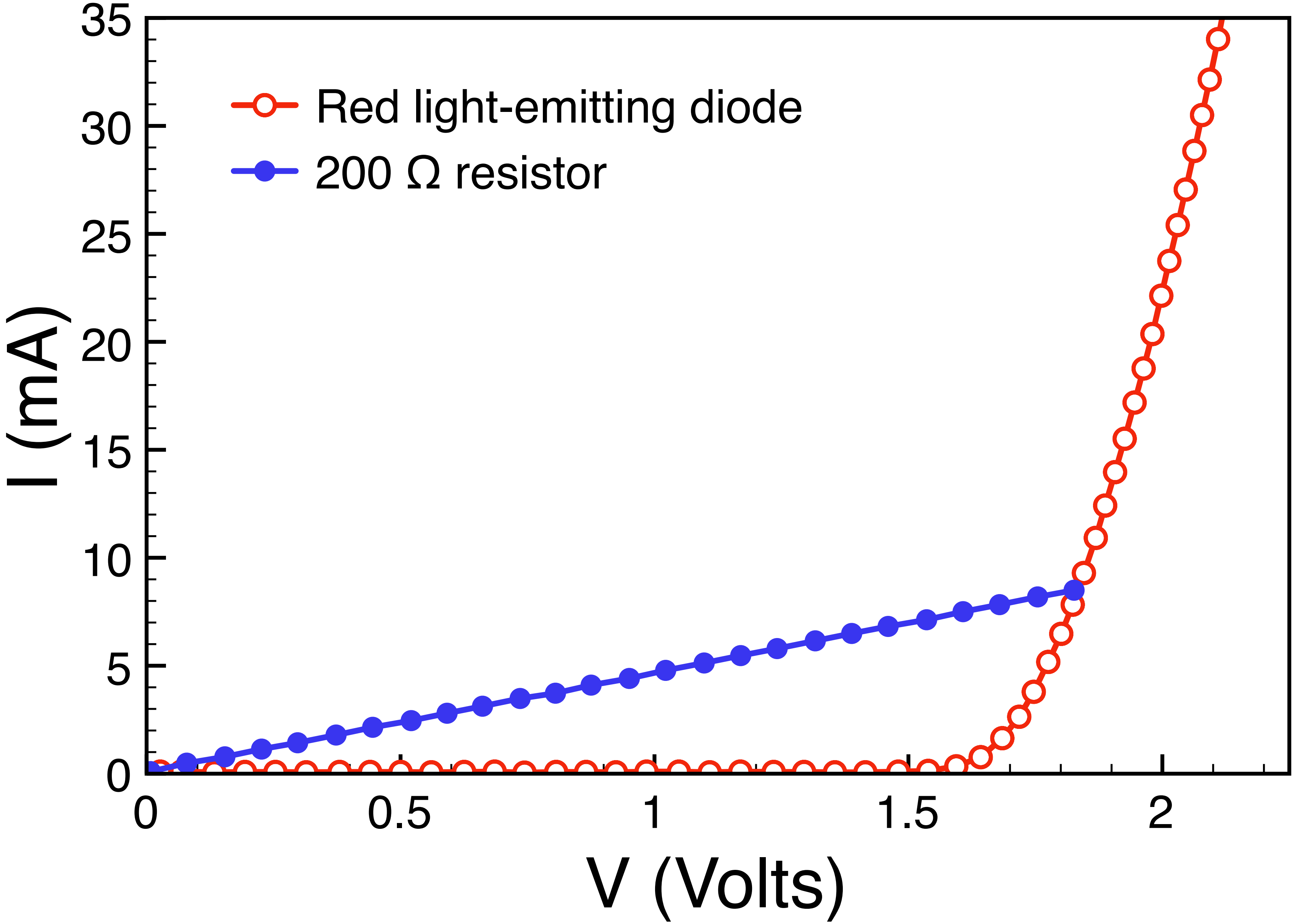
b)



CORRECT



I
R_{precise}
V



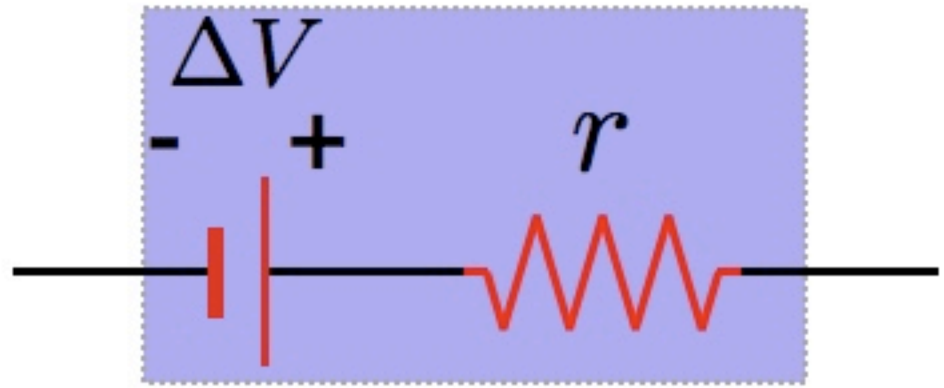
Red light-emitting diode
200 Ω resistor
I (mA)
V (Volts)
0
5
10
15
20
25
30
35
0
0.5
1
1.5
2

with the time left ...

let's get a jump on dc circuits

real battery = ideal battery + R

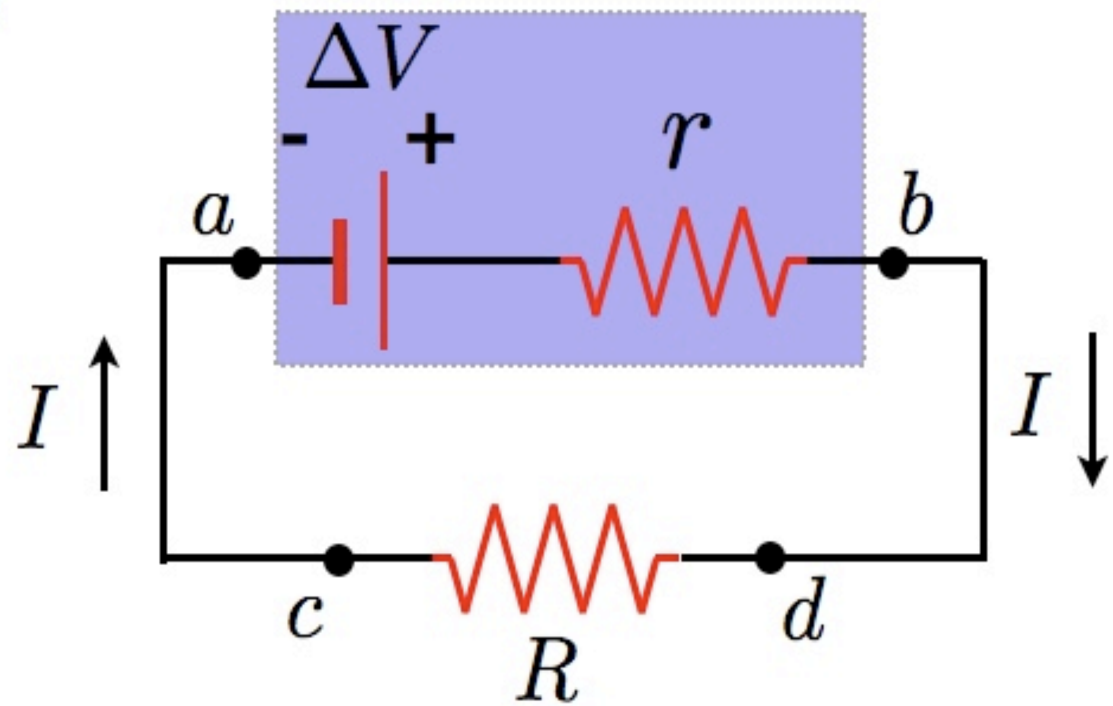
=



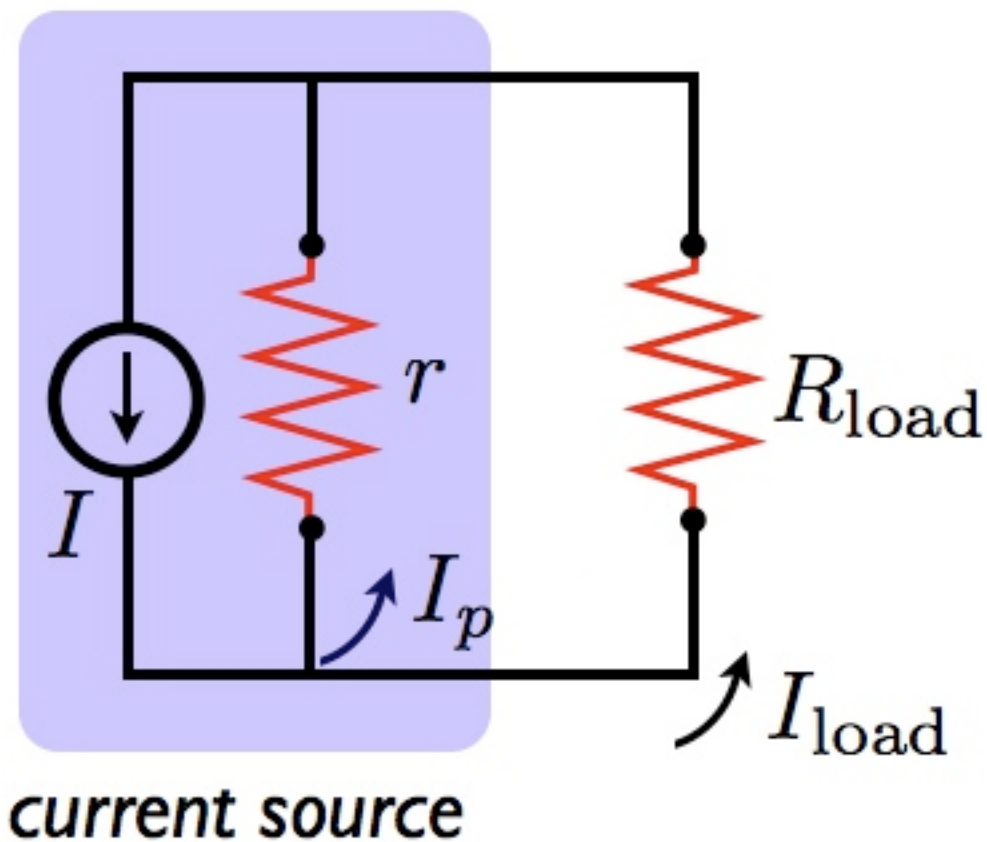
actual circuit has a parasitic r

a)

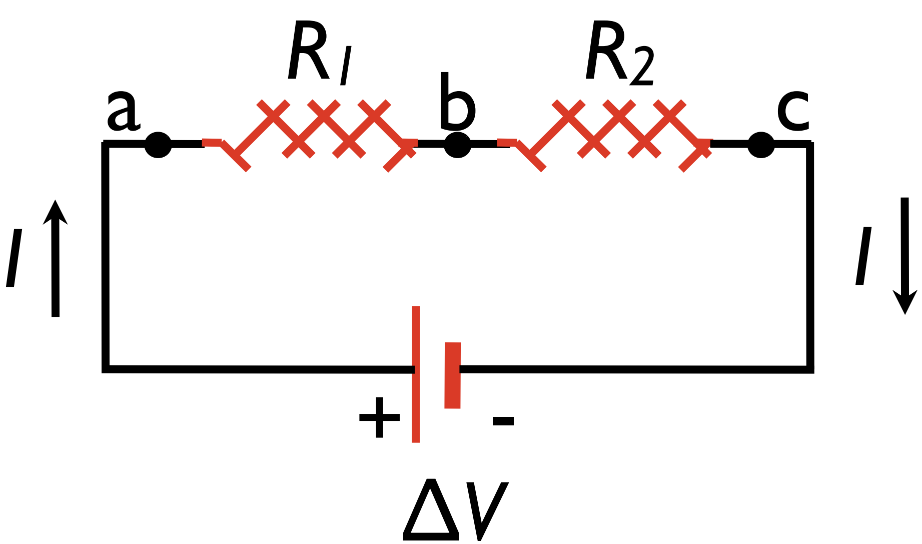
b)

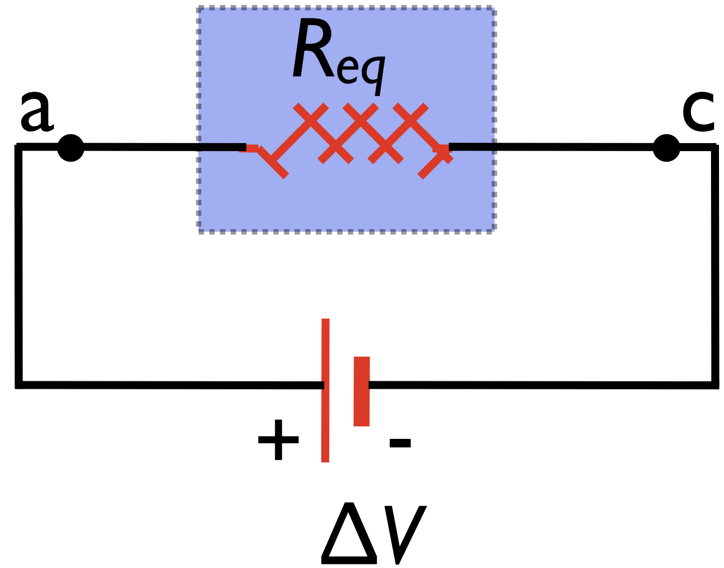


real current sources



series resistors: conservation of energy





Two Resistors in Series:

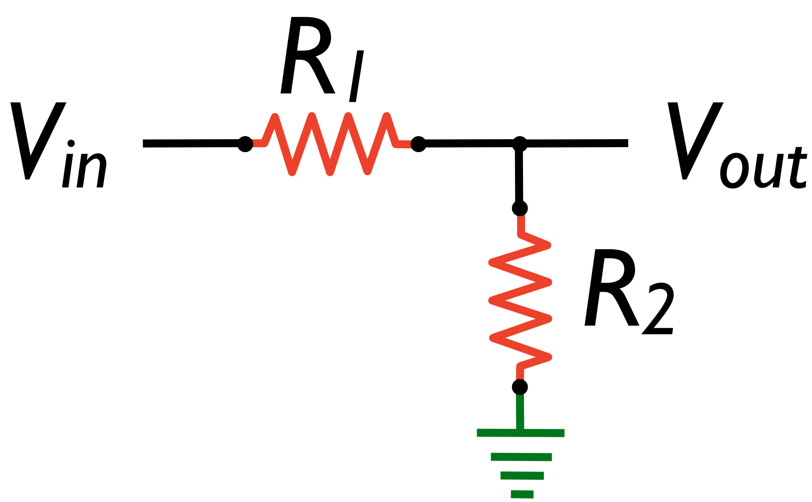
$$R_{\text{eq}} = R_1 + R_2$$

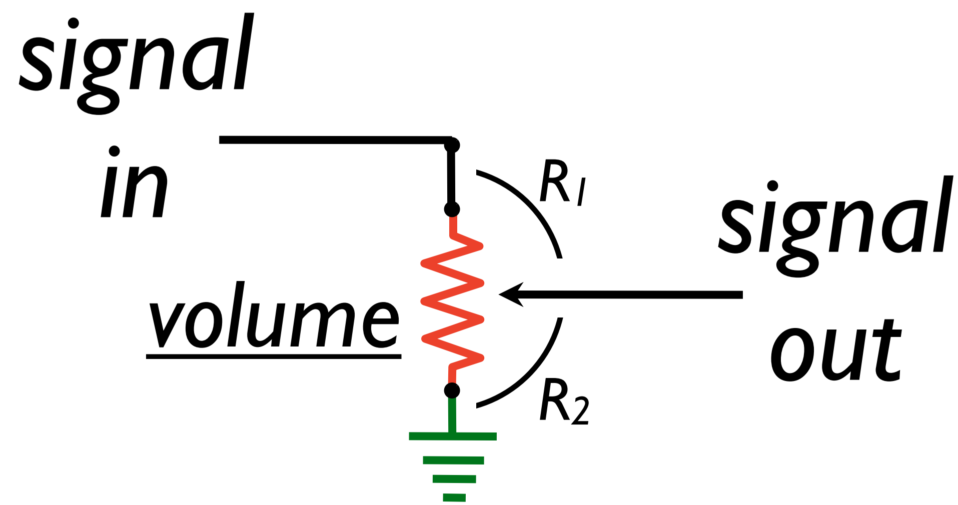
Three or More Resistors in Series:

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

The current through resistors in series is the same.

voltage divider

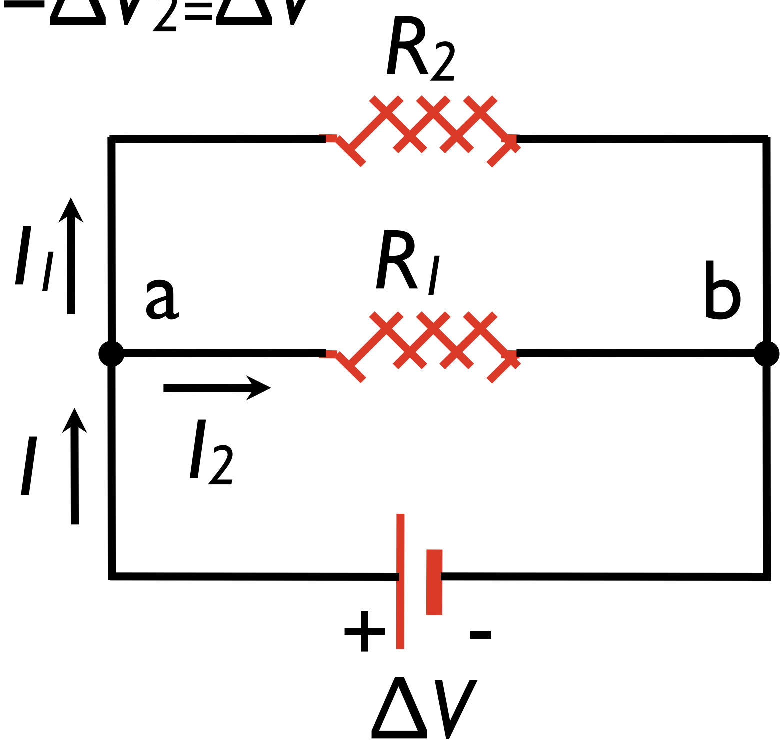




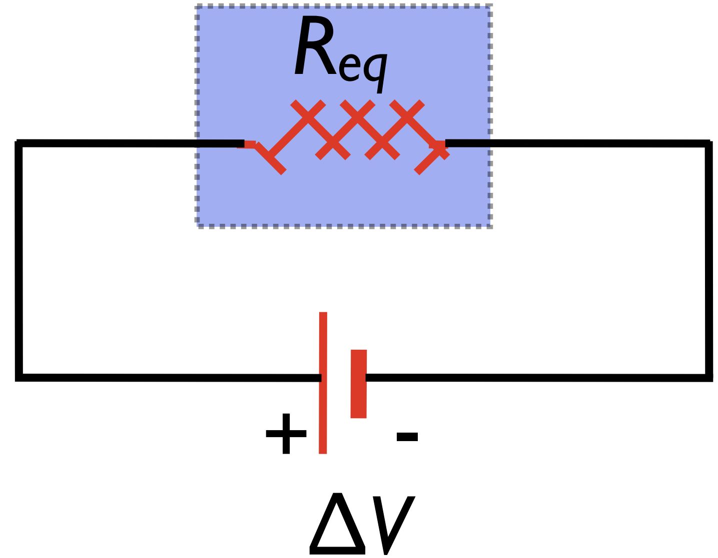
$$V_{out} = \frac{R_2}{R_1+R_2} V_{in}$$

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:

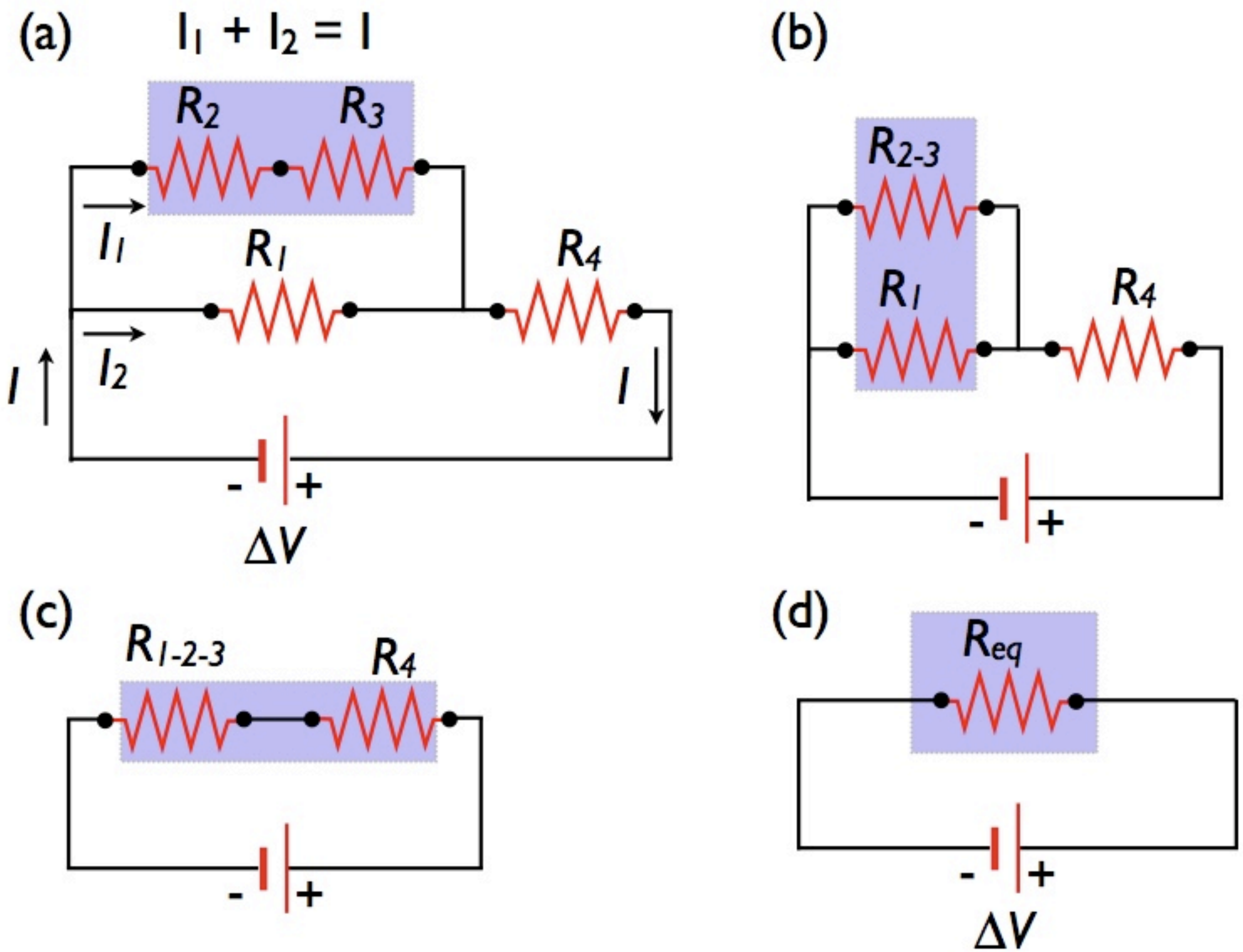
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Three or More Resistors in Parallel:

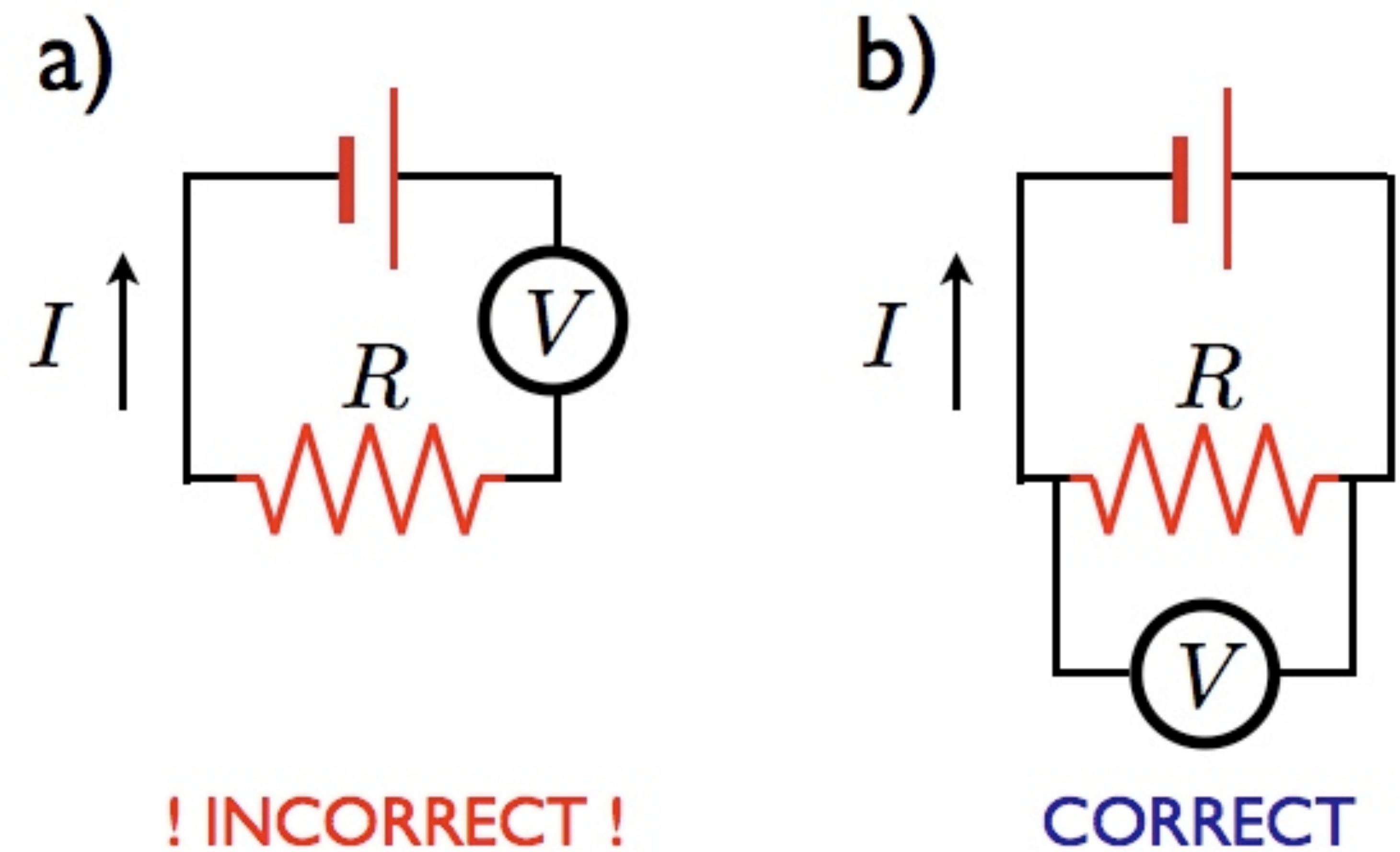
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

current divider

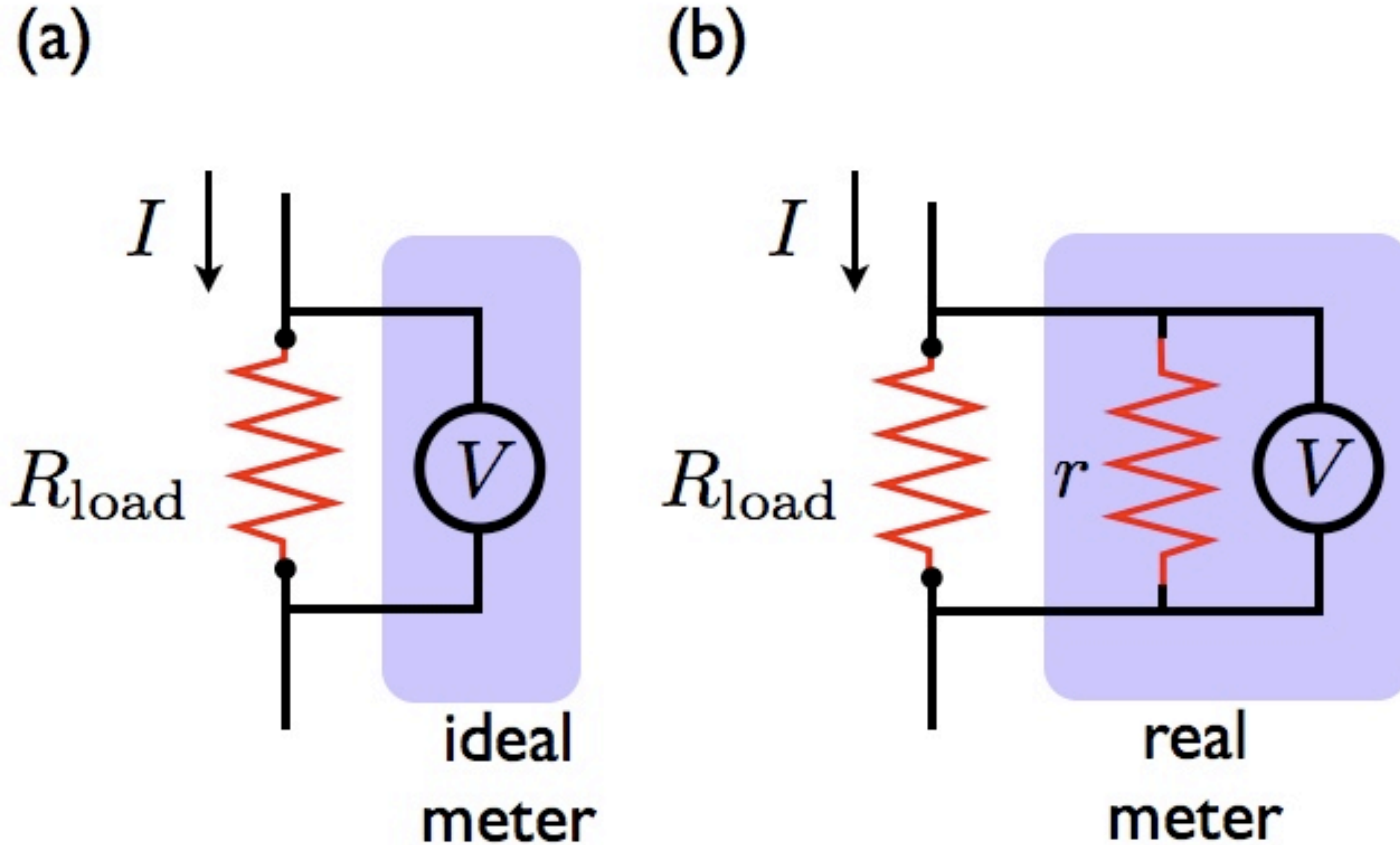
more complex arrangements



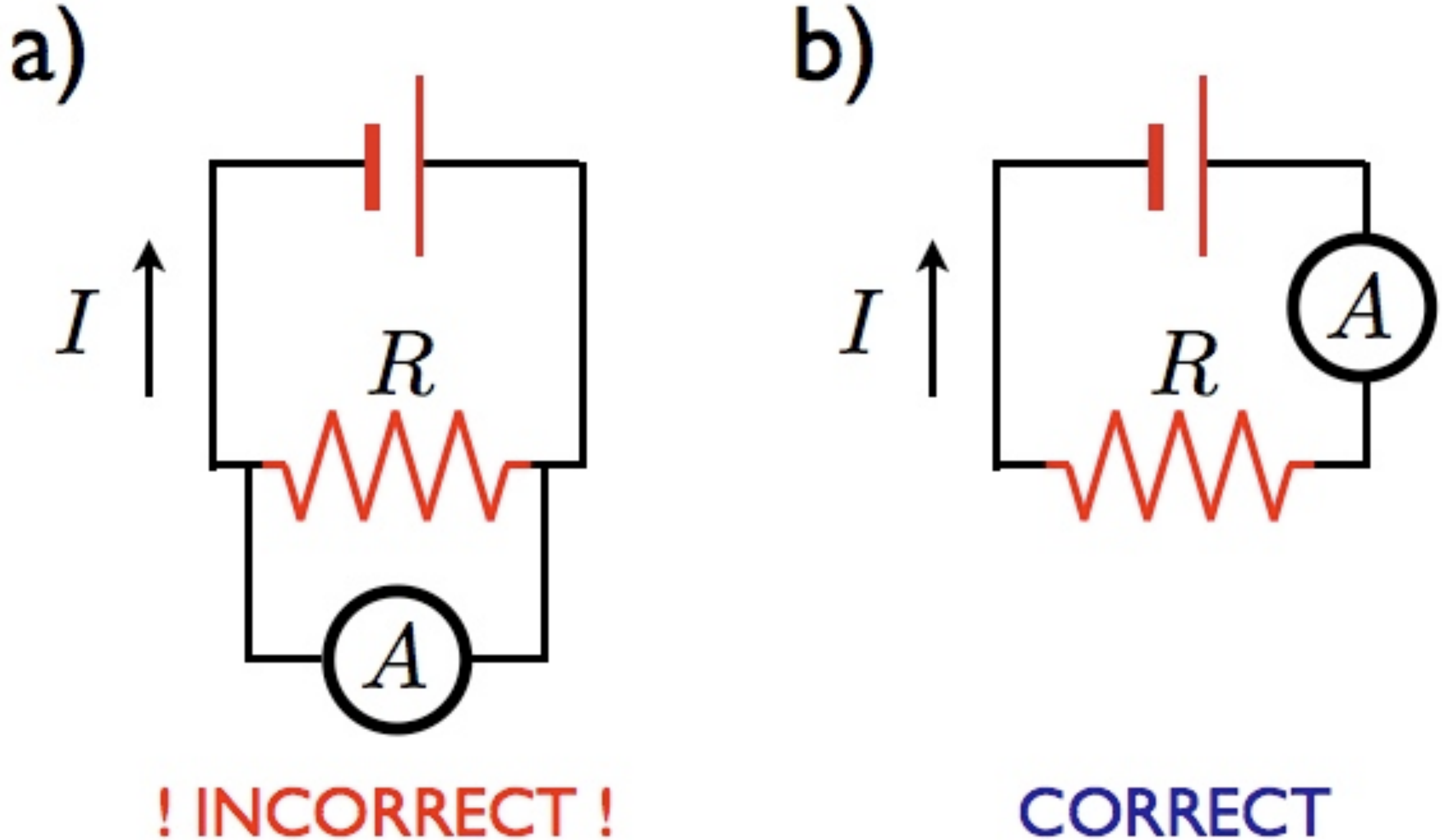
measuring voltage



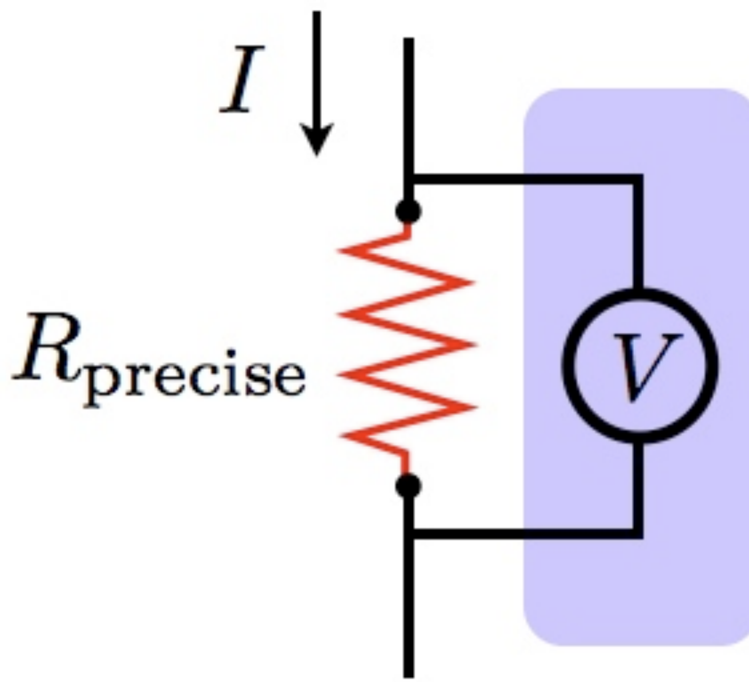
real voltmeters



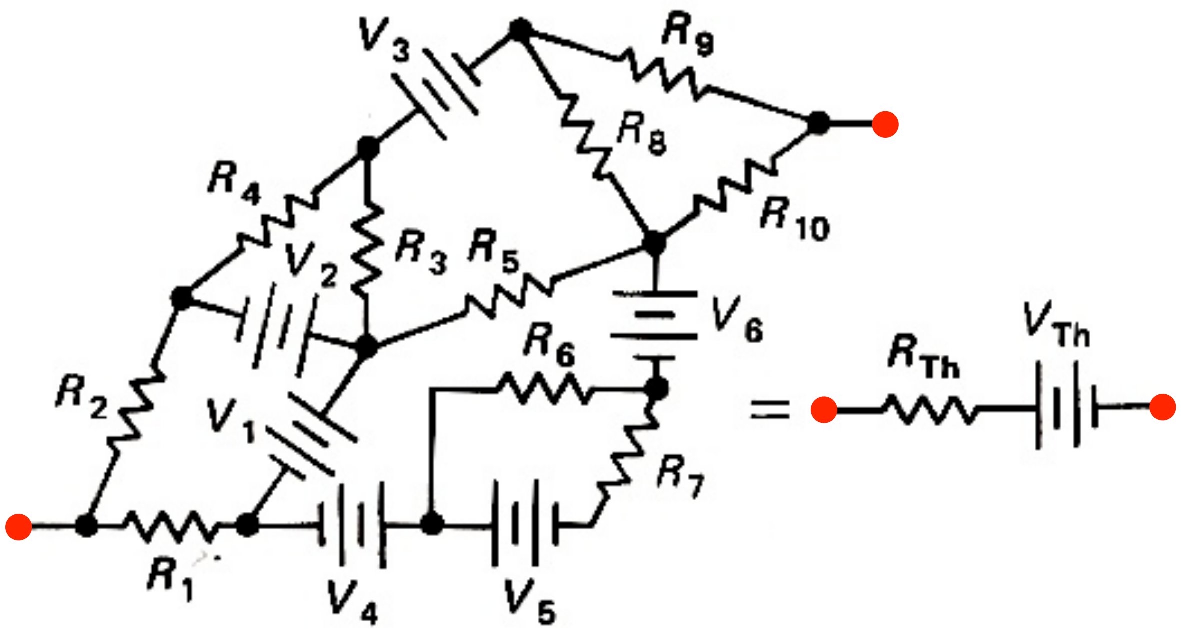
measuring current



a simple ammeter



Thévenin equivalents



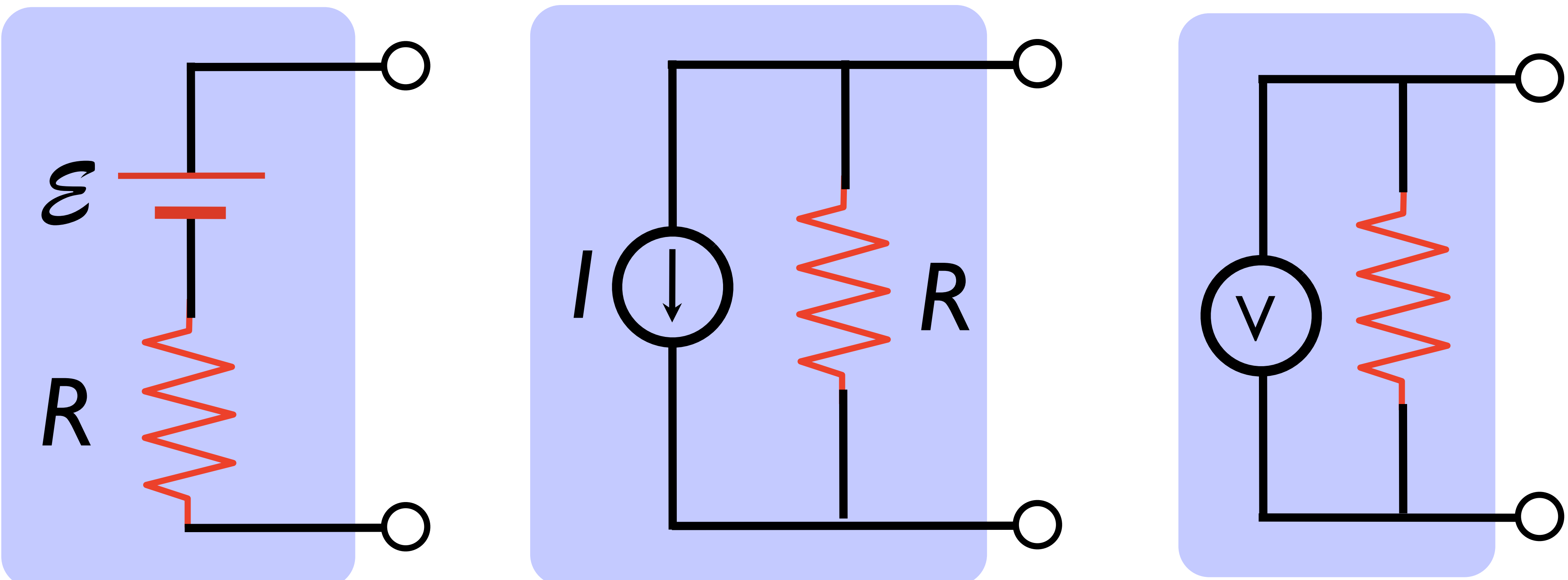
V_{th} = V (open circuit)

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

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)

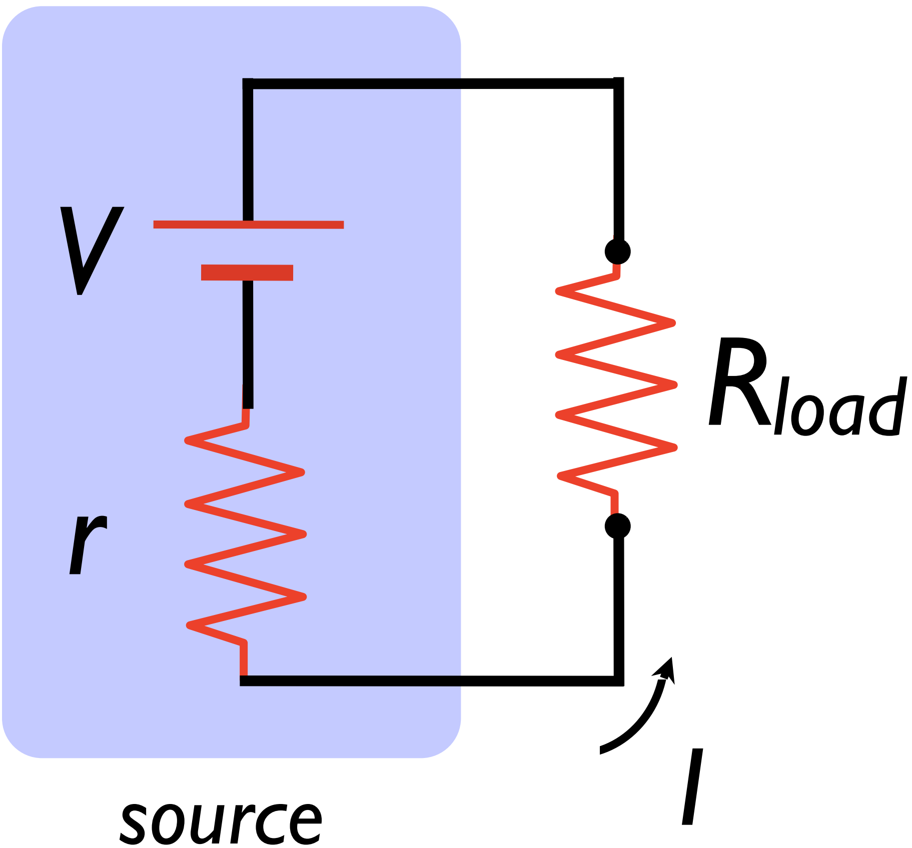
so what?



real sources =
ideal sources + R

real meter =
ideal meter with R

V source loading



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

for $r \ll R_{load}$,

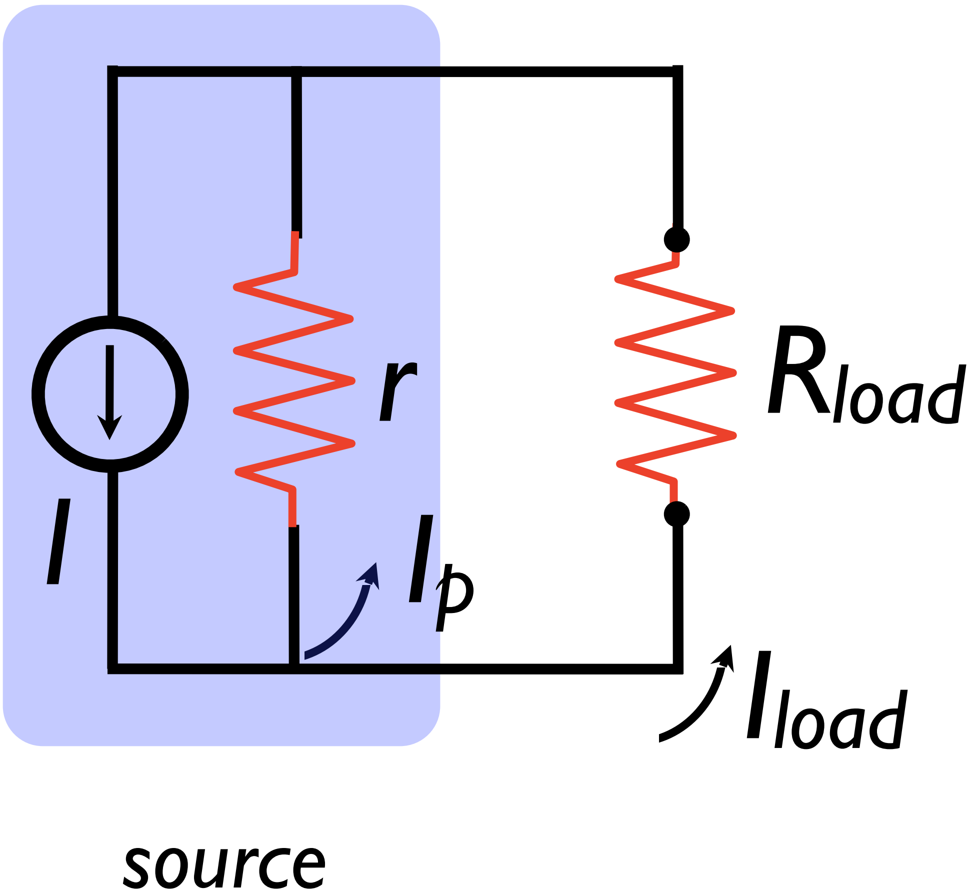
$$\Delta V_{load} \approx V$$

V source wants R **high**

like a battery

one easy solution:
large resistor in parallel with load

I source loading



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

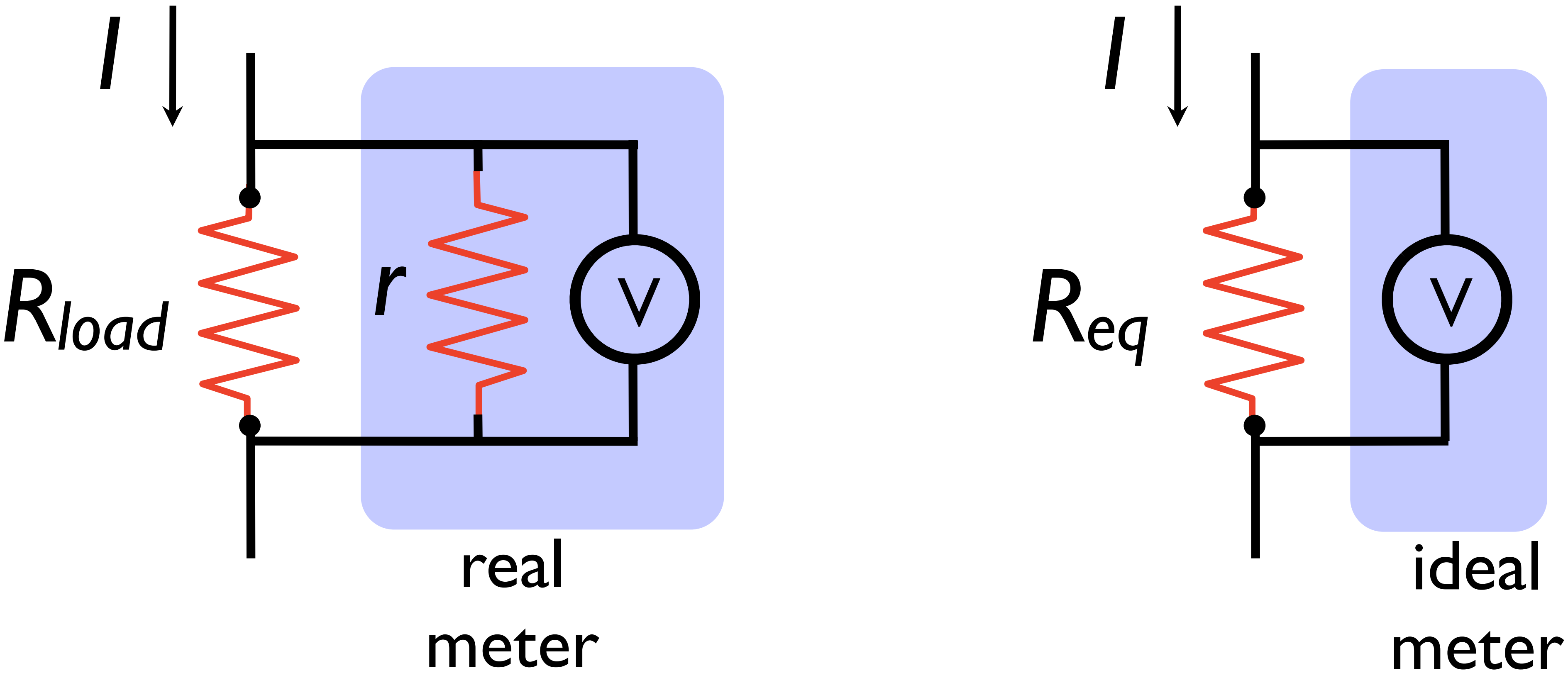
for $R_{load} \ll r$,

$$I_{load} \approx I$$

I source wants R **low**

sourcing currents at high R_{load} is hard

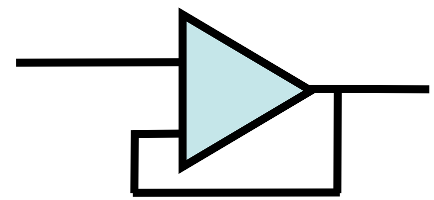
measuring the meter



$$\Delta V_{load} = IR_{eq} = \frac{R}{1+R/r} I$$

$$R_{load} \ll r, \ \Delta V_{load} \approx IR$$

summary



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

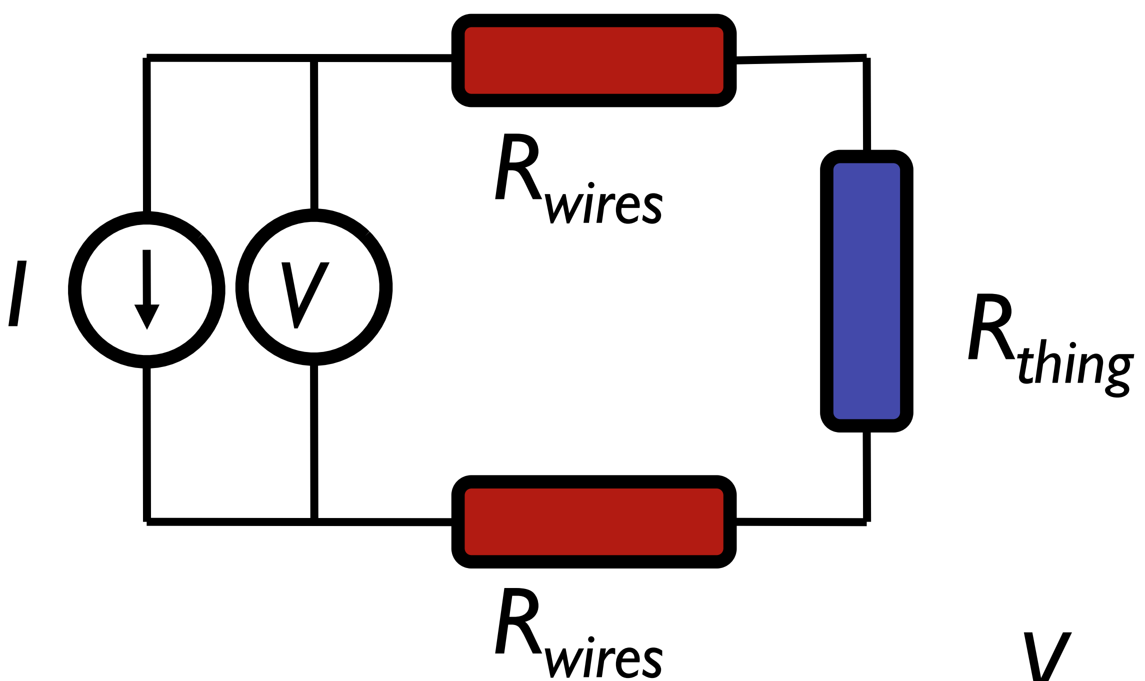
I source wants R **low**
transformer pre-amp
consider sourcing V

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

Sourcing current

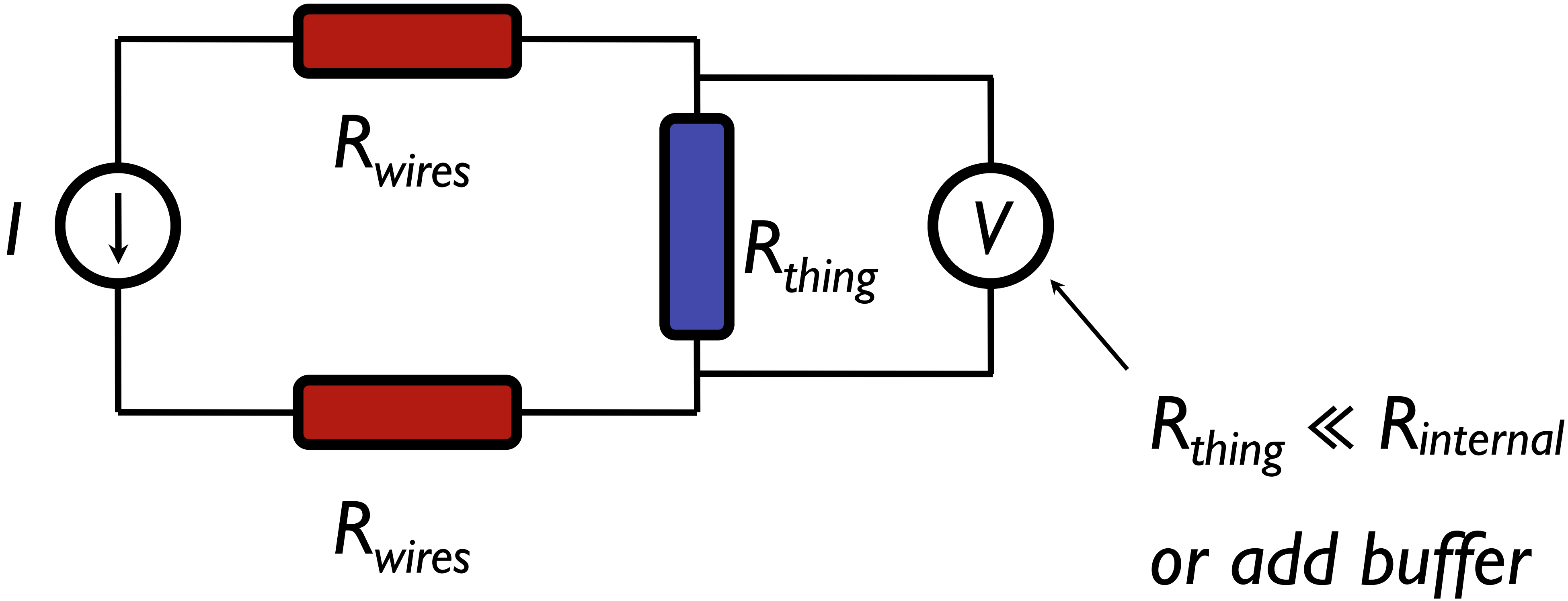
This is what a hand meter does.

Why is it no good?



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

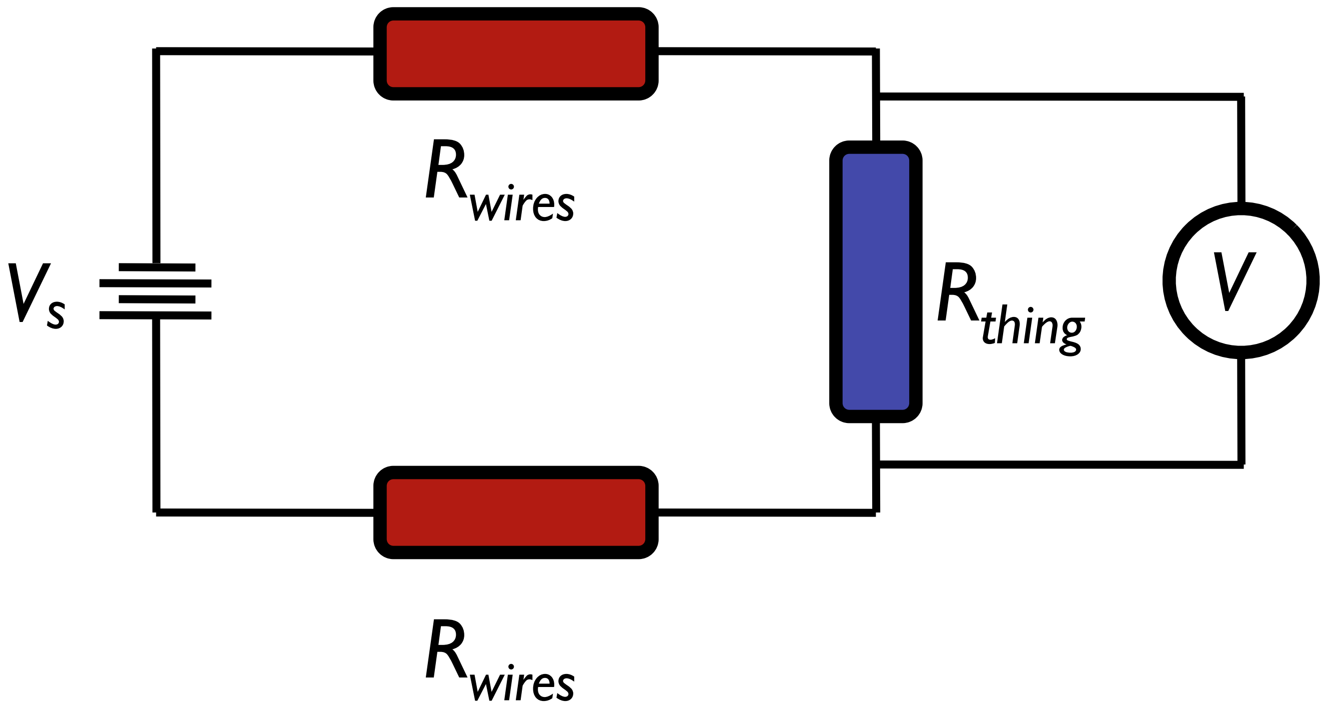
Sourcing current, properly



No problem.
You just need four wires.

What is still wrong?

Sourcing voltage

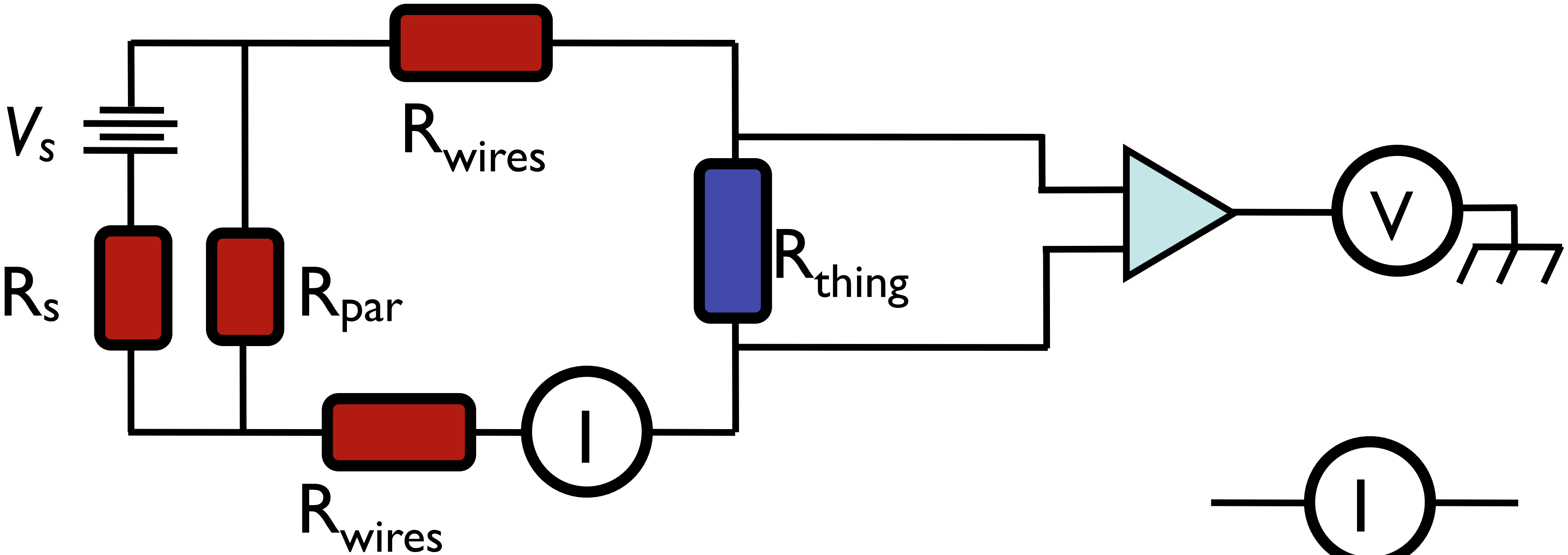


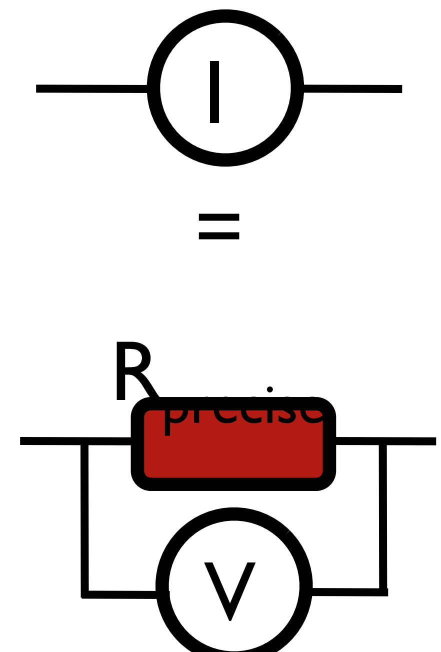
Still have to measure voltage on device

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?

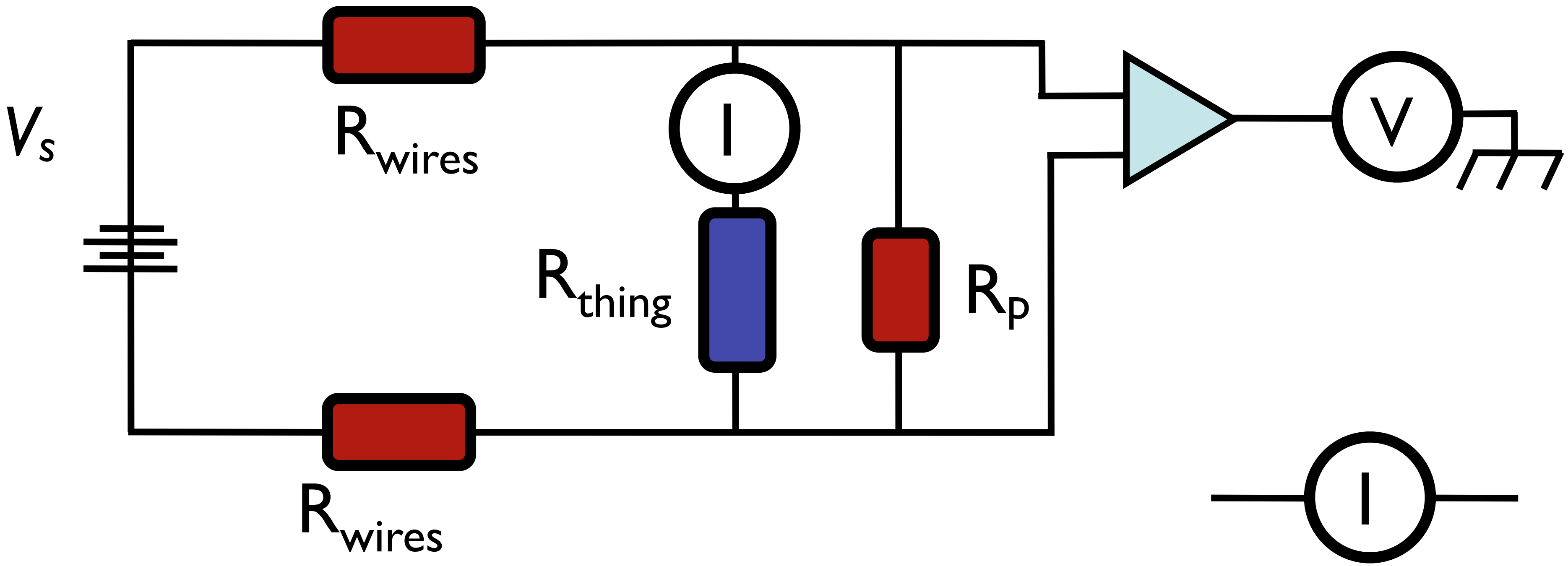
source/meter resistances

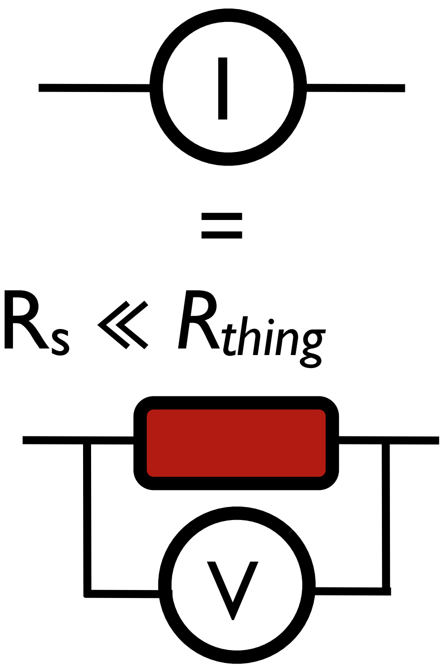
voltmeter wants R low
but V source wants R high

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?





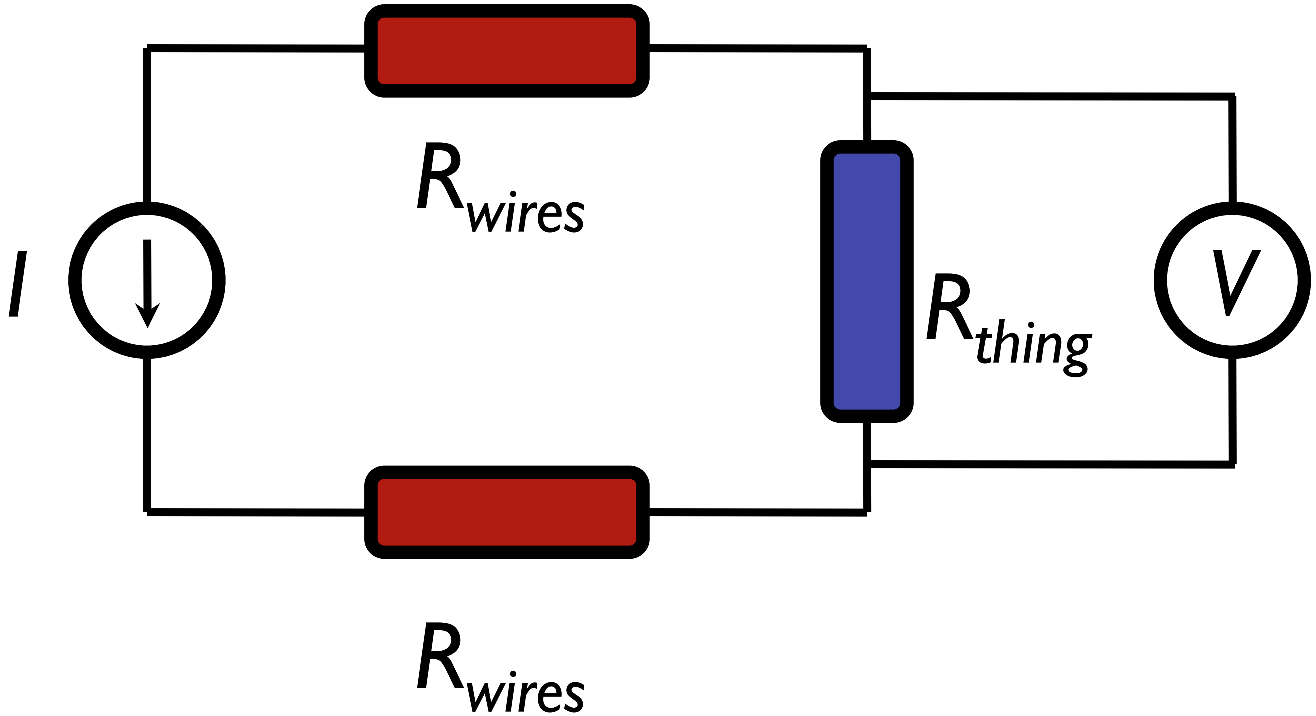
source *voltage*

R_p has same voltage as R_{thing}

R_s has same current

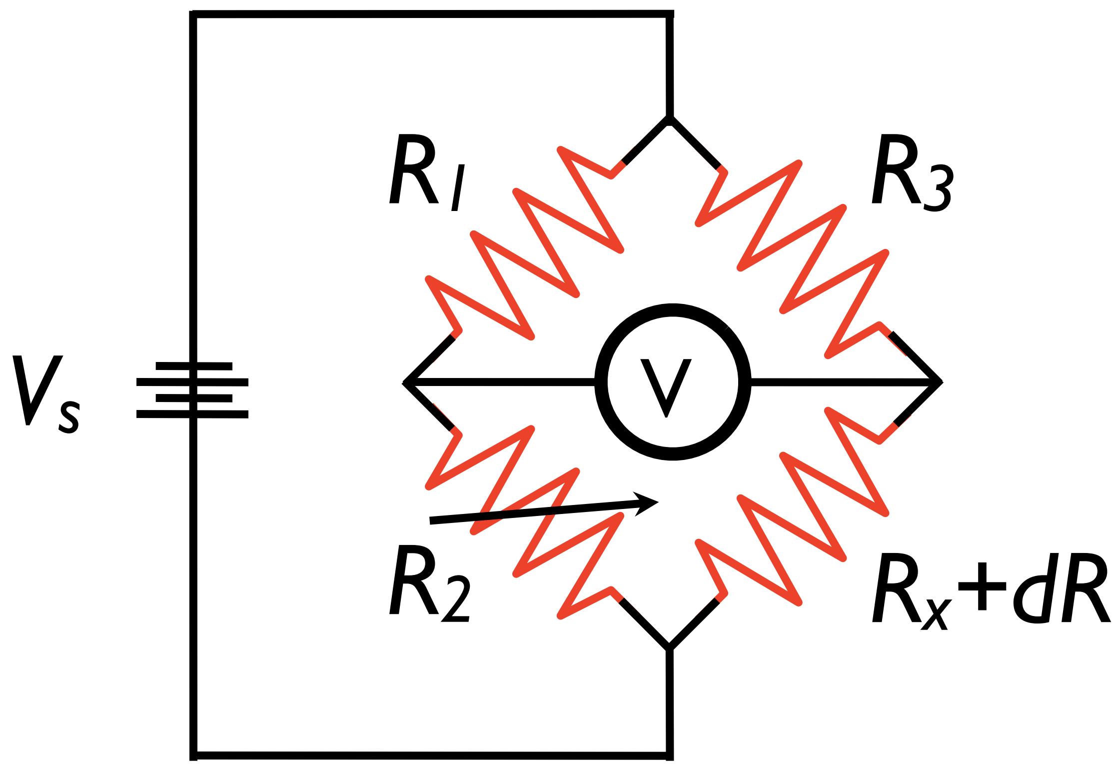
have done $>10^{10}$ Ohm

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

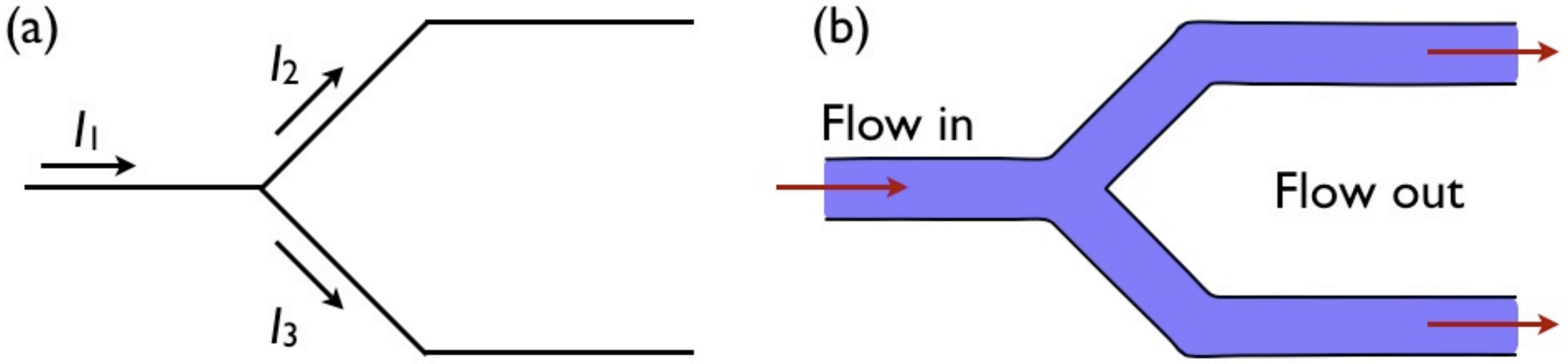
R_2 = 

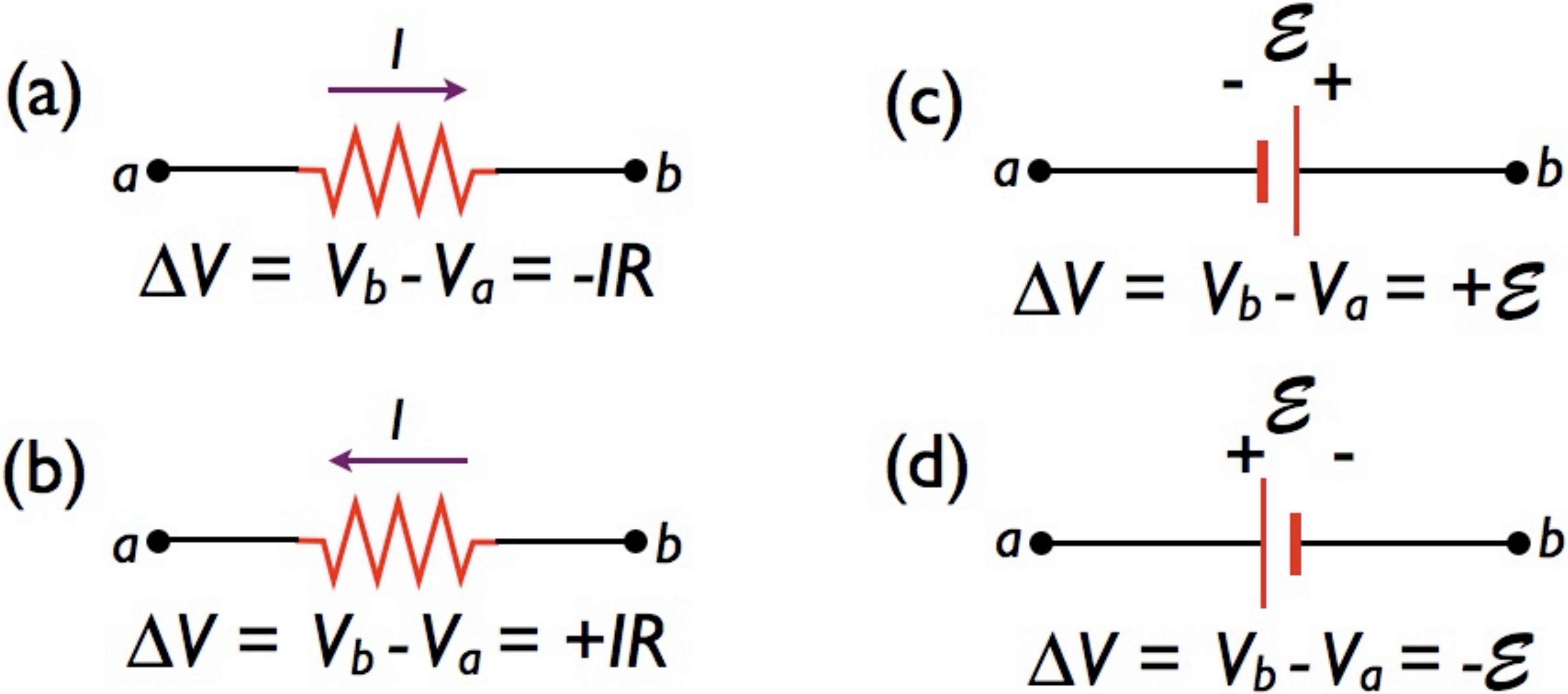
make R_1-R_3 about the same ≈ R_3

trimming resistor on R_2 = dR

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

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


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


(a)
I
a
b
$\Delta V = V_b - V_a = -IR$
(b)
I
a
b
$\Delta V = V_b - V_a = +IR$
(c)
$\mathcal{E}$
-
+
a
b
$\Delta V = V_b - V_a = +\mathcal{E}$
(d)
$\mathcal{E}$
+
-
a
b
$\Delta V = V_b - V_a = -\mathcal{E}$