today: dc circuits

Friday’s quiz:
• 5 question multiple choice. Only two require calculation.
• Formulas given.
• Electric forces & fields, current & resistance.
• Nothing beyond material from Wednesday's lecture.
real battery = ideal battery + R
actual circuit has a parasitic $r$
real current sources

current source
series resistors: conservation of energy

Two Resistors in Series:

\[ R_{eq} = R_1 + R_2 \]

Three or More Resistors in Series:

\[ R_{eq} = R_1 + R_2 + R_3 + \ldots \]

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

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

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

(a) \[ I_1 + I_2 = I \]

(b)

(c) \[ R_{1-2-3} + R_4 \]

(d) \[ R_{eq} \]
measuring voltage

a) \( I \uparrow \)

\[
\begin{align*}
&I \\
&V \\
&\text{! INCORRECT !}
\end{align*}
\]

\[
\begin{align*}
&I \\
&R \\
&\text{CORRECT}
\end{align*}
\]
real voltmeters

(a) real meter

(b) ideal meter

\[ V \]

\[ R_{\text{load}} \]

\[ I \]

\[ V \]

\[ R_{\text{load}} \]

\[ r \]

\[ I \]
measuring current

a) ![Diagram of incorrect measurement]

b) ![Diagram of correct measurement]

! INCORRECT !

CORRECT
a simple ammeter

$I$

$R_{\text{precise}}$

$V$
Thévenin equivalents

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

\[ V_{th} = V \text{ (open circuit)} \]
\[ R_{th} = \frac{V}{I} \text{ (closed circuit)} \]

(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

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

for $r \ll R_{\text{load}}$,  

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

$V$ source wants $R$ high

like a battery 

one easy solution: 
large resistor in parallel with load
I source loading

\[ I_{\text{load}} = I \frac{r}{r+R} \]

for \( R_{\text{load}} \ll r \),

\[ I_{\text{load}} \approx I \]

I source wants R low
sourcing currents at high \( R_{\text{load}} \) is hard
measuring the meter

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

\[
R_{\text{load}} \ll r, \quad \Delta V_{\text{load}} \approx IR
\]
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?

\[ V_{\text{meter}} = I(R_{\text{thing}} + 2R_{\text{wires}}) \]
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

\[ R = \frac{\Delta V}{I} \]

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?

\[ \text{source voltage} \]
\[ R_p \text{ has same voltage as } R_{\text{thing}} \]
\[ R_s \text{ has same current} \]

have done >10^{10} \text{ Ohm}
what if I want to measure a *really* low R?

\[ R \]

\[ R_{\text{wires}} \]

\[ R_{\text{thing}} \]

\[ V \]

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 $R_2 = dR$

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

$$R_x = \frac{R_3 R_2}{R_1}$$
(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) \[ \Delta V = V_b - V_a = -\mathcal{E} \]
\( \Delta V \) C R S

(a)

(b)

Voltage

Time (sec)