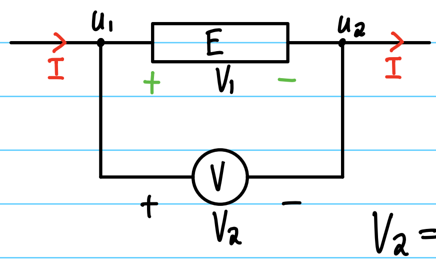
Discussion 7B ‼️

Anish's 16A Discussion
Office Hours: Tuesday 3-4
@Cory 144MA Friday 4-5

Voltmeters and Ammeters:

We use voltmeters to measure the voltage drop across elements of interest within a circuit.

- In order to do this, we must place the voltmeter in parallel with the element of interest such that it touches the same nodes as the element:



$\{V_1 = u_1 - u_2\}$

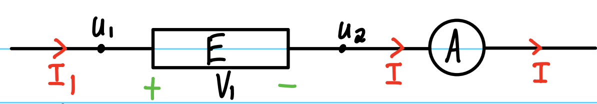
$V_2 = u_1 - u_2$

Ideally, we want our voltmeter to have no current flowing through it so that it does not mess with the rest of the circuit and only measures a voltage drop.

- We can achieve this by designing our voltmeter to have (nearly) infinite input resistance so that no current flows through it
  - Behaves as an open circuit

We use ammeters to measure the current flowing through elements of interest within a circuit.

- In order to do this, we must place the ammeter in series with the element of interest such that it is in-line with the element (i.e. there is an uninturrupted connection between the ammeter and the circuit element):



{Current through E and the ammeter are equivalent}

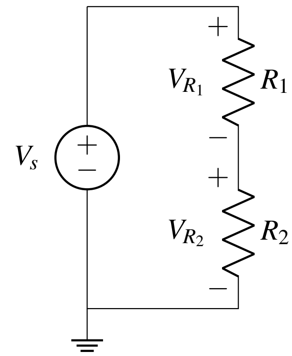
Ideally, we want our ammeter to have no voltage drop across it so that it does not change the behavior of the given circuit and only measures a current flow.

- We can achieve this by designing our ammeter to have (nearly) zero input resistance so that no voltage is dropped across it
  - Behaves as an ideal wire (aka short)

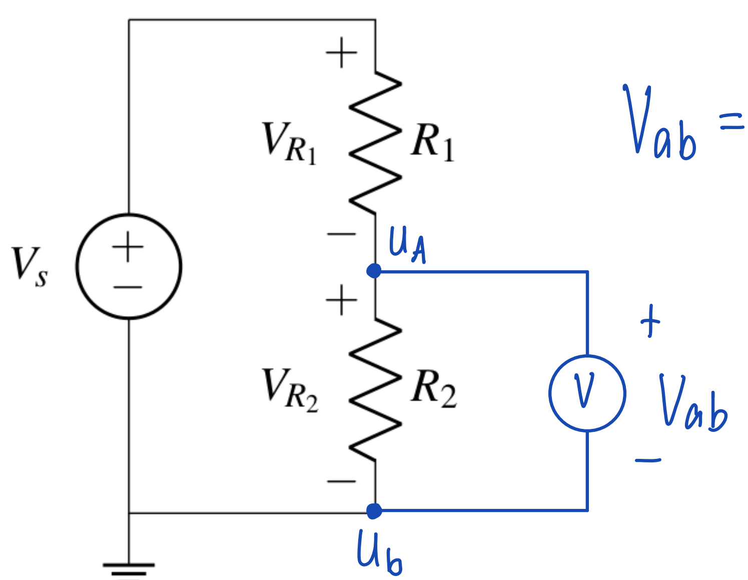
EECS 16A Designing Information Devices and Systems I
Fall 2022 Discussion 7B

1. **Volt and Ammeter**

(a) For the voltage divider below, how would we connect a voltmeter to the circuit to measure the voltage V_{R_2}?

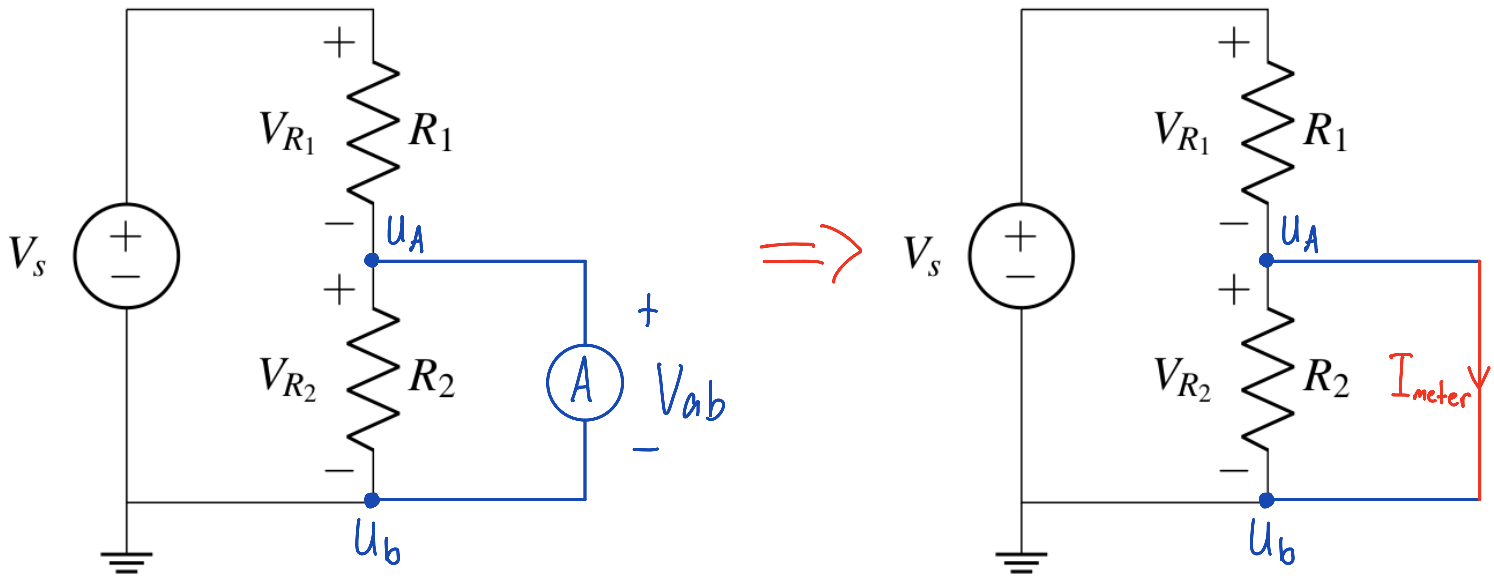


We must connect a voltmeter such that it captures the voltage drop across R_2 (i.e. in parallel with R_2)



$$V_{ab} = u_A - u_b = V_{R_2}$$

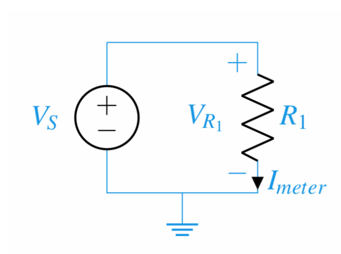
(b) What would happen if we accidentally connected an ammeter in the same configuration instead? Assume our ammeter is ideal.



An ideal ammeter behaves like a wire/short between two nodes.

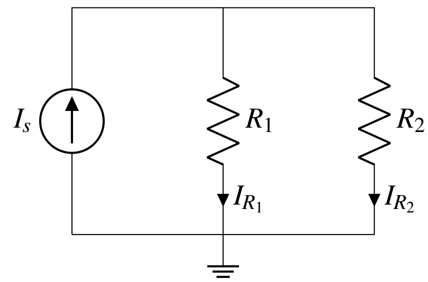
When we introduce this short, it serves as a new path of zero resistance through which current can flow

⇒ all the current leaving R_1 will flow through this short (note: u_a gets connected to u_b with the addition of this short ⇒ $u_a = u_b$)

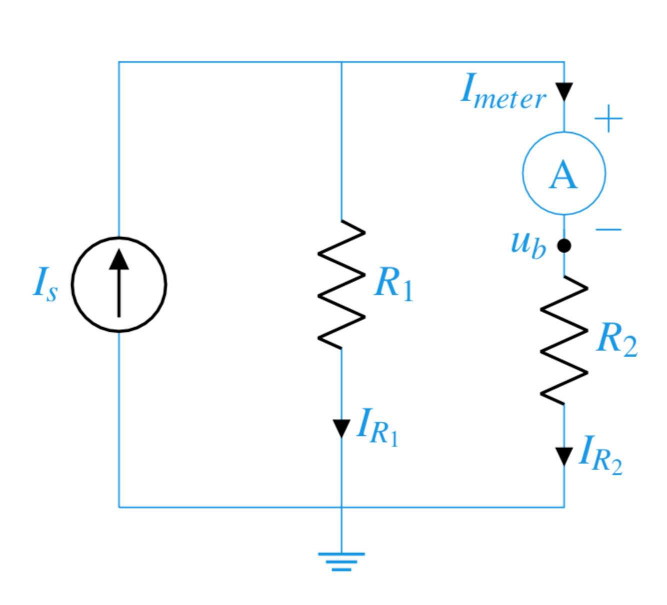


Circuit reduces to this!

(c) For the current divider below, how would we connect an ammeter to the circuit to measure the current I_{R_2}?



To measure the current I_{R_2} flowing through R_2, we must connect an ammeter in-line (aka in series) with R_2 as shown below:



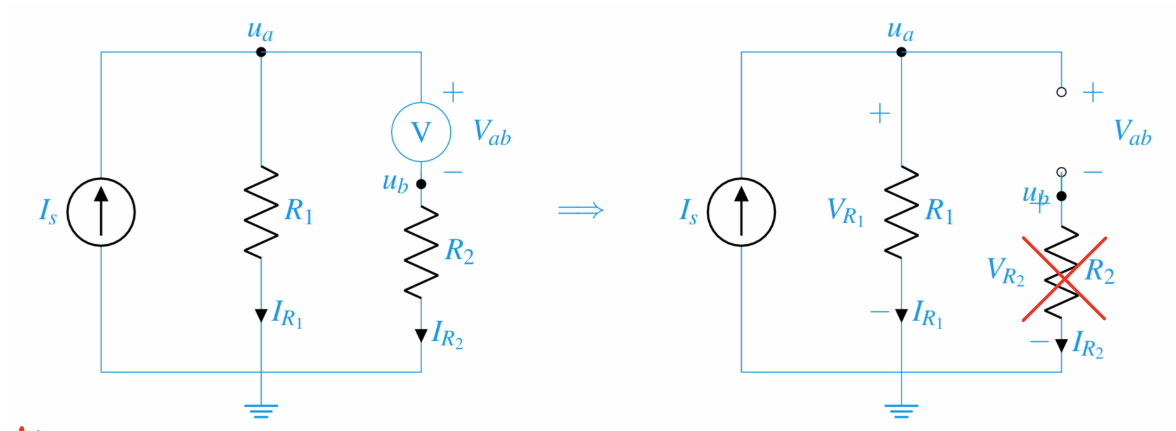
Additionally, KCL on node u_b gives us:

$$I_{meter} = I_{R_2}$$

Which is what we want

(d) What would happen if we accidentally connected a voltmeter in that configuration instead? Assume the voltmeter is ideal.

Remember, an ideal voltmeter behaves as an open-circuit:



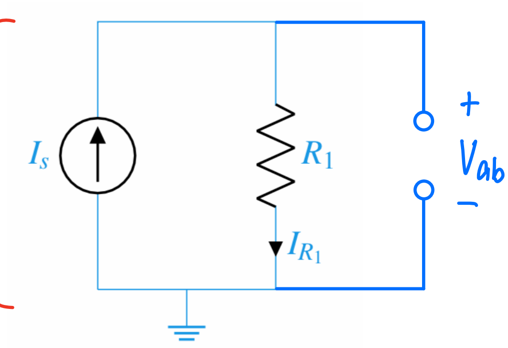
Now there is an open-circuit above R_2, which serves as a dead end for current $\Rightarrow I_{R_2} = 0A$

$$V_{R_2} = I_{R_2} \cdot R_2 = 0A \cdot R_2 = 0V$$

$$V_{R_2} = u_b - 0 = u_b \longrightarrow u_b = 0V$$

With this information, we can remove R_2 from the circuit and recognize that the voltmeter actually measures the voltage drop V_{R_1} across R_1: $V_{ab} = u_a - u_b = u_a - 0 = V_{R_1}$

Circuit reduces to this!

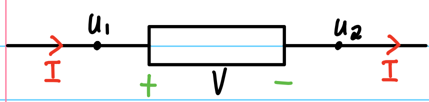


2. Cell Phone Battery

As great as smartphones are, one of their drawbacks is that their batteries don't last a long time. For example, a typical smartphone, under average usage conditions (internet, a few cat videos, etc.) uses 0.3W. We will model the battery as an ideal voltage source (which maintains a constant voltage across its terminals

Power:

- energy consumed per unit time



$\boxed{P = VI}$ → power consumed by the circuit element

By Passive Sign Convention:

$P > 0 \Rightarrow$ element is consuming power (e.g. resistor)

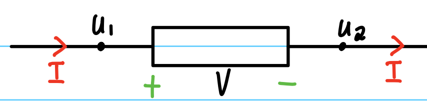
$P < 0 \Rightarrow$ element is supplying power (e.g. voltage source)

Total power in any circuit $= 0$

$$\left\{ \sum_{\text{all circuit elements}} P_{\text{element}} = 0 \right\}$$

Side Note → Derivation of the Power Formula:

$P = \dfrac{dE}{dt}$ (Energy per unit time)



Charges are moving from a higher to lower potential when they travel through the circuit element

$\Rightarrow$ The charge loses energy when it moves from a higher → lower potential

$$dE = V\,dq$$

→ change in energy for a small change dq

Taking the derivative: $\underbrace{\dfrac{dE}{dt}}_{P} = V \underbrace{\dfrac{dq}{dt}}_{I}$

P → Energy consumed per unit time

I = rate of flow of charge

$\Rightarrow P = VI$

regardless of current) except that we assume that the voltage drops abruptly to zero when the battery is discharged (in reality, the voltage drops gradually, but let's keep things simple).

Battery capacity is specified in mAh, which indicates how many mA of current the battery can supply for one hour before it needs to be recharged. Suppose the phone's battery has a capacity of 2770mAh at 3.8V. For example, this battery could provide 1000mA (or 3.8W) for 2.77 hours before the voltage abruptly drops from 3.8V to zero.

(a) How long will the phone's full battery last under average usage conditions?

$$P = IV$$

$$0.3\,W = 300\,mW \ \{\text{power}\}$$

$$I = \frac{P}{V} = \frac{300\,mW}{3.8\,V} = 79\,mA \text{ of current}$$

The 2770mAh battery can supply 79mA for:

$$\frac{2770\cancel{mA}h}{79\cancel{mA}} = 35h, \text{ or about a day and a half}$$

(b) How many coulombs of charge does the battery contain? How many usable electrons worth of charge are contained in the battery when it is fully charged? (An electron has 1.602×10^{-19} C of charge.)

$1C = 1A \times 1s \Rightarrow 1mC = 1mAs$

1 hour = 3600 seconds

Battery Capacity: $2770\ mA\cancel{h} \times 3600\ s/\cancel{h}$
$= 9.972 \times 10^6\ mAs = 9972\ As$
$= 9972\ C$

An electron has approximately $1.602 \times 10^{-19}\ C$

$\Rightarrow 9972\ C$ is $\dfrac{9972\ C}{1.602 \times 10^{-19}\ C} \approx 6.225 \times 10^{22}$ electrons (a lot!)

(c) Suppose the cell phone battery is completely discharged and you want to recharge it completely. How much energy (in J) is this? Recall that a J is equivalent to a W s.

Battery Capacity $\longrightarrow$ 2770 mAh at 3.8 V

Total Stored Energy $\Rightarrow 2770\ mAh \cdot 3.8\ V$
$= 10.5\ W\cancel{h} \cdot 3600\ s/\cancel{h}$
$= 37.9\ kJ$

tinyurl.com/16Anish

Password: power