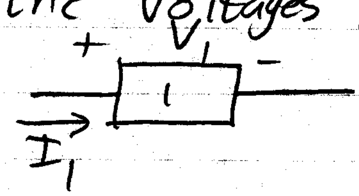
In this course we are going to learn about ~~Components,~~

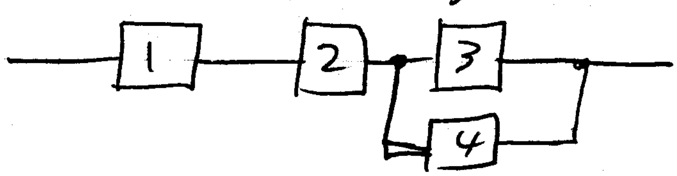
1.) The fundamental quantities in Electrical Circuits: Voltage and Current

	Voltage	Current
Constant (DC) →	V	I
Time Varying (AC, etc.) →	$v(t)$	$i(t)$
Units	Volts (V)	Amperes (A)
	Relative	Absolute

2.) Components and how they behave and affect the Voltages Across and Currents Through them.



3.) Circuits or Systems of Components, how ~~the~~ a collection of components behave when connected together:



~~We~~ You will learn how to analyze circuits and make predictions. You will learn how to calculate an even more fundamental quantity, energy, and how much is consumed in a circuit or a component. That is important, because in ~~most~~ many devices the most expensive part of the whole thing is the energy it uses.

Pg 4 of the text has 2 tables, one of important quantities + usual symbols and Units. The second has decimal prefixes. We will certainly expect you to know the "factors of 10^3"

prefixes
Giga (G) – 10^9
Mega (M) – 10^6
kilo (k) – 10^3
milli (m) – 10^{-3}
micro (μ) – 10^{-6}
nano (n) – 10^{-9}
pico (p) – 10^{-12}

and to recognize reciprocals:

$$\frac{1}{k} = m \Longleftrightarrow \frac{1}{m} = k$$

$$\frac{1}{M} = \mu \Longleftrightarrow \frac{1}{\mu} = M$$

The most fundamental units we will use are <u>charge</u> (Q or q(t)) and <u>energy</u> (Joules, J) (W or E)

Charge just has to be defined, so we have chosen the <u>Coulomb</u> (C). The smallest unit of charge is that of a single electron,

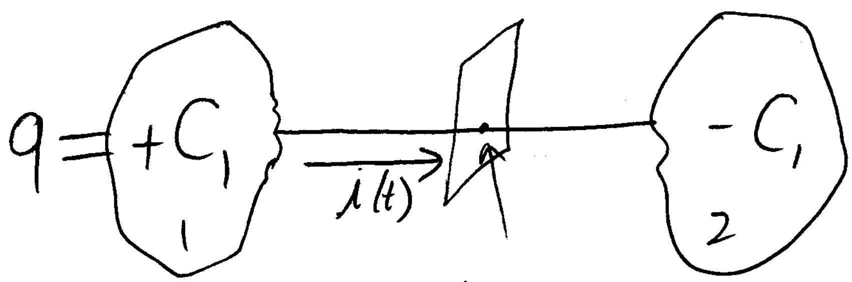
$$q_e = -1.6\times10^{-19}\,C = -.16\times10^{-18}\,C = -0.16 \text{ atto} C$$

A proton has the same, but positive, charge $q_p = +0.16\,aC$

This means that in 1 C of charge there are

$$\frac{1C}{0.16\,aC/\text{proton}} = 6.25\times10^{18} \text{ protons} = 6.25 \text{ exa protons}$$

We will usually talk about charge as the <u>current</u>, or how ~~many~~ much charge passes through a <u>wire</u> in one second:

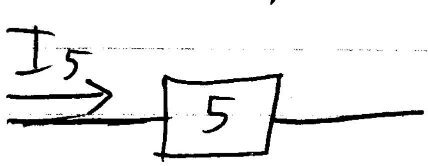


how many + charges pass through per second?

$$i = \frac{dq}{dt}$$

$$1\ \frac{C}{s} = 1\ \text{Ampere}\ (A)$$

In this course, we will talk about the movement of positive charge, for a variety of reasons. Yes, we all know that a current in a wire is really the movement of electrons (with negative charge) in the opposite direction, but we are going to stick with the model of "holes" of positive charge moving in the direction shown, which brings us to: The label for a current through a device includes both a magnitude, I or $i(t)$, and a direction:



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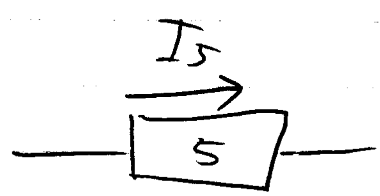

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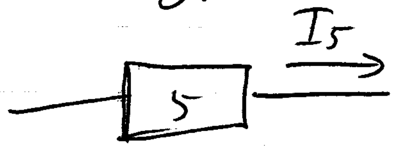
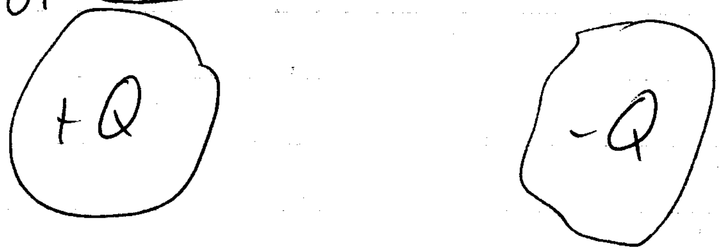
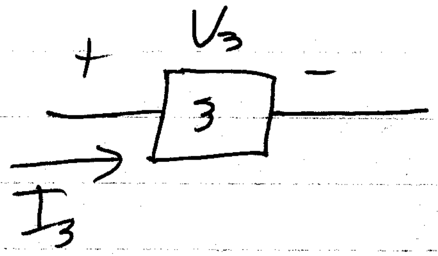


Now, in my previous diagram I showed a case of separated charges:

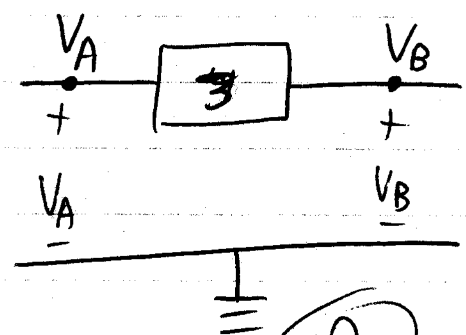


Presumably I (or someone or something) moved some + charges <u>from</u> the region on the right <u>to</u> the region on the left, leaving behind − charges. Since opposite charges <u>attract</u>, <u>pulling</u> a + charge requires me to exert a <u>force</u> against it, over a <u>distance</u>. <u>Force</u> times <u>distance</u> is <u>work</u>, or <u>energy</u>, so the +Q charges have a certain energy <u>relative to their original location</u>. We call this energy, per unit charge, their <u>Voltage</u>: $\text{Voltage}(V) = \frac{\text{Joules}}{\text{Coulomb}}$

- A voltage label always includes a magnitude (V or $v(t)$) and a label (explicit or implicit) as to where ~~+q~~ charge would have zero energy:



A



B

symbol for ground or 0V.

- A very good analogy for this is altitude. I can say "I will go down 10 feet when I walk down a flight of stairs." A or I can say "I will go from 670 feet above sea level to 660 feet above sea level as I go down a flight of stairs." B

- Both describe a change of 10 feet, one is direct, one is relative to a common point.

- In this case $V_3 = V_A - V_B$

$$\text{Voltage Drop Across Element 3} = \begin{pmatrix}\text{Voltage at + end, relative to ground}\end{pmatrix} - \begin{pmatrix}\text{Voltage at − end, relative to ground}\end{pmatrix}$$

Note that if I multiply Voltage and Current:

$$VI = \frac{\text{Joules}}{\text{Coulomb}} \cdot \frac{\text{Coulombs}}{\text{second}} = \frac{\text{Joules}}{\text{second}}$$

$$= J/s = \text{Watts}(W)$$

- Energy (dissipated or gained) per second is <u>Power</u>, the rate of change of energy, we will use P or $p(t)$ to ~~denot~~ stand for power; so

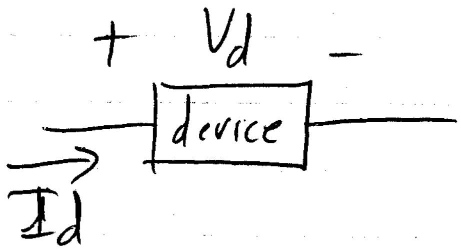
$$P = VI \text{ or } p(t) = v(t)\,i(t)$$

The energy (W) dissipated from time t_1 to t_2 by

- a voltage $v(t)$ with a current $i(t)$ flowing through it is $W = \int_{t_1}^{t_2} v(t)\,i(t)\,dt$

We will strictly adhere to the Passive Sign Convention:

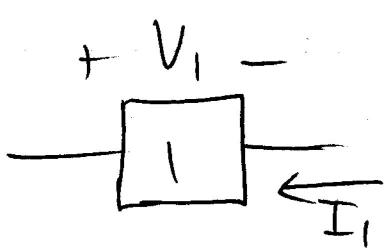
A positive current enters the positive labelled voltage terminal, and <u>dissipates</u> energy.



Current Enters + Terminal

$$P_d = + V_d I_d$$

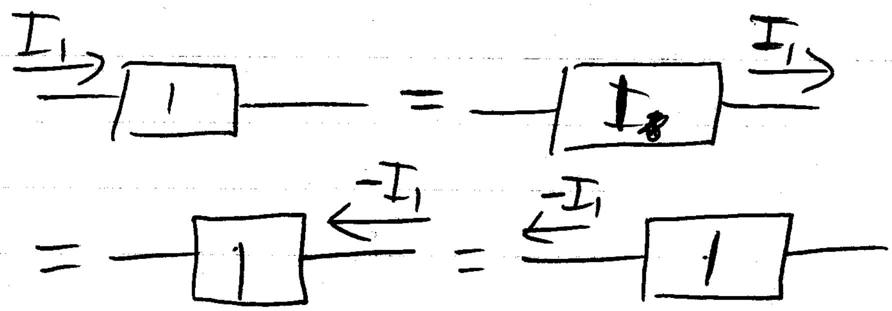
label with the voltage label I_d <u>enters</u>.



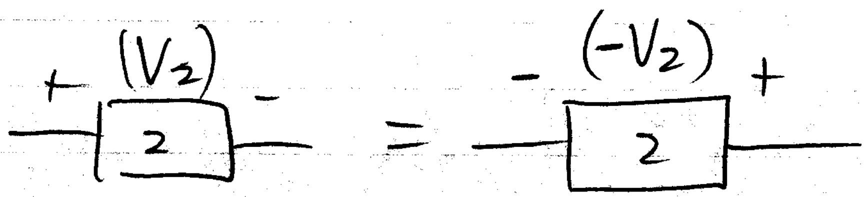
$$P_1 = - V_1 I_1$$

Now let's look at the variations.

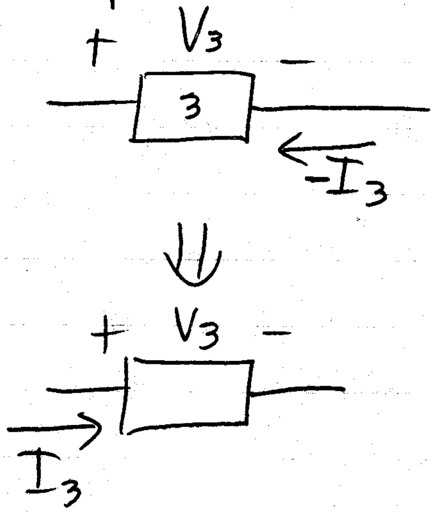
- Current:



Voltage:



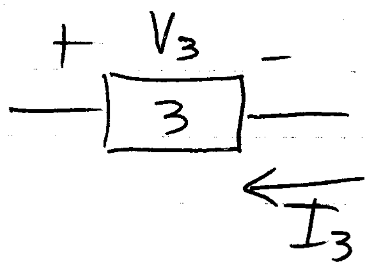
Examples:



$$P_3 = -(V_3)(-I_3) = +V_3 I_3$$

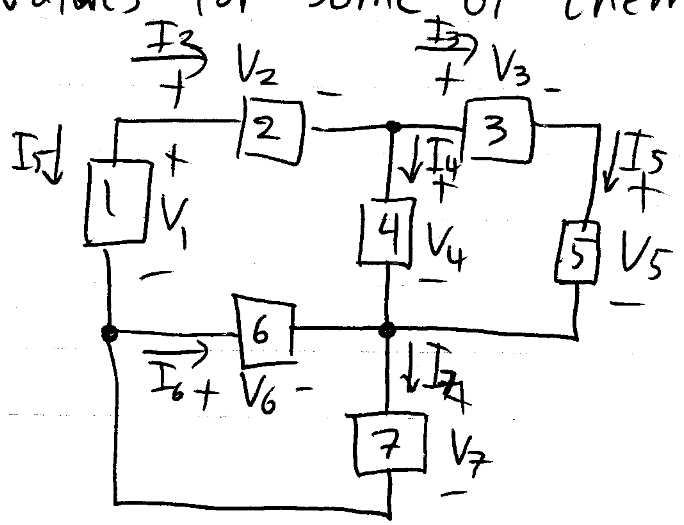
Recall: a <u>positive power</u> means a component is <u>dissipating</u> (or losing) energy (heat, light, etc.)

- Conversely: a <u>negative power</u> means a component is <u>providing</u> (or sourcing) energy (battery, power supply, etc.) to the circuit.

- So 

$P_3 = - V_3 I_3$ — providing power if both $V_3 + I_3$ are positive.

Now, here's a point that many people have problems with: Given a (complicated) circuit, you can simply <u>pick</u> labels and directions for voltages and currents. You will simply get negative values for some of them.



I usually start top left - Add labels and top to bottom

- Note, in a self-contained circuit, the total power must be zero, so at least one component must be ~~labelled "Backwards"~~ providing power to the circuit. That means either the Voltage across or the current through at least one device will be negative.

We have stated two quantities as derivatives:

$$i = \frac{dq}{dt} \quad \text{and} \quad p = \frac{dW}{dt}$$

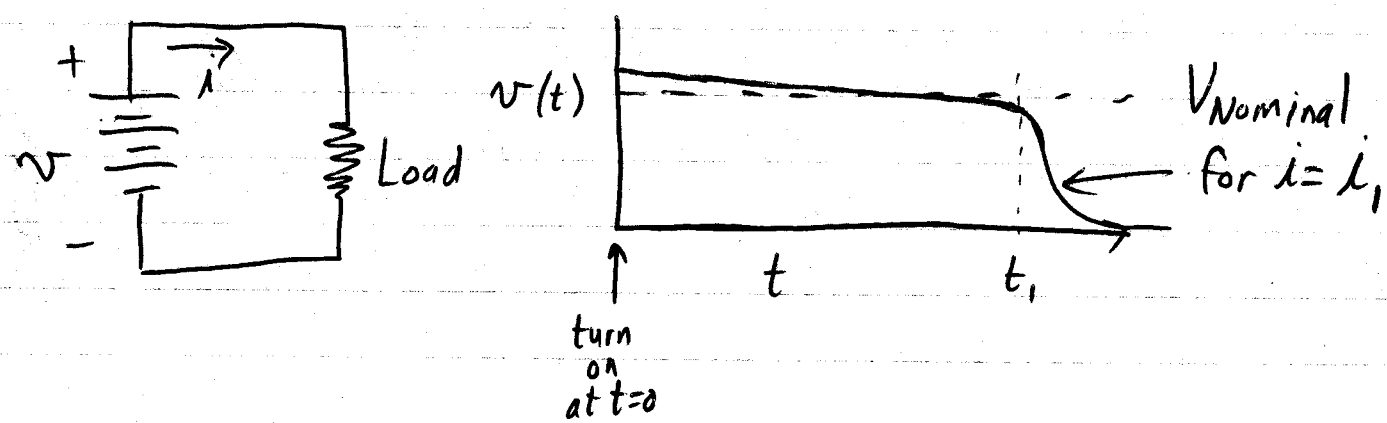
The inverse of these results in an integral:

$$q = \int_{t_1}^{t_2} i(t)\,dt \quad \text{and} \quad W = \int_{t_1}^{t_2} p(t)\,dt$$

Let's look at $W \longrightarrow$ recall that $p = v i$, so

$$W = \int_{t_1}^{t_2} v(t)\,i(t)\,dt$$

With batteries, if you look at $v(t)$ as a constant, small load is applied, we see this:



That is, v stays pretty constant until the "knee" at t_1, so we could say that

$$v(t) = \begin{cases} V_{nom} & 0 \le t \le t_1 \\ 0 & t > t_1 \end{cases}$$

this means that

Energy ~~Capacity~~ Delivered by Battery

$$W = \int_0^{t_1} -v(t)\, i(t)\, dt = \int_0^{t_1} -V_{nom}\, i(t)\, dt$$

$$= -V_{nom} \int_0^{t_1} i(t)\, dt$$

~~Now, for most devices, i(t) is proportional to v(t), so we would~~

Divide by V_{nom}: $\frac{W}{V_{nom}} = -\underbrace{\int_0^{t_1} i(t)\, dt}_{\text{units?}}$

units? Amps · Time

A · hrs

mA · hrs

So, for batteries of the same V_{nom}, we compare different types and sizes by their mAh ratings, or for big batteries it may be Ah ratings.