Chapter 1

Circuit Variables

Text: *Electric Circuits*, 9th Edition, by J. Nilsson and S. Riedel

Prentice Hall

Engr 17 Introductory Circuit Analysis

Instructor: Russ Tatro

Chapter 1 – Section 1.1

Engineering Overview

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Overview

This section introduces **Circuit Theory** which is the topic of this introductory course.

Circuit theory is a special *linear* case of electromagnetic field theory – the study of static and moving electric charges.

You have already been introduced to electromagnetism in your physics courses.

Engr 17 Course Assumptions

Linear, Lumped Parameter, Time Invariant

MIT 6.002X calls this the *Lumped Matter Abstraction*

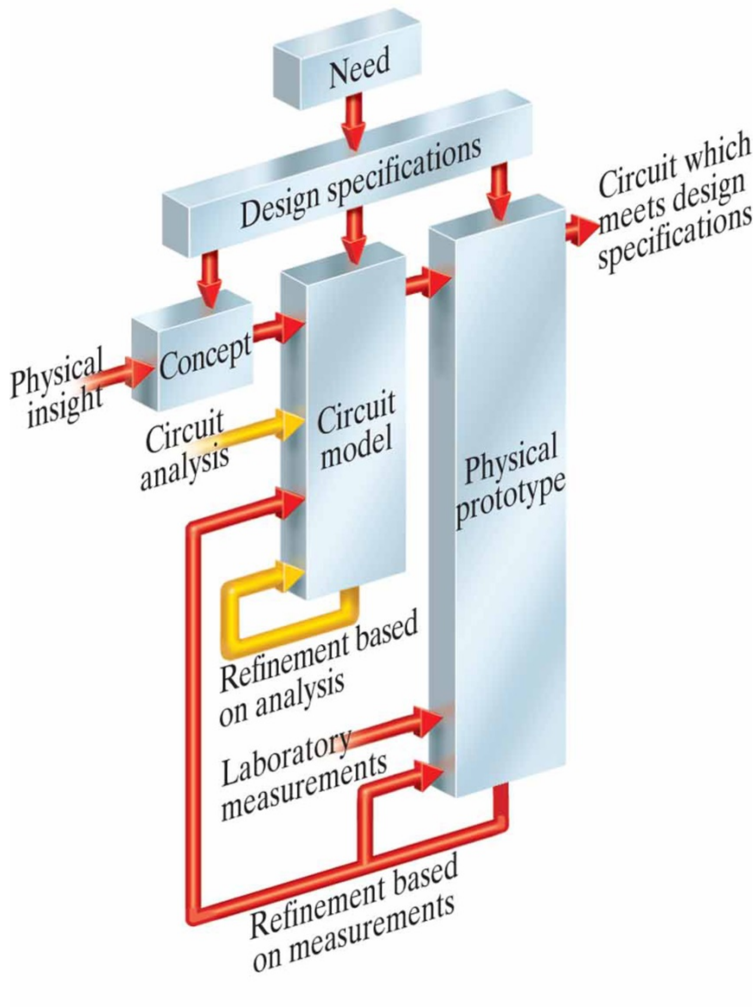
1. Electrical effects happen instantaneously throughout a system – i.e. Lumped Parameter which also implies the system is linear.

2. The *NET* charge on every component in the system = zero. This is a frequent restatement of conservation of energy. Separation of charge is OK.

3. There is *NO* magnetic coupling BETWEEN components in a circuit. Magnetic coupling INSIDE a circuit element is OK.

There is a much wider world in electrical and electronic systems than this restricted Linear, Lumped Parameter, Time Invariant case. But this is our playground (simplification) for this course.

Figure 1.4 A conceptual model for electrical engineering design.



Problem Solving

Engineer – solves problems, makes stuff, society is better for us!

Look up definition for attorney/lawyer as a comparison.

Hobby – something you do for pleasure – so do as you like, and when you like.

Engineering – you solve societal problems both large and small. Usually paid and definitely not a hobby.

Problem Solving

If you solve a lot of problems – you should have a method of problem solving – some way to get organized.

Here is the authors' suggestion:

Identify the problem – really!! Don't launch until you really know the destination.

Identify what you know and what you need to know.
Look up Donald Rumsfield – the Washington press corp had a field day with his "known knowns, known unknowns, unknown unknowns"

Visualize the problem - sketch out the system, employ useful models

Brainstorm – what is the RANGE of possible solutions?

Problem Solving

Calculate – this is core engineering – there is an equation or set of equations that applies to this problem. If there is no equation for this problem you have wandered into research and development which is where you create the needed equations.

Be creative! Engineering is a creative exercise. Invent, adopt, modify until you get what is needed.

Test your solution – Does it work on a rainy night? In the hot desert? In your lab? Test for where this solution will be used!

Rinse and Repeat all during your entire career.

Chapter 1 – Section 1.2

SI Units

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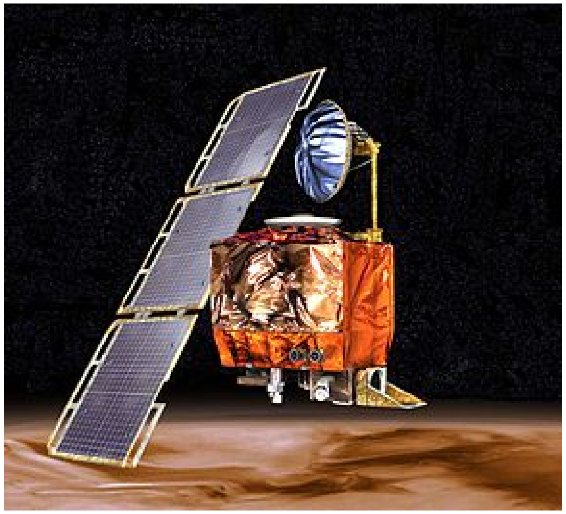
Mars Probe Lost Due to Simple Math Error
by Robert Lee Hotz, Los Angles Times, October 1, 1999

NASA lost its $125-million Mars Climate Orbiter because spacecraft engineers failed to convert from English to metric measurements when exchanging vital data before the craft was launched, space agency officials said Thursday.

A navigation team at the Jet Propulsion Laboratory used the <u>metric</u> system of millimeters and meters in its calculations, while Lockheed Martin Astronautics in Denver, which designed and built the spacecraft, provided crucial acceleration data in the <u>English</u> system of inches, feet and pounds.



http://mars.jpl.nasa.gov/msp98/orbiter

The SI units are seven *defined* quantities:

TABLE 1.1 The International System of Units (SI)

Quantity	Basic Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	degree kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

The Definitions – NIST http://physics.nist.gov/cuu/Units/meter.html

The **meter** is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. $\left(\text{distance} = \frac{speed\ \frac{m}{\sec}}{299,792,458\sec}\right)$

The **kilogram** is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

The **second** is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

The **ampere** is defined as a constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} newton per meter of length $\left(2\times10^{-7}\frac{N}{m}\right)$

The Definitions – NIST http://physics.nist.gov/cuu/Units/meter.html

The **kelvin**, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

$$Kelvin = \frac{T_{\text{water, triple point}}}{273.16}$$

The triple point of water is the temperature and pressure at which three phases of the water (gas, liquid and solid) coexist in *thermodynamic equilibrium.*

The **mole** is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

The **candela** is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

The *Defined* kilogram and meter

“ The Treaty of the Meter (1875) mandated the establishment of a permanent International Bureau of Weights and Measures, to be located at Sevres, France, which would … keep custody of the new prototype meter and kilogram…” – National Institute of Standards and Technology (NIST)

National Kilogram Prototype No. 20 – NIST Museum

National Meter Prototype No. 27 – NIST Museum

The SI quantities are the basis for many *derived* units:

TABLE 1.2 Derived Units in SI

Quantity	Unit Name (Symbol)	Formula
Frequency	hertz (Hz)	s^{-1}
Force	newton (N)	$kg \cdot m/s^2$
Energy or work	joule (J)	$N \cdot m$
Power	watt (W)	J/s
Electric charge	coulomb (C)	$A \cdot s$
Electric potential	volt (V)	J/C
Electric resistance	ohm (Ω)	V/A
Electric conductance	siemens (S)	A/V
Electric capacitance	farad (F)	C/V
Magnetic flux	weber (Wb)	$V \cdot s$
Inductance	henry (H)	Wb/A

Units Check

It is sometimes useful to include the SI units in your equations.

Then treat the SI unit as an algebraic quantity which can modify the other variables.

The end result should then have the correct SI units. This is the "Units Check".

For example, how many meters are in a mile?
1 meter = 39.370 inches
1 mile = 5280 feet
1 foot = 12 inches

$$\frac{5280\, feet}{mile} \times \frac{12\, inches}{feet} \times \frac{1\, meter}{39.370\, inches} = 1,609.347 \frac{meters}{mile}$$

Powers of 10

You will frequently see numbers expressed in the so-called scientific notation.

Using the power of 10 symbol often makes the number more readable.

But remember to enter a number correctly into your calculator! (a very common mistake on exams)

Memorize the power of 10 symbols. You are often expected to know the symbol.

TABLE 1.3 Standardized Prefixes to Signify Powers of 10

Prefix	Symbol	Power
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deka	da	10
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

Commodore Hopper

Personal story - I was at a computer conference in Montgomery, Alabama (yes, the conference was held way back before many of you were born).
A woman in Navy uniform was handing out these short pieces of wire which she called nanoseconds. These props were useful in showing non-scientific attendees the distance light travels in 1 nanosecond.

The woman was Grace Hopper who is also known as the finder of the first computer "bug".

She simplified the speed of signal travel in a wire to be the speed of light = max possible distance in 1 ns.

How long was the pieces of wire she handed out?

$$\frac{299{,}792{,}458\,m}{s} \times \frac{39.370\ inches}{m} \times 10^{-9}\,s = 11.80\ inches$$

Grace Hopper

Chapter 1 – Section 1.4

Voltage and Current

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Concept of Electric Charge

Charge is bipolar – positive and negative

a positive charge moving in a direction has the same properties as a negative charge moving in the opposite direction.

Charge comes in a quanta $\rightarrow$ $q = 1.6022 \text{ X } 10^{-19}$ Coulombs

Electrical effects result from:

separation of charge = voltage

motion of charge = current

Note: It is important to remember that in this course and in nearly all electrical circuits, there is only mobile charge free to move about within the electric circuit. That charge element is the electron. When an atom or molecule loses an electron, it leaves behind a vacancy that is positively charged. So we can have charge separation even with only one charge carrier!

Definition of Voltage

Voltage is the energy per unit charge created by the charge separation.

$$v = \frac{dw}{dq}$$

v = the voltage in *Volts*

w = the total energy of the separated charges in joules

q = the total charge in coulombs

Voltage is ALWAYS measured ACROSS two terminals.

Another but equivalent definition of voltage. *The voltage (or potential difference) between a pair of points across an element is the work required to move a particle with unit charge from one point to the other along some path against the force due to the electric field.* Agarwal and Lang, Foundations of Analog and Digital Electronic Circuits, 2005

Definition of Current

Current is the rate of charge flow.

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

i = the current in *Amperes*

q = the amount of charge that flowed past a specific point

t = the time of the charge flow in seconds

Current is ALWAYS measured THROUGH a device (past a terminal).

Chapter 1 – Section 1.5

The Ideal Basic Circuit Element

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Circuit drawing conventions

You will view numerous drawings that represent physical circuits. In these drawings, we will observe some conventions about what the drawing element means.

A wire is a drawn line which may be straight, curved, right angle or other geometry that connects circuit elements.

A wire is assumed ideal (in this course):

resistanceless (superconducting) = particle flow without voltage change

wire length, diameter or other physical property is ignored

A wire that "hangs in the air" is not connected to anything.

Thus that wire cannot allow particle flow past the end of the wire (to the left in this drawing).

Circuit drawing conventions

Crossing wires

Wires that cross each other for drawing convenience are NOT connected. The wires are assumed to NOT interact just because they cross over each other.

Connected wires

A dot at the crossing of wires means these wires are physically connected. Particles can flow from one wire to the other wires.

Wires that end at another wire ARE connected. Particles can flow from one wire to the other wires.

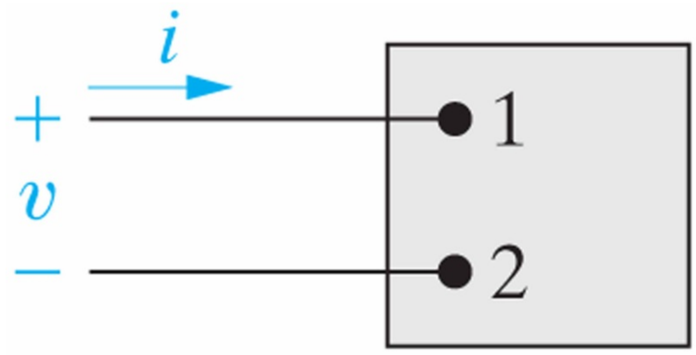
Circuit drawing conventions

Wires connecting circuit elements

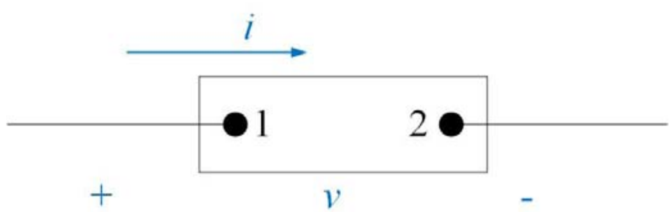
Wires that end at the terminal of a circuit element are assumed to connect to that circuit element. Particles can flow through the wire and into or out of the circuit element.

Ideal Circuit Element

Let’s draw an abstract ideal circuit element and get a feel for what we need to know about it.



Only two terminals

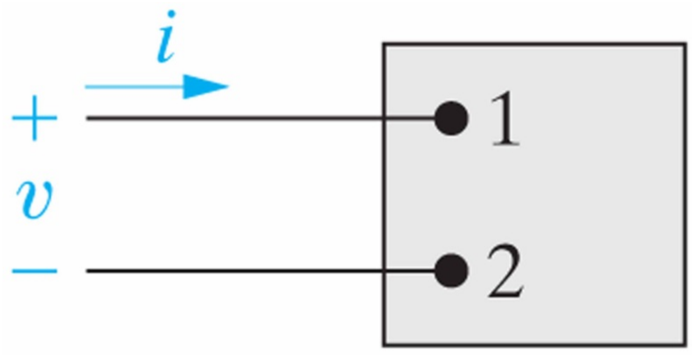


The element’s behavior can be described by an equation in terms of voltage and current.

It cannot be subdivided – this is the lowest level of the element’s description.

Passive Sign Convention

To make sense of the energy relation of this ideal element, we need to agree to use a standard.



Convention – whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element, use a positive sign in any expression that relates the voltage to the current.

Short version = Current in direction of voltage drop the use “+”

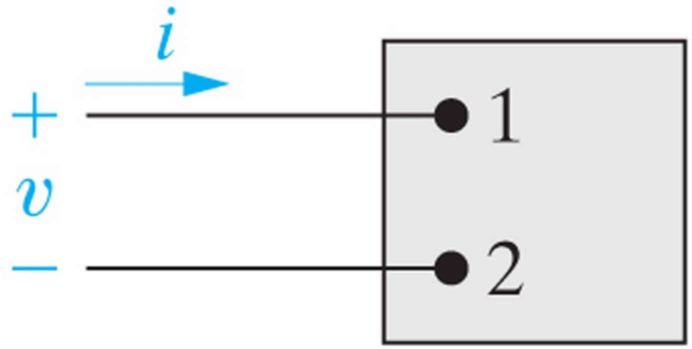
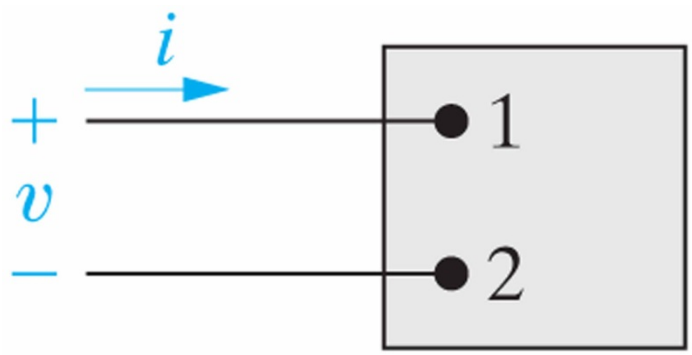


TABLE 1.4 Interpretation of Reference Directions in Fig. 1.5

	Positive Value	Negative Value
v	voltage drop from terminal 1 to terminal 2	voltage rise from terminal 1 to terminal 2
	or	*or*
	voltage rise from terminal 2 to terminal 1	voltage drop from terminal 2 to terminal 1
i	positive charge flowing from terminal 1 to terminal 2	positive charge flowing from terminal 2 to terminal 1
	or	*or*
	negative charge flowing from terminal 2 to terminal 1	negative charge flowing from terminal 1 to terminal 2

Passive Sign Convention

A positive current flow top to bottom is the same as a negative current flowing bottom to top.



Whether you fill the glass from the top (positive flow)
Or from the bottom (negative flow)
The glass still gets filled.

Chapter 1 – Section 1.6

Power and Energy

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Power and Energy

Power is the time rate of work = the amount of energy consumed per some unit of time.

Energy often defined as the capacity of a system to perform work.

But energy comes in a bewildering array of types – heat, light, kinetic, gravitational, magnetic, ……

Power = energy used per unit time

$$p = \frac{dw}{dt}$$

p = (real) power in Watts

w = the energy in joules

t = the time in seconds

We are looking at electrical systems where the variables are voltage and current flow – so we can write the power equation as

$$p = \frac{dw}{dt} = \underbrace{\frac{dw}{dq}}_{v} * \underbrace{\frac{dq}{dt}}_{i} = vi$$

Lower case variables imply a time varying value.

Upper case implies a steady value (DC for example).

But now we have to determine if the circuit element is delivering power or absorbing power.

For example, you can start a car with its battery. The battery is delivering power.

While the car engine is working, you can charge the battery. The battery is now absorbing power.

Power and the Passive Sign Convention

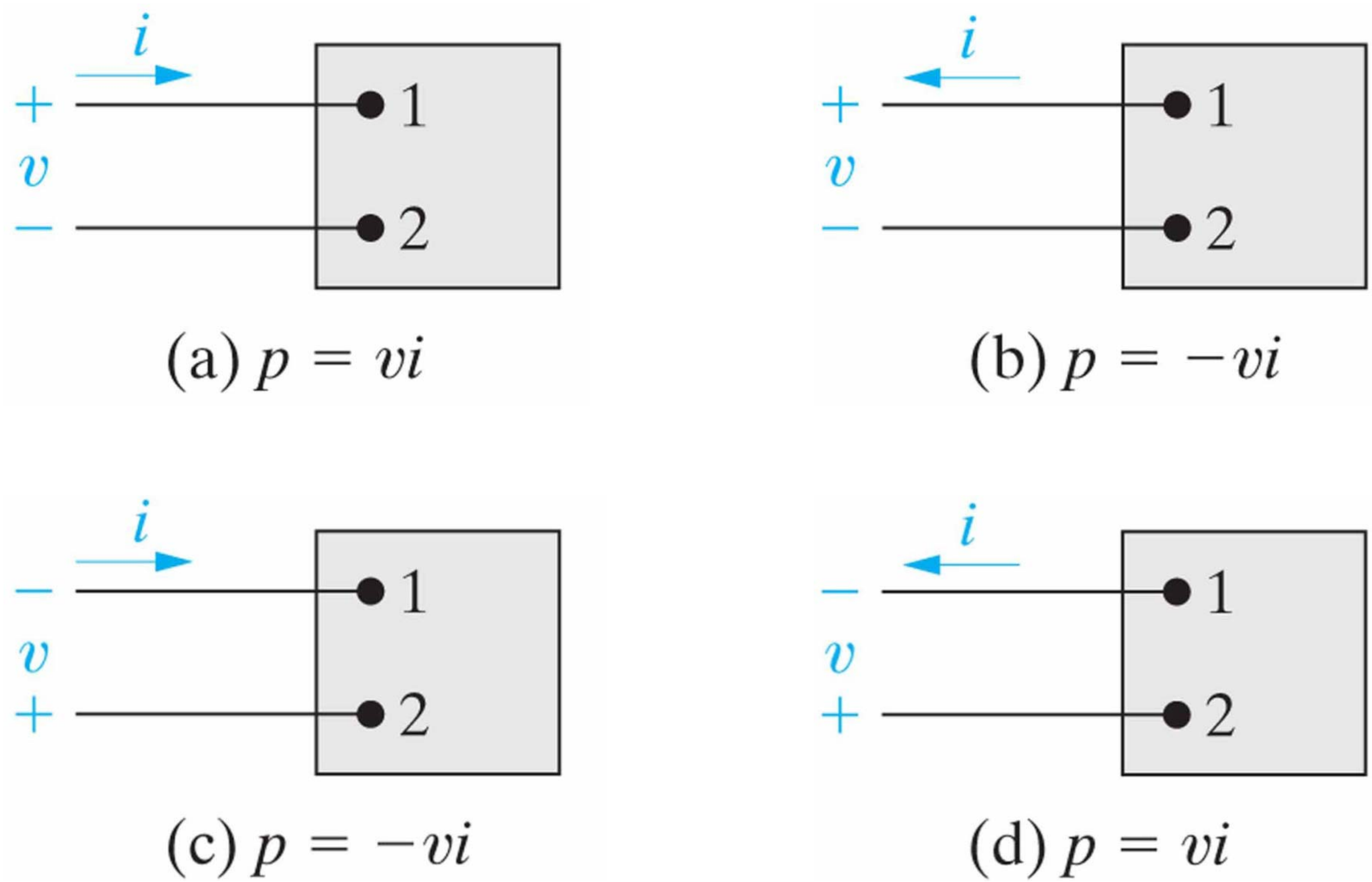
Absorbing power when current is in the direction of the voltage drop (in accordance with the passive sign convention)

$$p = (+)vi$$

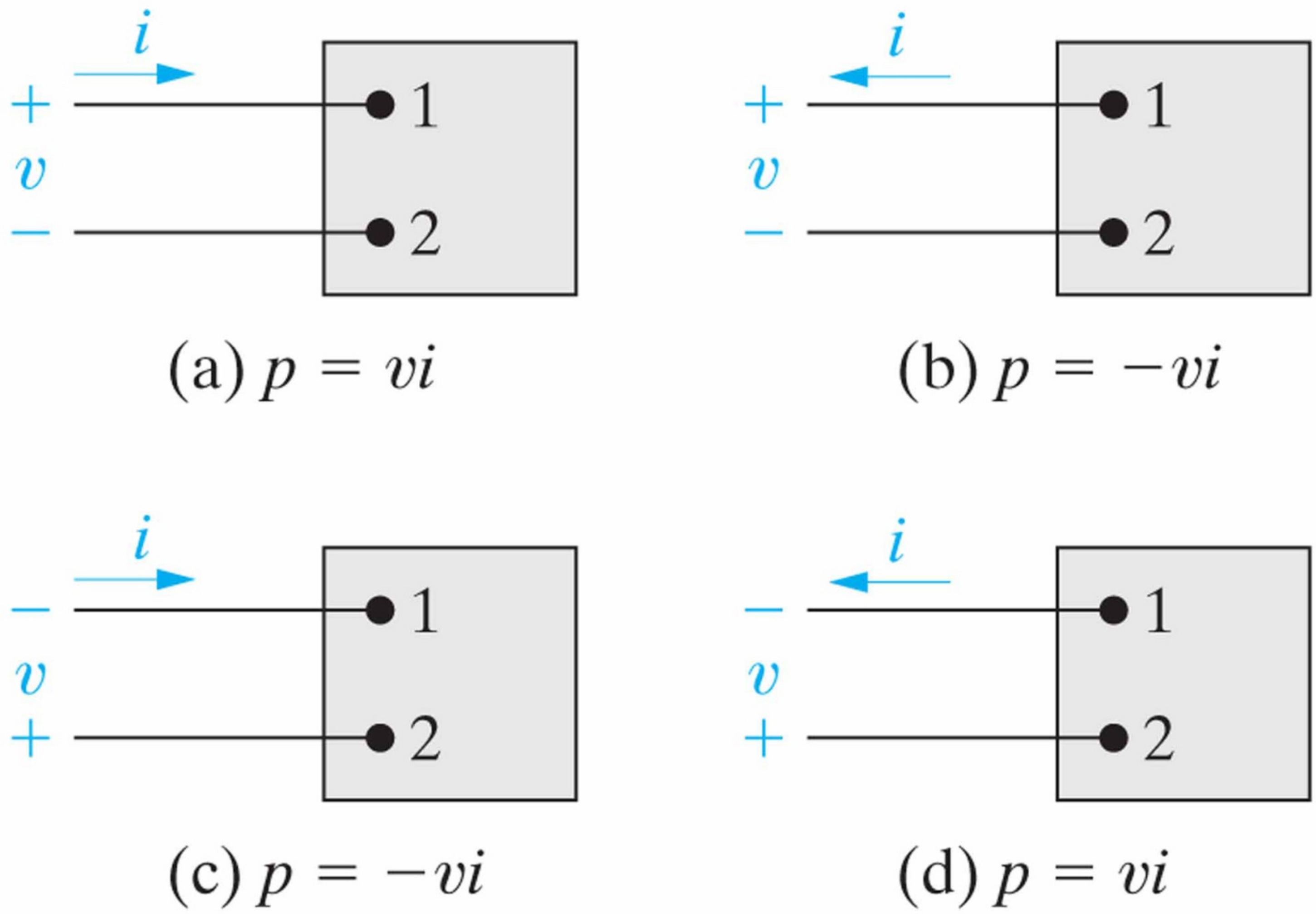
Delivering power when current is in the direction of the voltage rise (in accordance with the passive sign convention)

$$p = (-)vi$$

Power and the Passive Sign Convention



Power and the Passive Sign Convention



The iPhone 5 battery specifications is listed as

1,440 mAh

or 5.45 Wh

Now which is it? 1,440 mAh or 5.45 Wh?

Remember those SI Units?

Each capacity rating is just a different way to state energy.

Current versus charge

$$1,440\times10^{-3}\,Ah = 1,440\times10^{-3}\,Ah * \frac{60s}{\min} * \frac{60\min}{hour} = 5,184\,As = 5,184\,Coulombs$$

Power versus energy

$$5.45\,Wh = 5.45Wh * \frac{60s}{\min} * \frac{60\min}{hour} = 19,620\,Ws = 19,620\frac{J}{s}s = 19,620\,J$$

So what appears to be a (roughly) average voltage across the battery while it is delivering power?

$$V = \frac{J}{C} = \frac{19,620\ J}{5,184\ C} = 3.785\,Volts$$

How long will a dead (zero energy) iPhone battery take to charge from a USB cable connected to a computer? (by the way zero energy LiPo battery means you are going to buy a new battery)

USB 2.0 specification:

+5 Volts

500 mA if no other devices are connected to the USB port

100 mA (or so) with other devices connected

Some of the charging power will be wasted as heat which we will ignore.

iPhone 5 stores 5.45 Wh.

$$Shortest\ time\ \frac{5.45\,Wh}{5*0.5\,VA} = \frac{5.45\,Wh}{2.5\,W} = 2.18\ hours$$

$$Longer\ time\ \frac{5.45\,Wh}{5*0.1\,VA} = \frac{5.45\,Wh}{0.5\,W} = 10.9\ hours$$

Chapter 1

Circuit Variables

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