ENGR12
Circuit Theory

Chapter 1

Basic Concepts

LECTURE DEMO: DVM + Battery

Basic Concepts - Chapter 1

1.1 Systems of Units.

1.2 Electric Charge.

1.3 Current.

1.4 Voltage.

1.5 Power and Energy.

1.6 Circuit Elements.

1.1 System of Units (1)

Six basic units

Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	Kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

1.1 System of Units (2)

The derived units commonly used in electric circuit theory

Quantity	Unit	Symbol
electric charge	coulomb	C
electric potential	volt	V
resistance	ohm	Ω
conductance	siemens	S
inductance	henry	H
capacitance	farad	F
frequency	hertz	Hz
force	newton	N
energy, work	joule	J
power	watt	W
magnetic flux	weber	Wb
magnetic flux density	tesla	T

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Decimal multiples and submultiples of SI units

CLEO Example Problem 4

- Beginning in Beijing, China, you need to travel about 11,000 km to reach New York City. Fiber optic signals traveling between these two cities move at close to the speed of light (3×10^8 meters per second). The eye blink duration of a human is approximately 300 milliseconds. So, is it possible for a communication signal to jump from Beijing to New York in the "blink of an eye?"

Is $T_{Beij \to NY} < T_{eye\ blink}$?

Eye blink = 300 ms

Beijing → NY : 11,000 km

Equation: $D = RT$

$$T_{Beij \to NY} = \frac{D_{Beij-NY}}{R} = \frac{11{,}000 \text{ km}}{3 \times 10^8 \text{ m/s}} \left(\frac{1000 \text{ m}}{1 \text{ km}} \right) = \frac{11 \times 10^6}{3 \times 10^8} \text{ s}$$

$$= 3.66 \times 10^{-2} \text{ s} \left(\frac{1000 \text{ ms}}{1 \text{ s}} \right) = 36.6 \text{ ms} < 300 \text{ ms}$$

YES!

What is Circuit Analysis?

- Solution of circuit unknowns
  - Charge
  - Current
  - Voltage
  - given a circuit and sources applied to it

- An exercise in building a complex mental model
  - Similar to many engineering areas of investigation
  - Applying extended logical reasoning to an area of unfamiliar laws and behaviors
  - An extremely valuable skill, even if you never study circuits again

Why do I need to learn this?

- Circuit theory is a foundation for
  - Electrical Engineering:
    - Consumer Electronics, Communication systems
    - Control Theory, Power systems
  - Mechanical Engineering:
    - Most mechanical systems involve electricity
    - Mechanical devices obey similar laws and techniques
      - Mechanical dampers → Resistors
      - Springs → Capacitors
      - Flywheel → Inductors
  - Civil Engineering:
    - Electrical systems are present in all large and small building and infrastructure projects

Problem Solving Method

- A way to navigate unfamiliar territory
  - draw circuit
  - label unknowns
  - apply known laws and equations
  - simplify
  - if you get stuck, backtrack, try a different approach
- TIP #1: keep a positive attitude
- TIP #2: but always check for errors

1.2 Electric Charges

- Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).

- The charge e on one electron is negative and equal in magnitude to 1.602×10^{-19} C which is called as electronic charge. The charges that occur in nature are integral multiples of the electronic charge.

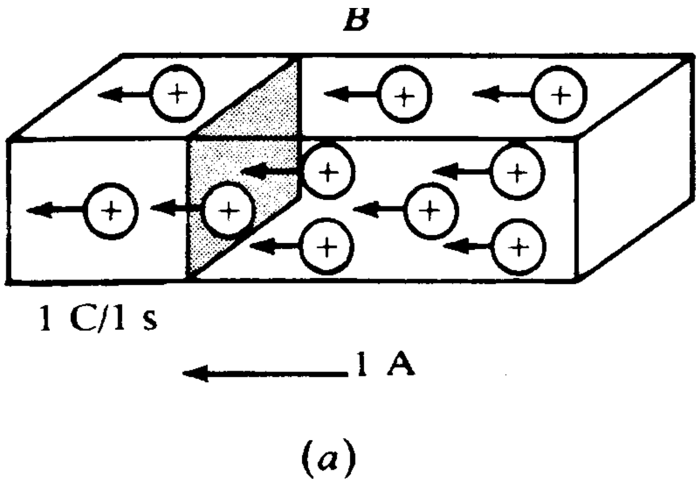
  - 1 electron = 1.6×10^{-19} Coulombs of charge
  - 1 Coulomb = 6.25×10^{18} charges (electrons or protons)

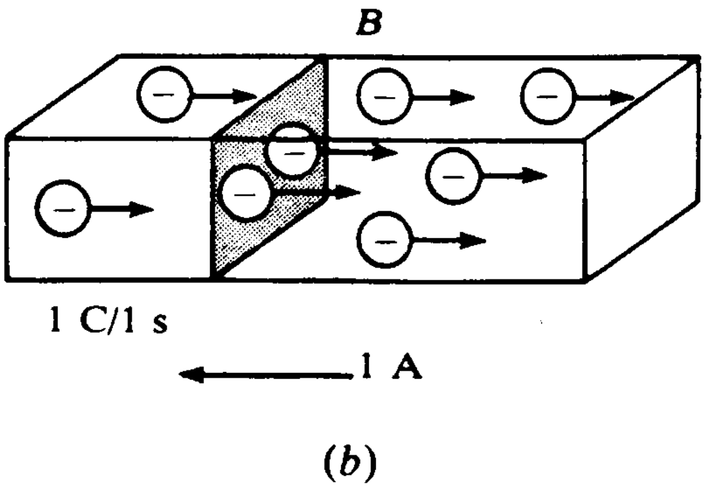
1.3 Current (1)

- Electric current $i = dq/dt$. The unit of ampere can be derived as $1\ A = 1C/s$.
- A direct current (dc) is a current that remains constant with time.
- An alternating current (ac) is a current that varies sinusoidally with time. (reverse direction)

1.3 Current (2)

- The direction of current flow





Positive ions

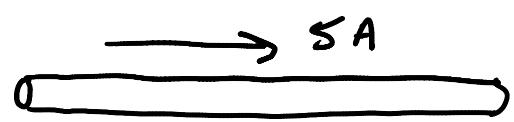
Negative ions

1.3 Current (3)

Example 1

A conductor has a constant current of 5 A.

How many electrons pass a fixed point on the conductor in one minute?



Total Charge:

$$5A \text{ for } 1 \text{ minute} = (5\ C/s)(60\ s/min) = 300\ C/min$$

Total # electrons:

$$300\ C/min \left(\frac{1 \text{ electron}}{1.6 \times 10^{-19} C} \right) = 1.87 \times 10^{21} \text{ electrons/min}$$

1.4 Voltage (1)

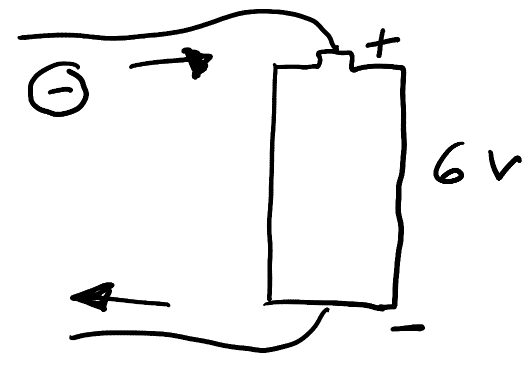
- Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).

- Mathematically, $$v_{ab} = dw / dq$$ (volt)
  - w is energy in joules (J) and q is charge in coulomb (C).

- Electric voltage, v_{ab}, is always across the circuit element or between two points in a circuit.
  - $v_{ab} > 0$ means the potential of a is higher than potential of b.
  - $v_{ab} < 0$ means the potential of a is lower than potential of b.

How much energy is imparted to an electron as it flows through a 6 V battery from the positive to the negative terminal? Express your answer in attojoules.

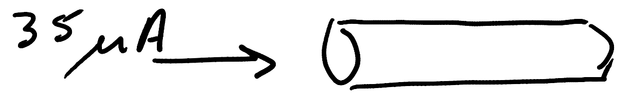
$$V = \frac{dw}{dq} = 6\,V = 6\,J/C$$



$$\left(6\,J/e\right)\left(\frac{1\,e}{6.25\times10^{18}\,\text{elect}}\right) = 9.6\times10^{-19}\,J/\text{elect}$$

$$9.6\times10^{-19}\,J/\ominus \cdot \frac{1\ \text{atto-J}}{10^{-18}\,J} = \underline{.96\ \text{atto-Joules}}$$

In electronic circuits it is not unusual to encounter currents in the microampere range. Assume a 35 μA current, due to the flow of electrons. What is the average number of electrons per second that flow past a fixed reference cross section that is perpendicular to the direction of flow?



$$35\,\cancel{\mu A}\left(\frac{1\,\cancel{A}}{10^{6}\,\cancel{\mu A}}\right)\cdot\left(\frac{1\,\cancel{C}/s}{1\,\cancel{A}}\right)\left(\frac{1\,\ominus}{1.602\times10^{-19}\,\cancel{C}}\right) = 2.18\times10^{14}\,\ominus/s$$

1.5 Power and Energy (1)

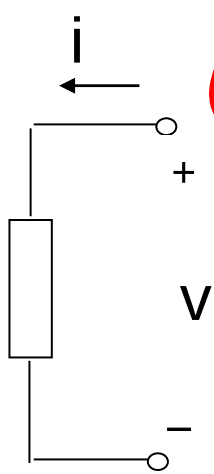
- W = energy (J)
- P = power = $\frac{\Delta W}{\Delta s}$ (J/s) or (Watts)

- Power is the time rate of expending or absorbing energy, measured in watts (W).
- Mathematical expression:

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$$

V I

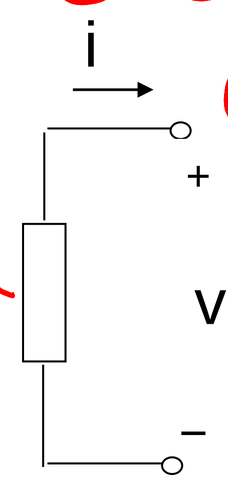
Passive Sign Convention:



i enters + terminal

$p = +vi$

Active Sign Convention



i exits + terminal

$p = -vi$

$p > 0 \rightarrow$ element absorbs power
$p < 0 \rightarrow$ " delivers power

1.5 Power and Energy (2)

- The law of conservation of energy

$$\sum p = 0$$

In each circuit
some elements absorb
others deliver power

- Energy is the capacity to do work, measured in joules (J).

Energy for an element

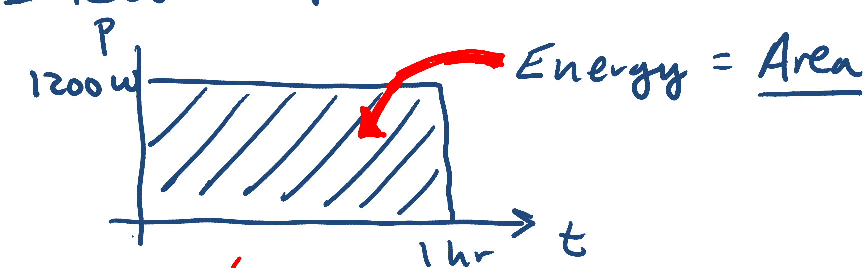
- Mathematical expression $w = \int_{t_0}^{t} p dt = \int_{t_0}^{t} vi dt$

CLEO Example Problem 1

- (a) Suppose that a 12-volt automobile battery with 100 amp-hour capacity is fully charged. How much energy (in joules) is stored in the battery?

100 A-hr → can deliver 100 A for 1 hour (or 1 A for 100 hours)

Suppose $I = 100\text{ A}$, given $V = 12\text{ V}$ → $P = 1200\text{ W}$ for 1 hour

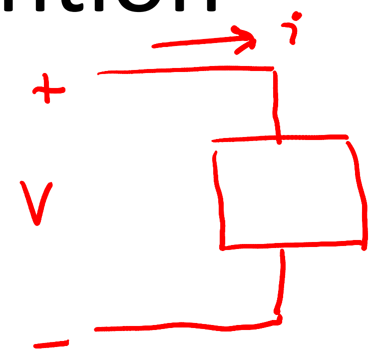


Energy = $PT = 1200\text{ W-hr}$

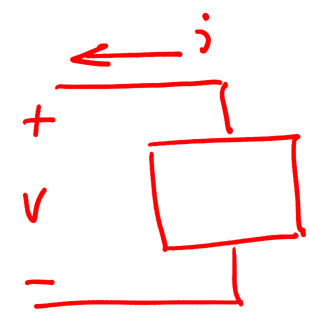
$$1200\ \text{W-hr}\left(\frac{1\ \text{J/s}}{1\ \text{W}}\right)\left(\frac{3600\ \text{s}}{1\ \text{hr}}\right) = 4.3\times10^{6}\ \text{J}$$

Passive vs Active Sign Convention

- Passive Sign Convention
  - Applies to a circuit element
  - Circuit element has i flowing into + side of v
  - Use P = I V for power
    - if P > 0 the device ABSORBS power
    - if P < 0 the device RELEASES or DELIVERS power into the circuit



- Active Sign Convention
  - Circuit element has i flowing OUT of + side of v
  - Use P = - I V for power
  - same rule applies for ABSORB (P>0) or DELIVER (P < 0)



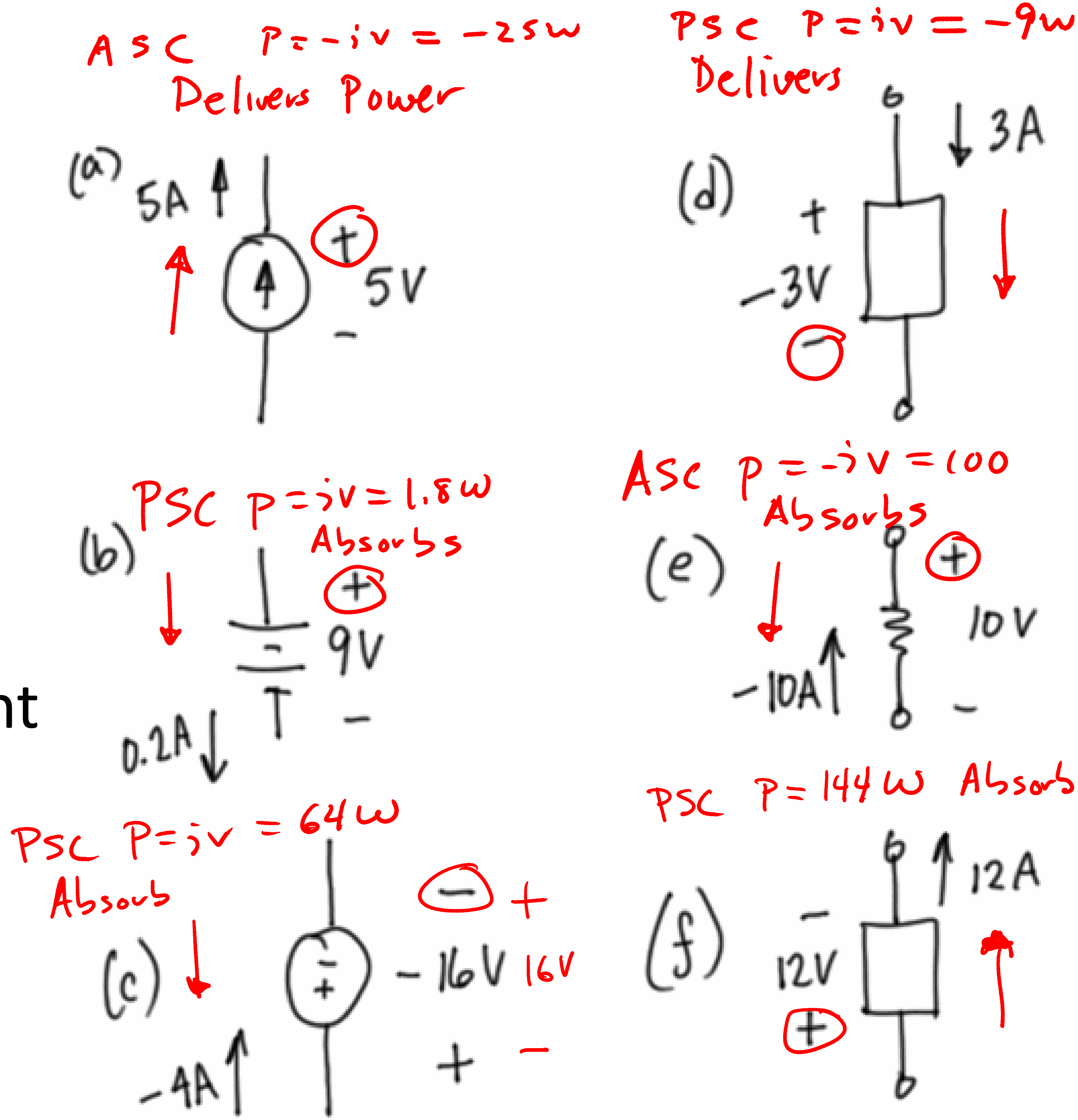
CLEO Problem 2

- For each device, state whether Passive Sign Convention (PSC) or Active Sign Convention (ASC) is used for the defined current and voltage. Then determine whether the device is absorbing or delivering power. Then For labeled currents, draw an arrow to show the direction of positive current. For labeled voltages, circle the node that is at the highest potential.
-

- active or passive?
- Energy: absorbing or delivering?

show pos current

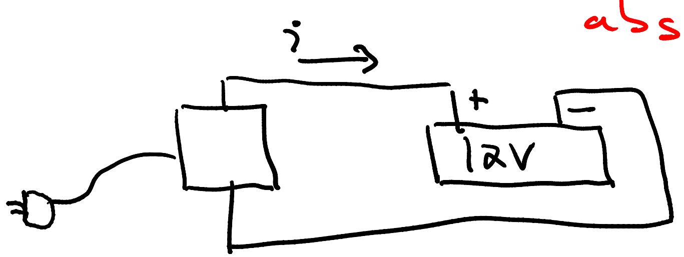
show higher V



Voltage and Current Sources

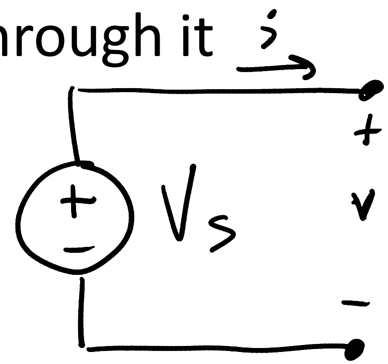
- Circuit elements are either:
  - passive – dissipate energy (resistors, light bulbs, rail guns...)
  - active – provide energy (voltage and current sources)
  - SOMETIMES a V or I source will dissipate energy!
    - depending on circuit

For example, battery charger makes battery absorb energy



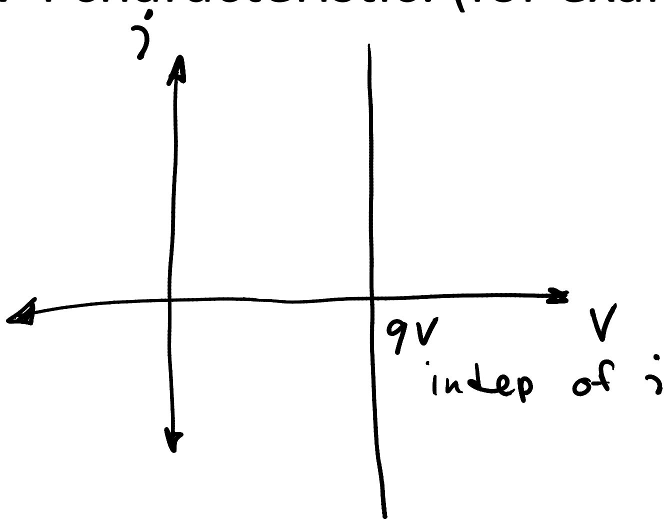
Voltage source:

– Like a constant pressure water pump
  - maintains steady voltage (pressure) no matter what the current flow through it
  - Symbol:



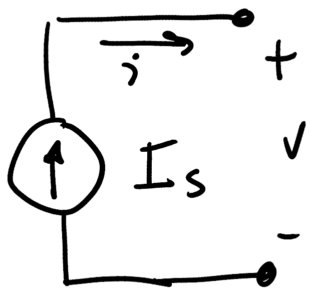
$v = V_s$ volts

  - V-I characteristic: (for example, a 9V source)



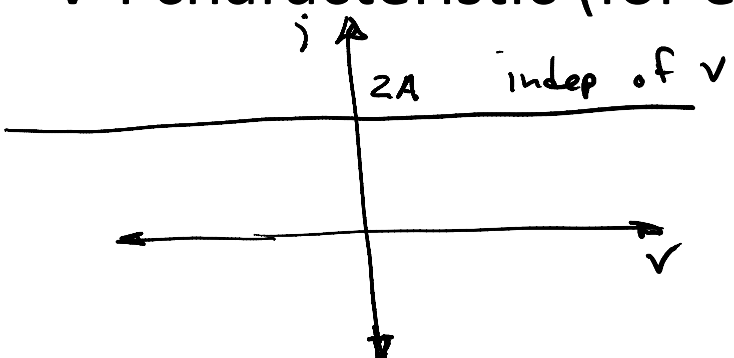
Current source:

- Like a constant flow water pump
  - maintains current flow no matter what the voltage change across it
  - Symbol (dual or complement of voltage source):



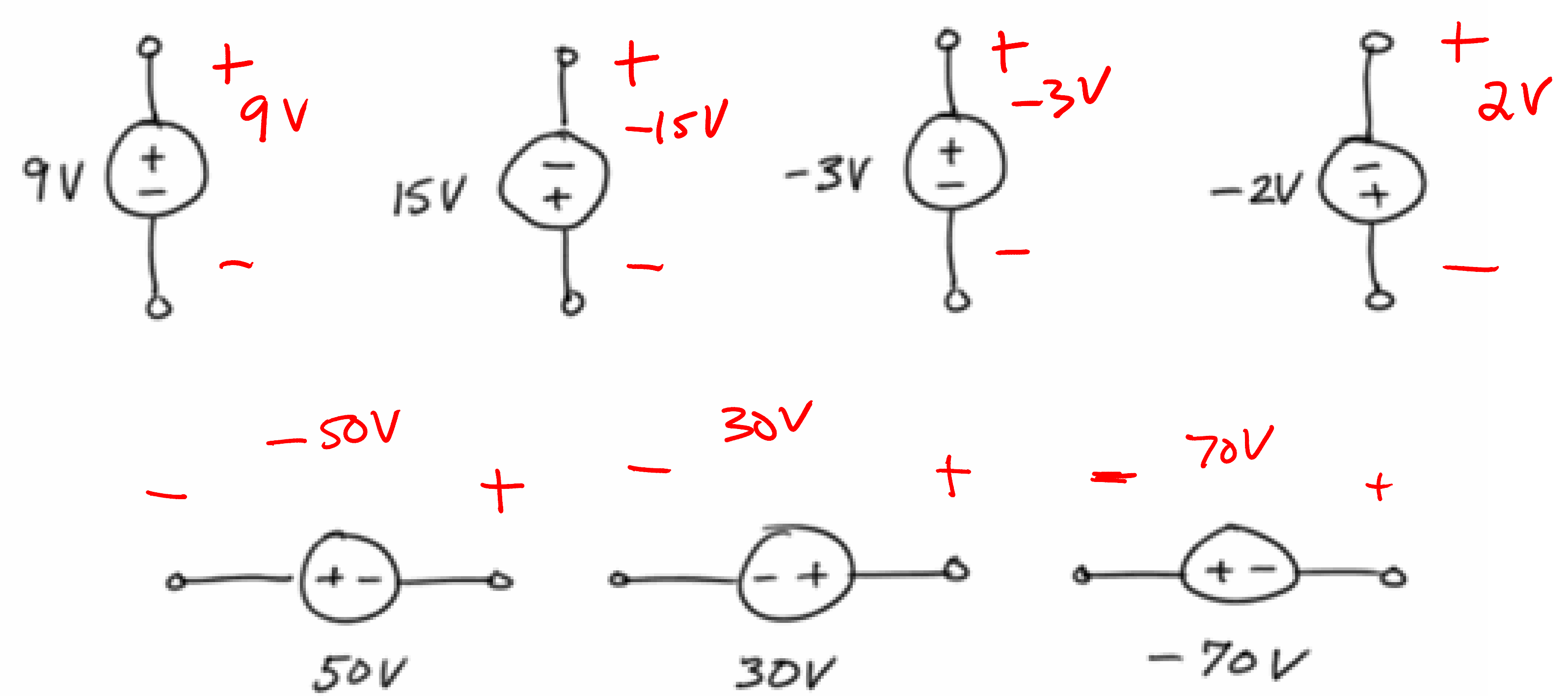
$i = I_s$

  - V-I characteristic (for example, a 2A source)

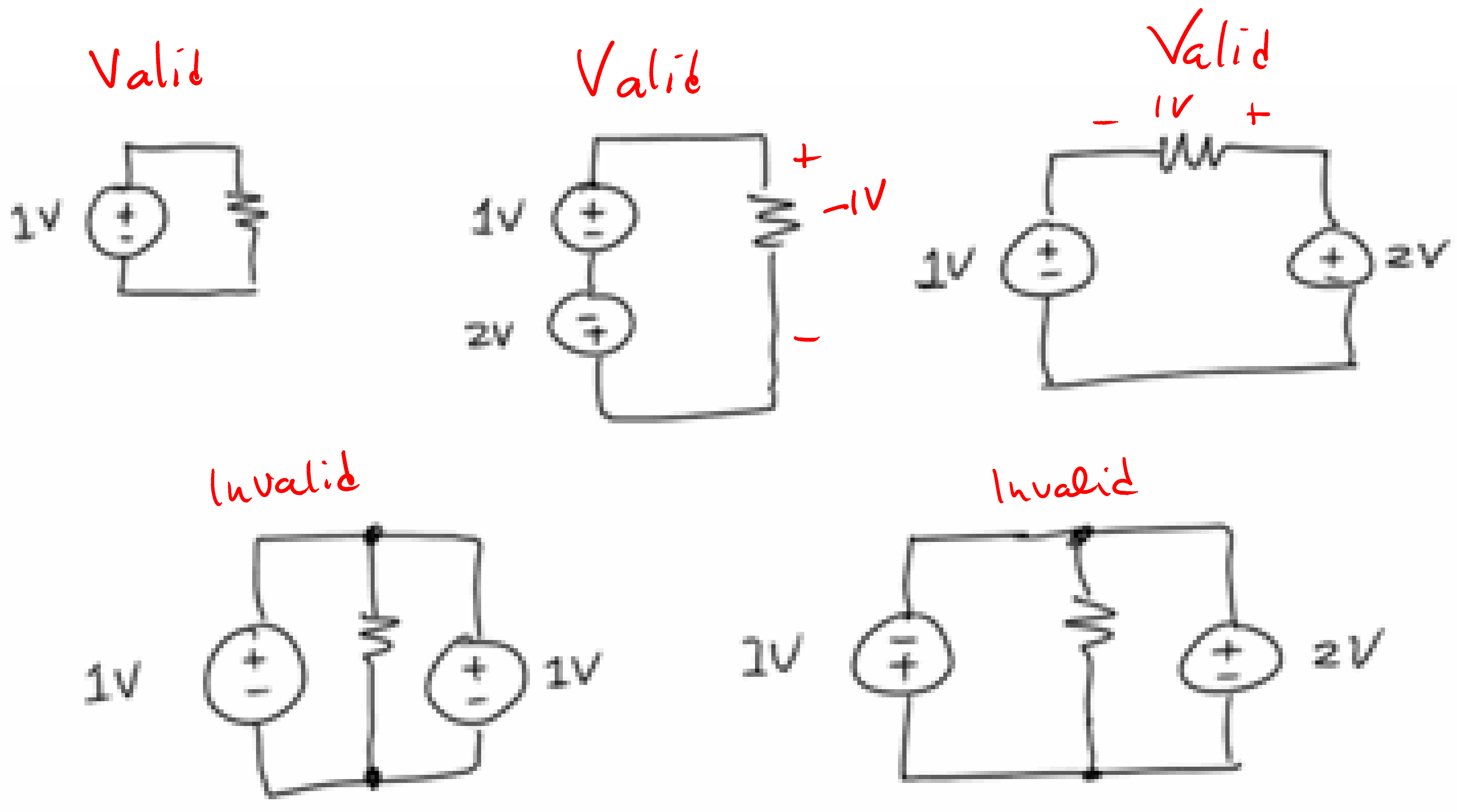


VOLTAGE Source Examples

- Problem 1 For each voltage source, draw a voltage label (polarity indicators and value) with the positive indicator at the top or to the right that is equivalent to the indicated voltage.

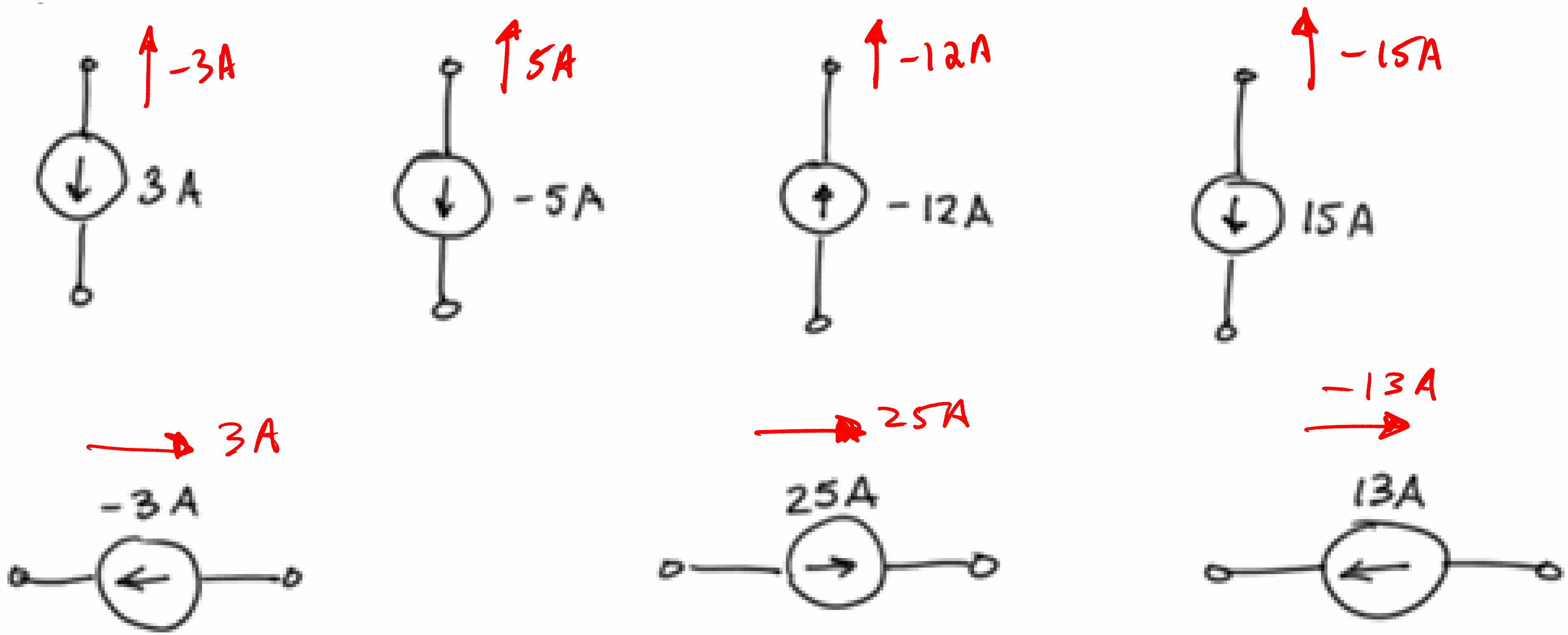


Problem 2 Which of the following circuit connections are invalid?



CURRENT Source Examples

- Problem 1 For each current source, draw a current label (arrow and value) pointing up or to the right that is equivalent to the indicated current.



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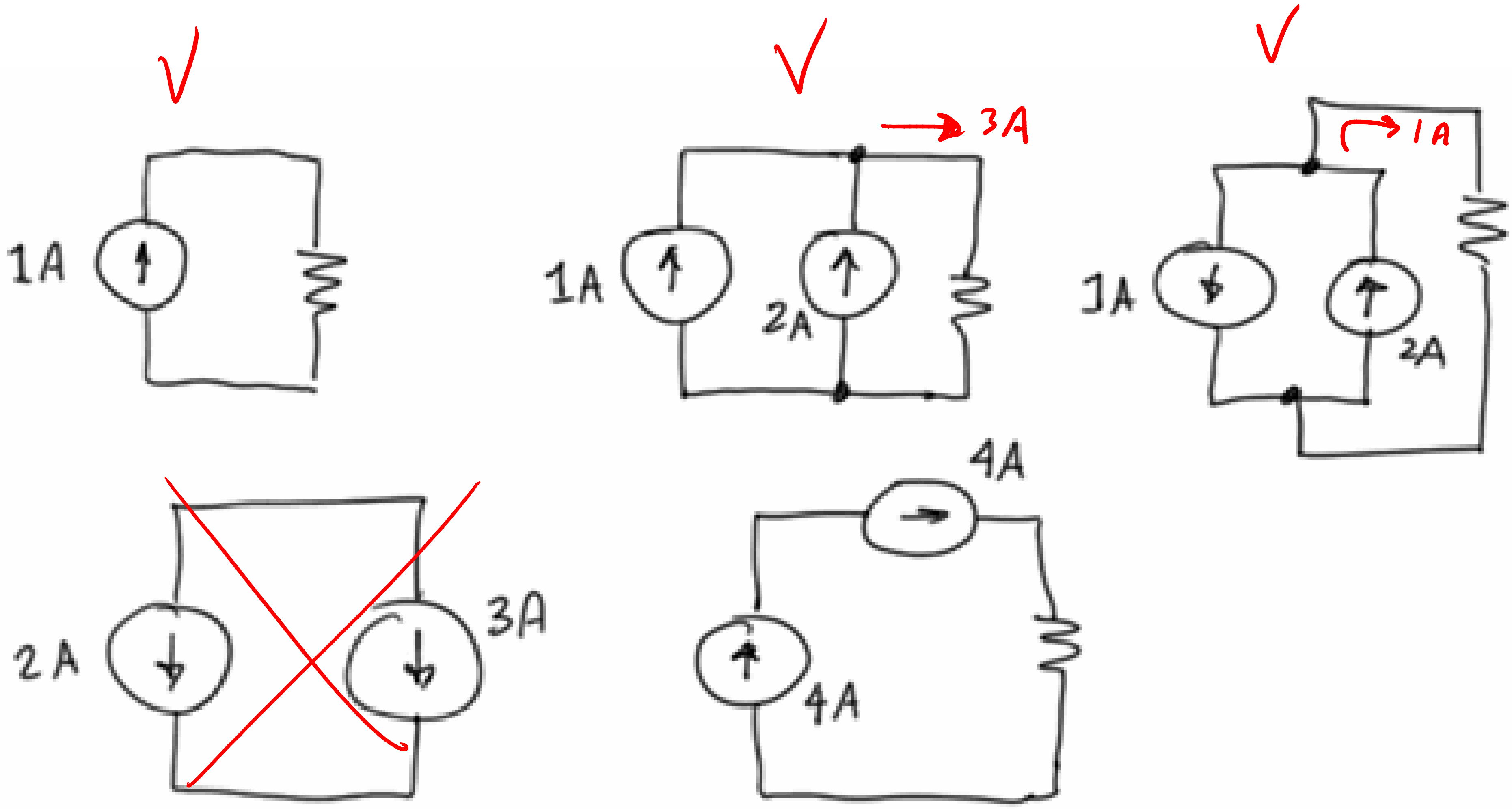
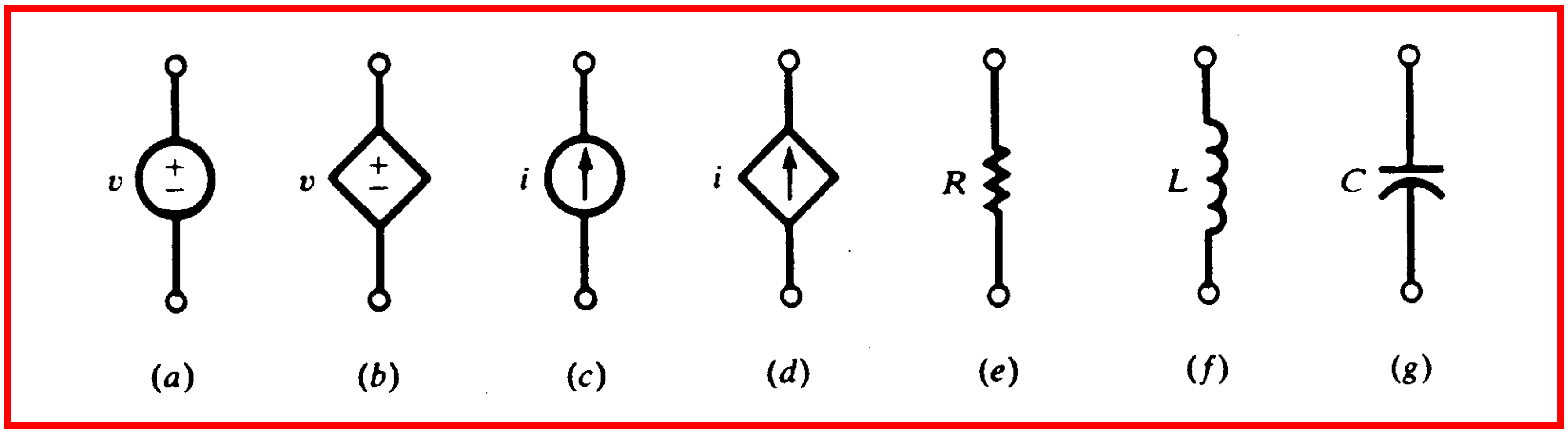
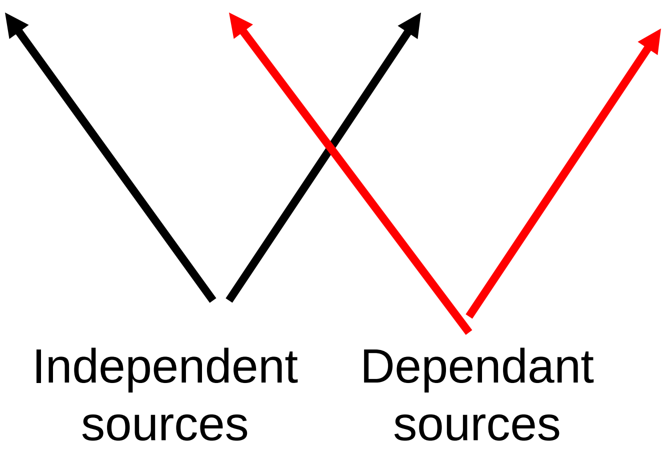


1.6 Actual Circuit Elements

Active Elements | **Passive Elements**





- **A dependent source is an active element in which the source quantity is controlled by another voltage or current.**
- **They have four different types: VCVS, CCVS, VCCS, CCCS. Keep in minds the signs of dependent sources.**

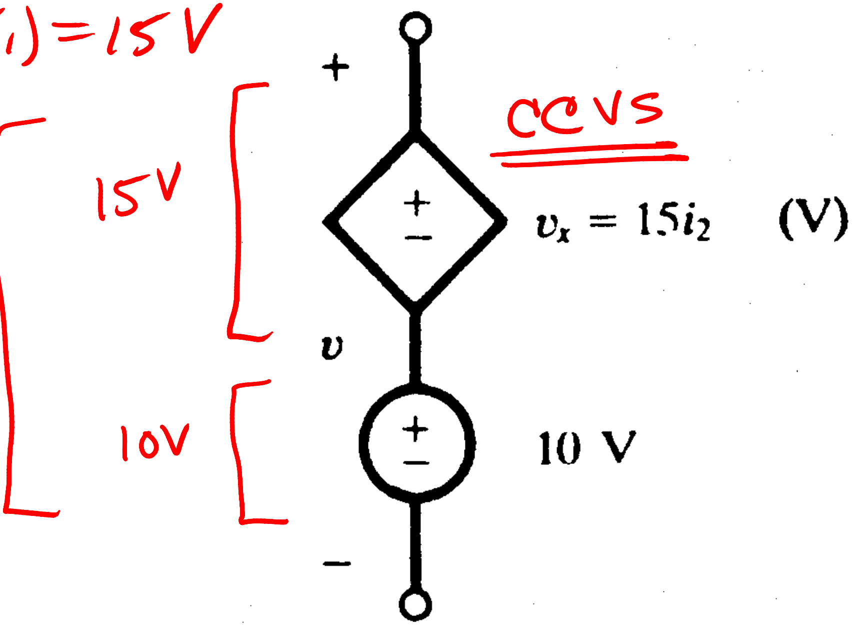
1.6 Circuit Elements

Example 2

Obtain the voltage v in the branch shown in Figure 2.1.1P for $i_2 = 1A$.

$V_x = 15(i_2) = 15(1) = 15V$

$V = 10 + 15 = 25V$



Handouts

CLEO Example Problem 1

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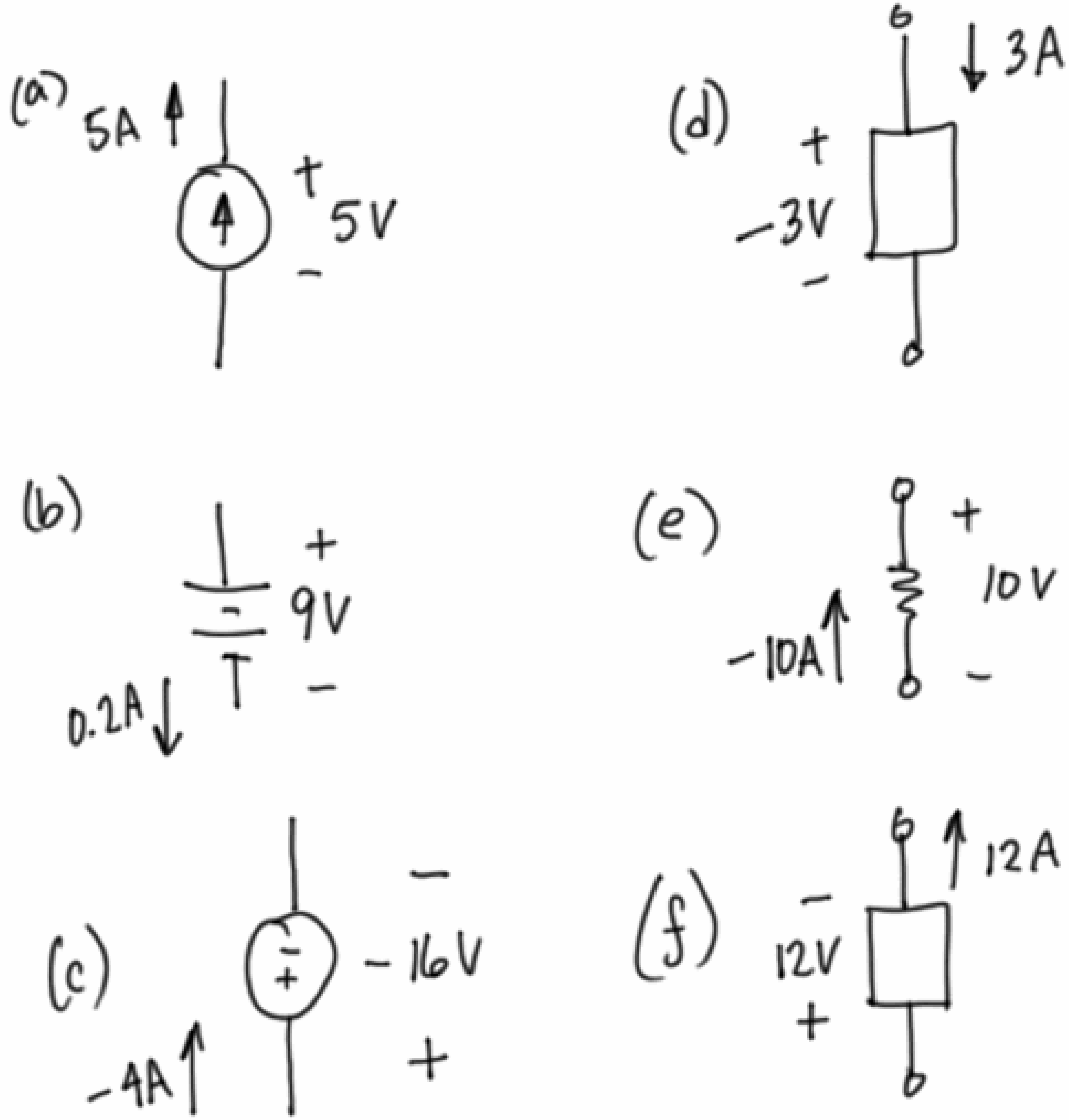
- Energy: absorbing or delivering?

show pos current

show higher V



VOLTAGE Source Examples

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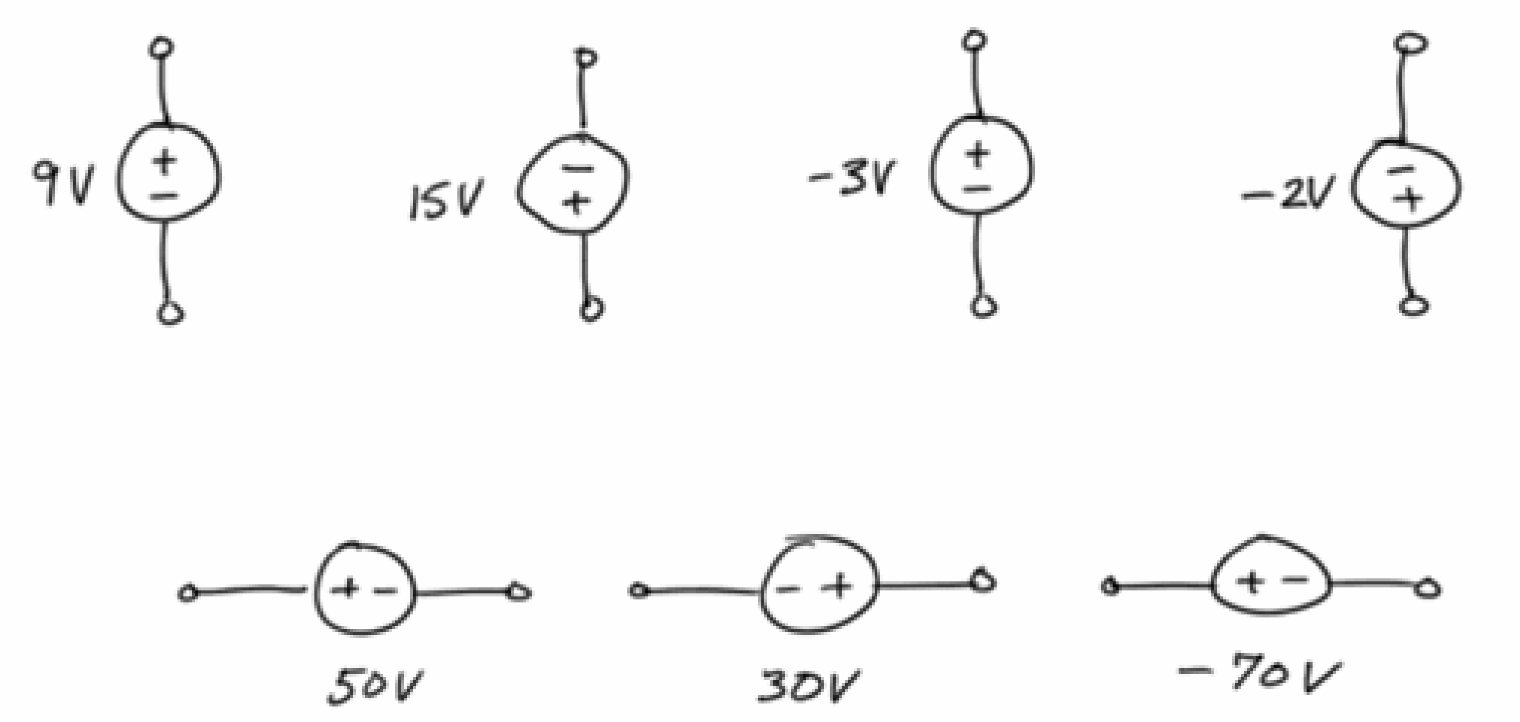

CURRENT Source Examples

- Problem 1 For each current source, draw a current label (arrow and value) pointing up or to the right that is equivalent to the indicated current.