ECE 203 Circuits I

Lecture 3

Voltage, Current, Power, and Circuit Elements

The Ideal Basic Circuit Element

An **ideal basic circuit element** has three attributes:

(1) it has only two terminals, which are points of connection to other circuit components;

(2) it is described mathematically in terms of current and/or voltage;

(3) it cannot be subdivided into other elements.

So we use the word ***ideal*** to imply that an ideal basic circuit element probably does not exist as a realizable physical component. However, ideal elements can be connected to model actual devices and systems.

We use the word ***basic*** to imply that the circuit element cannot be further reduced or subdivided into other elements. So basic circuit elements form the building blocks for constructing circuit models, but they themselves cannot be modeled with any other type of element.

Figure 1.5. An ideal basic circuit element

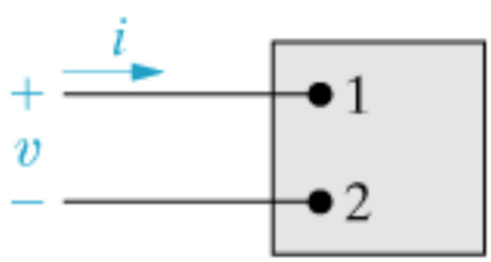
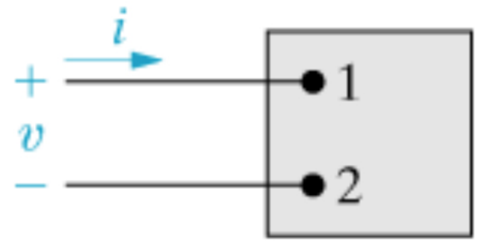


Figure 1.5. An ideal basic circuit element



The box can represent various different circuit elements.

The voltage across the terminals of the box is denoted by v, and the current through the circuit element is denoted by i.

The polarity reference for the voltage is indicated by the plus and minus signs, and the reference direction for the current is shown by the arrow

Note: Positive charge flowing in one direction is algebraically equivalent to negative charge flowing in the opposite direction.

The interpretation of these references for positive or negative numerical values of v and i is seen later!

Basic Electrical Quantities

- Basic quantities: current, voltage and power
  - *Current*: time rate of change of electric charge

    1 Amp = 1 Coulomb/sec

  - *Voltage*: electromotive force or potential, V

    1 Volt = 1 Joule/Coulomb = 1 N·m/coulomb

  - *Power*: $P = I\,V$

    1 Watt = 1 Volt·Amp = 1 Joule/sec

Electrical Analogies (Physical)

	Electrical	Hydraulic
Base	Charge (q)	Mass (m)
Flow	Current (I)	Fluid flow (G)
Potential	Voltage (V)	Pressure (p)
Power	$P = I\,V$	$P = G\,p$

James Watt

1736 - 1819

James Watt was born on January 19, 1736 in Scotland. He worked as an instrument maker at the University of Glasgow. He worked with Joseph Black and studied the properties of steam.

In 1769 he patented a condenser for condensing steam. A few years later, he patented a steam engine used to pump water out of mines. Other inventions included a twin-action piston engine, used to obtain power from the expansion of steam inside a cylinder. He also developed a centrifuge governor to hold a steam engine at a constant speed. His steam engine, although not the first to be developed, was the first practice device for converting steam into useful work. James Watt died on August 25, 1819.

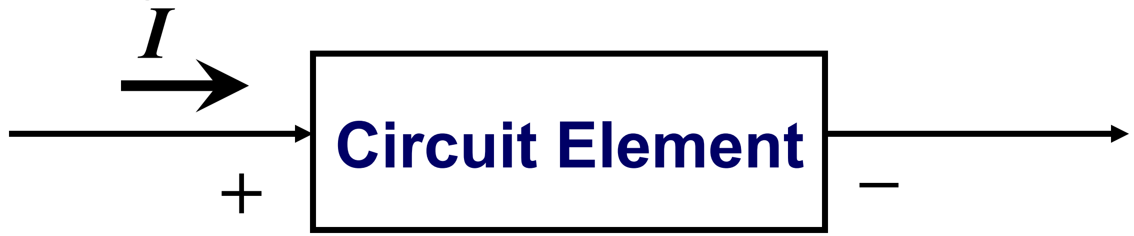
James Prescott Joule (1818 – 1889)

JOULE, James Prescott (1818-89), British physicist, born in Salford, Lancashire, England. One of the outstanding physicists of his day, Joule is best known for his research in electricity and thermodynamics. In the course of his investigations of the heat emitted in an electrical circuit, he formulated the law, now known as Joule's law, of electric heating, which states that the amount of heat produced each second in a conductor by a current of electricity is proportional to the resistance of the conductor and to the square of the current.

Joule experimentally verified the law of conservation of energy in his study of the transfer of mechanical energy into heat energy. Using many independent methods, Joule determined the numerical relation between heat and mechanical energy, or the mechanical equivalent of heat. The unit of energy called the joule is named after him; it is equal to 1 watt-second, or 10 million ergs, or about 0.000948 British thermal unit. Together with the physicist William Thomson (later Baron Kelvin), Joule found that the temperature of a gas falls when it expands without doing any work. This principle, which became known as the Joule-Thomson effect, underlies the operation of common refrigeration and air conditioning systems.

Example of Sign Convention

- ***Passive sign convention*** : positive current enters the positive voltage terminal



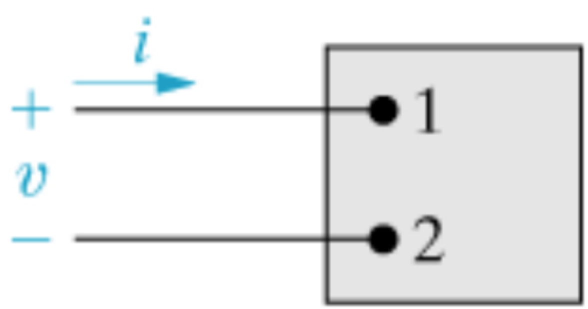
dissipates

- Consequence for $P = I\,V$
  - – Positive (+) Power: element **absorbs** power
  - – Negative (-) Power: element **supplies** power

Generates or delivers or produces

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
v		*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
i		*or*	*or*
		negative charge flowing from terminal 2 to terminal 1	negative charge flowing from terminal 1 to terminal 2



The assignment of the reference polarity for voltage and the reference direction for current **are entirely arbitrary**.

However, **once you have assigned the references, you must write all subsequent equations to agree with the chosen references.**

The most widely used sign convention applied to these references is called the **passive sign convention**, which we use throughout this course. The passive sign convention can be stated as follows:

PASSIVE SIGN CONVENTION

Whenever the reference direction for the current is in the same direction as the reference voltage drop across the element (as in Fig. 1.5), use a positive sign in any expression that relates the voltage to the current. Otherwise, use a negative sign.

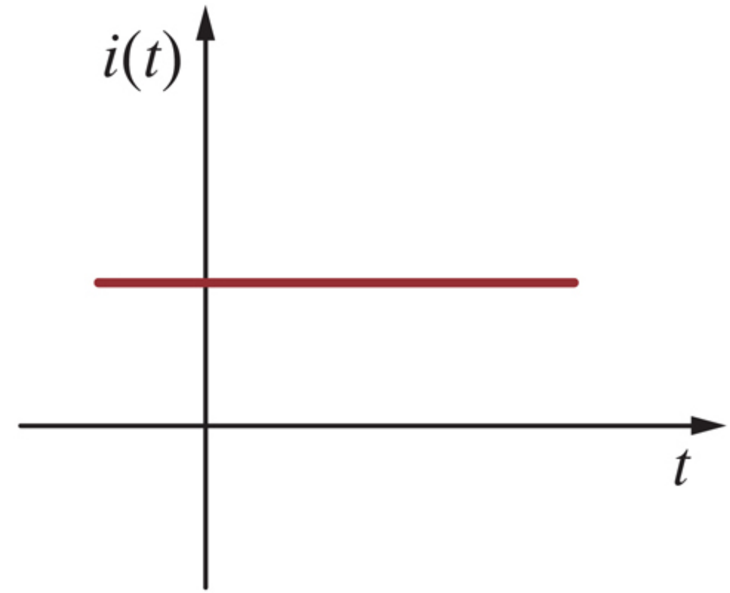
Current, *I*

- Normally we talk about the movement of positive charges although we know that, in general, in metallic conductors current results from electron motion. This is called conventional current flow.
- The sign of the current indicates the direction of flow Go to example 2-1
- Types of current:
  - *direct current* (**dc**): batteries and some special generators
  - *alternating current* (**ac**): household current which varies with time at 60 cycles per second

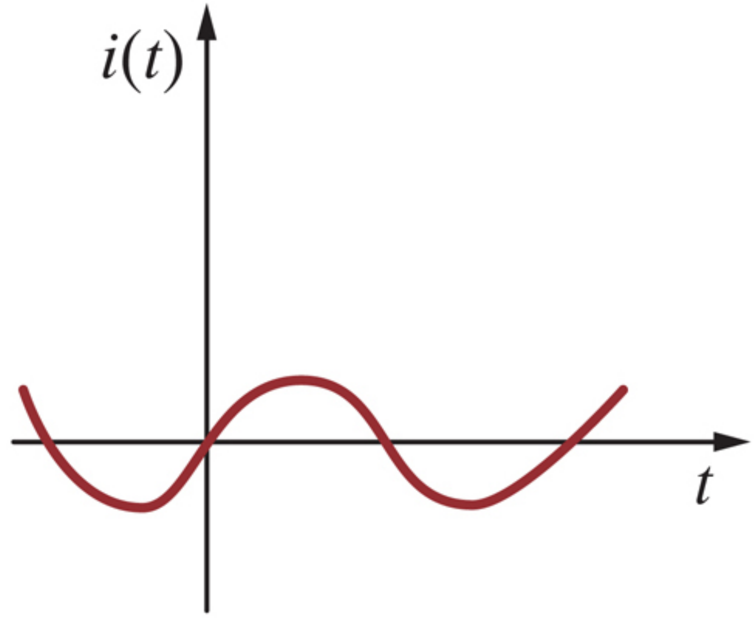
Voltage, *V*

- *Voltage* is the difference in energy level of a unit charge located at each of two points in a circuit, and therefore, represents the energy required to move the unit charge from one point to the other
- Can also be dc or ac

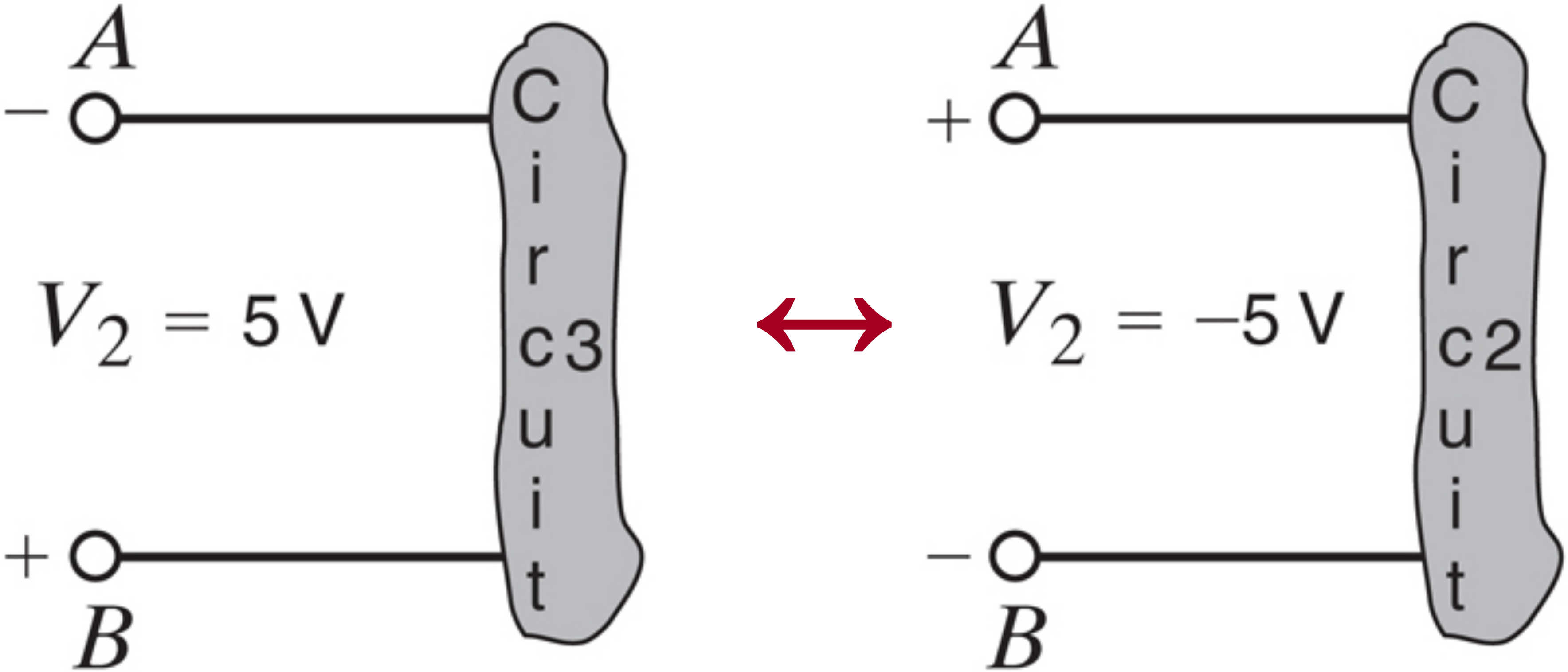
Direct Current or "dc" signal

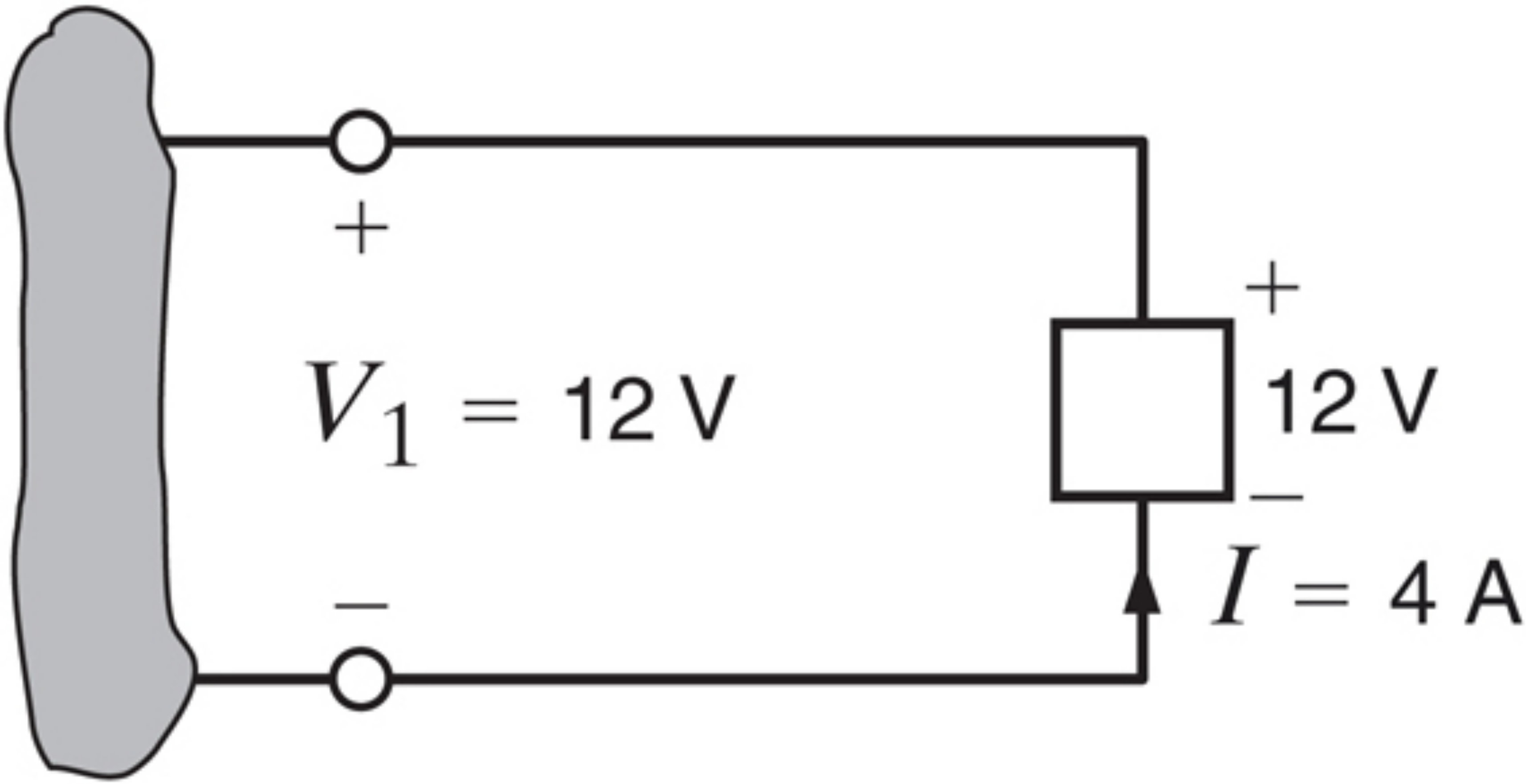


Alternating Current or "ac" signal



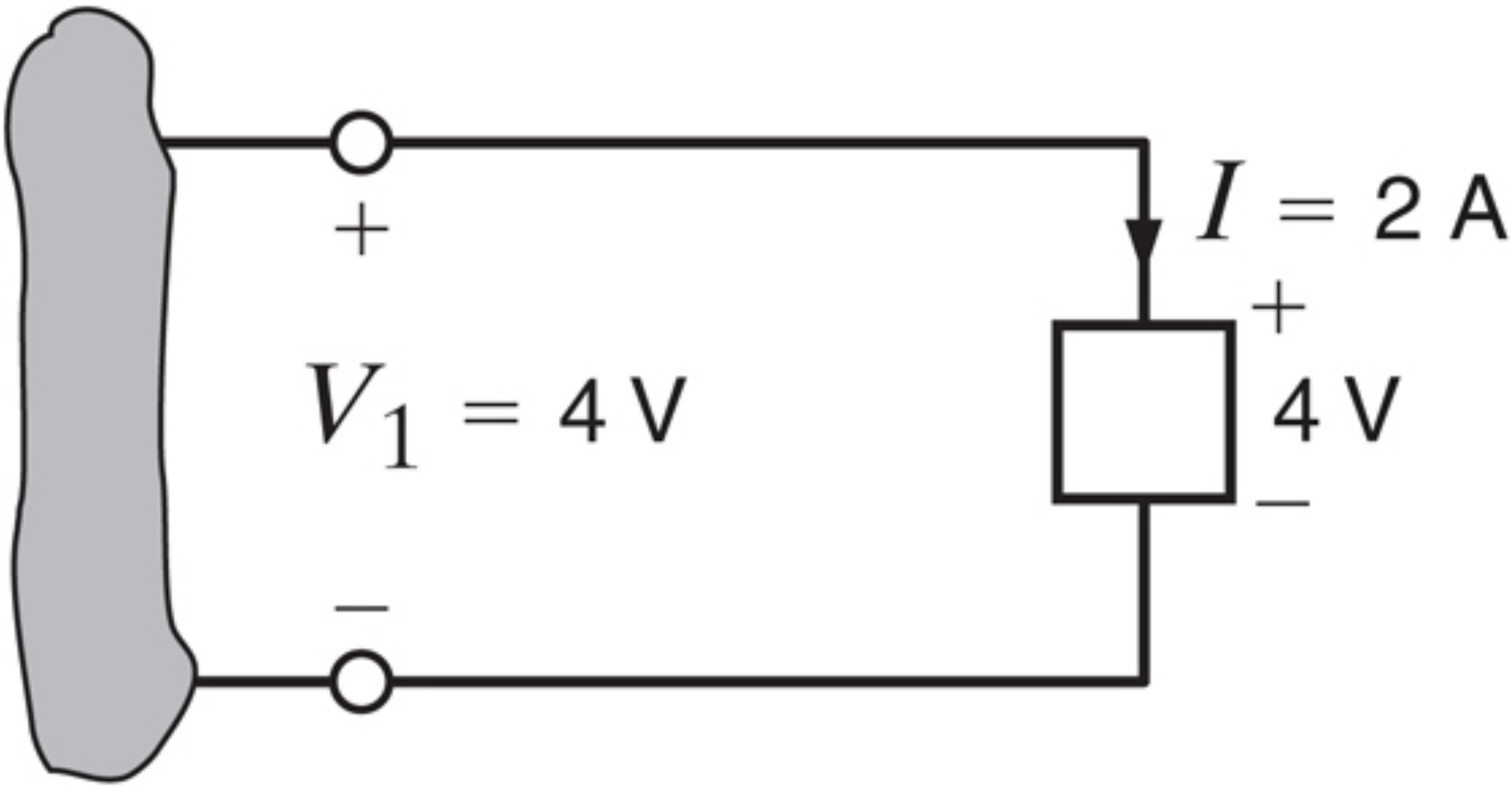
The choice of voltage polarity at a terminal is arbitrary. These two representations are equivalent.





P = V I = (12) (-4) = -48 Watts

Power <u>generated</u> by Box

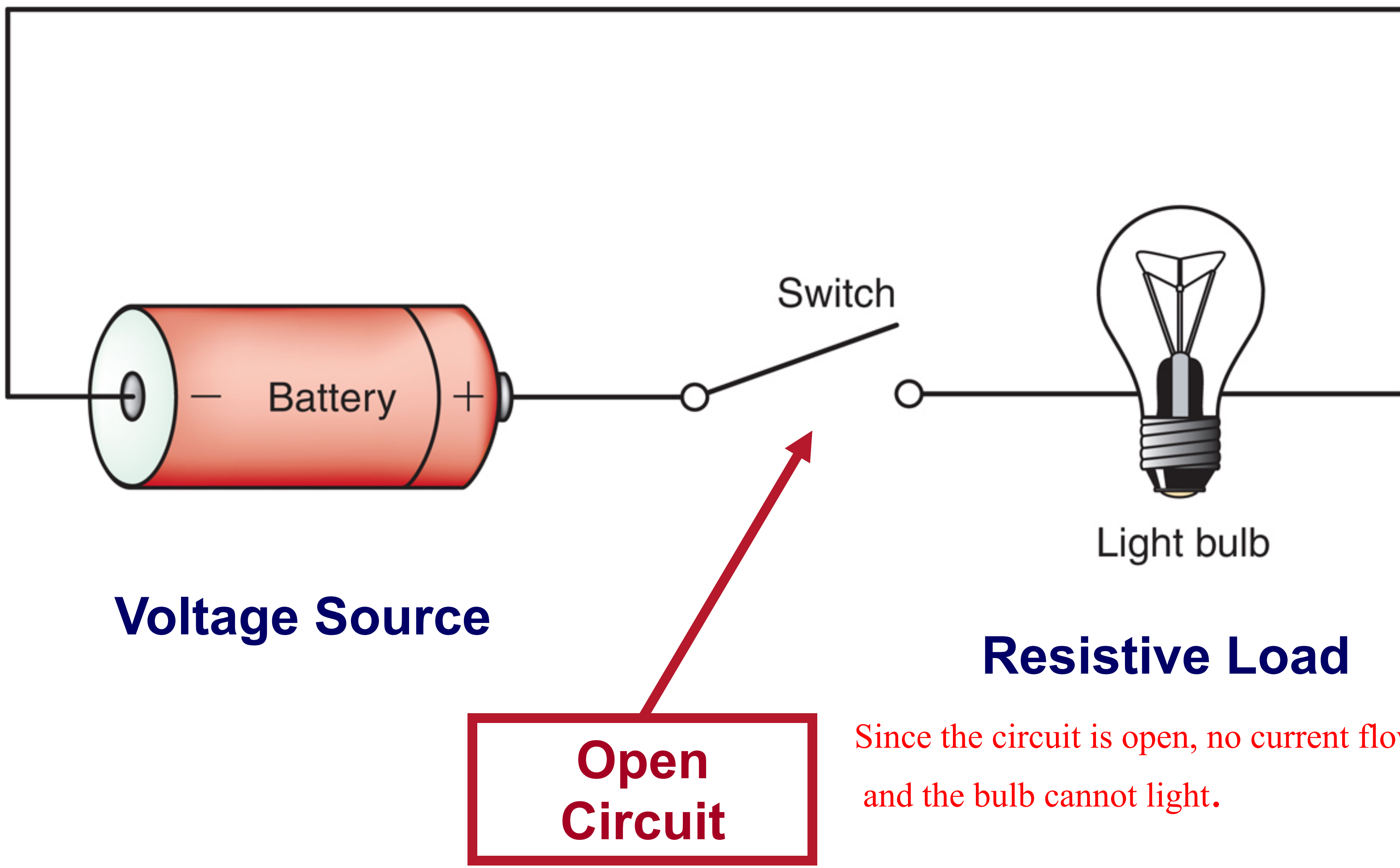


P = V I = (4) (2) = 8 Watts

Power <u>absorbed</u> by Box

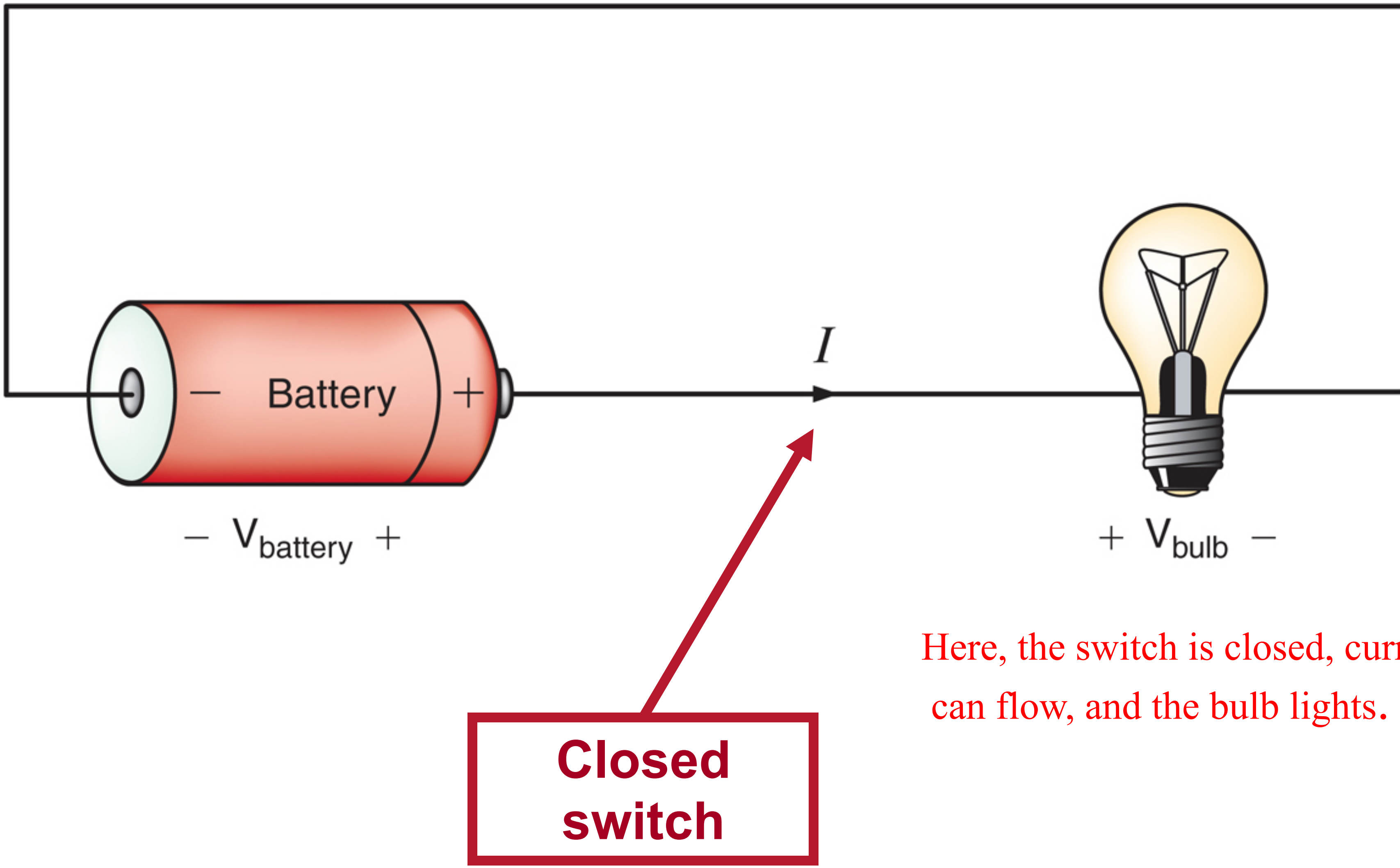
Terminology: Open vs. closed circuit

When there is an open connection in a circuit that interrupts the circularity, it is called an open circuit.



Since the circuit is open, no current flows and the bulb cannot light.

Current flow in the completed circuit!

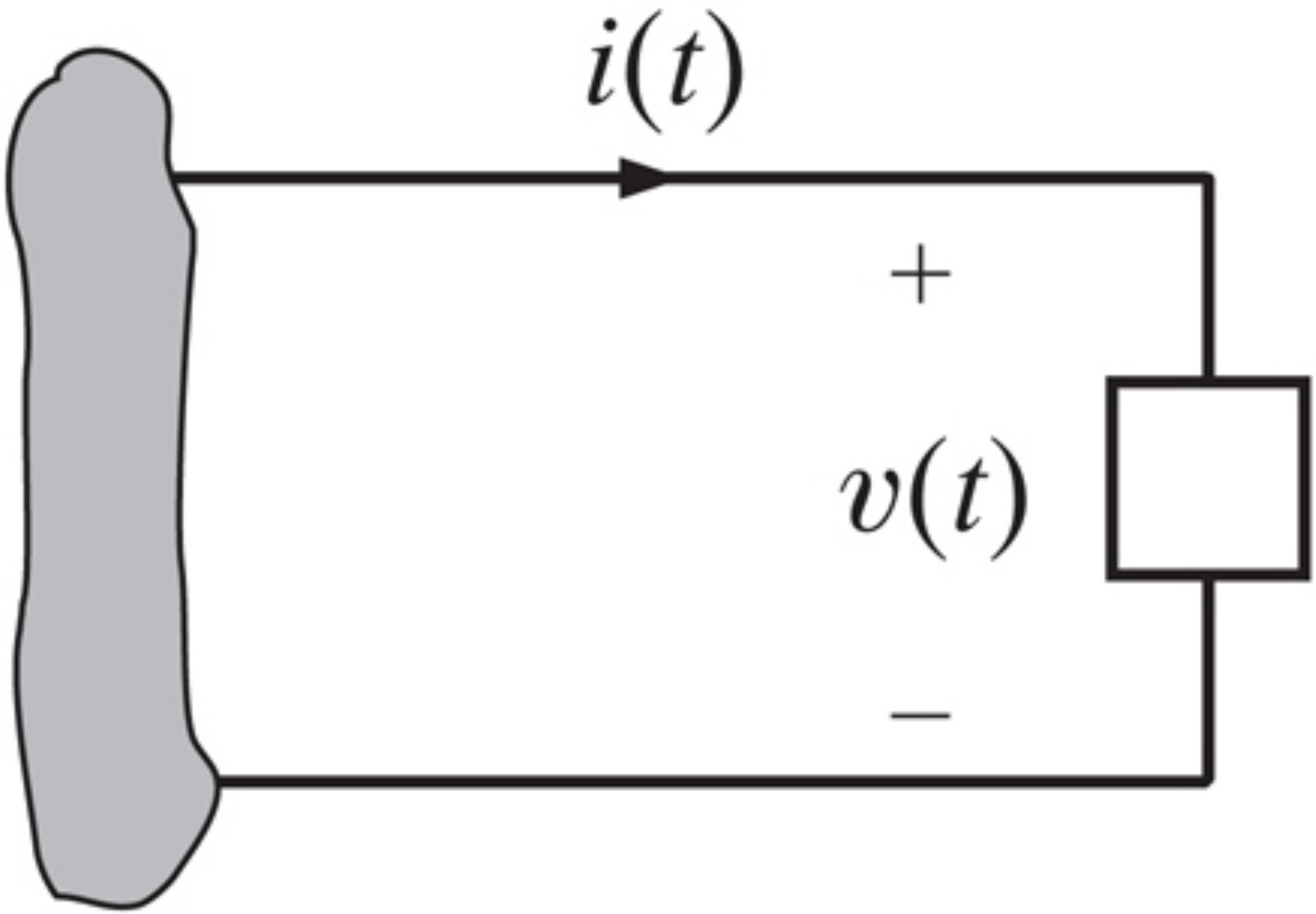


Here, the switch is closed, current can flow, and the bulb lights.

If two points in a circuit are connected, it is known as a "short circuit." Put another way, the two points in the circuit are shorted.

A short can be intentional, or inadvertent.

Go to examples 2-2 and 2-3

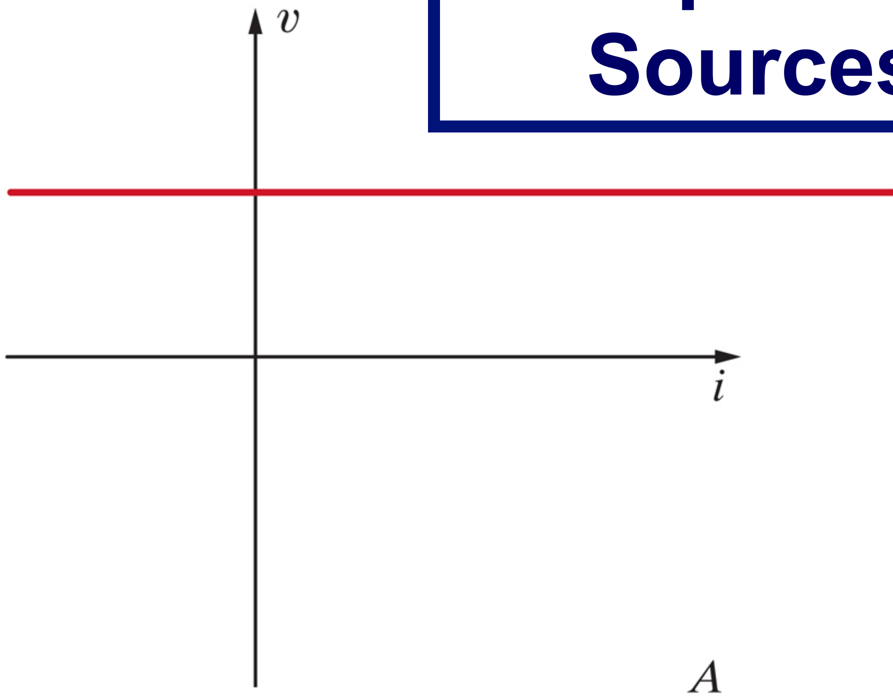


In general the voltage and current can be time dependent.

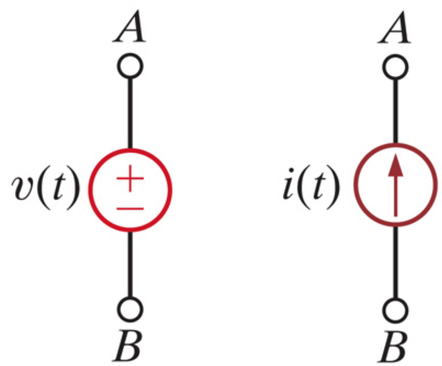
Active vs. Passive Elements

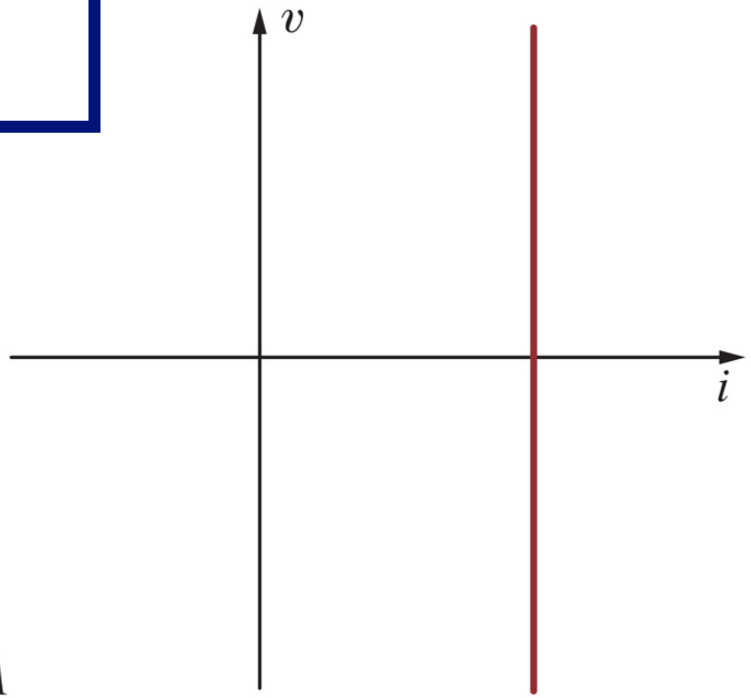
- ***Active elements*** can generate energy
  - Batteries
  - Voltage and current sources
- ***Passive elements*** cannot generate energy
  - Resistors (but can dissipate energy)
  - Capacitors and Inductors (but CAN store energy)

Ideal Independent Sources



Constant Voltage

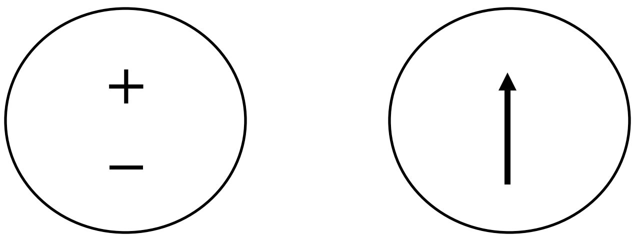




Constant Current

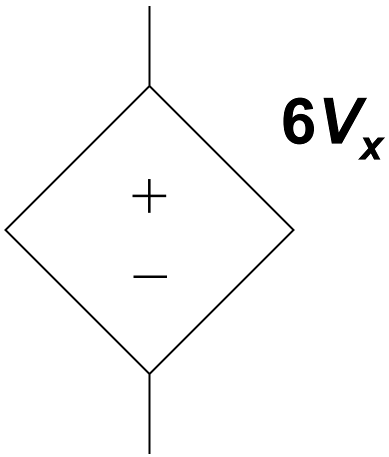
Independent vs. Dependent Sources

An ***independent*** *source* (voltage or current) may be DC (constant) or time-varying, but does not depend on other voltages or currents in the circuit.

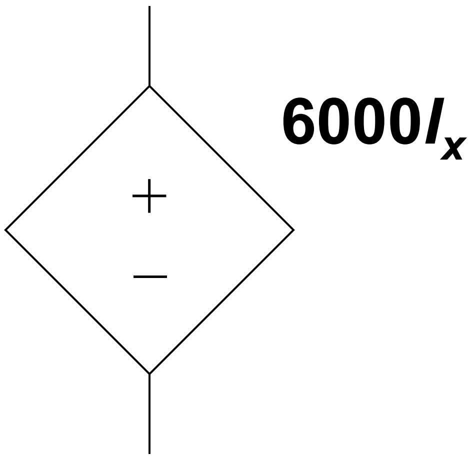


The **dependent** *source* magnitude is a function of another voltage or current in the circuit.

Dependent Voltage Sources

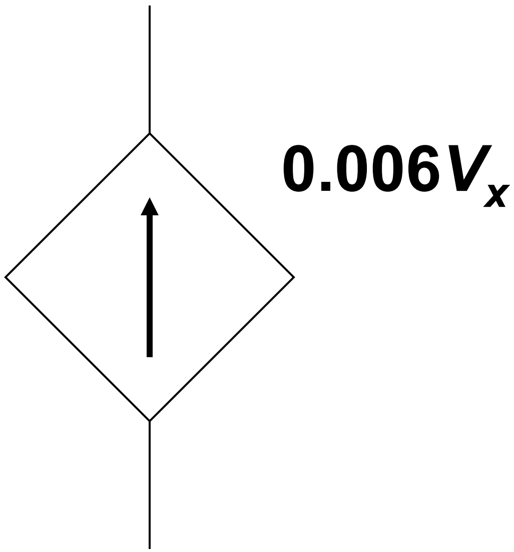


Voltage Controlled Voltage Source

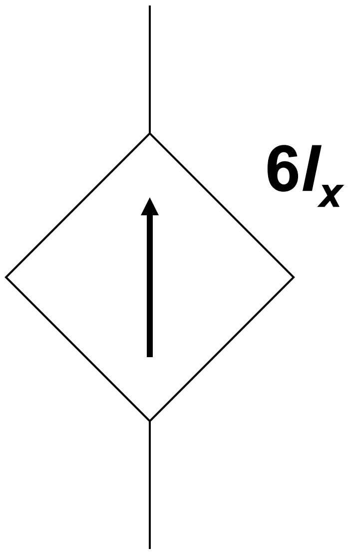


Current Controlled Voltage Source

Dependent Current Sources



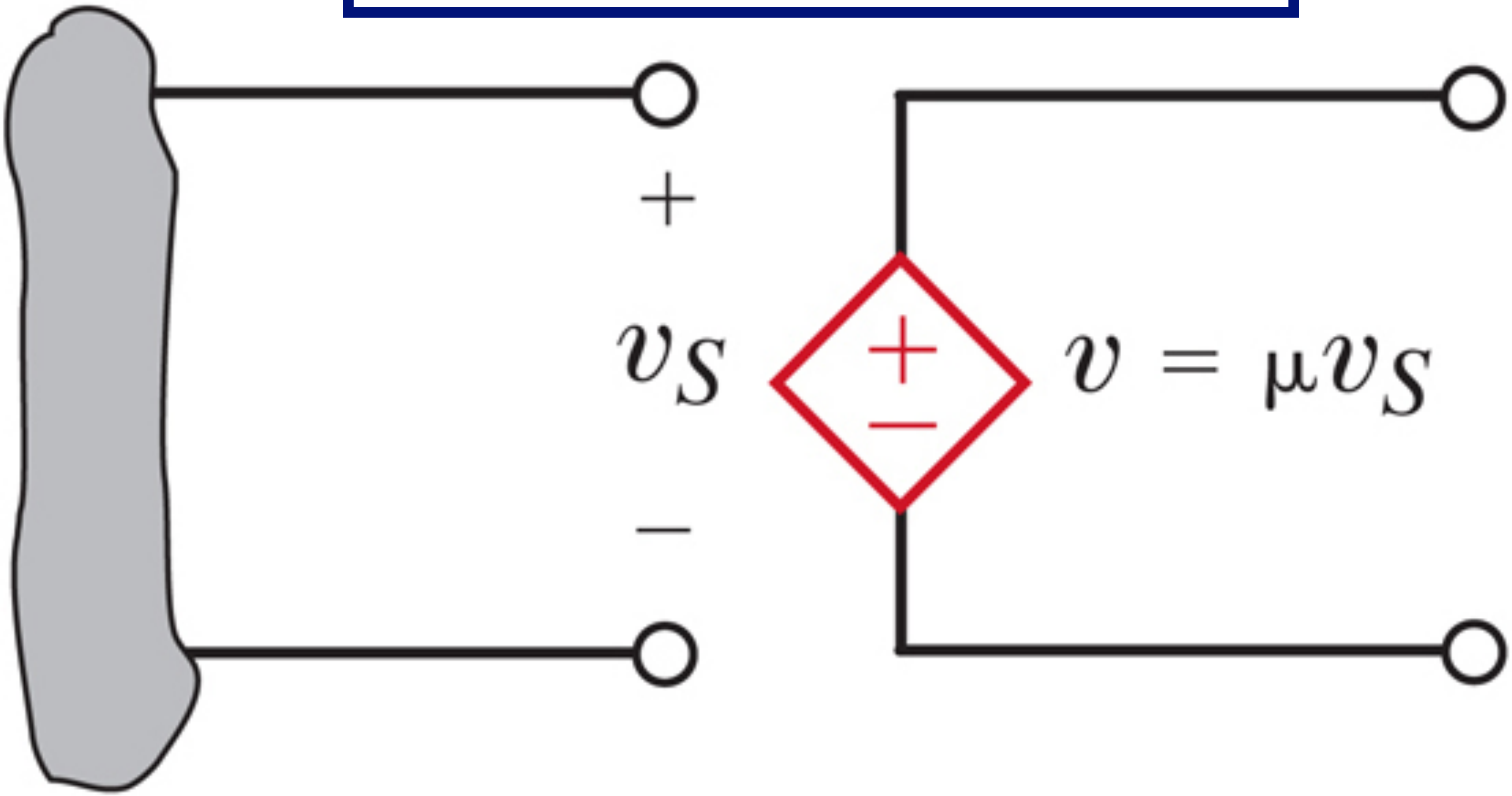
Voltage
Controlled
Current
Source



Current
Controlled
Current
Source

Dependent Voltage Source

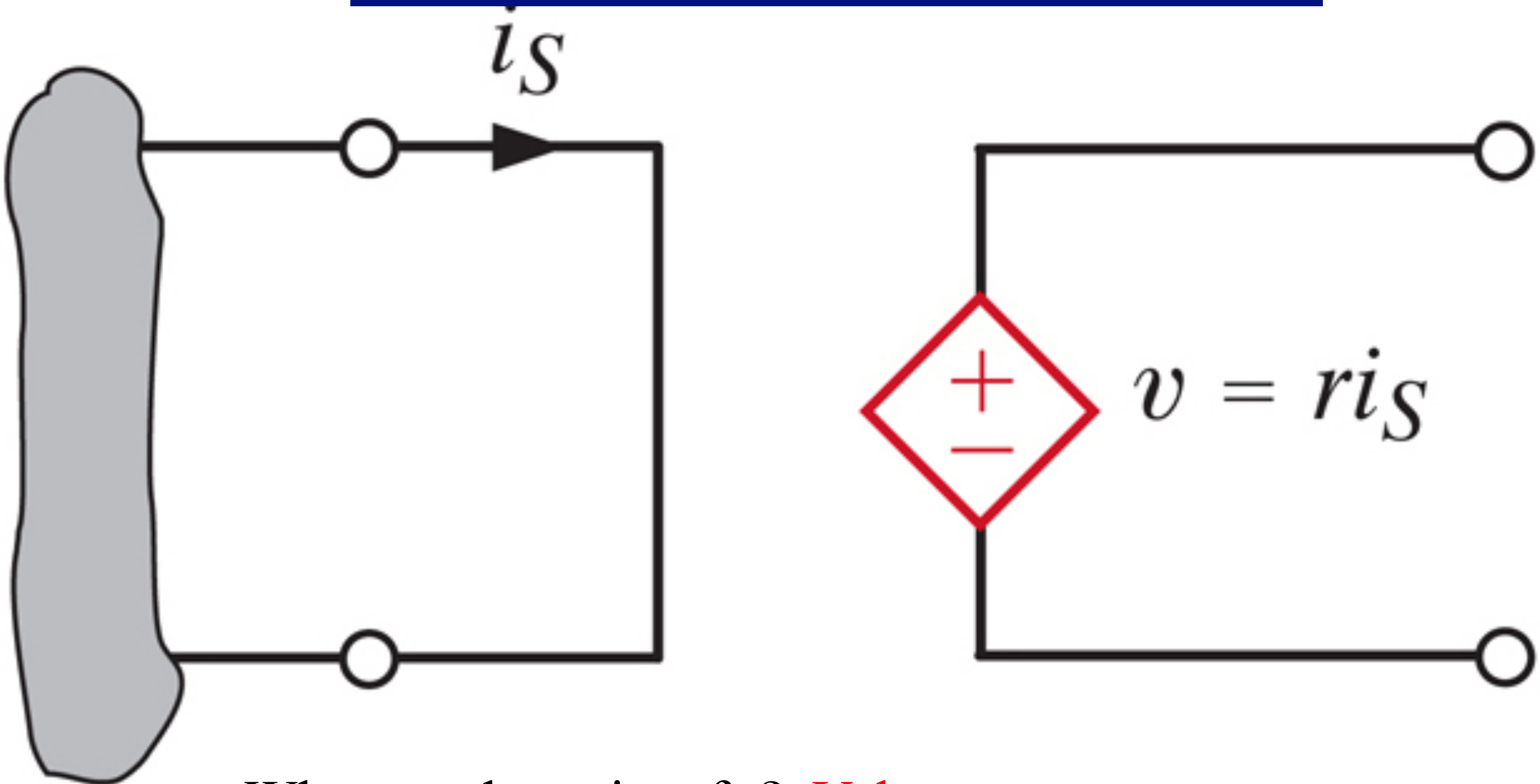
(note the symbol)



What are the dimensions of μ? It's dimensionless.

Voltage Dependent Voltage Source

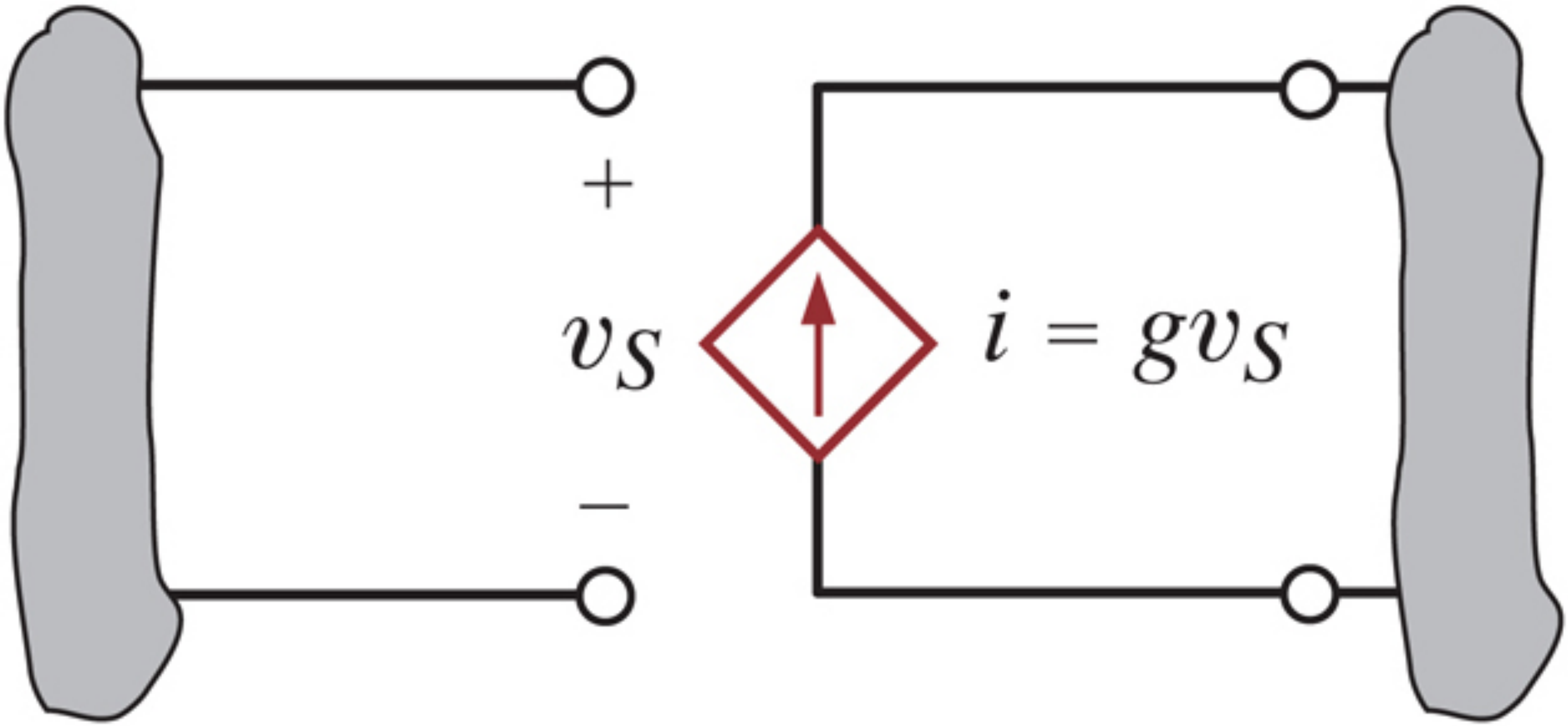
Dependent Voltage Source
(note the symbol)



What are the units of r? Volts per amp.

Current Dependent Voltage Source

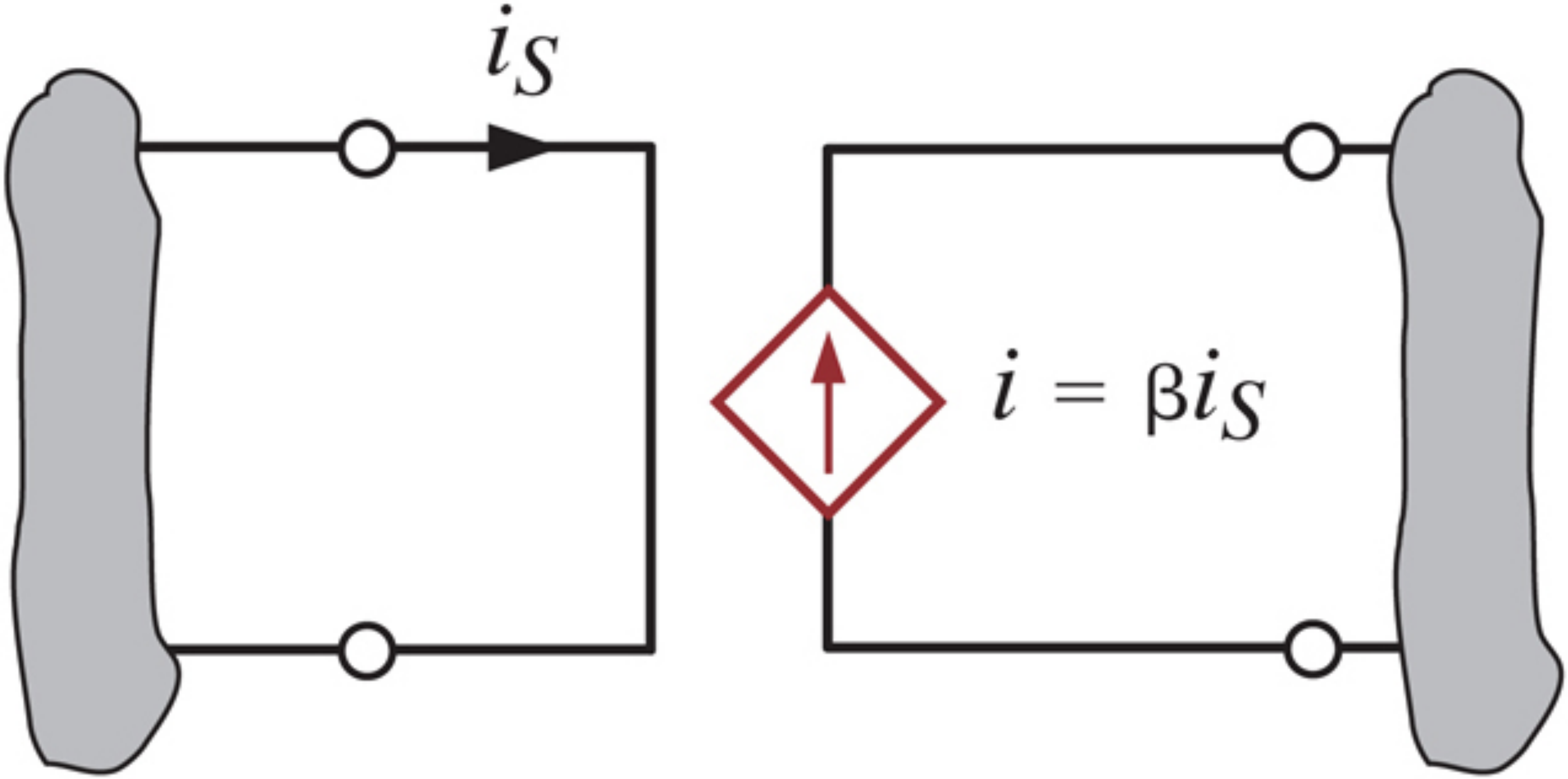
Dependent Current Source
(note the symbol)



What are the units of g? Amps per volt.

Voltage Dependent Current Source

Dependent Current Source
(note the symbol)

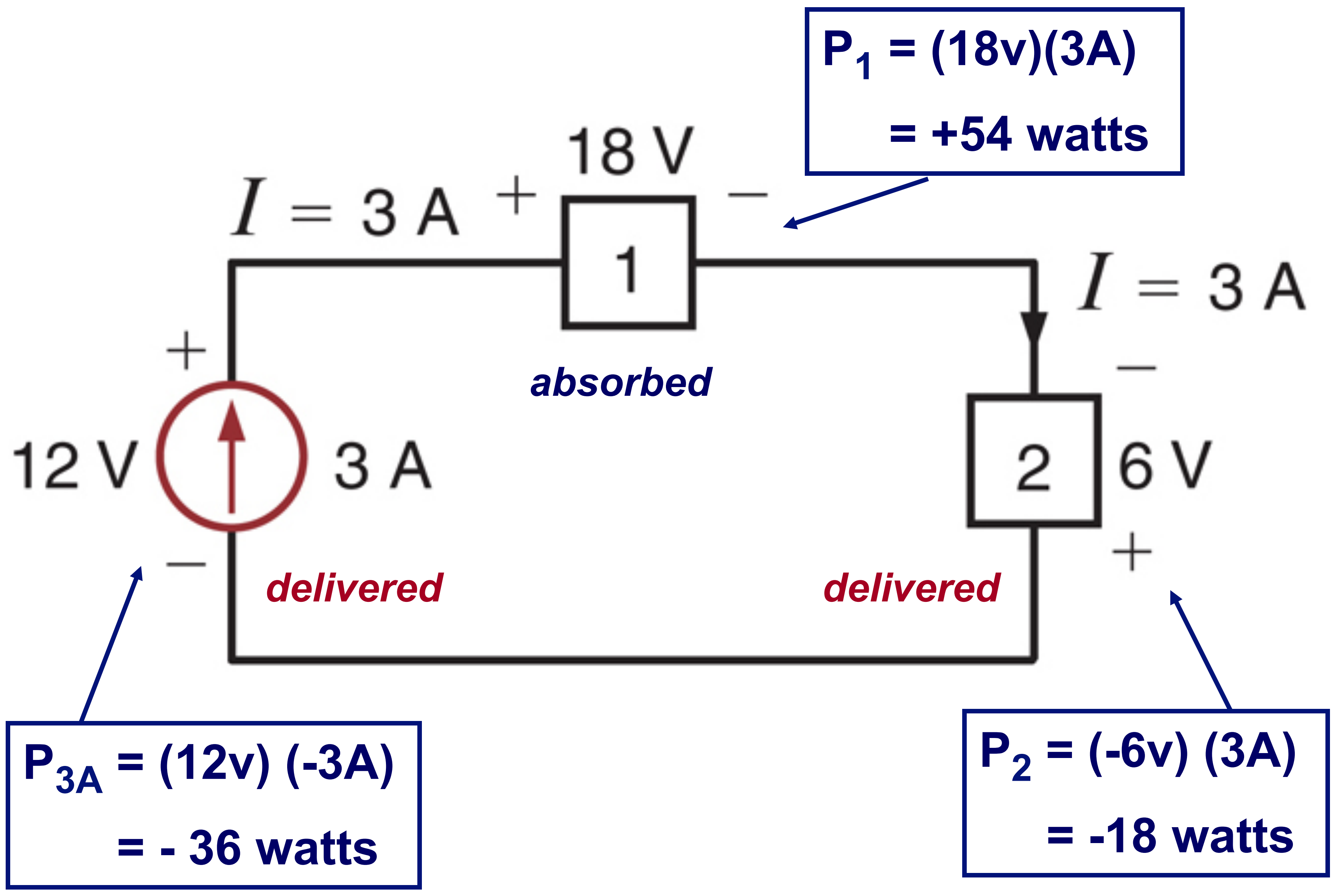


What are the units of β? It's dimensionless.

Current Dependent Current Source

Tellegen's Theorem

- **Electrical networks satisfy the principle of conservation of energy.**
- **Because of the relationship between energy and power, it can be implied that power is also conserved in an electrical network.**
- **This result was formally stated in 1952 by Tellegen and is known as Tellegen's theorem.**
- **The sum of the powers absorbed by all elements in an electrical network is zero.**



P1 = (18v)(3A)
= +54 watts
18 V
I = 3 A
+
−
1
I = 3 A
absorbed
+
−
12 V
3 A
2
6 V
−
+
delivered
delivered
P3A = (12v) (-3A)
= - 36 watts
P2 = (-6v) (3A)
= -18 watts