



Lecture 1

Circuit Terminology

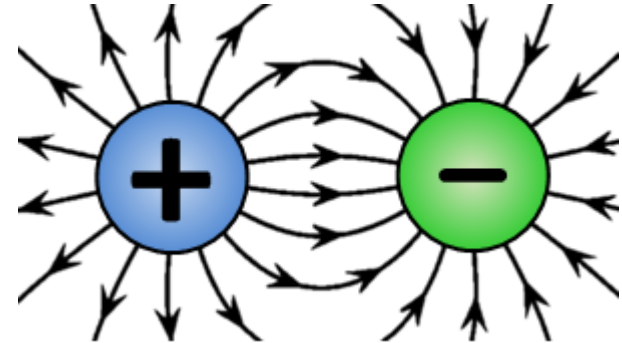


Outline

- Circuit Terminology
 - Charge, Current, Voltage, Power and Energy
- Ideal basic circuit elements
 - Sign conventions
 - I-V characteristics

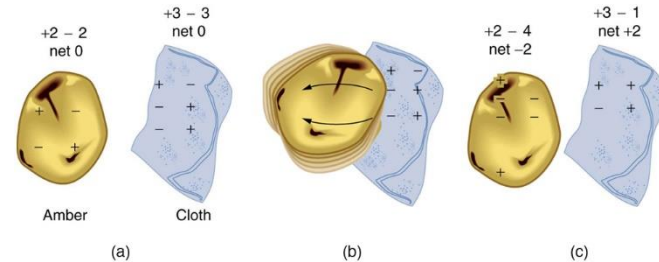
Electric Charge

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



- Microscopically, matter is full of electric charges
 - Electric charge exists in discrete quantities, integral multiples of the electronic charge -1.602×10^{-19} *Coulomb*.
- Electrical effects are due to
 - Separation of charge \rightarrow electric force
- Charge can neither be created nor destroyed.

Etymology

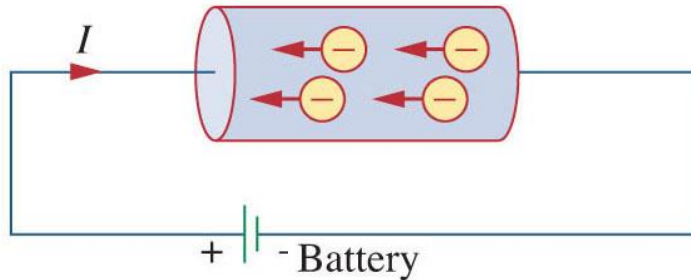


- The word **electric** is derived from the Greek **elektron** (Latin **electrum**) denoting amber.
- It was discovered in ancient times that when amber is rubbed, it attracts feathers, dried leaves, etc.
 - Because amber becoming charged (discovered much later).
- These are the roots of our subject.

Electric Current

- Charges in motion -> electric flow (current)

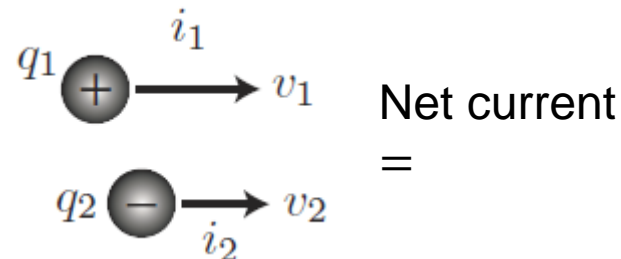
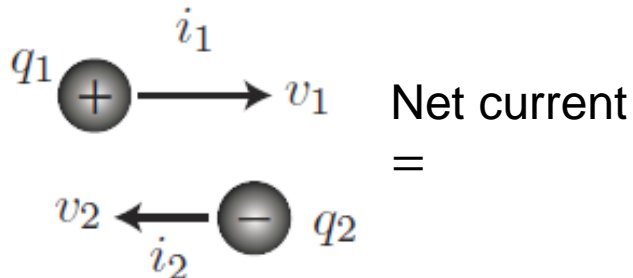
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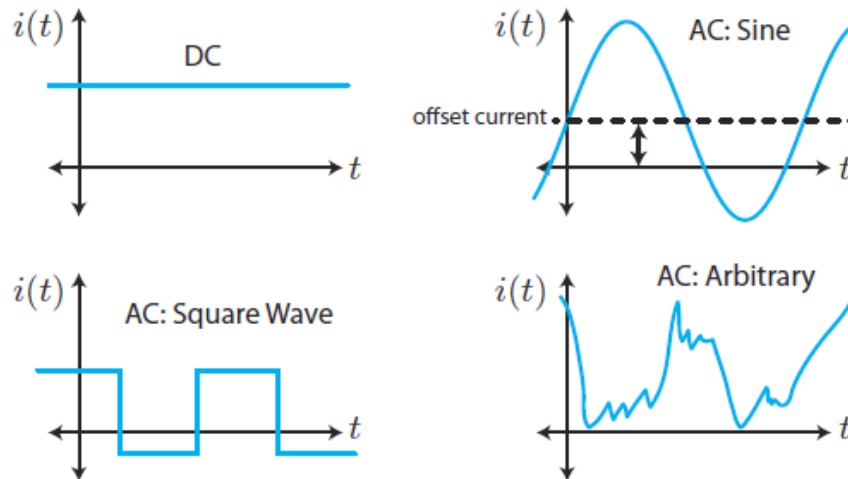
- The current flowing through a surface can be defined as

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

- Conventional to take the current flow as the movement of positive charges



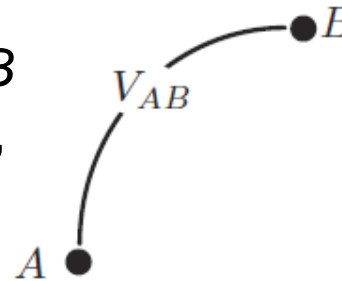
DC versus (vs.) AC



- A constant current is called a "Direct Current" (DC). Otherwise it's AC (alternating current).
 - Some AC typical waveforms are shown above. Sine waves are the waveforms coming out of an electric outlet. A square wave is the clock signal in a digital circuit.
 - Any time-varying current is known as an AC. Note that the sign of the current does not necessarily have to change (the current does not have to alter direction), as the name implies.

Voltage difference

- The voltage difference V_{AB} between A and B is the amount of potential energy difference, when moving a unit of (positive) charge from A to B .



$$V_{AB} = \frac{dE}{dq}$$

- If a total charge of Δq is moved from $A \rightarrow B$, the energy **difference** is

$$E_A - E_B = \Delta E = \Delta q \cdot V_{AB}, \quad V_{AB} \equiv V_A - V_B$$

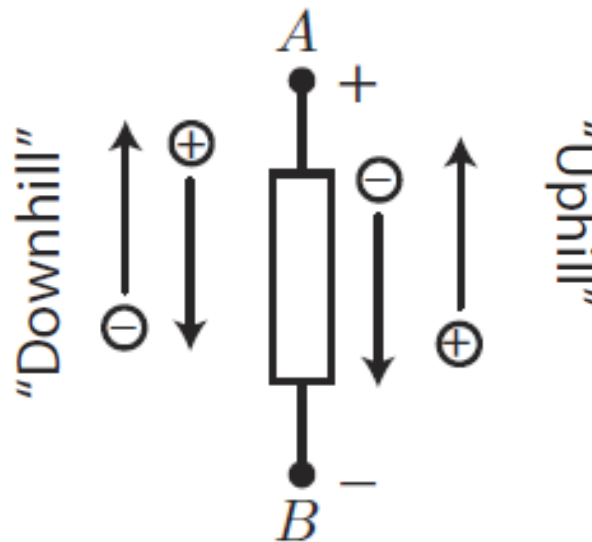
If the **energy difference** is positive, then energy is lost by the charges as they move “downhill (*in terms of energy level*)”.

Charge moves from A to B:

$$\Delta E = E_A - E_B = \Delta q \cdot V_{AB}$$

Charge moves from B to A:

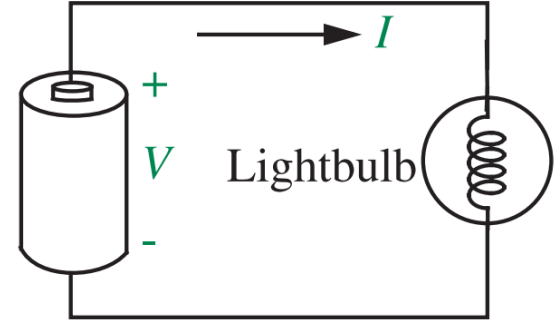
$$\Delta E = E_B - E_A = \Delta q \cdot V_{BA}$$



If the ΔE is positive, then energy is lost by the charges as they move “downhill (*in terms of energy level*)”.

If the ΔE is negative, then energy must be supplied externally to move the charges “uphill (*in terms of energy level*)”.

Voltage across a Component



- In electrical circuits, the path of motion is well defined by wires/circuit components (also known as elements).
- We usually label the terminals of a component **as *positive* and *negative*** to denote the voltage drop across the component.
- Voltage is a relative quantity and usually is implicitly referenced to a known point in the circuit (ground) or in some cases a point at infinity.



Power and Energy

- Definition: transfer of energy per unit time.

$$p \triangleq \frac{dE}{dt}$$

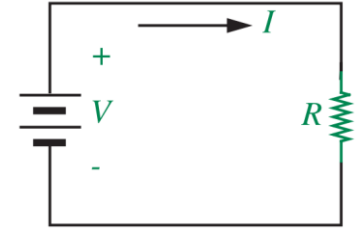


Outline

- Circuit Terminology
 - Charge, Current, Voltage, Power and Energy
- Ideal basic circuit elements
 - Sign conventions
 - I-V characteristics



The Ideal Basic Circuit Element

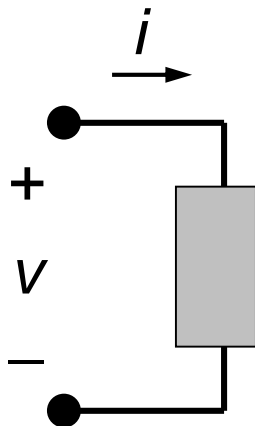


Attributes:

- Two terminals (points of connection)
- Mathematically described in terms of current and/or voltage
- Cannot be subdivided into other elements

Reference directions

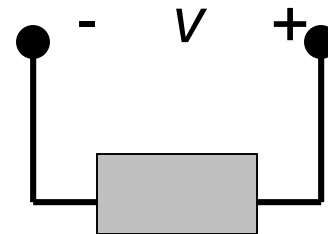
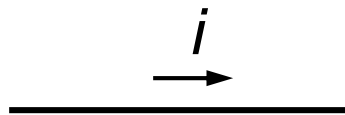
- In order to perform circuit analysis to determine the voltages and currents in an electric circuit, you need to specify reference directions.



- Polarity **reference for voltage** can be indicated by plus and minus signs.
- **Reference direction for the current** is indicated by an arrow.

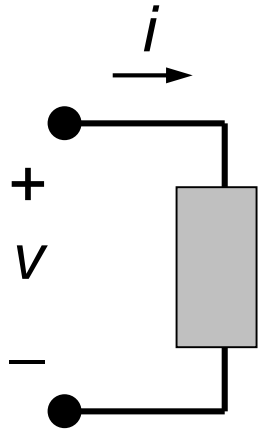
Sign Convention

- A problem like “Find the current” or “Find the voltage” is always accompanied by a definition **of the direction**:

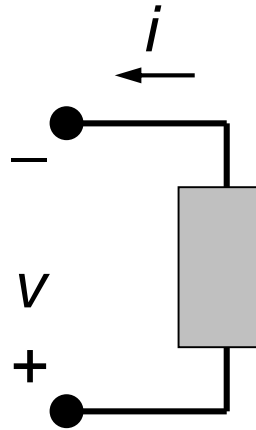


- In this case, if the current turns out to be 1 mA flowing to the left, we would say $i = ?$.

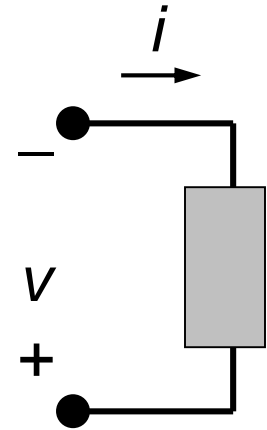
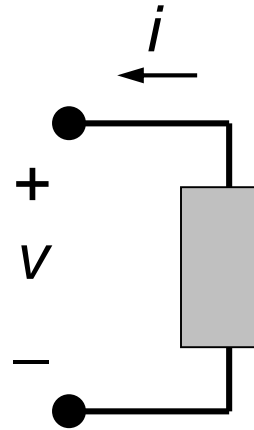
Passive Sign Convention



$$p = vi$$



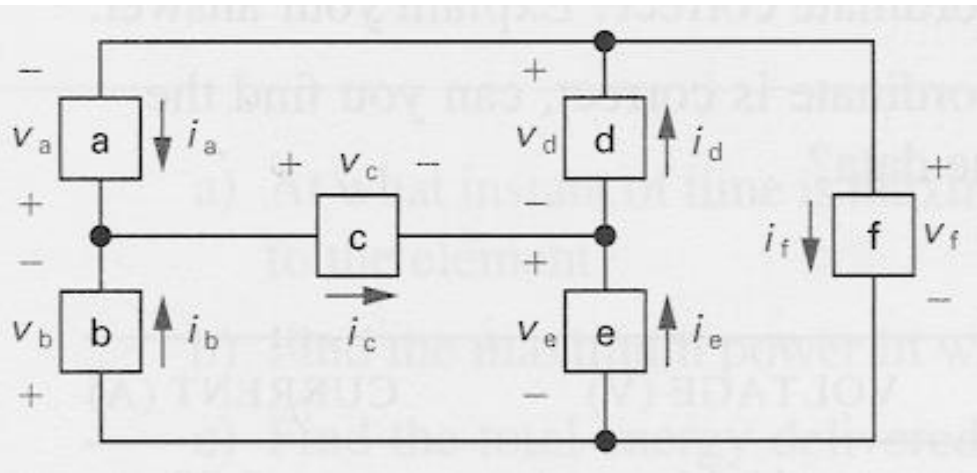
$$p = -vi$$



- If $p > 0$, power is absorbed by the element.
 - electrical energy into heat (resistors in toasters), light (light bulbs), or acoustic energy (speakers); by storing energy (charging a battery).
- If $p < 0$, power is extracted from the element.

Power Calculation Exercise

Find the power **absorbed** by each element:



ELEMENT	VOLTAGE (V)	CURRENT (A)
a	-18	-51
b	-18	45
c	2	-6
d	20	-20
e	16	-14
f	36	31

Conservation of energy:

Does total power delivered equal total power absorbed?



Circuit Elements

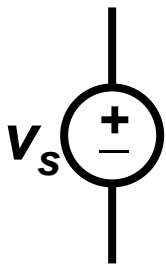
- 5 ideal basic circuit elements:
 - voltage source
 - current source
 - resistor
 - inductor
 - capacitor
- active elements***, capable of generating electric energy
- passive elements***, incapable of generating electric energy



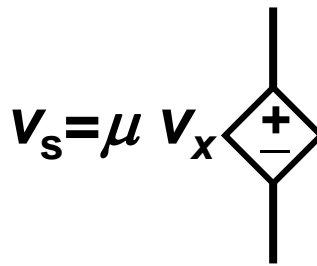
Ideal Voltage Source

- Circuit element that maintains a prescribed voltage across its terminals, **regardless of the current flowing in those terminals**.
 - Voltage is known, but current is determined by the circuit to which the source is connected.
- The voltage can be either **independent** or **dependent** on a voltage or current elsewhere in the circuit, and can be constant or time-varying.

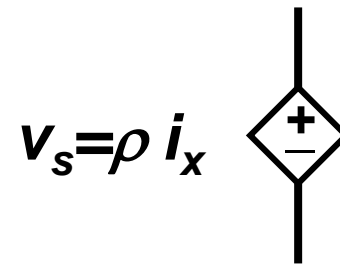
Device symbols:



independent



voltage-controlled



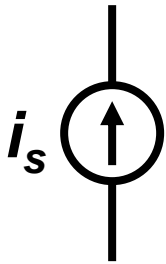
current-controlled



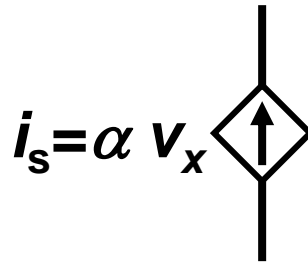
Ideal Current Source

- Circuit element that maintains a prescribed current through its terminals, **regardless of the voltage across those terminals**.
 - Current is known, but voltage is determined by the circuit to which the source is connected.
- The current can be either **independent or dependent** on a voltage or current elsewhere in the circuit, and can be constant or time-varying.

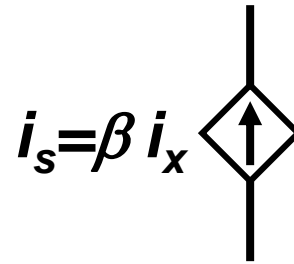
Device symbols:



independent



voltage-controlled



current-controlled



Ideal Sources

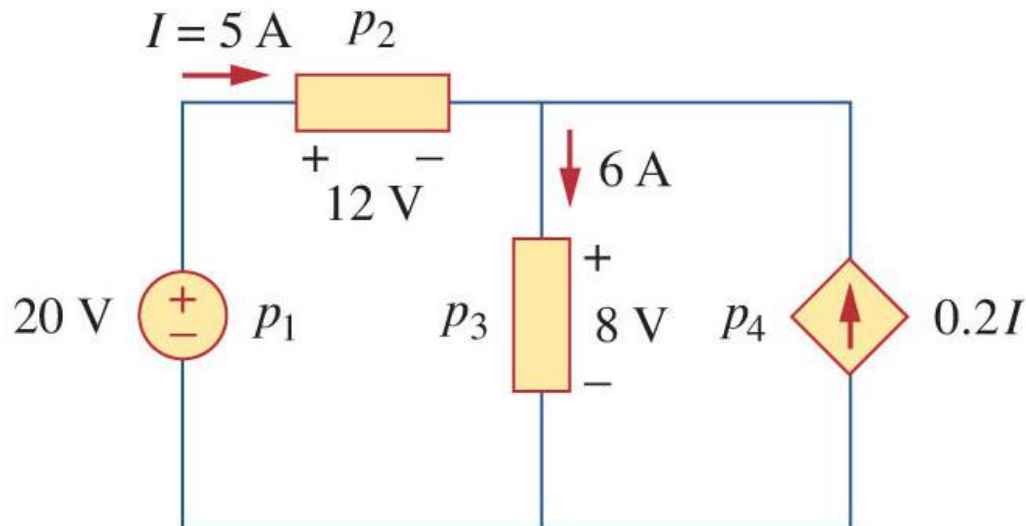
- Both the voltage and current source ideally can generate infinite power.
- They are **also capable of absorbing** power from the circuit.
- It is important to remember that these sources do have limits in reality:
 - Voltage sources have an upper current limit.
 - Current sources have an upper voltage limit.



Exercise

- Calculate the power supplied or absorbed by each element in the following figure.

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Electrical Resistance/Conductance

- Resistance: the ratio of voltage drop and current. The circuit element used to model this behavior is the resistor.

Circuit symbol: 

- The current flowing in the resistor is proportional to the voltage across the resistor:

$$v = i R$$

(Ohm's Law)

- Conductance** is the reciprocal of resistance

$$G = \frac{1}{R} = \frac{i}{v}$$

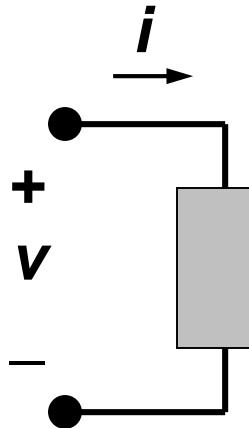


Werner von Siemens
1816-1892



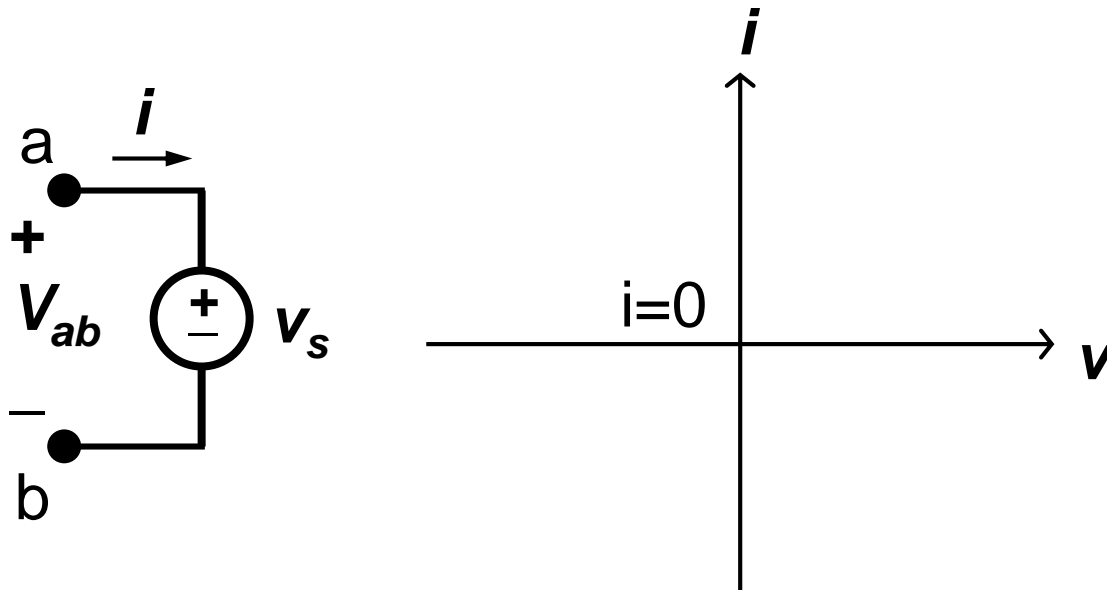
Current vs. Voltage (i - v) Characteristic

- Voltage sources, current sources, and resistors can be described by plotting the current (i) as a function of the voltage (v).





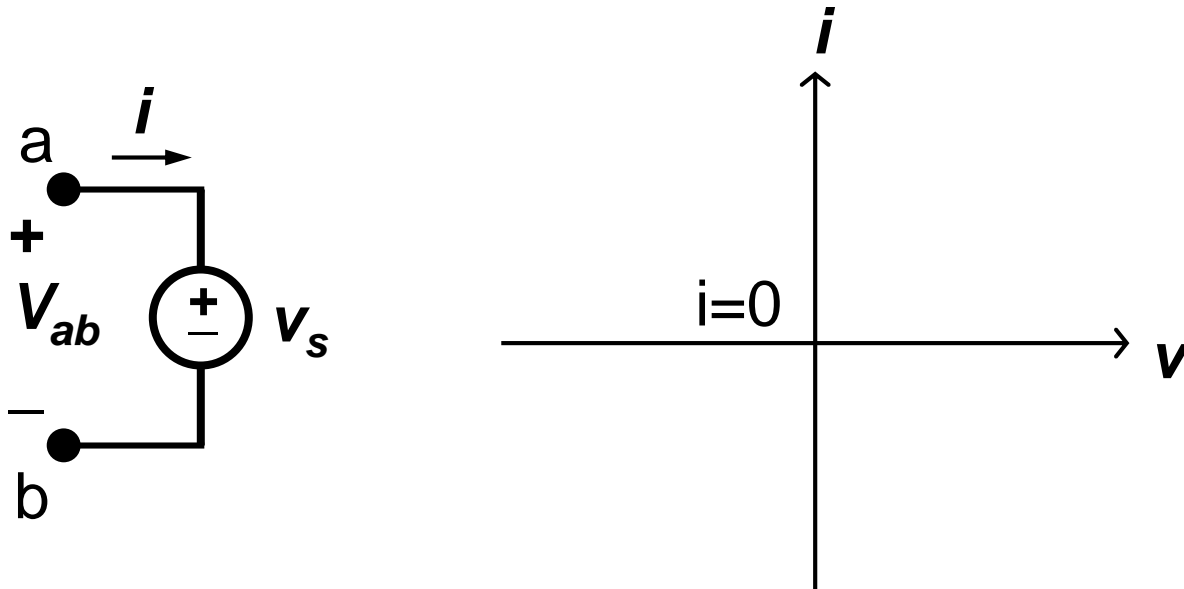
I - V Characteristic of Ideal Voltage Source



Plot the I - V characteristic for $v_s > 0$. For what values of i does the source absorb power? For what values of i does the source release power?



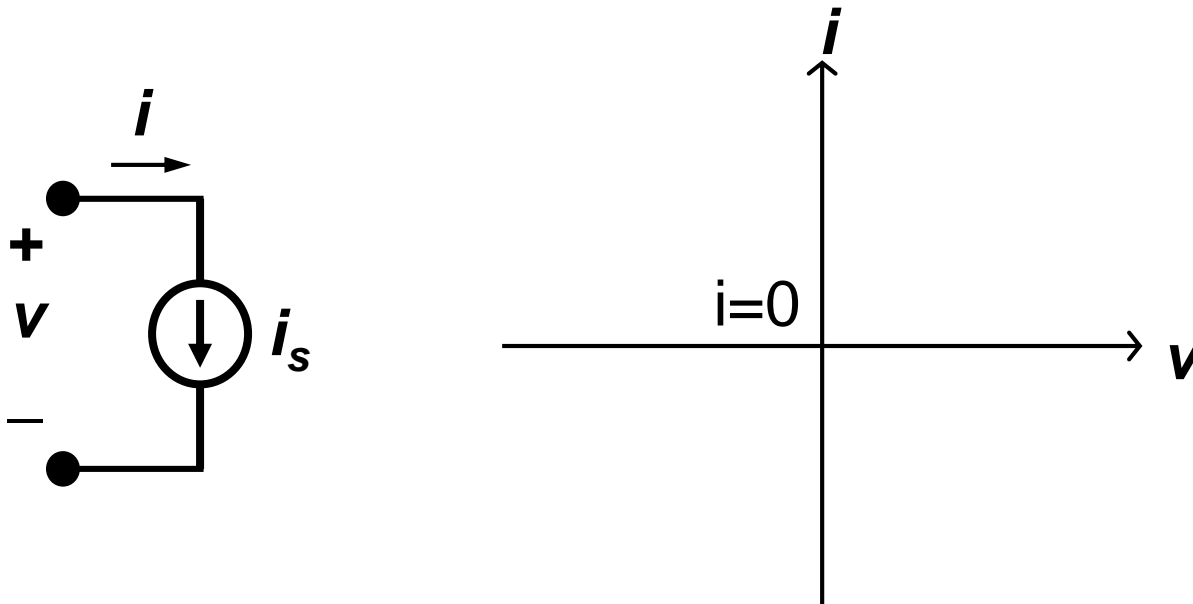
I - V Characteristic of Ideal Voltage Source



Plot the I - V characteristic for $v_s < 0$. For what values of i does the source absorb power? For what values of i does the source release power?



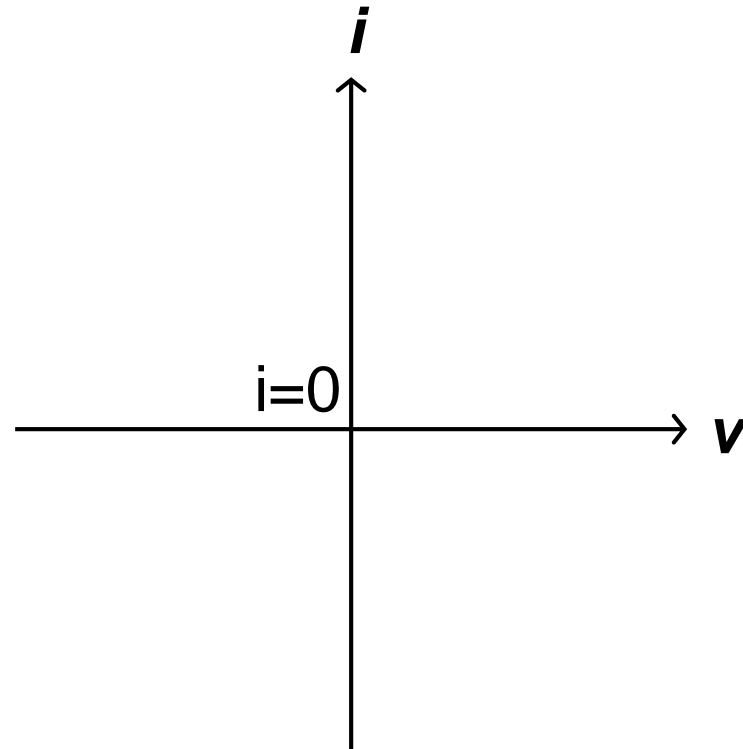
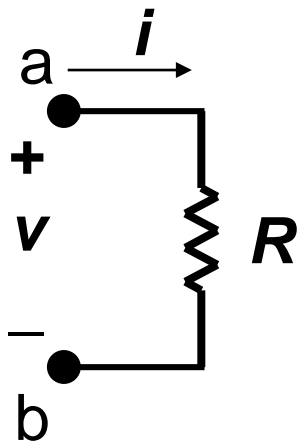
I - V Characteristic of Ideal Current Source



Plot the I - V characteristic for $i_s > 0$. For what values of v does the source absorb power? For what values of v does the source release power?



I - V Characteristic of Ideal Resistor



Plot the I - V characteristic for $R = 1 \text{ k ohm}$.
What is the slope?



Summary

- **Current** = rate of charge flow, $i = dq/dt$
- **Voltage** = energy per unit charge created by charge separation
- **Power** = energy per unit time
- **Ideal Basic Circuit Elements**
 - two-terminal component that cannot be sub-divided
 - described mathematically in terms of its terminal voltage/current
 - An **ideal voltage source** maintains a prescribed voltage regardless of the current in the device.
 - An **ideal current source** maintains a prescribed current regardless of the voltage across the device.
 - A **resistor** constrains its voltage and current to be proportional to each other: $v = iR$ (Ohm's law)