Circuits
-
Basic concepts

Spring 2022

Value of quantity

Measurable quantity

Both:

- a number
- a unit

Examples

- 12 kilograms
- 81.3 kilometers
- 11.5 degree celsius
- 22 minutes
- ...

System of Units

International System of Units (**SI**)

Base quantity	**Name**	**Symbol**
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol
luminosity	candela	cd

System of Units

No other units?

How about **joules** (energy), **watts** (power), **newtons** (force), **volts** (voltage), . . . ?

Every other unit can be derived from the 7 base units.

Examples

- 1 joule = 1 J = 1 $kg.m^2.s^{-2}$
- 1 watt = 1 W = 1 $J.s^{-1}$ = 1 $kg.m^2.s^{-3}$
- 1 newton = 1 N = 1 $kg.m.s^{-2}$
- 1 volt = 1 V = 1 $kg.m^2.s^{-3}.A^{-1}$

Scales

Decimal system for larger and smaller units

Factor	Name	Symbol	Factor	Name	Symbol
10^{-24}	yocto	y	10^{24}	yotta	Y
10^{-21}	zepto	z	10^{21}	zetta	Z
10^{-18}	atto	a	10^{18}	exa	E
10^{-15}	femto	f	10^{15}	peta	P
10^{-12}	pico	p	10^{12}	tera	T
10^{-9}	nano	n	10^{9}	giga	G
10^{-6}	micro	μ	10^{6}	mega	M
10^{-3}	milli	m	10^{3}	kilo	k
10^{-2}	centi	c	10^{2}	hecto	h
10^{-1}	deci	d	10^{1}	deca	da
10^{0}					

Charge

Charge conservation

Physics law of conservation of charge: charge cannot be created or destroyed, only transferred

We will consider the **flow of charges** instead (referred to the **current**)

Unit of charge

- 1 coulomb = 1 C (= 1 A.s)

2 types of charge

- positive: 1 proton = 1.602 x 10^{-19} C
- negative: 1 electron = -1.602 x 10^{-19} C

Current

Electric current

It is the **rate of change of charge**, measured in amperes (A)

Two main types of current

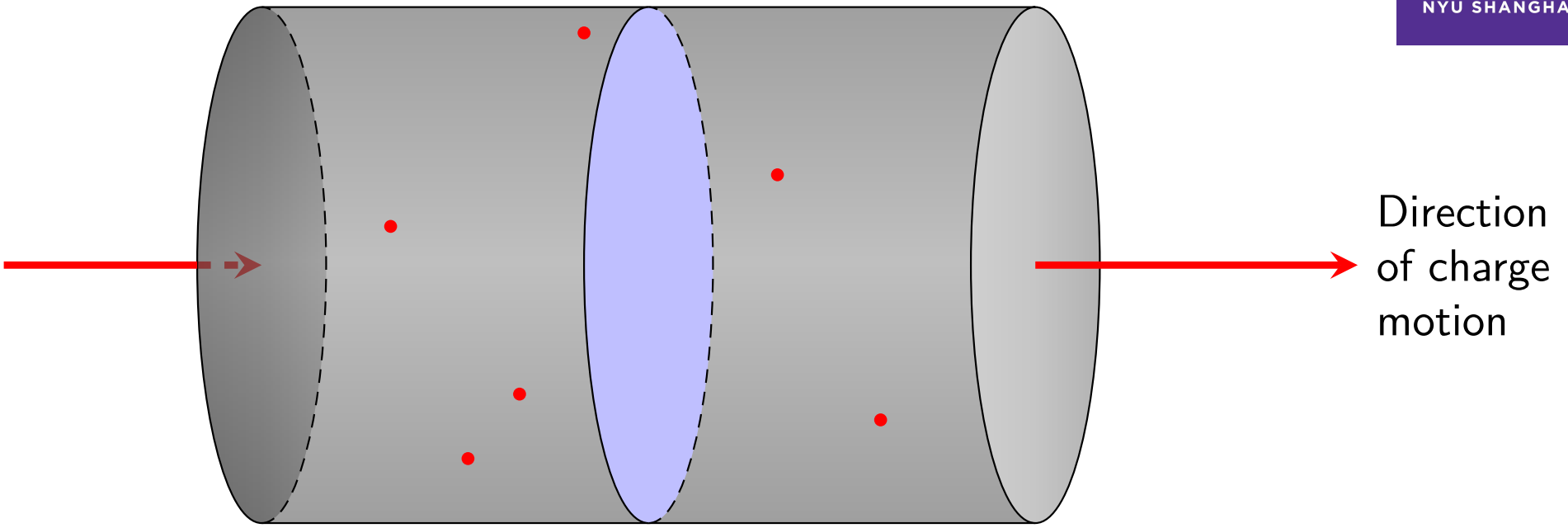
- **Direct Current (DC)**: current remains constant
- **Alternating Current (AC)**: current varies sinusoidally with time

Formula

$$i = \frac{\mathrm{d}q}{\mathrm{d}t}$$

i: current in amperes
q: charge in coulombs
t: time in seconds

Current



- individual charges

Definition of current: 1 ampere corresponds to 1 coulomb of (positive) charges passing though the cross section in 1 second

Current

Current: proton or electron movement?

Physically, current in circuits are obtained from the movement of electrons.
Protons are not moving.

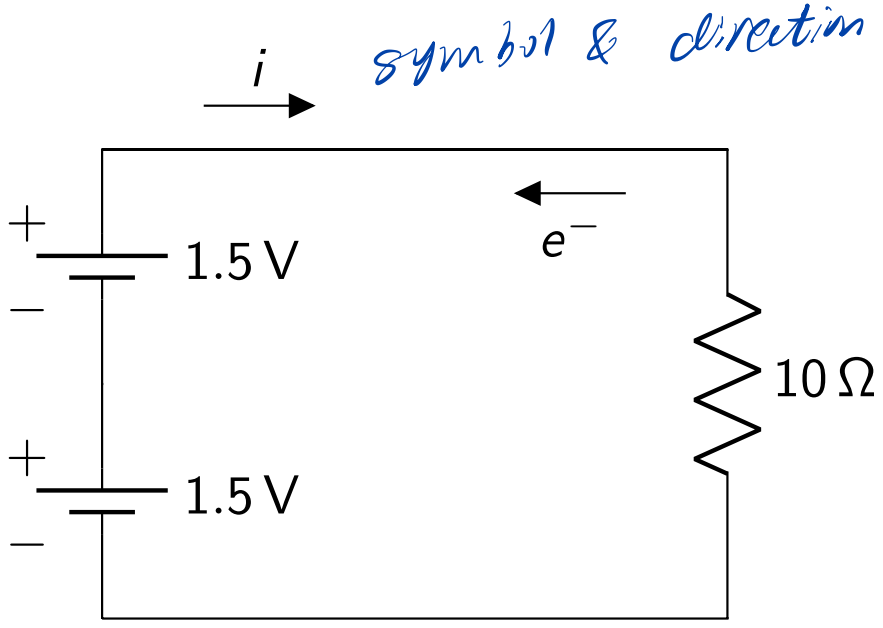
Representation

Direction of current must be specified by an **arrow**

Current/electron directions

Electrons move in the opposite direction of current

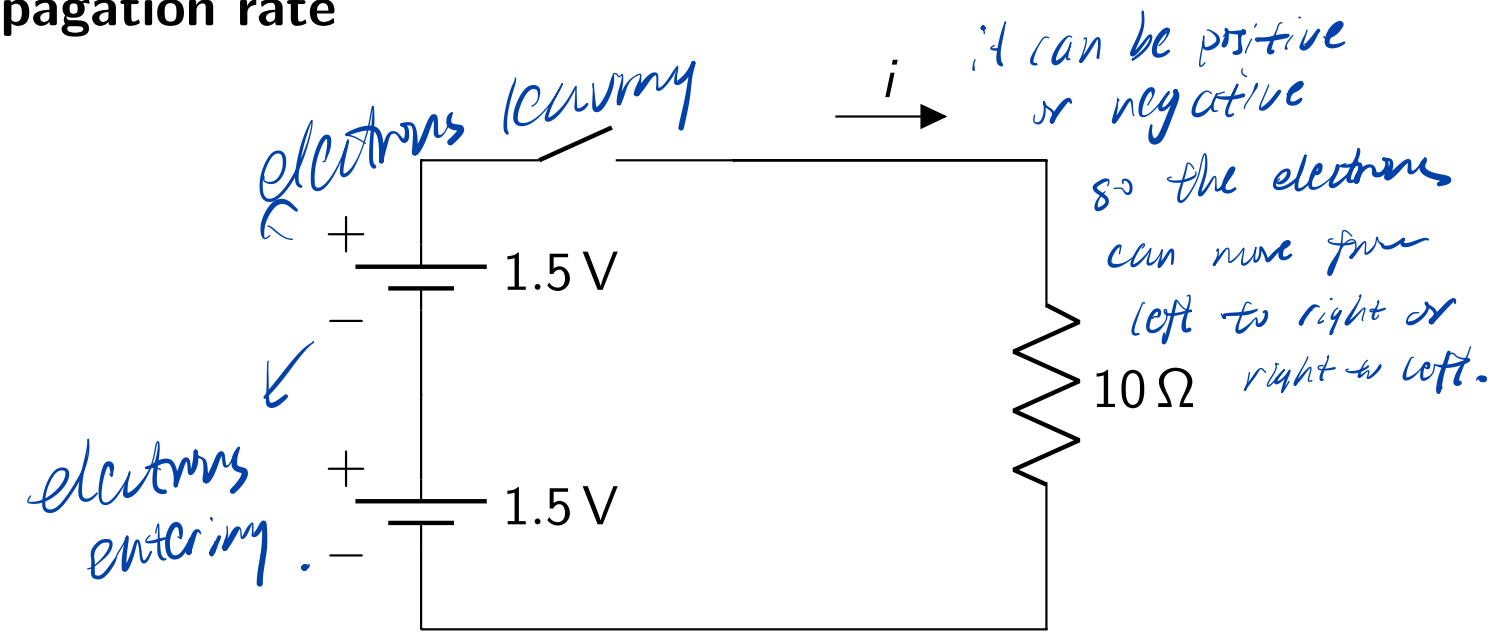
Current



i is defined positively in the opposite direction to electron movement

Current

Propagation rate



- Propagation is close to speed of light
- Effects are supposed instantaneous

Current

Assumptions for this course

- Lumped-parameter system (propagation is instantaneous)
- **No charge** can be stored
  (every circuit element has a net charge of **zero**)
- No magnetic effect

Voltage

Definition

It is the **difference in electric potential** between **two points**

Other names: electric potential difference, electric pressure or electric tension

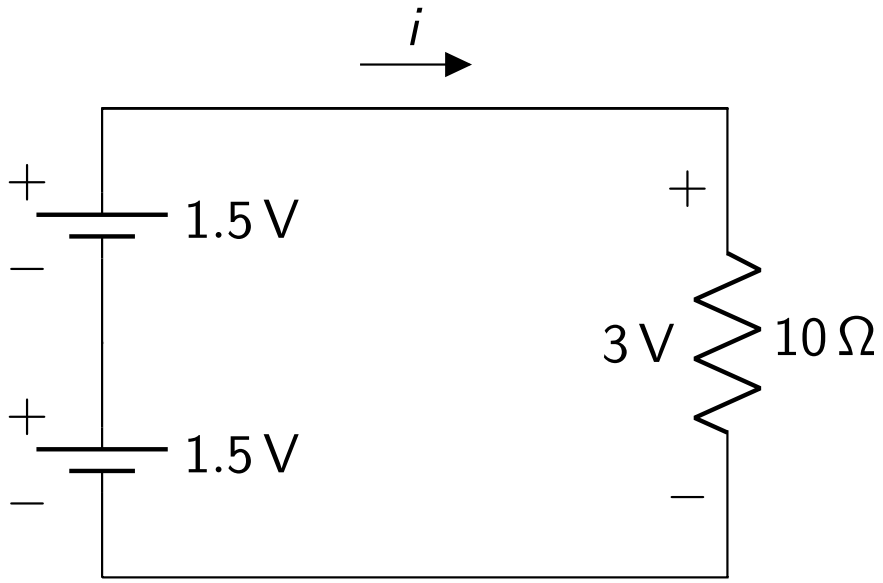
Physical interpretation

- Quantity of energy needed per unit of charge to move a test charge between the two points
- Voltage can push charges in one direction

Representation

We use polarity ($+$ and $-$ on batteries for example) to indicate the direction of voltage

Voltage



- the voltage sources push current through the circuit
- the resistor resists the flow of charge

Power

Power

It is the **time rate of energy transfer** p, measured in watts (W)

Convention

- Circuit elements that **absorb power** have a **positive** value of p
- Circuit elements that **produce power** have a **negative** value of p

Formula

$$p = \frac{\mathrm{d}w}{\mathrm{d}t} = \pm v \cdot i$$

p: power in watts
w: energy in joules
t: time in seconds
v: voltage in volts
i: current in amperes

Power

Conservation of energy

The **net power** absorbed by a **circuit** is equal to **0**

Interpretation

$$\sum_n p_n = 0$$

The watts absorbed by some circuit elements have been produced by some other elements

Power

if its negative. then this element is producing power.

Passive sign convention (PSC)

Current enters the **positive** terminal of an element

but what about a battery ?

Sign in power formula

- PSC satisfied: $p = v \cdot i$ → we are calculating the absorbed power
- PSC not satisfied: $p = -v \cdot i$ → current doesn't enter from the positive polarity.

always the absorbing power of one element

IMPORTANT!!!

it will never be the producing power

PSC rule is very important and should be examined very carefully!!!

$p = -vi$
$= v(-i)$
$= vi$

Independent voltage source

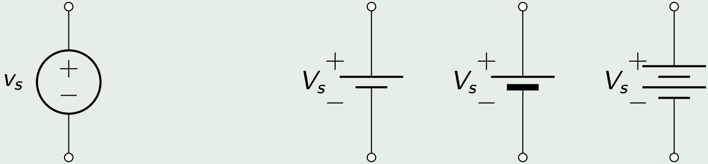
When is the voltage ever dependent on current?
正常不是V固定，I根据R来变化吗？

Definition (ideal)

An independent voltage source is characterized by a terminal voltage which is completely independent of the current through it

this is never the real case. the energy will be infinite.

Symbols



Usual

Batteries are voltage sources

$P = IV$ may be infinite.

Independent current source

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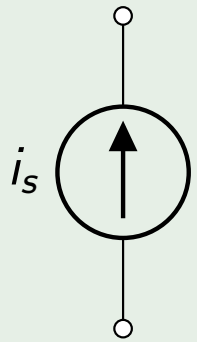
Definition (ideal)

An independent current source is characterized by a current which is completely independent of the voltage across it

Symbols



What's a current source? isn't current a product of potential different

Ideal sources

light has dim when the AC is turned on for seconds

Model

Be careful! The independent sources are **models** for real sources.

These models do not represent exactly the real physical devices. The idealized sources could theoretically deliver infinite power, which is not possible in real life.

But, for example, 12 V batteries in cars really maintain a constant 12 V terminal voltage as long as the current does not exceed several amperes.

Dependent voltage sources

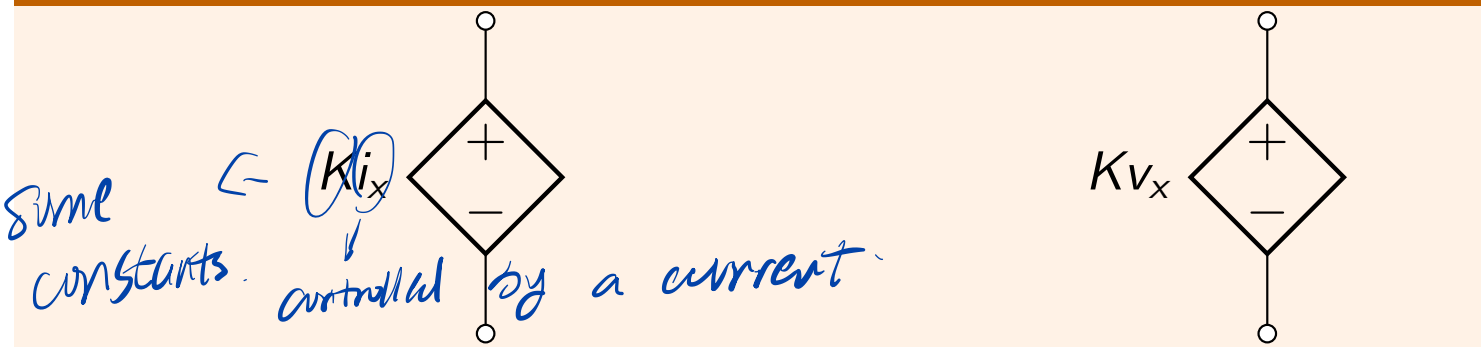
Definition

A dependent voltage source is characterized by a terminal voltage which depends on a quantity (voltage or current) existing somewhere else in the circuit. analyzing complex & integrated circuits

Purpose

The models of dependent voltage sources usually appear in equivalent electrical models for some electronic devices (transistors, operational amplifiers, ...).

Symbol



some constants. ← Ki_x controlled by a current.

Current-controlled Voltage-controlled

Dependent current sources

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Definition

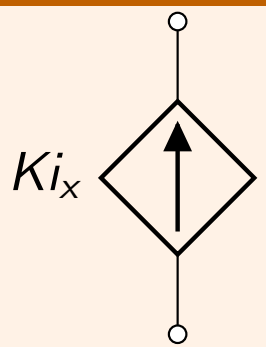
A dependent current source is characterized by a current which depends on a quantity (voltage or current) existing somewhere else in the circuit.

Purpose

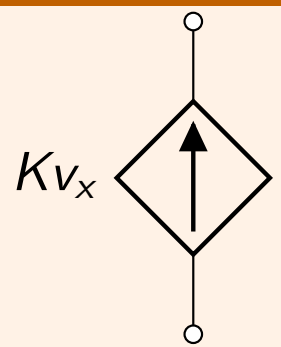
The models of dependent current sources usually appear in equivalent electrical models for some electronic devices (transistors, operational amplifiers, ...).

sources are called active elements in circuits.

Symbol



Current-controlled



Voltage-controlled

Ohm's law

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Simplest passive element: resistor

The voltage across a conductive material is **directly proportional** to the current flowing through it

Ohm's law

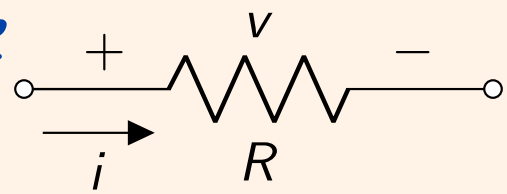
$$v = R \cdot i$$

R is called the **resistance**

The unit of resistance is **ohm** (Ω, equivalent to $1\,\mathrm{V/A}$)

here the v & i should follow the PSC otherwise. R will be a negative #

Symbol



resistor is a passive element. they absorb power. no matter PSC. is satisfied or not the power for all resistors is positive

Ohm's law

Precautions

Be careful with Ohm's law and the **directions** of current and voltage

Similarly to the definition of power absorbed, a more accurate formula should be $v = \pm R \cdot i$

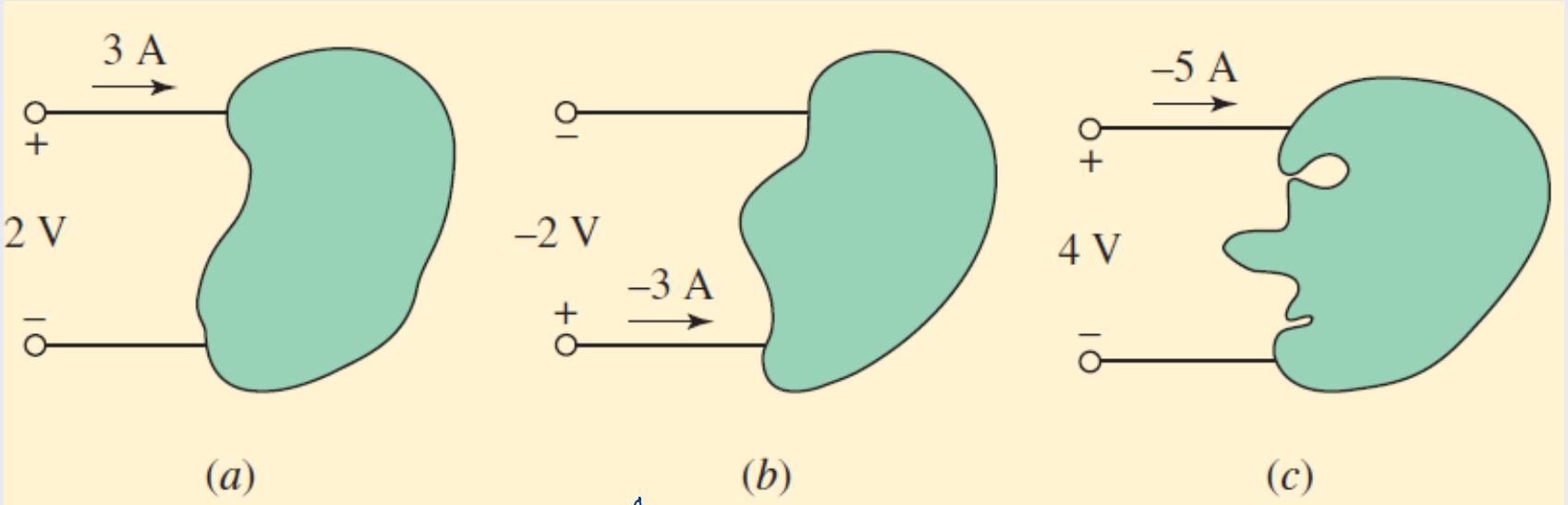
Passive sign convention (again)

Current enters the **positive** terminal of an element

- PSC satisfied: $v = R \cdot i$
- PSC not satisfied: $v = -R \cdot i$

Ohm's law

Compute the power absorbed by each part.



6 W

absorbing power.

6 W

−2 W

which means some part here is producing power

Ohm's law

Power absorbed

A resistor **Joule effect** power (check exercise)

The absorbed power is dissipated into **heat**.
This phenomena is called **Joule effect**