Chapter 1
Circuit Variables

Key points

- What is the lumped-parameter assumption upon which all the circuit analysis methods introduced in this course are founded?
- What is the passive sign convention that is used in unambiguously defining the sign of each formula in circuit analysis?

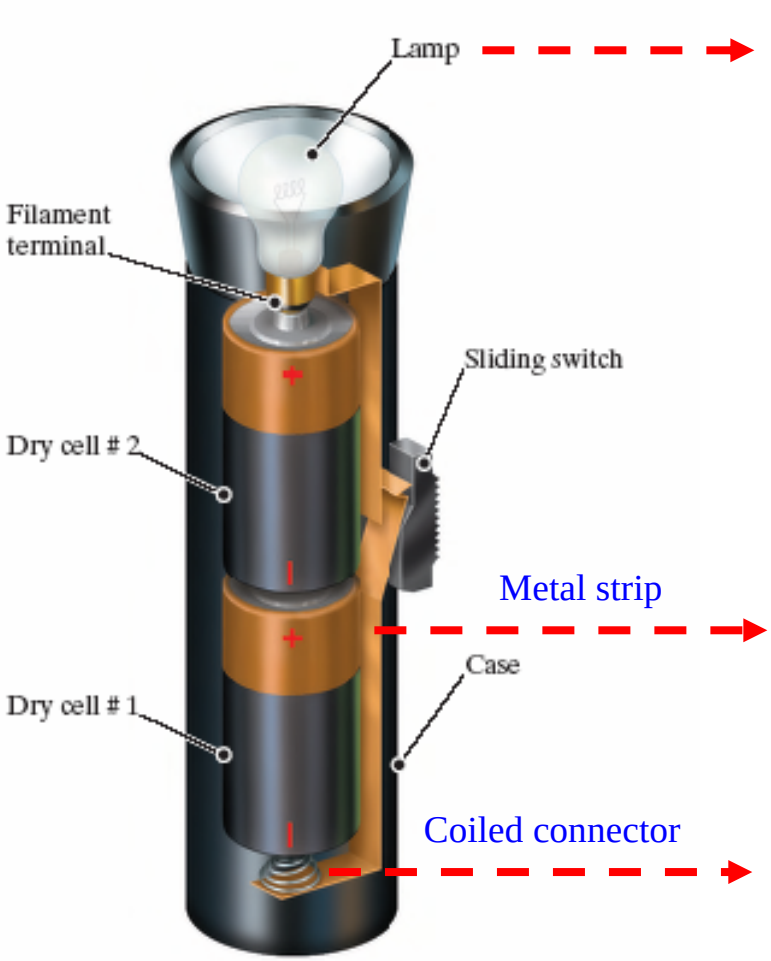
Section 1.1
Electrical Engineering: An Overview

1. Electric circuits
2. Lumped-parameter assumption

What is an electric circuit?

- A mathematical model that approximates the behavior of an actual electrical system.

Example: Electric Circuit of a Flash Lamp (1)



Physics: Filament is heated to a temperature high enough to radiate the visible light.

Modeling: a resistor R_l (only accounts for conversion of electric energy to thermal energy, not light energy).

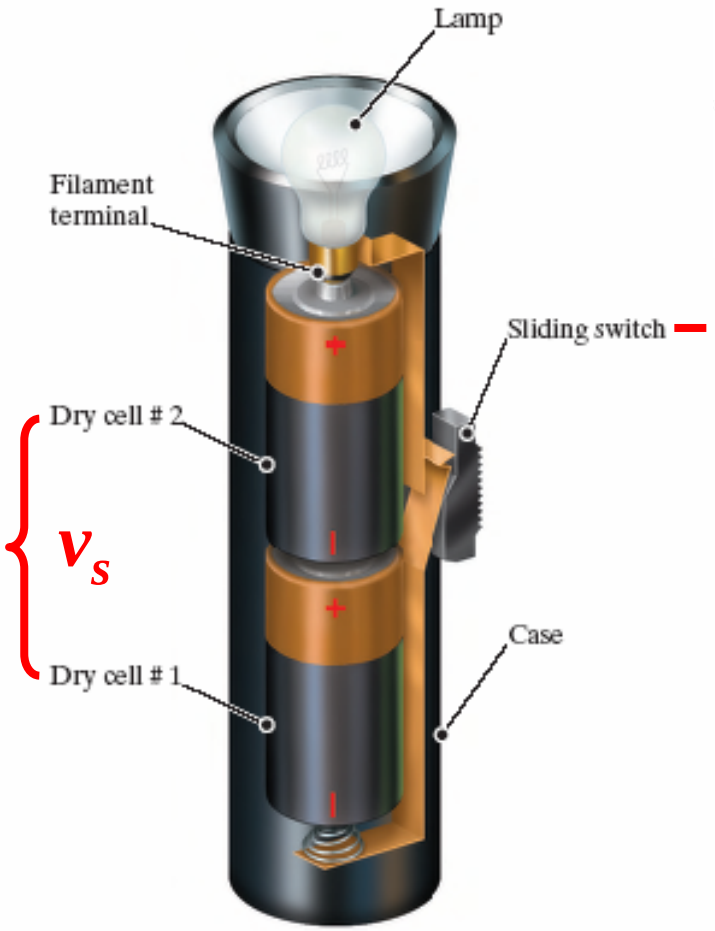
Physics: Conductive connection.

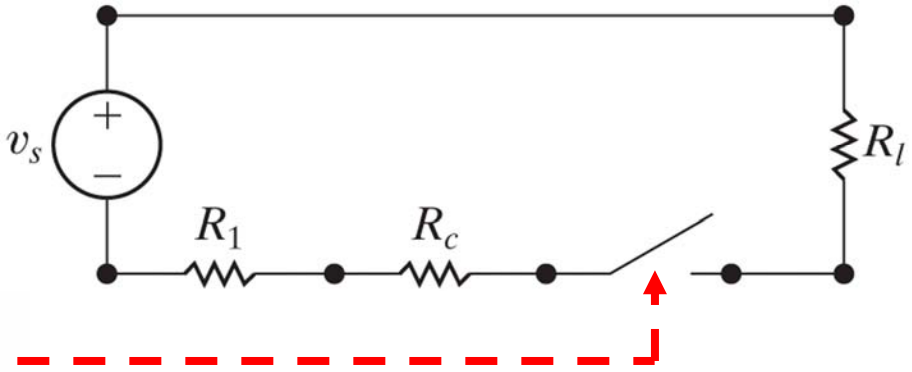
Modeling: a resistor R_c

Physics: Conductive connection.

Modeling: a resistor R_1

Example: Electric Circuit of a Flash Lamp (2)





- Only electric behavior is accounted: lamp, coiled connector, metal strip are modeled by the same element (resistor).
- Modeling requires approximations: ignore internal dissipation of the dry cells.

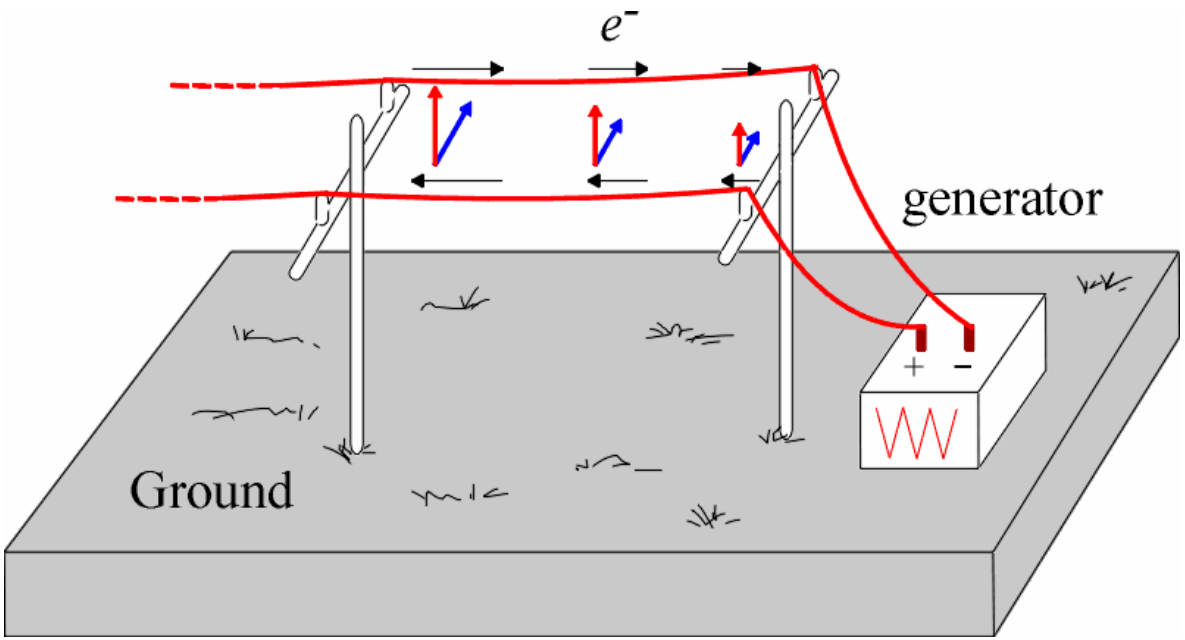
What is the circuit theory?

- A simplified version of electromagnetic field theory, which is accurate under low frequency condition.

What is the electromagnetic theory?

- Electric charge → electric field.
- Electric current (moving charge) → magnetic field.
- Time-varying fields → electromagnetic wave with properties of propagation, reflection, …

E.g.



Lumped-parameter assumption

- If the circuit size is $< \lambda/10$ ($\lambda = c/f$), electrical effects are supposed to reach every corner of the circuit instantaneously. $\Rightarrow$ Electric signals do not change along the wire. All changes take place across the "lumped" elements.
- E.g. Electric power is distributed with $f = 60$ Hz, $\Rightarrow \lambda = (3\times10^8)/60 = 5\times10^6$ m. Power distribution networks smaller than $\lambda/10 = 500$ km can be treated by circuit theory.

Taiwan

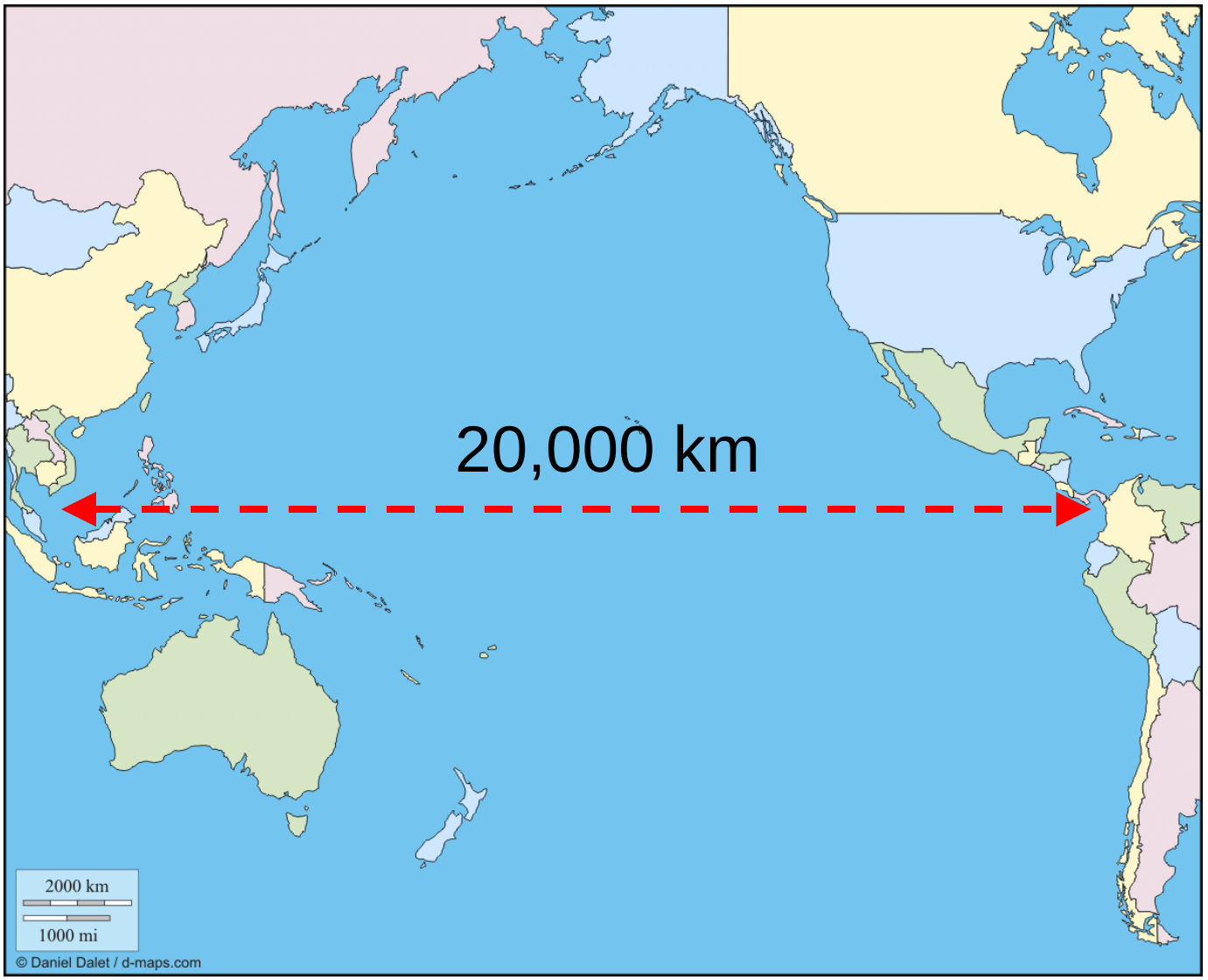
400 km

Continental US

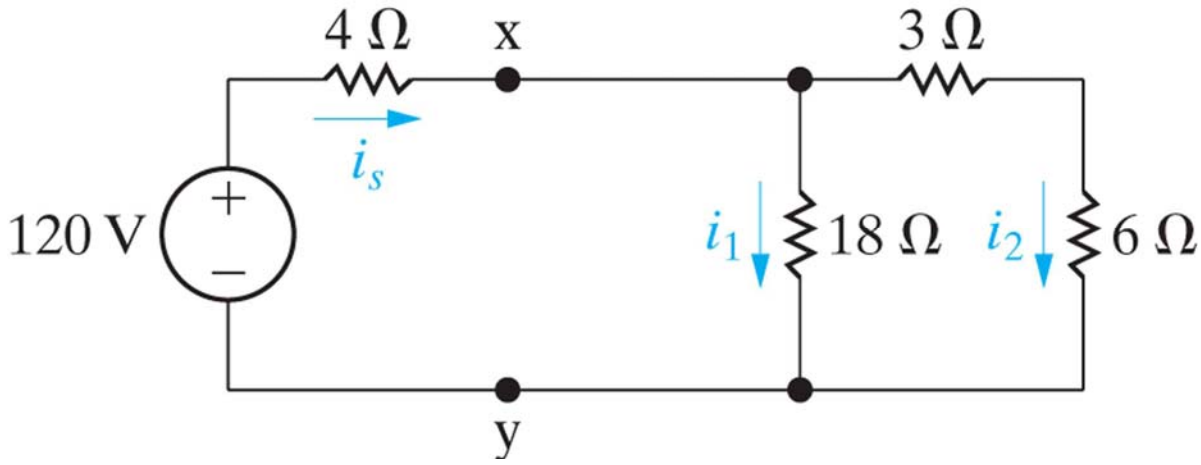
Russia


RUSSIA
7,680 km
Moscow
St. Petersburg
Arkhangel'sk
Murmansk
Noril'sk
Tiksi
Yakutsk
Magadan
Petropavlovsk-Kamchatskiy
Khabarovsk
Sakhalin
Irkutsk
Krasnoyarsk
Novosibirsk
Omsk
Yekaterinburg
Chelyabinsk
Perm'
Kazan'
Nizhniy Novgorod
Samara
Ufa
Volgograd
Saratov
Rostov
Voronezh
Kharkiv
Kiev
Minsk
Warsaw
Riga
Tallinn
Helsinki
Stockholm
Oslo
Copenhagen
Astana
KAZAKHSTAN
Qaraghandy
Almaty
Atyraū
Ulaanbaatar
MONGOLIA
Ürümqi
Baotou
Beijing
Tianjin
Jinan
Qingdao
Harbin
Changchun
Shenyang
Vladivostok
Pyongyang
Seoul
Sapporo
Tokyo
Yokohama
Nagoya
Osaka
Fukuoka
JAPAN
NORTH KOREA
SOUTH KOREA
Tehrān
IRAN
Mashhad
Eşfahān
Tabrīz
Baku
AZERBAIJAN
Yerevan
Tbilisi
GEORGIA
ARMENIA
Ashgabat
TURKMENISTAN
Tashkent
UZBEKISTAN
Bishkek
KYRGYZSTAN
Dushanbe
TAJIKISTAN
Kashi
Kābul
Svalbard (NORWAY)
NOVAYA ZEMLYA
SEVERNAYA ZEMLYA
FRANZ JOSEF LAND
NEW SIBERIAN ISLANDS
Wrangel Island
Providenya
Anadyr'
Cherskiy
Arctic Ocean
Barents Sea
Kara Sea
Laptev Sea
East Siberian Sea
Bering Sea
Sea of Okhotsk
Sea of Japan
Norwegian Sea
North Sea
Caspian Sea
Aral Sea
Lake Baikal
Lake Onega
Lake Balkhash
Arctic Circle
NORWAY
SWEDEN
FINLAND
BELA.
UKR.
POL.
RUS.
EST.
LAT.
LITH.
Vilnius
Kuril Islands
occupied by the Soviet Union in 1945, administered by Russia, claimed by Japan.
Demarcation Line
Yellow Sea

Pacific Ocean



Example: A resistive circuit



- Once the 120-V voltage is connected, currents $i_1 = 4$ A, $i_2 = 8$ A are assumed to immediately flow through the 18-Ω and 6-Ω resistors.
- According to electromagnetic theory, different resistors will sense the 120-V at different times.

Section 1.2
The International System (SI) of Units

1. Units
2. Prefixes

What are SI units?

- Abbreviation from French “Système international d'unités”, established in 1960.
- The SI Units are based on 7 defined quantities: length (m), mass (kg), time (s), current (A), temperature (K), amount (mol), luminous intensity (cd).
- SI units enable engineers to communicate in a meaningful way about quantitative results.

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

Prefixes to signify powers of 10 (1)

- Engineers often use powers divisible by 3, and base numbers between 1 and 1,000.

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}

Prefixes to signify powers of 10 (2)

Prefix	Symbol	Power
deka	da	10
hecto	h	10^2
kilo	k	10^3
mega	M	10^6
giga	G	10^9
tera	T	10^{12}

- E.g. 10^{-5} s is denoted by 10 μs, instead of 0.01 ms.

Section 1.4
Voltages and Currents

1. Definition of voltage
2. Definition of current

Voltages

- Voltage is the energy per unit charge.

$$v = \frac{dw}{dq}$$ …definition of magnitude

v = the voltage in volts

w = the energy in joules

q = the charge in coulombs ($e = 1.6022 \times 10^{-19}$ C)

Currents

- Current is the rate of charge flow.

$$i = \frac{dq}{dt}$$ …definition of magnitude

i = the current in amperes

q = the charge in coulombs

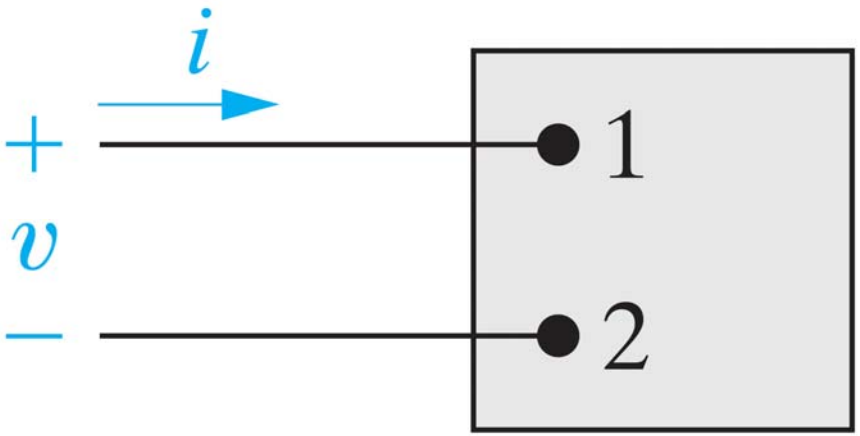
t = the time in seconds

Section 1.5
The Ideal Basic Circuit Element

1. Definition of basic circuit element
2. Passive sign convention

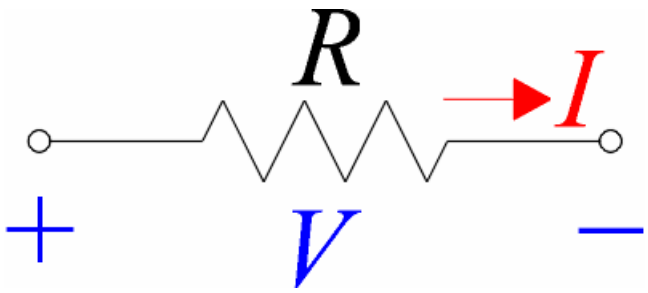
Three attributes & symbol

1. Only two terminals, which are points of connection to other circuit components.
2. Described mathematically in terms of the voltage across it and/or the current through it.
3. Cannot be subdivided into other elements.



Passive sign convention

- If the reference current through the element is in the direction of the reference voltage drop across the element, we can use a positive sign in the i-v relation of the element.
- E.g. Let the reference current and voltage of the resistor satisfy the passive sign convention, $\Rightarrow$ we have $v = +R \times i$, though the values of v, i can be > 0 or < 0.



Section 1.6
Power and Energy

1. Definition and formula of power
2. Sign of power

Powers

- Power is the energy per unit time.

$$p = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = v \times i.$$

p = the power in watts

w = the energy in joules

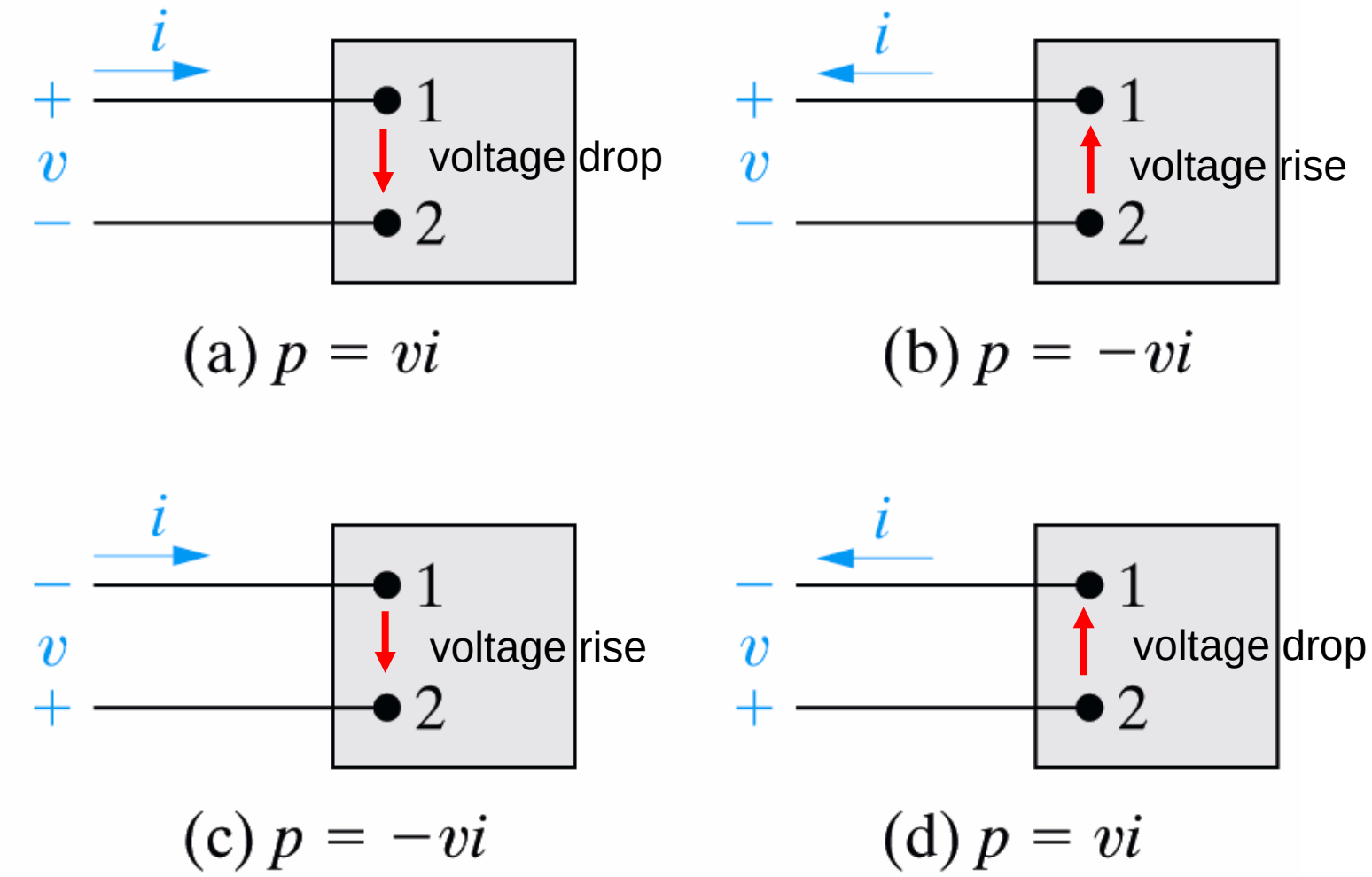
t = the time in seconds

v = voltage in volts

i = current in amperes

- Power is associated with two terminals.

Polarity references and power expressions



Power dissipation and extraction

- As positive charges experience voltage drop, they lose energy.
- $p > 0$ (not $p = +vi$): power is dissipated by the circuit inside the box.
- $p < 0$ (not $p = -vi$): power is being extracted.

Key points

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- What is the passive sign convention that is used in unambiguously defining the sign of each formula in circuit analysis?