1-1 INTRODUCTION

Why start with circuit theory?

The solution of an engineering problem normally proceeds:
First, a real-world problem is identified;
second, the problem is modeled;
third, the model is analyzed;
and fourth, the results are applied to the original physical problem.

1-2 BASIC CONCEPTS

An electric circuit is an interconnection of electrical elements.

Active elements: capable of generating energy such as generators, batteries etc.

Passive elements: resistors, capacitors and inductors.

Ideal circuit elements: 理想电路元件

Lumped parameter elements 集中参数元件

Ideal independent source 理想电源元件

Ideal load 理想负载元件

Ideal coupling elements 理想耦合元件

Lumped parameter elements & distributed elements 集中参数与分布参数

1. 电流：CURRENT

Electric current is the time rate of change of charge, measured in amperes (A).

$$i(t) = dq(t)/dt$$

An alternative current (ac) is a current that varies sinusoidally with time. 时变电流

A direct current (dc) is a current that remains constant with time. 直流电流

1A=1C/1s(秒)

1kA=1000A，1mA=10^{-3}A，1μA=10^{-6}A，1nA=10^{-9}A

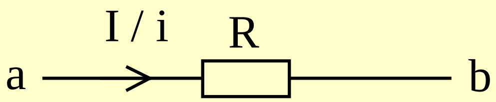
Andre-Marie Ampere (1775-1836)

安培

Assigning reference directions

电流的参考方向

To specify the current in a conductor, we need both a reference direction and numerical value, which can be positive or negative.



2. 电位 Voltage of Potential

Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V). $U_a = \Delta W / \Delta q$

V，kV，mV，μV

Alessandro Antonio Volta (1745-1827)

伏特

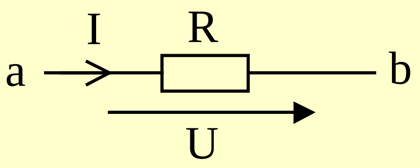
Voltage reference directions

电位的参考极性

参考点：⊥

3. 电压 VOLTAGE

Uab=Ua-Ub，point a is at a potential of Uab volts higher than point b.

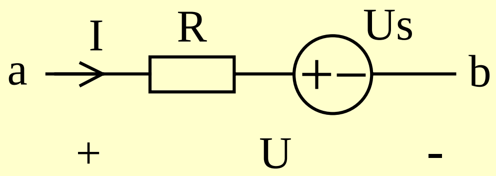


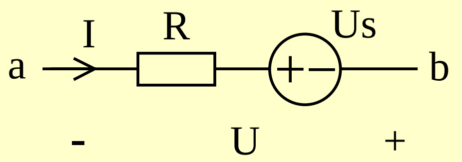
Voltage reference directions

Keep in mind that electric current is always through an element and that electric voltage is always across the element or between two points.

Check Your Understanding

What the difference between Uab and U ?





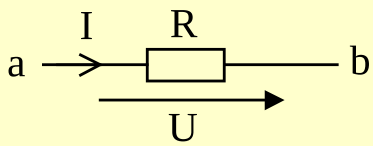
U=Us+RI　　　　　　U=－Us－RI；

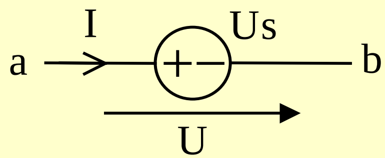
4. 电功率 Power

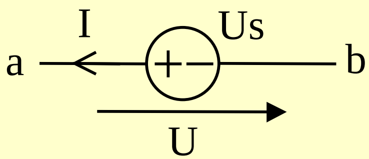
Power is the time rate of expending or absorbing energy, measured in watts (W).

$$p = \frac{dw}{dt} = ui \qquad P=UI \qquad W，kW，1MW=10^6W$$

When the current enters through the positive terminal of an element, p=+ui. If the current enters through the negative terminal, p=-ui.







(a)：$P=UI>0$，

Power absorb

$P=UI<0$，

Power supply

(b)：$P=UI<0$，

Power supply

(c): $P=UI>0$，

Power supply

In a source set, the current reference direction is directed out of the + polarity marking (or the first subscript) of the voltage.

In a load set, the current reference direction is directed into the + polarity marking (or the first subscript) of the voltage reference direction.

Example：The electron beam in a TV picture tube caries 10^{15} electrons per second. As a design engineer, determine the voltage U_0 needed to accelerate the electron beam to achieve 4W.

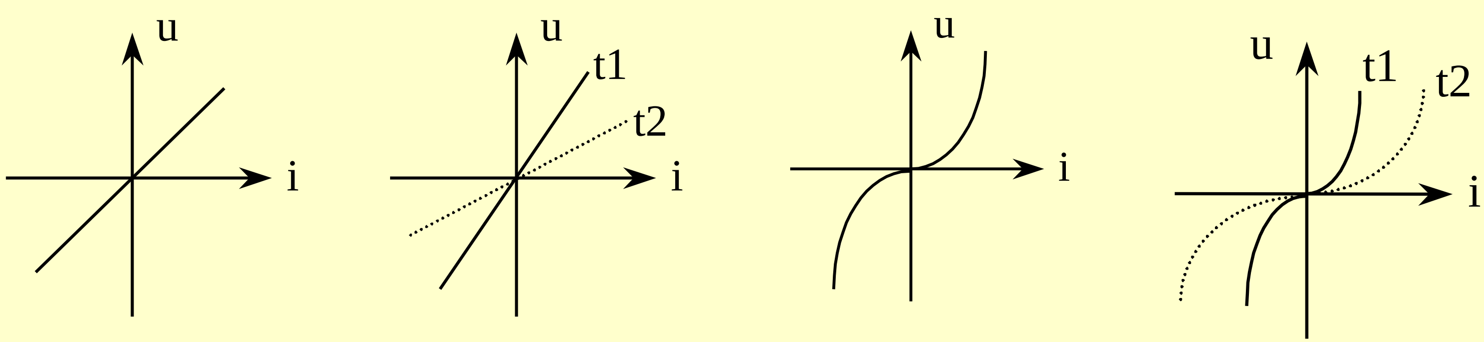
Solution：

$$i = \frac{dq}{dt} = (-1.6\times10^{-19})(10^{15}) = -1.6\times10^{-4}\ A$$

$$U_0 = \frac{p}{i} = \frac{4}{1.6\times10^{-4}} = 25,000\,V$$

1-2 电阻、电感、电容元件
Resistors, Inductors and Capacitors

一、电阻元件 Resistors



R=∞，开路/断路

Open circuit: a circuit element with resistance approaching infinity.

R=0，短路

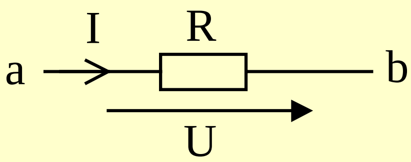
Short circuit: a circuit element with resistance approaching zero.

Ohm’s law states that the voltage across a resistor is directly proportional to the current flowing through the resistor.

$u(t)=Ri(t)$

$U=RI$，$I=GU$

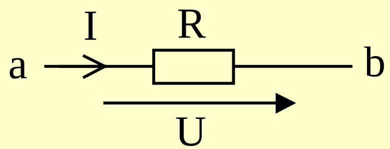
$U=10I+100I^2$

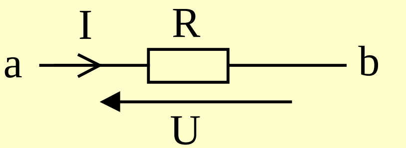


Georg Simon Ohm (1787-1845)，欧姆

$G=1/R$ mhos or siemens (S)

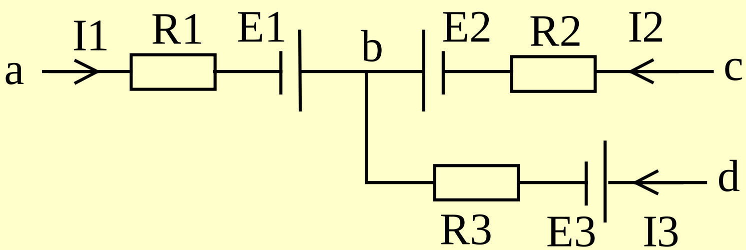
$P=UI=RI^2=U^2/R=GU^2$





Check Your Understanding

Uab= ? Uad=? Uac=? Ucd=?



$U_a-R_1I_1+E1=U_b$；

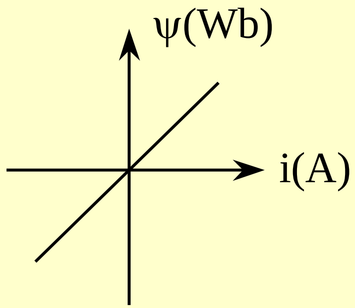
$U_{ab}=R_1I_1-E_1$；

$U_{ad}=R_1I_1-E_1-R_3I_3-E_3$；

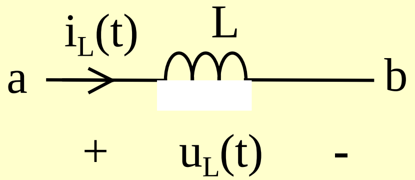
$U_{ac}=R_1I_1-E_1+E_2-R_2I_2$；

$U_{cd}=R_2I_2-E_2-R_3I_3-E_3$；

二、电感器 INDUCTORS



$\Psi(t)=Li(t)$



亨利（H），$1mH=10^{-3}H$

Joseph Henry (1797-1878)，

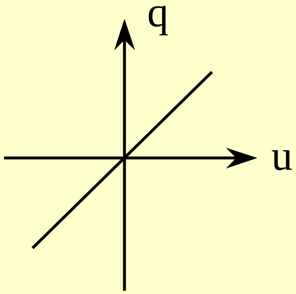
亨利

The voltage-current characteristics of an inductor

$$u_L(t)=L\frac{di_L(t)}{dt}$$

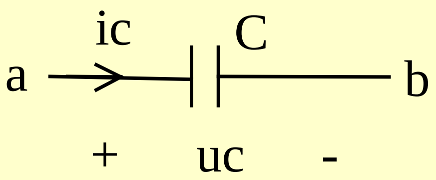
The energy stored in the inductor: $w = \frac{1}{2} i\psi = \frac{1}{2} L i^2 = \frac{1}{2}\frac{\psi^2}{L}$

三、电容器 CAPACITOR



Circuit-theory definition of a capacitor: q(t)=Cu(t)

法拉（F），1μF=10^{-6}F，1pF=10^{-12}F



Michael Faraday (1791-1867)，

法拉弟

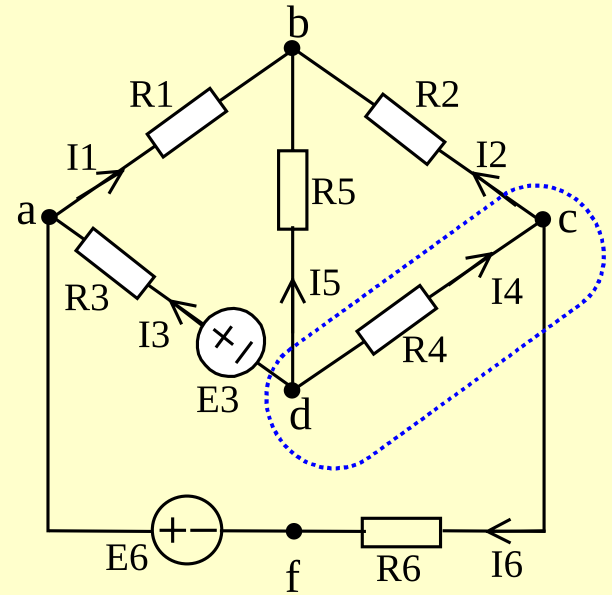
The voltage-current characteristics of an capacitor: $i = dq/dt = C\frac{du_c}{dt}$

The energy stored in the capacitor: $w = \frac{1}{2}qu_C = \frac{1}{2}cu_C^2 = \frac{1}{2}\frac{q^2}{C}$

1-3 基尔霍夫定律 KIRCHHOFF'S LAW

一、 NODES, BRANCHES, AND LOOPS

1．A branch represents a single element such as a voltage source or a resistor. In other words, branch represents any two-terminal element.



2．A node is the point of connection between two or more branches.

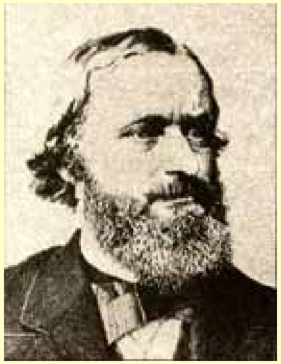
3．A loop is any closed path in a circuit.

A network with b branches, n nodes, and l independent loops will satisfy the fundamental theorem of network topology：$b=l+n-1$

二、基尔霍夫电流定律 Kirchhoff's Current Law (KCL)

Gustav Robert Kirchhoff (1824-1887)，

基尔霍夫/克西霍夫

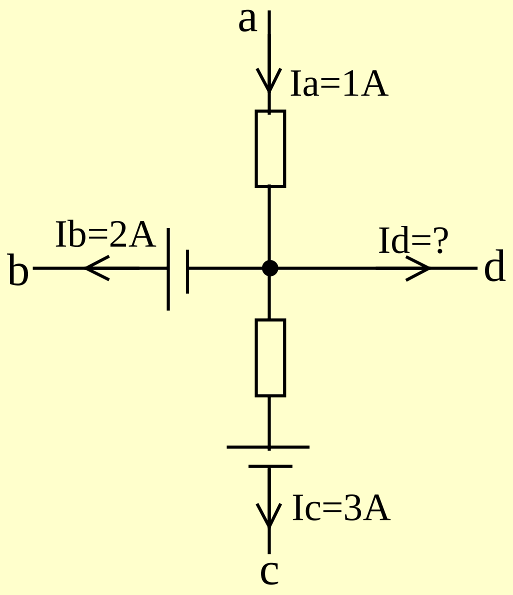


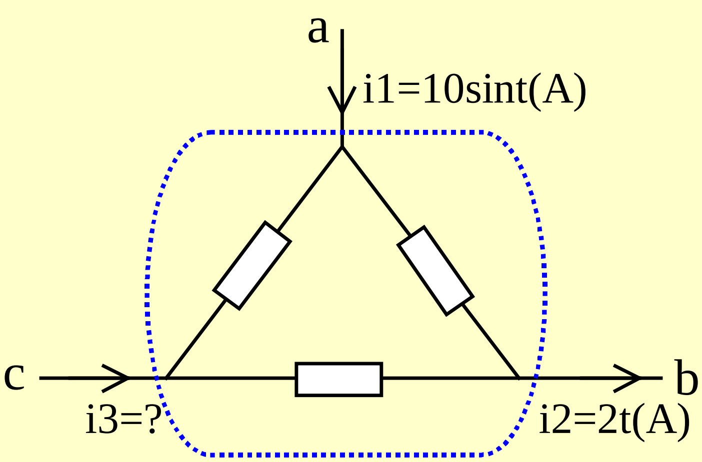
Kirchhoff's current law (KCL) states that the algebraic sum of currents entering a node is zero. $\Sigma i=0$

The sum of the currents entering a node is equal to the sum of the currents leaving the node. $\Sigma I_{出}=\Sigma I_{入}$

Kirchhoff's current law (KCL) states that the algebraic sum of currents entering a closed boundary is zero. $\sum_{S} i = 0$

Check Your Understanding:





Find the current Id

Id=Ia-Ib-Ic=1-2-3=-4(A)

Find the current i3

i3=i2-i1=2t-10sint (A)

三、基尔霍夫电压定律　Kirchhoff's Voltage Law (KVL)

Kirchhoff's voltage law (KVL) states that the algebraic sum of all voltages around a closed path (or loop) is zero.　$\Sigma U=0$

adcfa：$Uad+Udc+Ucf+Ufa=0$

$Ua-Ud+Ud-Uc+Uc-Uf+Uf-Ua=0$

$\Sigma U=0$

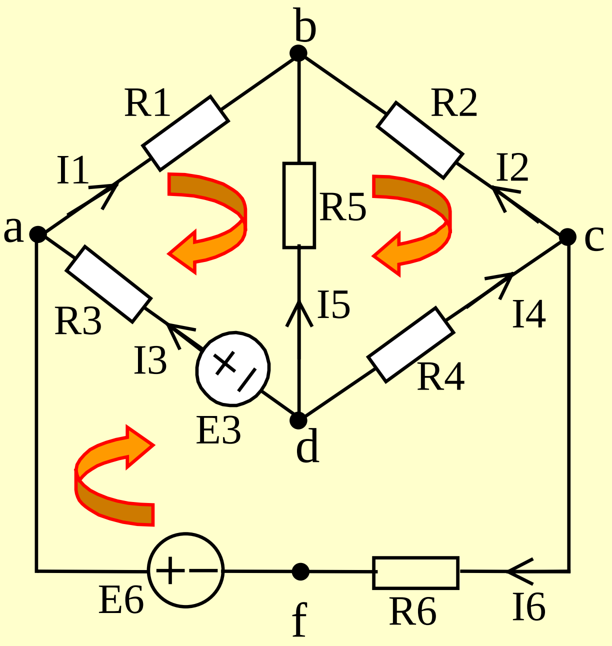
adcfa：$Uad=-R_3I_3+E_3$；$Udc=R_4I_4$；$Ucf=R_6I_6$；$Ufa=-E6$；

$-R_3I_3+R_4I_4+R_6I_6=E_6-E_3$

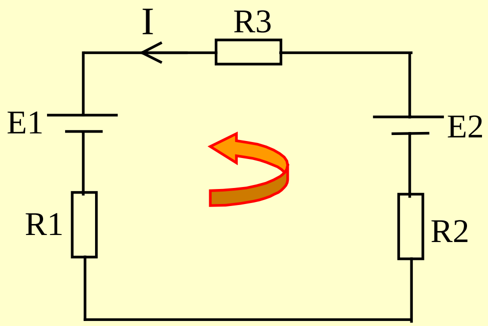
$Udf=?$

$-R_3I_3+E_3+Udf-E_6=0$；$Udf=E_6+R_3I_3-E_3$

Or: $R_4I_4+R_6I_6-Udf=0$；$Udf=R_4I_4+R_6I_6$



Example: Find the current I .

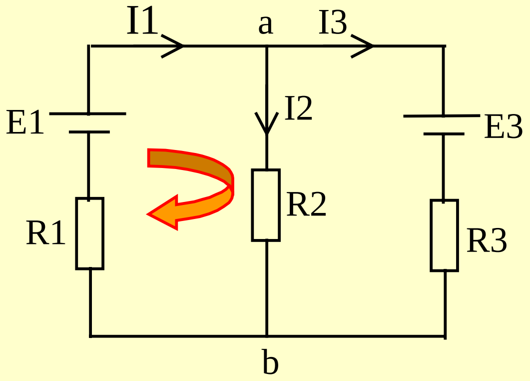


Solution:

$R_3I+E_1+R_1I+R_2I-E_2=0$

$$I=\frac{E_2-E_1}{R_3+R_1+R_2}$$

例：$R_1=1\Omega$，$R_2=2\Omega$，$R_3=3\Omega$，E3=3V，$I_3=3A$，求I_1、I_2与两电源的功率。



解：

$R_2I_2=E3+R_3I_3=3+3\times3=12V$

$I_2=12/2=6A$；$I_1=I_2+I_3=9A$；

$E_1=R_2I_2+R_1I_1=12+1\times9=21V$

$P_1=E_1I_1=21\times9=189W$， $P_3=E_3I_3=3\times3=9W$

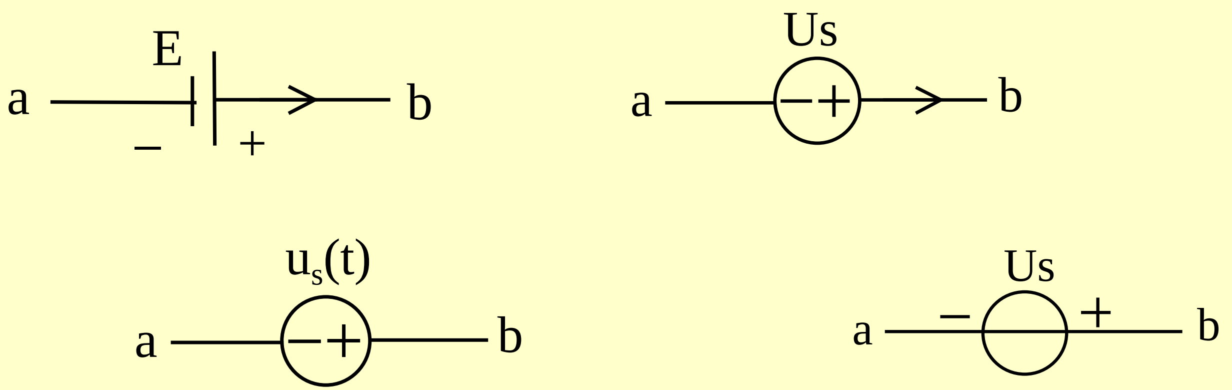
1-4 Ideal Independent Sources and Their Actual Models

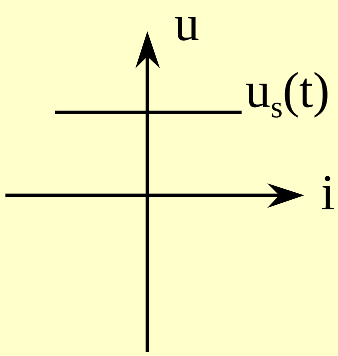
An ideal independent source is an active element that provides a specified voltage or current that is completely independent of other circuit variable.

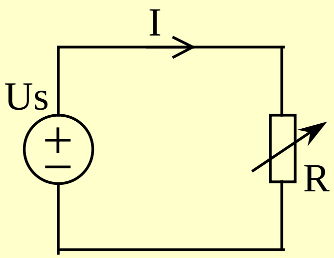
一、独立电压源 Ideal Voltage Source

The ideal voltage source maintains its prescribed voltage, independent of its output current.

General symbol for a voltage source/ graphical characteristic of a dc voltage source:







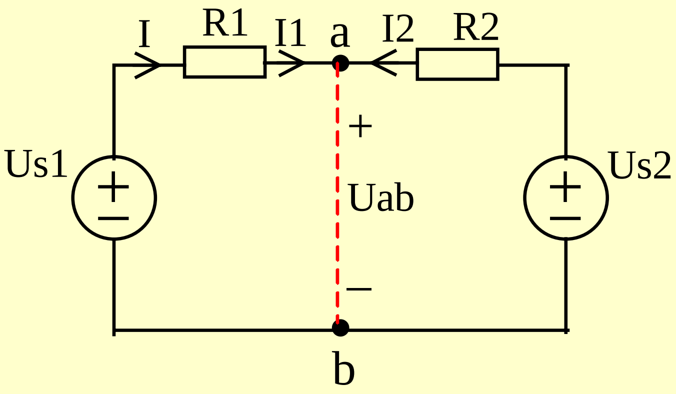
maintains its voltage

the current is determined by the load

U=0， Short circuit

例：

R_1=1Ω，R_2=2Ω，U_{S1}=1V，当U_{S2}=2V或U_{S2}= –2V时，求开路电压Uab和短路电流Iab。



解：当U_{S2}=2V

$$I=\frac{U_{S1}-U_{S2}}{R_1+R_2}=\frac{1-2}{3}=-\frac{1}{3}A$$

$$U_{ab}=U_{S1}-R_1I=1-(-\frac{1}{3})\times 1=\frac{4}{3}V$$

$$U_{ab}=U_{S2}+R_2I=2+2\times(-\frac{1}{3})=\frac{4}{3}V$$

$$I_1=\frac{U_{S1}}{R_1}=1A$$

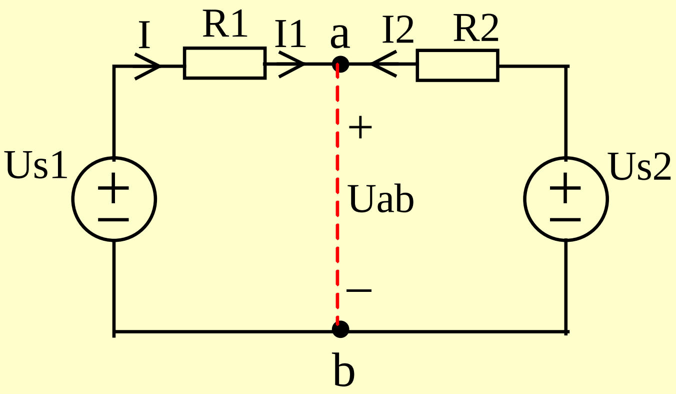
$$I_2=\frac{U_{S2}}{R_2}=1A$$

Iab=2A

强迫同位点

当 $U_{S2}= -2V$

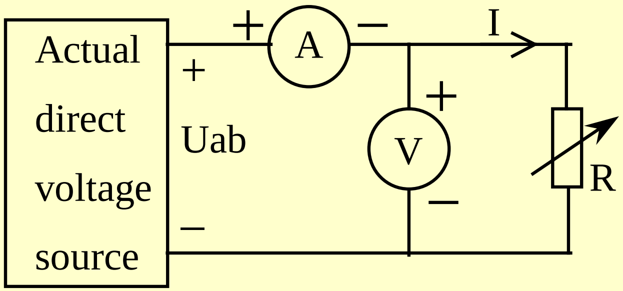
$$I=\frac{U_{S1}-U_{S2}}{R_1+R_2}=\frac{1+2}{3}=1A$$

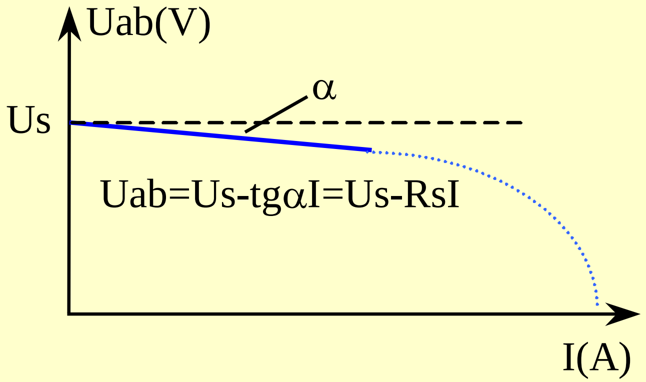


$Uab=Us_1-R_1I=1-1\times1=0V$；$I_1=1A$；$I_2= -1A$；$Iab=0A$

自然同位点

Actual model of direct voltage source

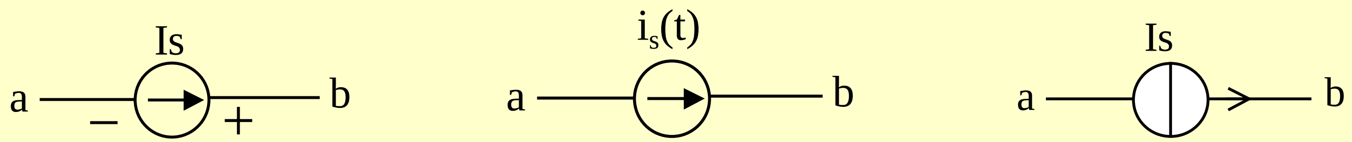


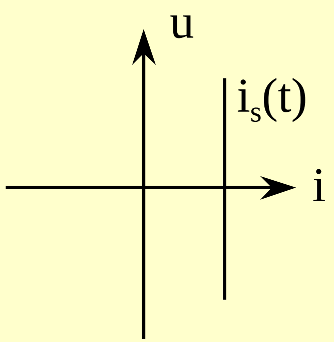


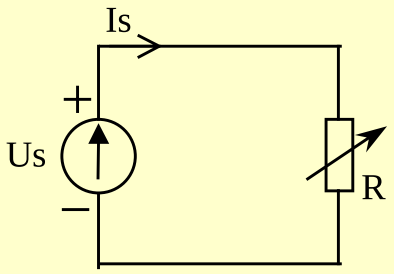
三、独立电流源 Ideal Current Source

The ideal current source produces its prescribed current, independent of its output voltage.

General symbol of a current source / graphical characteristic of a dc current source

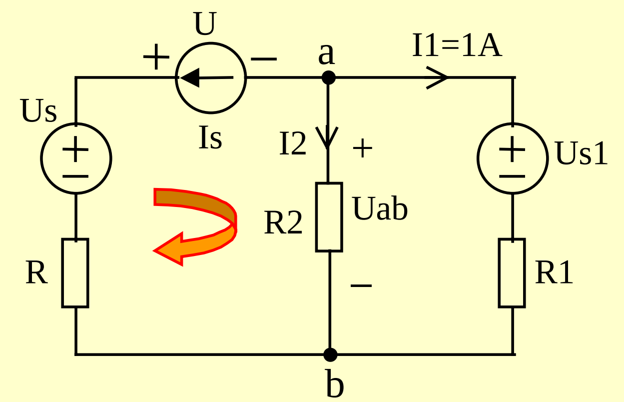






maintains its current, the voltage is determined by the load

例：$R_1=1\Omega$，$R_2=2\Omega$，$R_3=3\Omega$，$U_{S1}=1V$，$I_1=1A$，$U_S=10V$，求：Is，P_{Is}。



解：

$Uab=U_{S1}+R_1I_1=1+1\times1=2V=R_2I_2$；

$\Rightarrow I_2=1A$

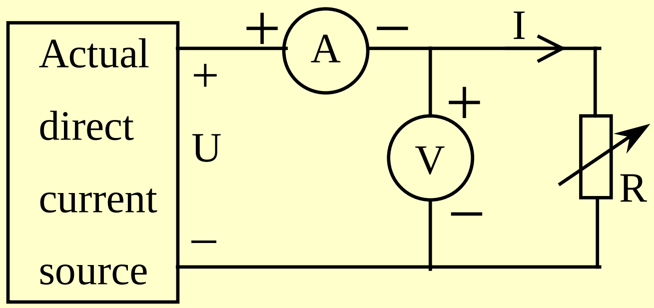
$I_S=-(I_1+I_2)=-(1+1)=-2A$；

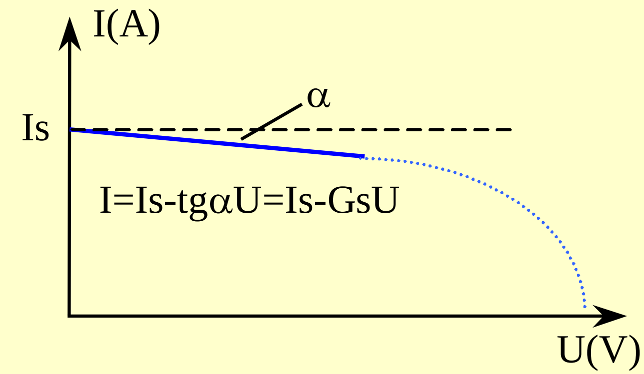
U-Us-RIs+Uab=0

$U=Us+RIs-Uab=10+3\times(-2)-2=2V$

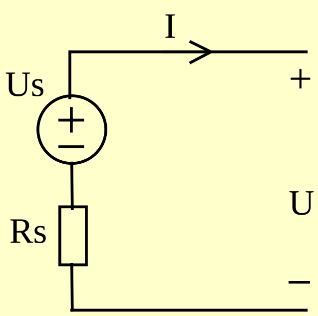
$P_{IS}=UIs=2\times(-2)=-4W$

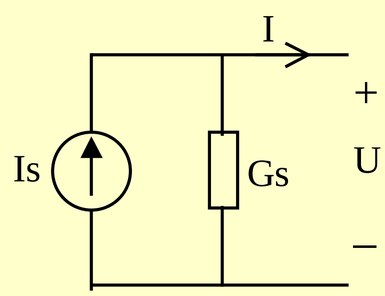
Actual model of direct current source





Source Transformations





令 $\frac{U_S}{R_S} = I_S$

$U=U_S - R_S I$

$\frac{U}{R_S} = \frac{U_S}{R_S} - I$

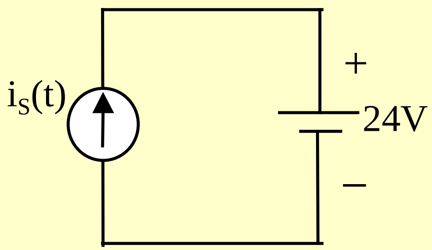
$\Rightarrow \quad I = I_S - \frac{U}{R_S}$

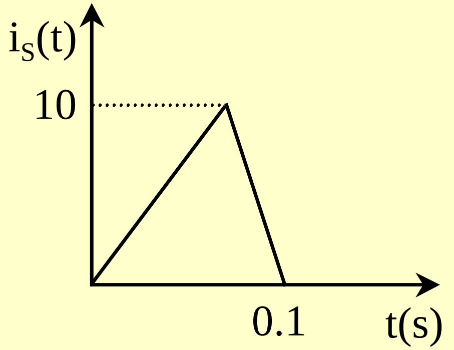
A source transformation is the process of replacing a voltage source Us in series with a resistor R by a current source Is in parallel with a resistor R, or vice versa.

Note: the arrow of the current source is directed toward the positive terminal of the voltage source.

Example： Voltage and Current Sources

A constant voltage source is connected in series with a current source that produces a pulse of current. The pulse is 0.1s in duration and triangular in shape, as shown in Fig. Find the energy out of the current source.





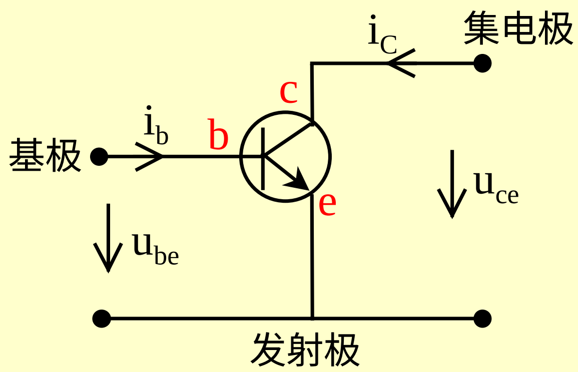
Solution：

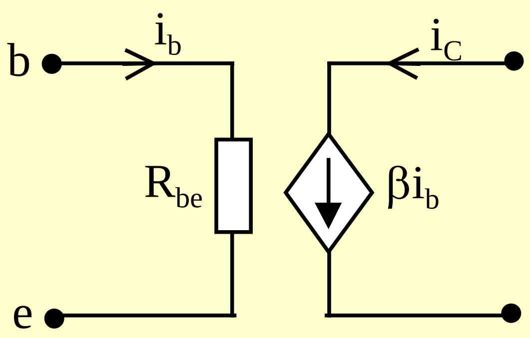
$$p_{out} = 24 \times i_S(t) \quad \Rightarrow \quad W_{out} = \int p_{out} dt = 24\int_0^{0.1} i_S(t)$$

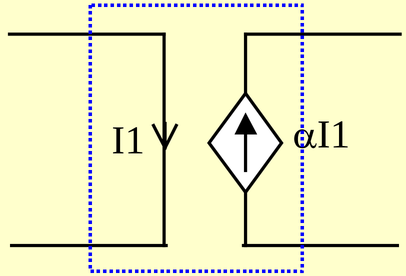
$$Area = \frac{1}{2}(0.1)(10) = 0.5C \quad \Rightarrow \quad W_{out} = 24 \times 0.5 = 12\ J$$

1-5 受控电源 CONTROLLED SOURCES

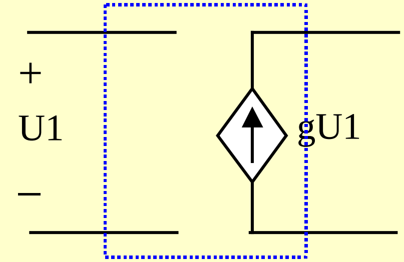
An ideal dependent (or controlled) source is an active element in which the source quantity is controlled by another voltage or current.







CCCS



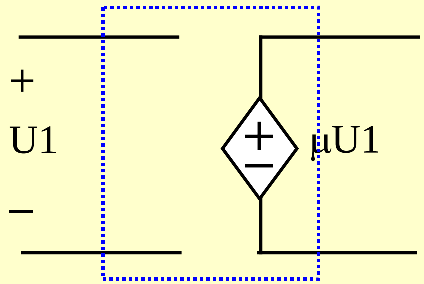
VCCS

CCCS：A current-controlled current source

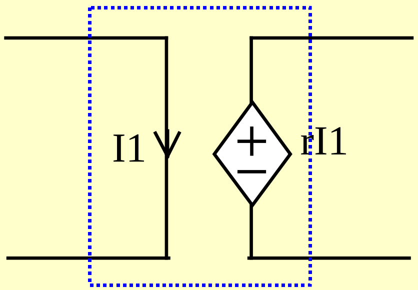
α：current gain, dimensionless

VCCS：A voltage-controlled current source

g：transconductance （S）



VCVS



CCVS

VCVS：A voltage-controlled voltage source

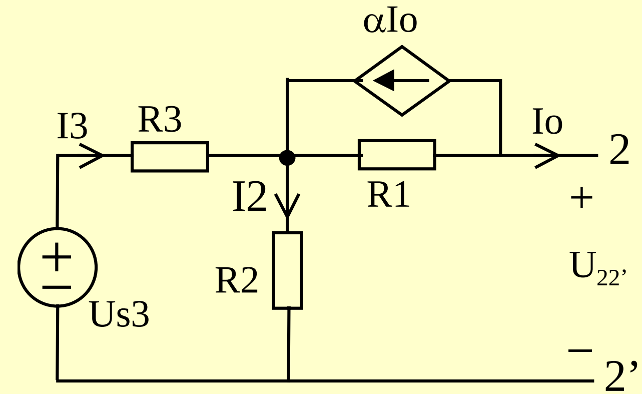
μ：voltage gain, dimensionless

CCVS：A current-controlled voltage source

r：transresistance （Ω）

例：

R_1=1Ω，R_2=2Ω，R_3=3Ω，α=3，U_{S3}=3V，求开路电压$U_{22'}$。



解：

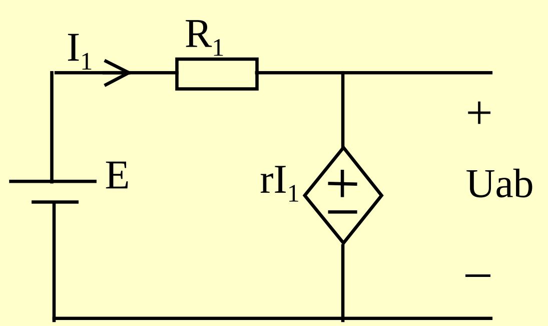
22'开路：Io=0，αIo=0，

$$I_3 = I_2 = \frac{U_{S3}}{R_2 + R_3} = \frac{3}{5} A \qquad U_{22'} = R_2 I_2 = 2 \times \frac{3}{5} = \frac{6}{5} V$$

Check Your Understanding: find the open circuit voltage Uab

$$U_{ab} = r\,I_1 = r\,\frac{E - r\,I_1}{R_1}$$

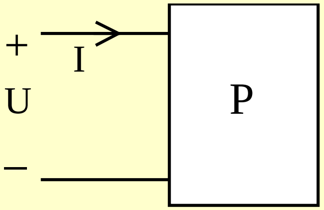
$$\because I_1 = \frac{E - r\,I_1}{R_1} \Rightarrow I_1 = \frac{E}{R_1 + r} \qquad \therefore U_{ab} = \frac{r\,E}{R_1 + r}$$



1-6 Passive Two-terminal Circuit

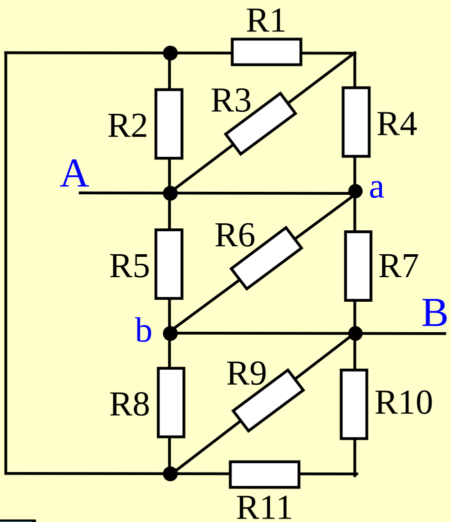
The equivalent resistance of any number of resistors connected in series is the sum of the individual resistances.

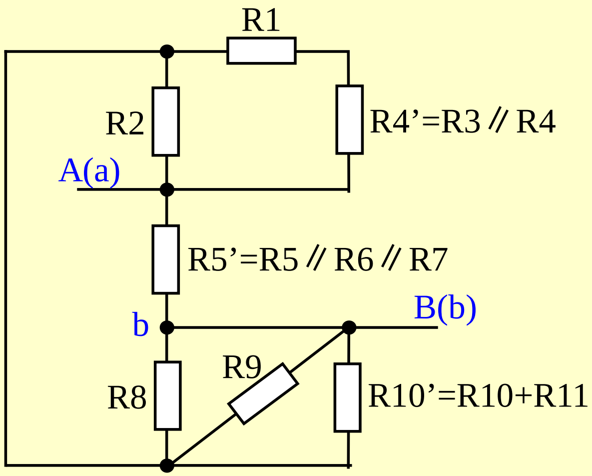
The equivalent resistance of two parallel resistors is equal to the product of their resistances divided by their sum.

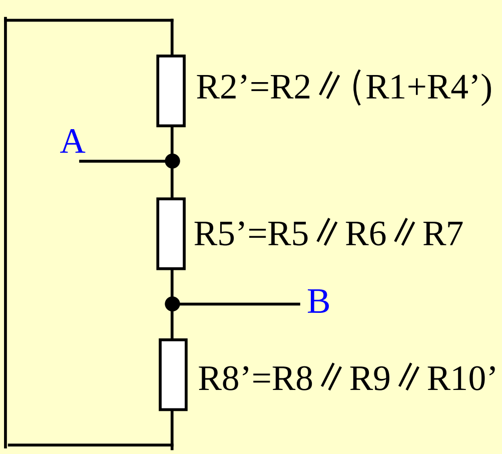


例：求关于AB端的等值电阻R_{AB}。

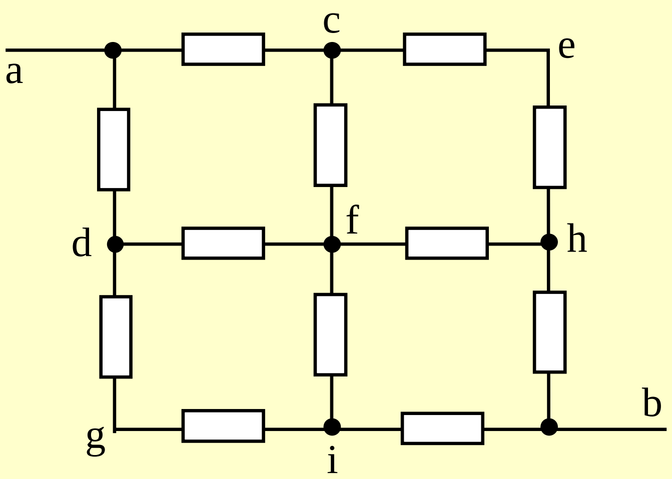
$R_{AB}=R5'//(R2'+R8')$







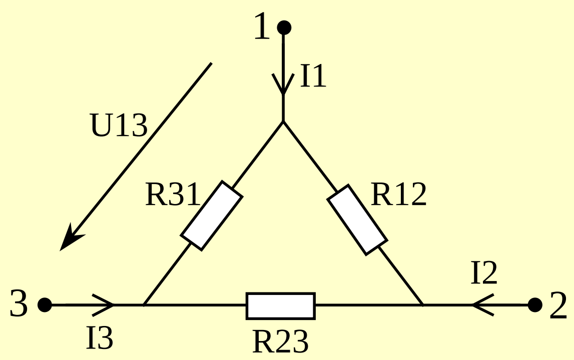
例：图中各电阻都是R，求ab间的等效电阻。

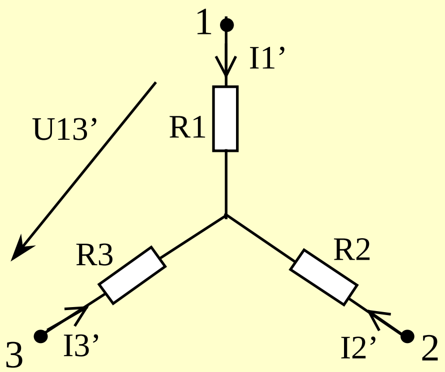


解：

$$R_{ab}=\frac{R}{2}+\frac{R}{4}+\frac{R}{4}+\frac{R}{2}=\frac{3R}{2}$$

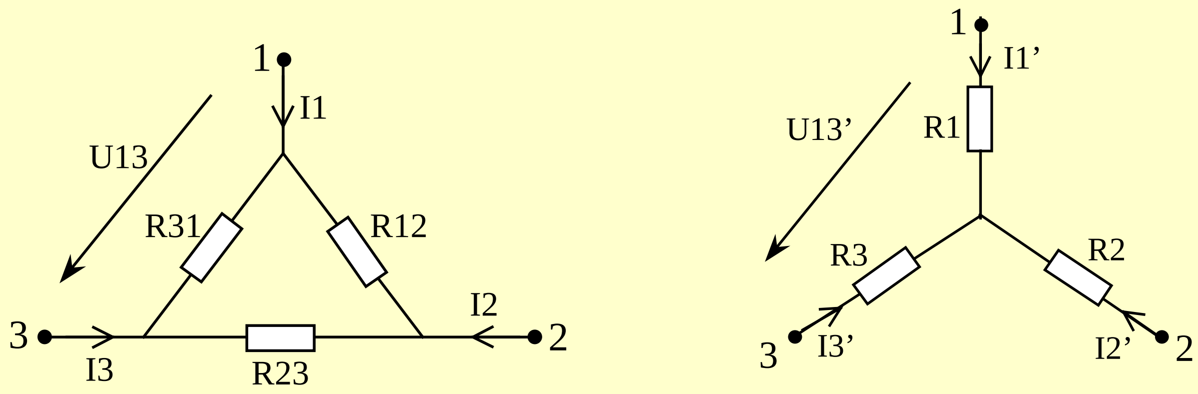
四、星网变换 WYE-DELTA TRANSFORMATIONS





Delta to Wye Conversion：Each resistor in the Y network is the product of the resistors in the two adjacent Δ branches, divided by the sum of the three Δ resistors.

Y接电阻＝Δ接夹边电阻之乘积/Δ接三边电阻之和

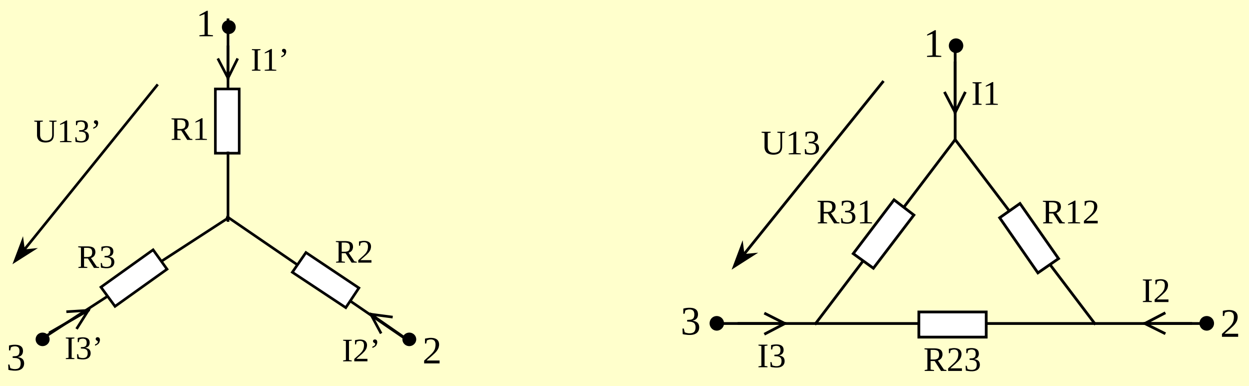


$$R_1 = \frac{R_{31}R_{12}}{R_{12}+R_{23}+R_{31}} \qquad R_2 = \frac{R_{12}R_{23}}{R_{12}+R_{23}+R_{31}} \qquad R_3 = \frac{R_{31}R_{23}}{R_{12}+R_{23}+R_{31}}$$

$R_{12}=R_{23}=R_{31}$ $$R_1 = R_2 = R_3 = \frac{1}{3}R_\Delta$$

Wye to Delta Conversion：Each resistor in the Δ network is the sum of all possible products of Y resistors taken two at a time, divided by the opposite Y resistor.

Δ接电阻＝Y接电阻两两依次连乘之和/与所求Y接电阻不相关的Y电阻



$$R_{12}=\frac{R_1R_2+R_2R_3+R_1R_3}{R_3}\qquad R_{23}=\frac{R_1R_2+R_2R_3+R_1R_3}{R_1}\qquad R_{31}=\frac{R_1R_2+R_2R_3+R_1R_3}{R_2}$$

$$R_1=R_2=R_3 \quad \Rightarrow \quad R_\Delta=3R_Y$$