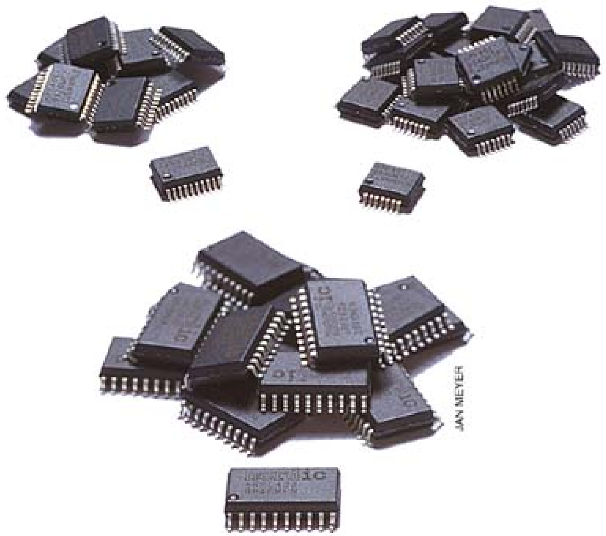
Chapter 1
Basic Electric Circuit Concepts



BASIC CONCEPTS

LEARNING GOALS

- System of Units: The SI standard system
- Systeme International unit (=International System of Units)
- (法) 國際單位制

- Basic Quantities: Charge, current, voltage, power and energy

- Circuit Elements: Active and Passive

http://physics.nist.gov/cuu/index.html

The NIST Reference on Constants, Units, and Uncertainty

International System of Units (SI)

SI base units

The SI is founded on seven *SI base units* for seven *base quantities* assumed to be mutually independent, as given in Table 1.

Table 1. SI base units

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

For detailed information on the SI base units, see Definitions of the SI base units and their Historical context.

Definitions of the SI base units

Unit of length	**meter**	The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
Unit of mass	**kilogram**	The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
Unit of time	**second**	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
Unit of electric current	**ampere**	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.
Unit of thermodynamic temperature	**kelvin**	The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Unit of amount of substance	**mole**	1. The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; its symbol is "mol."

The 20 SI prefixes used to form decimal multiples and submultiples of SI units are given in Table 5.

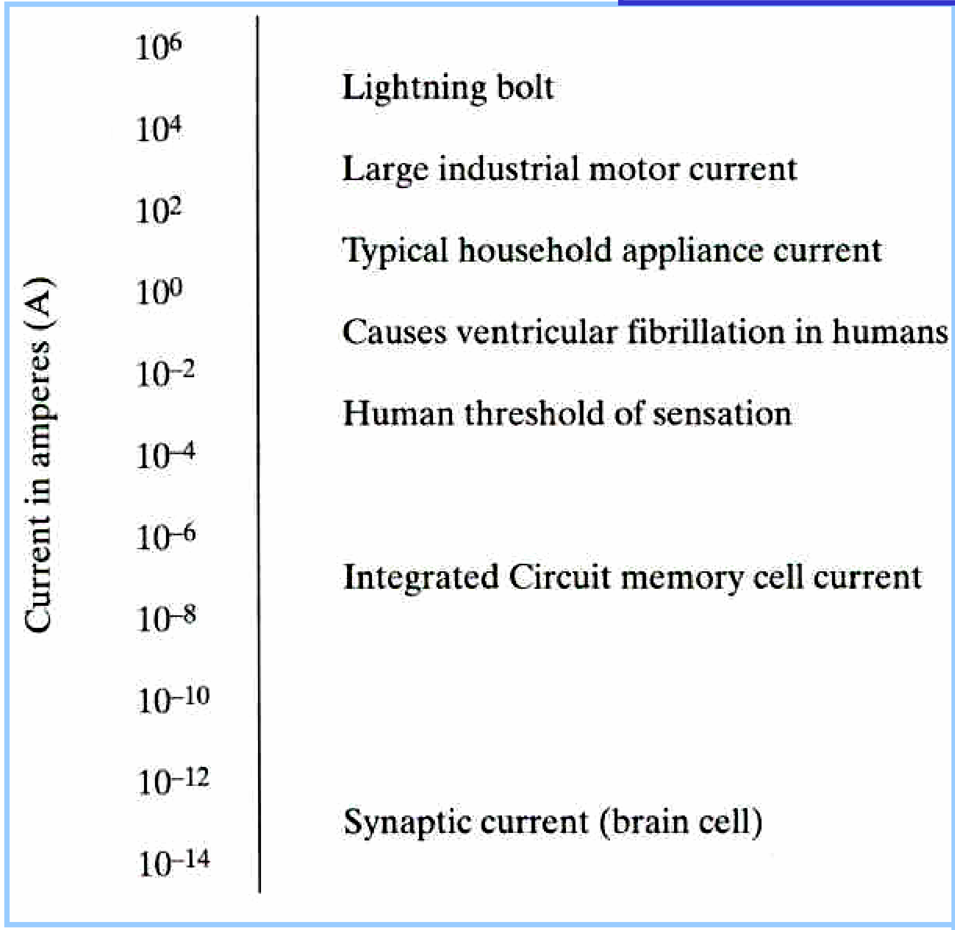
Table 5. SI prefixes

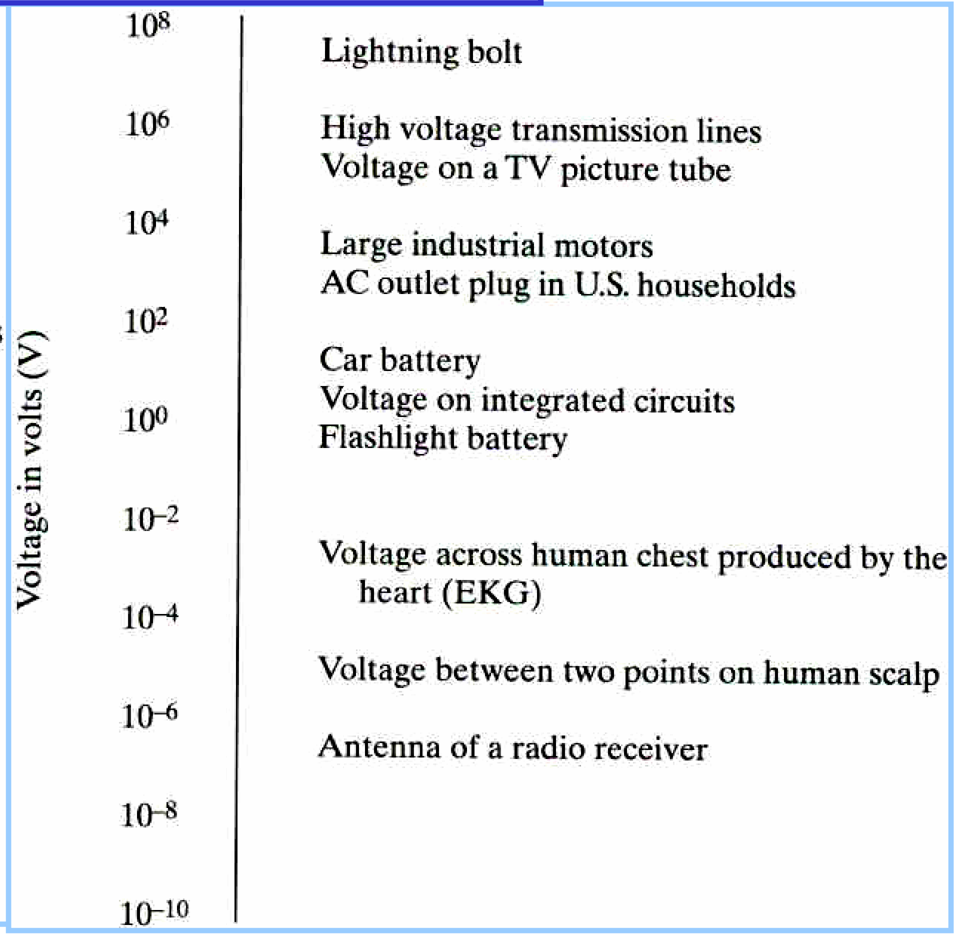
Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	µ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}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

SI DERIVED BASIC ELECTRICAL UNITS

power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C	-	$s \cdot A$
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	V·s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$

CURRENT AND VOLTAGE RANGES



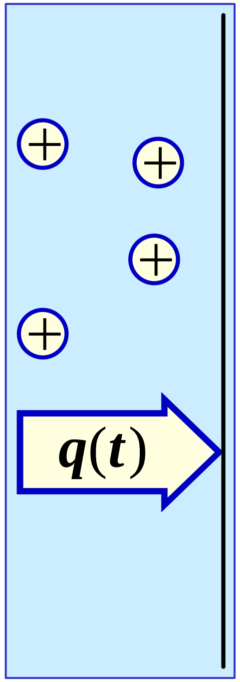


Strictly speaking current is a basic quantity and charge is derived. However, physically the electric current is created by a movement of charged particles.

An electric circuit is essentially a pipeline that facilitates the transfer of charge from one point to another. The time rate of change of charge constitutes an electric *current*. Mathematically, the relationship is expressed as

$$i(t) = \frac{dq(t)}{dt} \quad \text{or} \quad q(t) = \int_{-\infty}^{t} i(x)\,dx$$

Although we know that current flow in metallic conductors results from electron motion, the conventional current flow, which is universally adopted, represents the movement of positive charges.

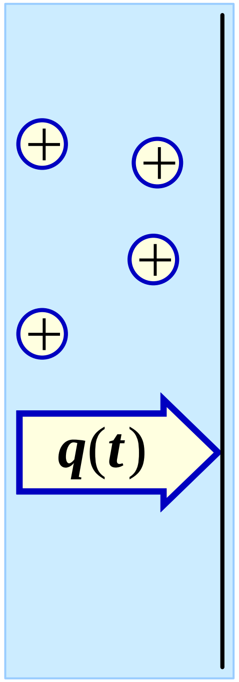


What is the meaning of a negative value for *q(t)?*

<u>PROBLEM SOLVING TIP</u>
IF THE CHARGE IS GIVEN DETERMINE THE CURRENT BY DIFFERENTIATION
IF THE CURRENT IS KNOWN DETERMINE THE CHARGE BY INTEGRATION

A PHYSICAL ANALOGY THAT HELPS VISUALIZE ELECTRIC CURRENTS IS THAT OF WATER FLOW.
CHARGES ARE VISUALIZED AS WATER PARTICLES

EXAMPLE



$$q(t) = 4\times 10^{-3}\sin(120\pi t)[C]$$

$$i(t) = 4\times 10^{-3}\times 120\pi\cos(120\pi t)\,[A]$$

$$i(t) = 0.480\pi\cos(120\pi t)[mA]$$

EXAMPLE

$$i(t) = \begin{cases} 0 & t < 0 \\ e^{-2t}mA & t \geq 0 \end{cases}$$

FIND THE CHARGE THAT PASSES DURING IN THE INTERVAL 0<t<1

$$q = \int_0^1 e^{-2x}dx = -\frac{1}{2}e^{-2x}\Big|_0^1 = -\frac{1}{2}e^{-2} - \left(-\frac{1}{2}e^{0}\right)$$

$$q = \frac{1}{2}(1 - e^{-2})$$

Units?

FIND THE CHARGE AS A FUNCTION OF TIME

$$q(t) = \int_{-\infty}^{t} i(x)dx = \int_{-\infty}^{t} e^{-2x}dx$$

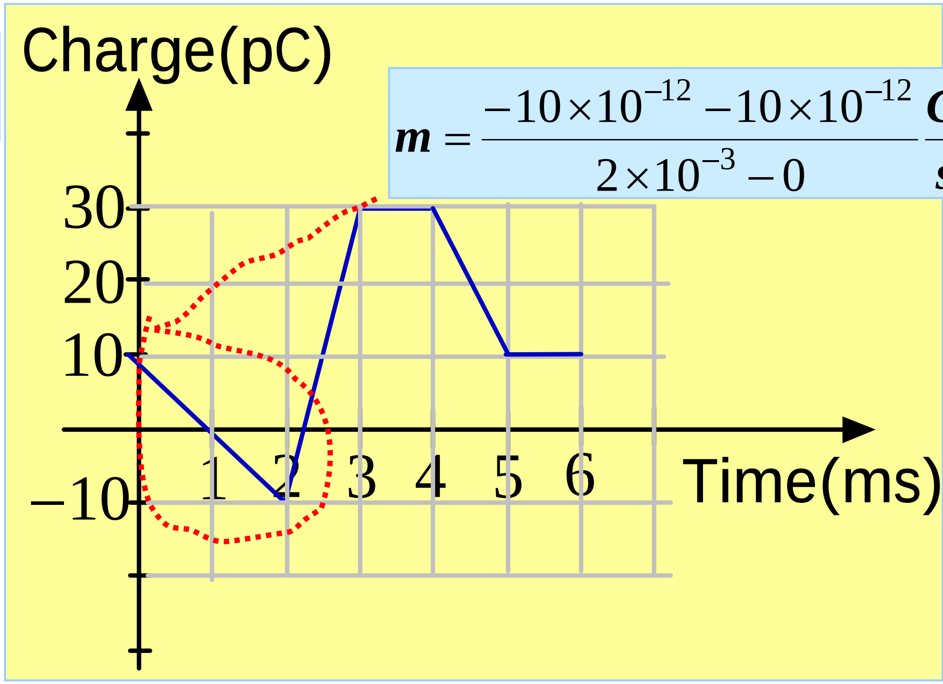
$$t \leq 0 \Rightarrow q(t) = 0$$

$$t > 0 \Rightarrow q(t) = \int_0^t e^{-2x}dx = \frac{1}{2}(1 - e^{-2t})$$

And the units for the charge?...

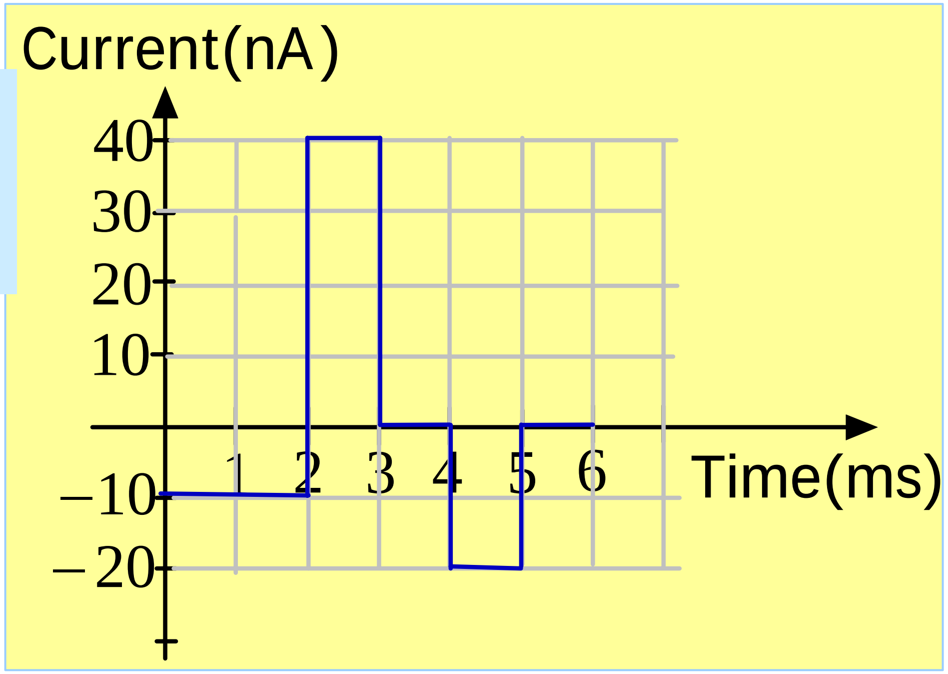
DETERMINE THE CURRENT

Here we are given the charge flow as function of time.



$$m = \frac{-10\times10^{-12} - 10\times10^{-12}}{2\times10^{-3} - 0}\frac{C}{s} = -10\times10^{-9}(C/s)$$

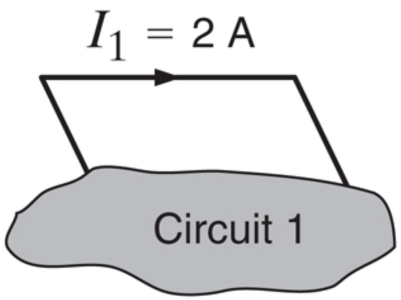
To determine current we must take derivatives.
<u>PAY ATTENTION TO UNITS</u>



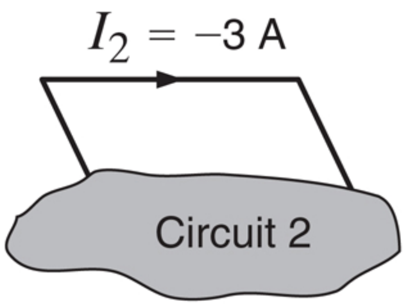
CONVENTION FOR CURRENTS

IT IS ABSOLUTELY NECESSARY TO INDICATE THE DIRECTION OF MOVEMENT OF CHARGED PARTICLES.

THE UNIVERSALLY ACCEPTED CONVENTION IN ELECTRICAL ENGINEERING IS THAT CURRENT IS FLOW OF POSITIVE CHARGES.
AND WE INDICATE THE DIRECTION OF FLOW FOR POSITIVE CHARGES
-THE REFERENCE DIRECTION-



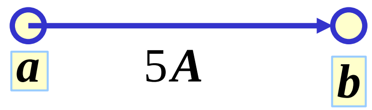
A POSITIVE VALUE FOR THE CURRENT INDICATES FLOW IN THE DIRECTION OF THE ARROW (THE REFERENCE DIRECTION)



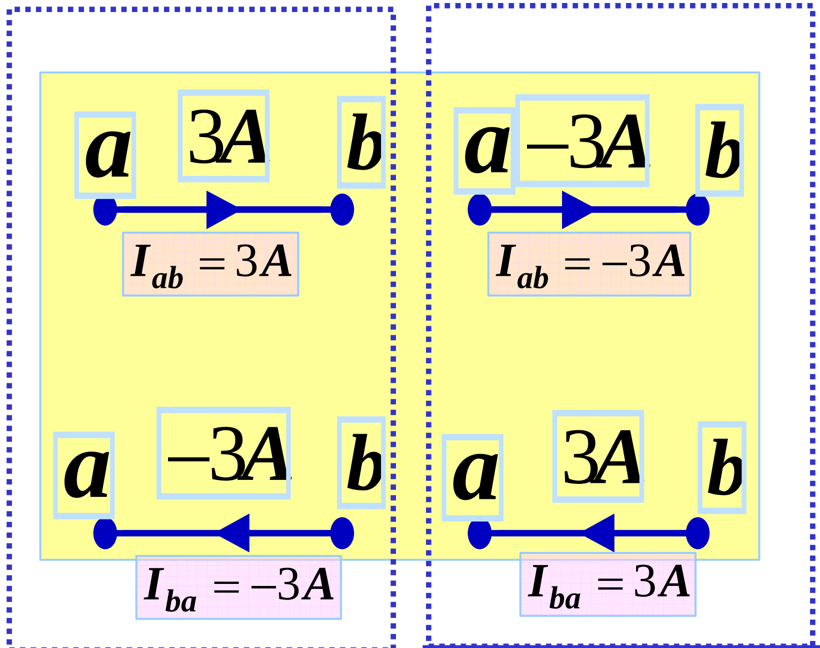
A NEGATIVE VALUE FOR THE CURRENT INDICATES FLOW IN THE OPPOSITE DIRECTION THAN THE REFERENCE DIRECTION

THE DOUBLE INDEX NOTATION

IF THE INITIAL AND TERMINAL NODE ARE LABELED ONE CAN INDICATE THEM AS SUBINDICES FOR THE CURRENT NAME



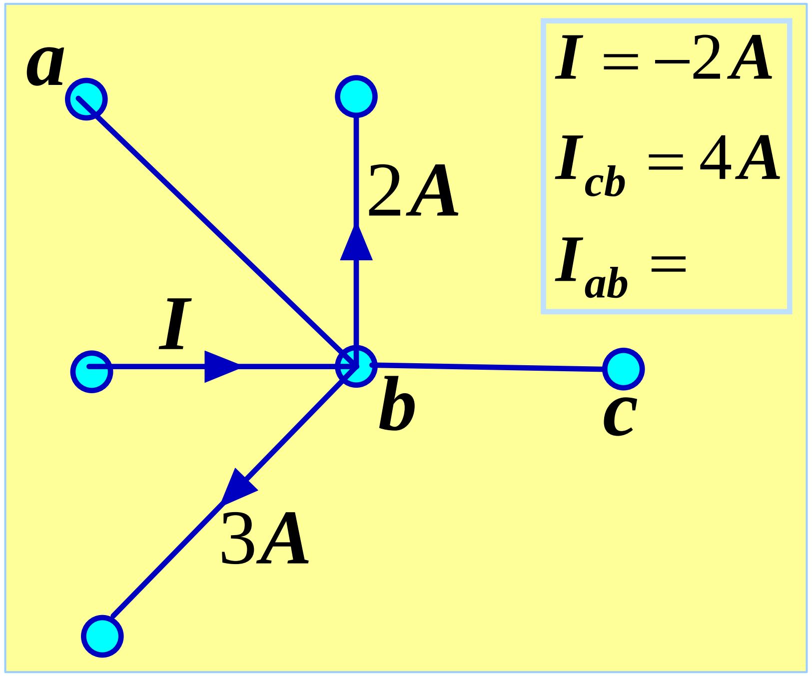
$$I_{ab} = 5A$$



POSITIVE CHARGES FLOW LEFT-RIGHT

POSITIVE CHARGES FLOW RIGHT-LEFT

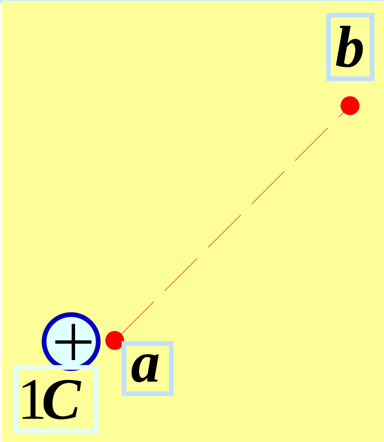
$$I_{ab} = -I_{ba}$$



This example illustrates the various ways in which the current notation can be used

CONVENTIONS FOR VOLTAGES

ONE DEFINITION FOR VOLT
TWO POINTS HAVE A VOLTAGE DIFFERENTIAL OF ONE VOLT IF ONE COULOMB OF CHARGE GAINS (OR LOSES) ONE JOULE OF ENERGY WHEN IT MOVES FROM ONE POINT TO THE OTHER



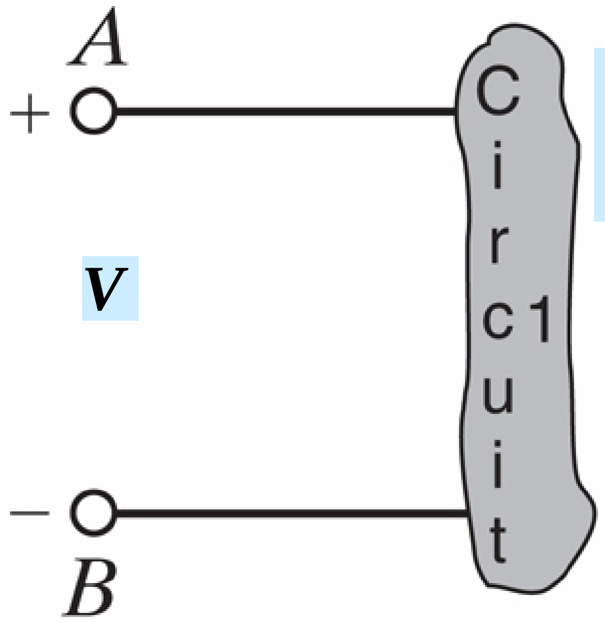
IF THE CHARGE GAINS ENERGY MOVING FROM a TO b THEN b HAS HIGHER VOLTAGE THAN a.
IF IT LOSES ENERGY THEN b HAS LOWER VOLTAGE THAN a

DIMENSIONALLY VOLT IS A DERIVED UNIT

$$\text{VOLT} = \frac{\text{JOULE}}{\text{COULOMB}} = \frac{N \bullet m}{A \bullet s}$$

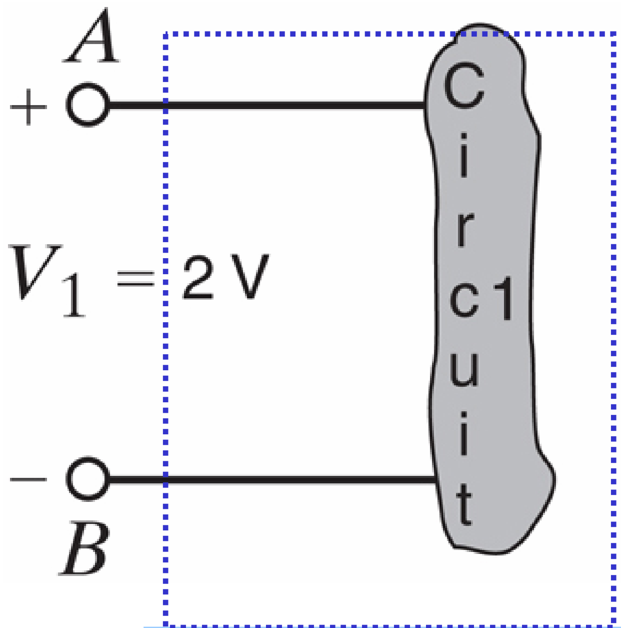
VOLTAGE IS ALWAYS MEASURED IN A RELATIVE FORM AS THE VOLTAGE DIFFERENCE BETWEEN TWO POINTS

IT IS ESSENTIAL THAT OUR NOTATION ALLOWS US TO DETERMINE WHICH POINT HAS THE HIGHER VOLTAGE

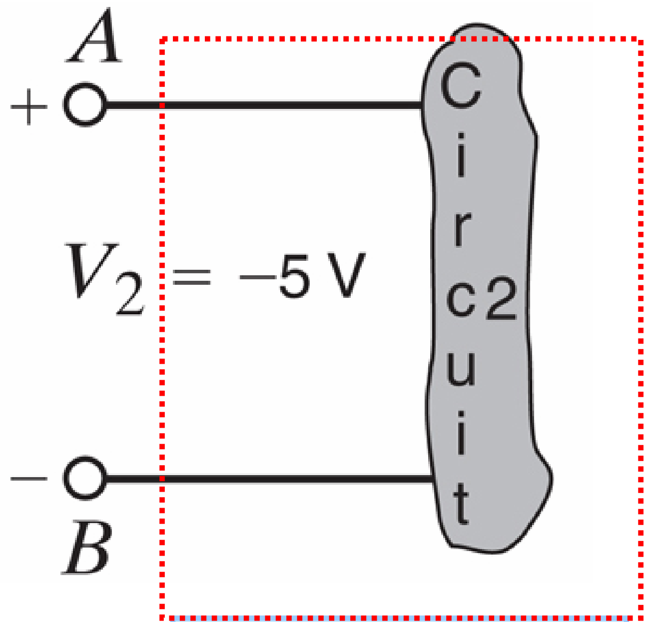


THE + AND - SIGNS DEFINE THE REFERENCE POLARITY

IF THE NUMBER V IS POSITIVE POINT A HAS V VOLTS MORE THAN POINT B.
IF THE NUMBER V IS NEGATIVE POINT A HAS |V| LESS THAN POINT B



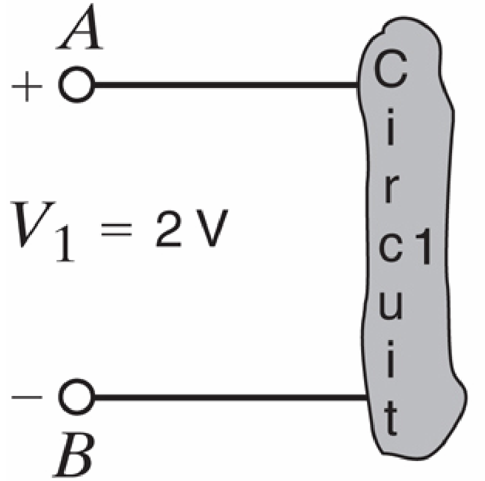
POINT A HAS 2V MORE THAN POINT B



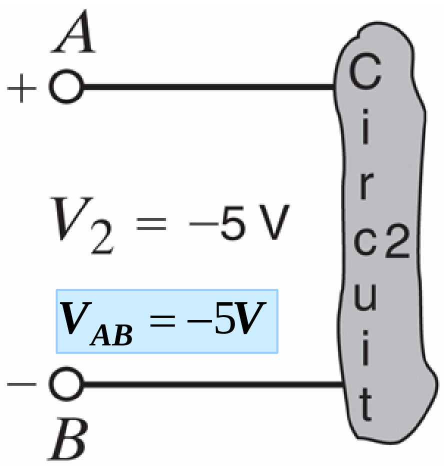
POINT A HAS 5V LESS THAN POINT B

THE TWO-INDEX NOTATION FOR VOLTAGES

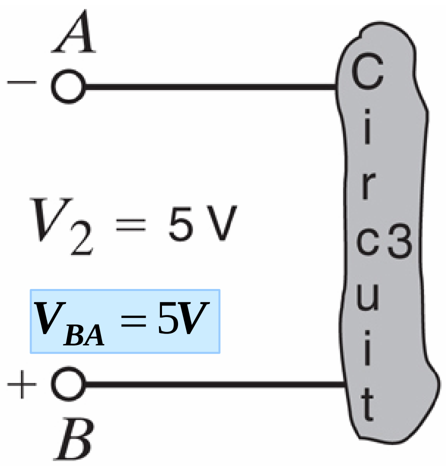
INSTEAD OF SHOWING THE REFERENCE POLARITY WE AGREE THAT THE FIRST SUBINDEX DENOTES THE POINT WITH POSITIVE REFERENCE POLARITY



$$V_{AB} = 2V$$



$$V_{AB} = -5V$$

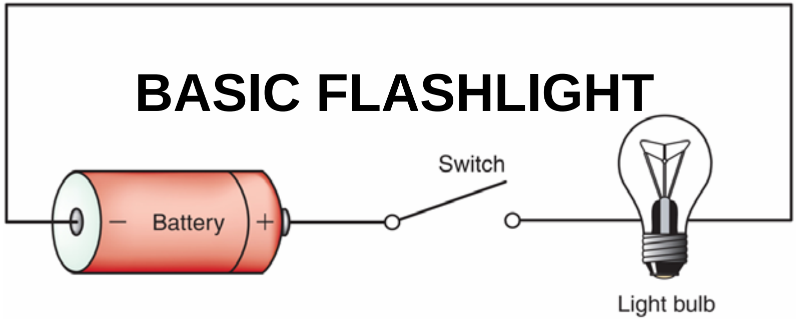


$$V_{BA} = 5V$$

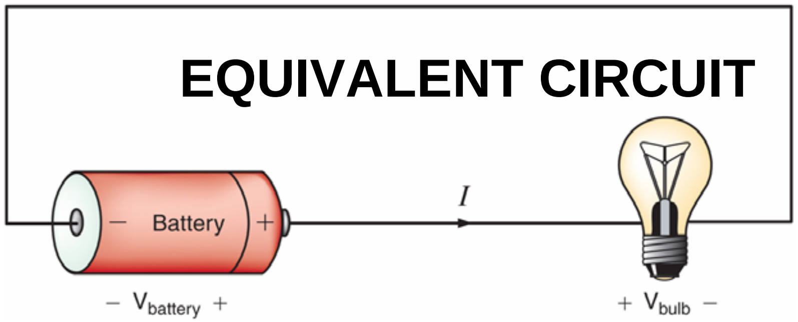
$$V_{AB} = -V_{BA}$$

ENERGY

VOLTAGE IS A MEASURE OF ENERGY PER UNIT CHARGE…
CHARGES MOVING BETWEEN POINTS WITH DIFFERENT VOLTAGE ABSORB OR RELEASE ENERGY – THEY MAY TRANSFER ENERGY FROM ONE POINT TO ANOTHER



Converts energy stored in battery to thermal energy in lamp filament which turns incandescent and glows



The battery supplies energy to charges.
Lamp absorbs energy from charges.
The net effect is an energy transfer

Charges gain energy here

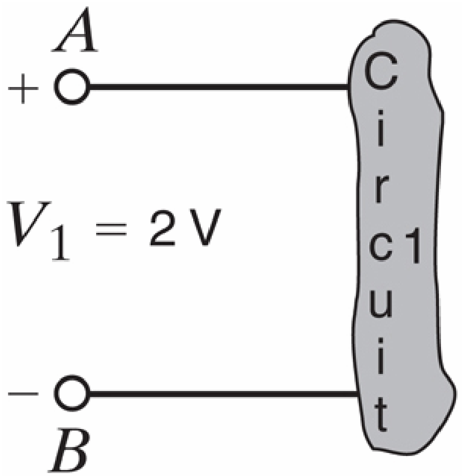
Charges supply Energy here

ENERGY

VOLTAGE IS A MEASURE OF ENERGY PER UNIT CHARGE…
CHARGES MOVING BETWEEN POINTS WITH DIFFERENT VOLTAGE ABSORB OR RELEASE ENERGY

WHAT ENERGY IS REQUIRED TO MOVE 120[C] FROM POINT B TO POINT A IN THE CIRCUIT?

THE CHARGES MOVE TO A POINT WITH HIGHER VOLTAGE -THEY GAINED (OR ABSORBED) ENERGY
THE CIRCUIT SUPPLIED ENERGY TO THE CHARGES



$$V_{AB} = 2V$$

$$V = \frac{W}{Q} \Rightarrow W = VQ = 240J$$

EXAMPLE
A CAMCODER BATTERY PLATE CLAIMS THAT THE UNIT STORES 2700mAHr AT 7.2V.
WHAT IS THE TOTAL CHARGE AND ENERGY STORED?

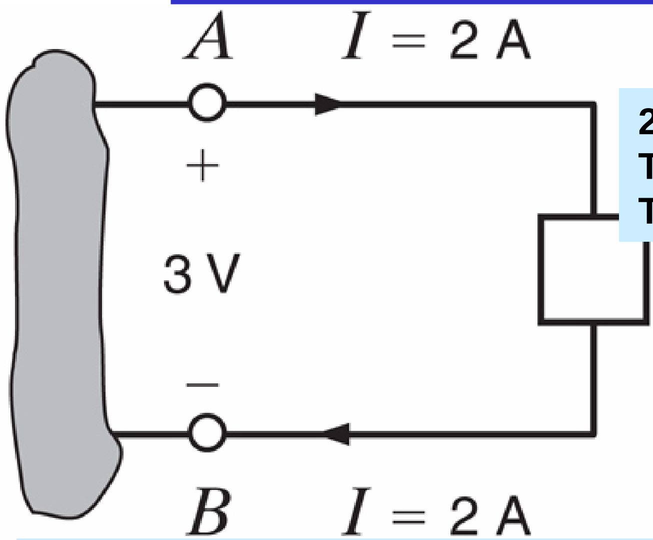
CHARGE
THE NOTATION 2700mAHr INDICATES THAT THE UNIT CAN DELIVER 2700mA FOR ONE FULL HOUR

$$Q = 2700\times10^{-3}\left[\frac{C}{S}\right]\times3600\frac{s}{Hr}\times1Hr$$
$$= 9.72\times10^{3}[C]$$

TOTAL ENERGY STORED
THE CHARGES ARE MOVED THROUGH A 7.2V VOLTAGE DIFFERENTIAL

$$W = Q[C]\times V\left[\frac{J}{C}\right] = 9.72\times10^{3}\times7.2[J]$$
$$= 6.998\times10^{4}[J]$$

ENERGY AND POWER



2[C/s] PASS THROUGH THE ELEMENT

EACH COULOMB OF CHARGE LOSES 3[J] OR SUPPLIES 3[J] OF ENERGY TO THE ELEMENT

THE ELEMENT RECEIVES ENERGY AT A RATE OF 6[J/s]

THE ELECTRIC POWER RECEIVED BY THE ELEMENT IS 6[W]

IN GENERAL

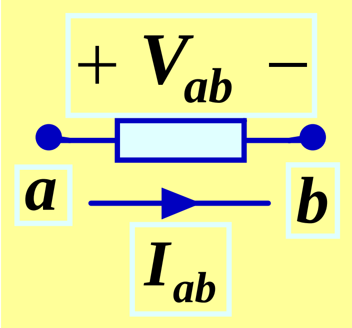
$$P = VI$$

$$w(t_2,t_1) = \int_{t_1}^{t_2} p(x)dx$$

HOW DO WE RECOGNIZE IF AN ELEMENT SUPPLIES OR RECEIVES POWER?

PASSIVE SIGN CONVENTION (慣例)

POWER RECEIVED IS POSITIVE WHILE POWER SUPPLIED IS CONSIDERED NEGATIVE

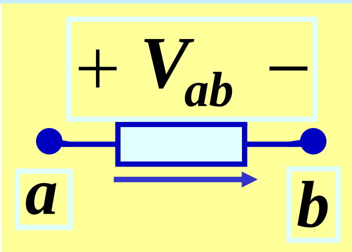


$$P = V_{ab} I_{ab}$$

IF VOLTAGE AND CURRENT ARE BOTH POSITIVE THE CHARGES MOVE FROM HIGH TO LOW VOLTAGE AND **THE COMPONENT RECEIVES ENERGY** --IT IS A **PASSIVE ELEMENT**

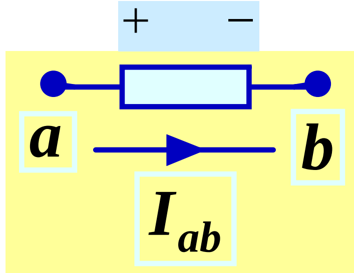
A CONSEQUENCE OF THIS CONVENTION IS THAT THE REFERENCE DIRECTIONS FOR CURRENT AND VOLTAGE ARE NOT INDEPENDENT -- IF WE ASSUME PASSIVE ELEMENTS

GIVEN THE REFERENCE POLARITY



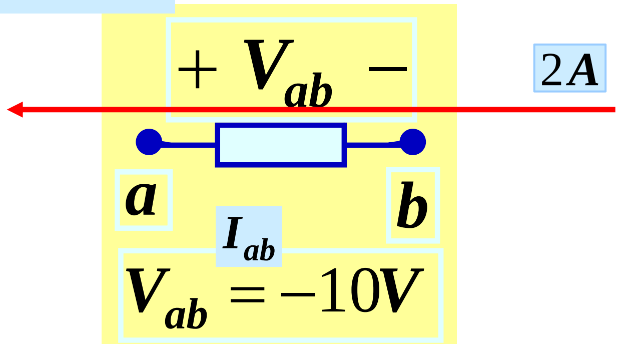
REFERENCE DIRECTION FOR CURRENT

THIS IS THE REFERENCE FOR POLARITY



IF THE REFERENCE DIRECTION FOR CURRENT IS GIVEN

EXAMPLE



THE ELEMENT RECEIVES 20W OF POWER. WHAT IS THE CURRENT?

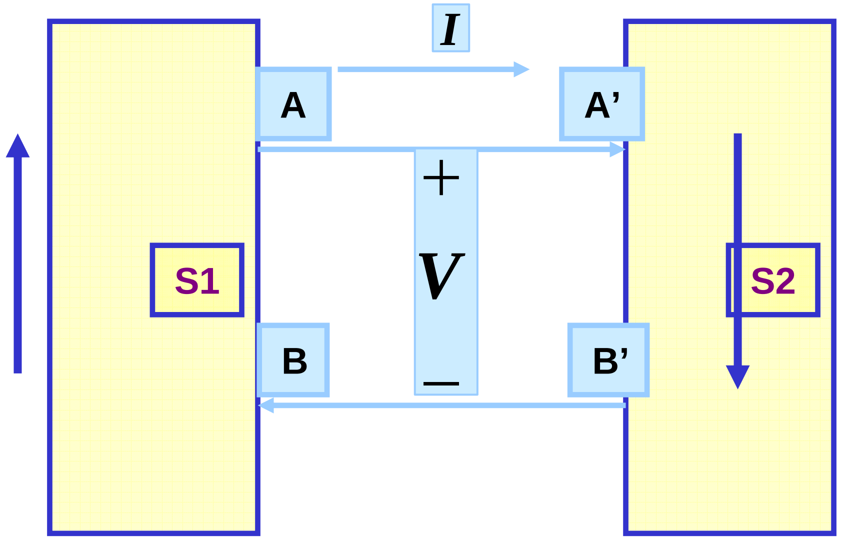
SELECT REFERENCE DIRECTION BASED ON PASSIVE SIGN CONVENTION

$$20[W] = V_{ab} I_{ab} = (-10V) I_{ab}$$

$$I_{ab} = -2[A]$$

UNDERSTANDING PASSIVE SIGN CONVENTION

We must examine the voltage across the component and the current through it



$$P_{S1} = V_{AB} I_{AB}$$
$$P_{S2} = V_{A'B'} I_{A'B'}$$

Voltage(V)	Current A - A'	S1	S2
positive	positive	supplies	receives
positive	negative	receives	supplies
negative	positive	receives	supplies
negative	negative	supplies	receives

ON S_1

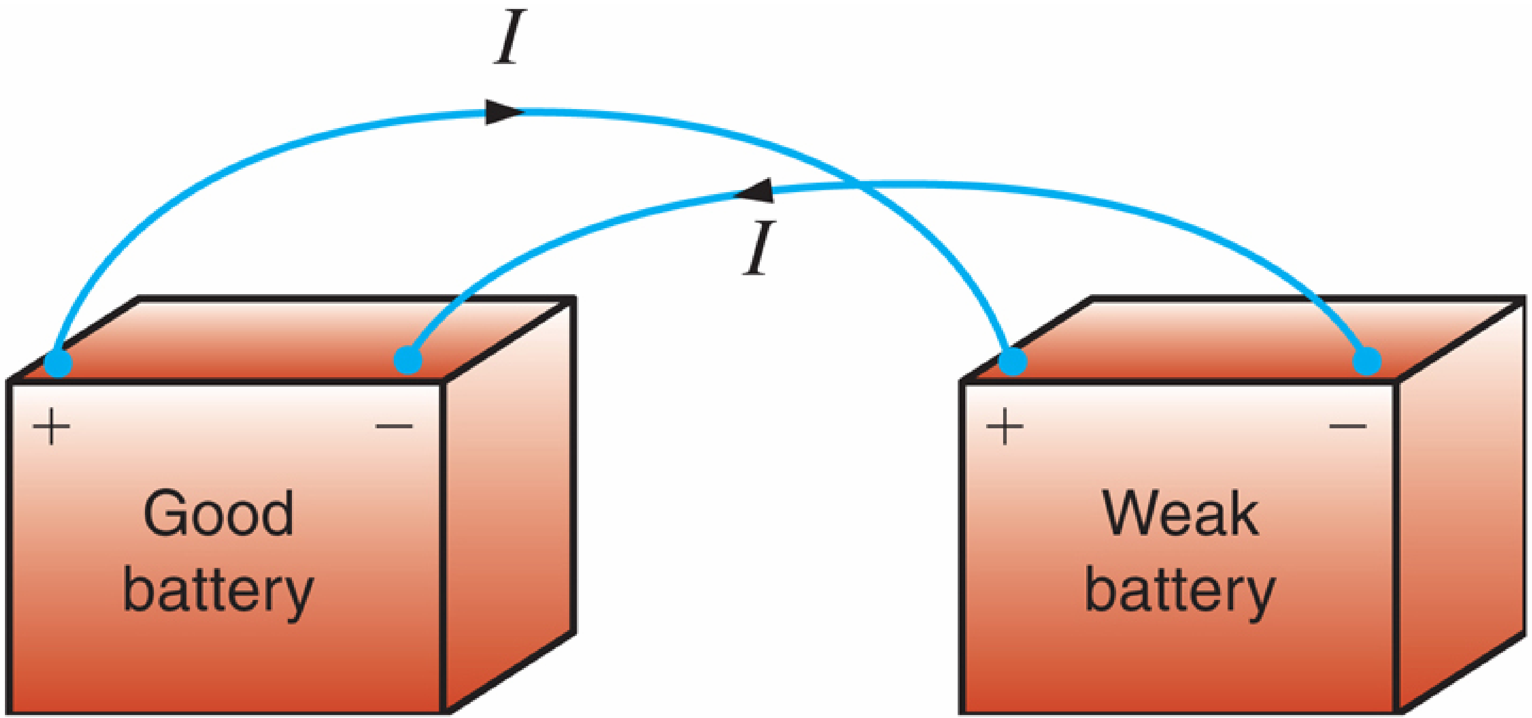
$V_{AB} > 0, I_{AB} < 0$

ON S_2

$V_{A'B'} > 0,\ I_{A'B'} > 0$

ON S2

$V_{A'B'} < 0,\ I_{A'B'} > 0$

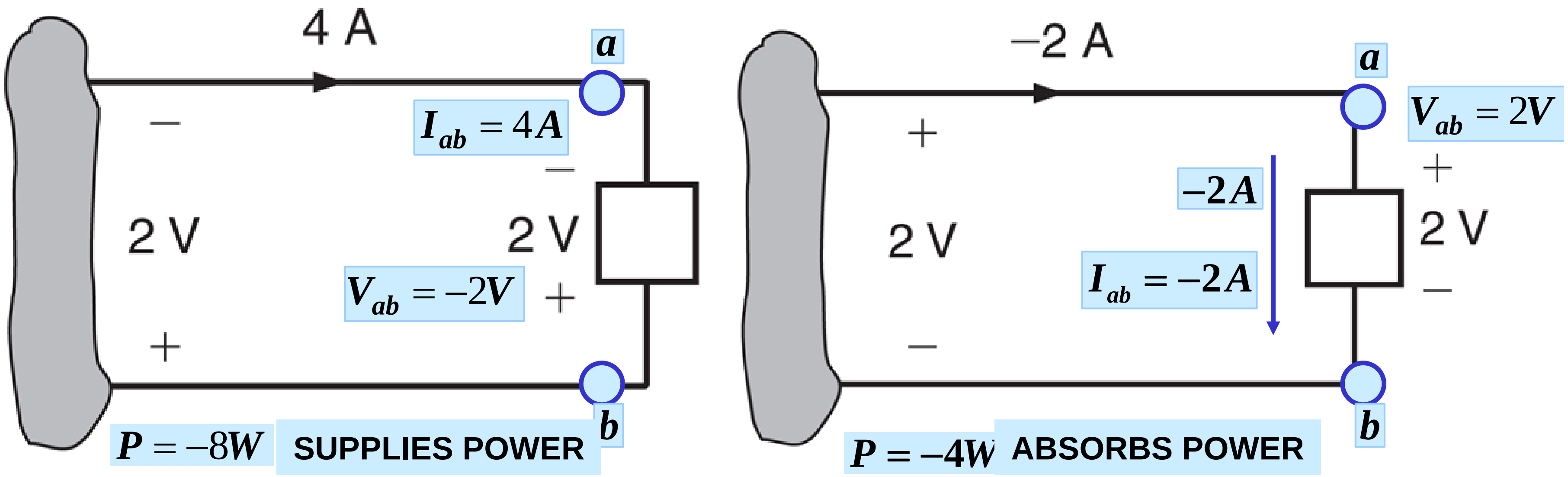


CHARGES RECEIVE ENERGY.
THIS BATTERY SUPPLIES ENERGY

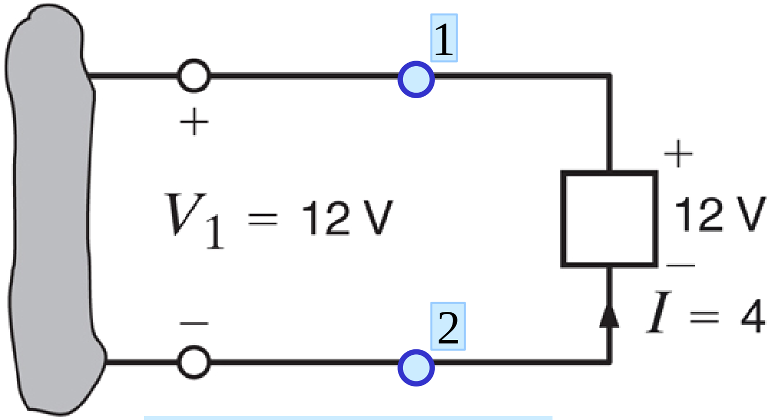
CHARGES LOSE ENERGY.
THIS BATTERY RECEIVES THE ENERGY

WHAT WOULD HAPPEN IF THE CONNECTIONS ARE REVERSED IN ONE OF THE BATTERIES?

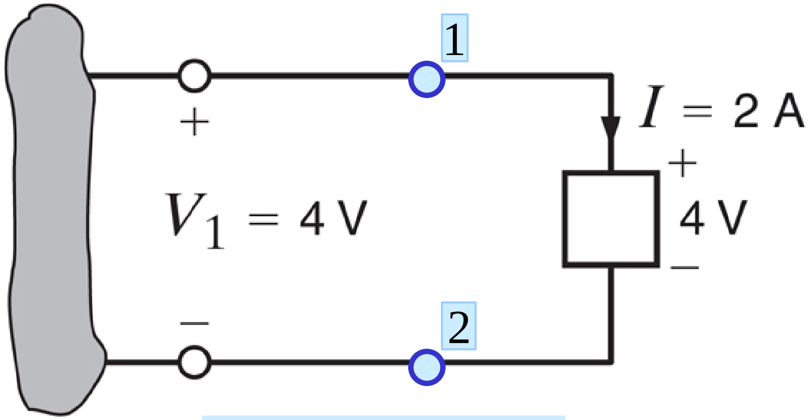
Determine whether **the elements** are supplying or receiving power and how much.



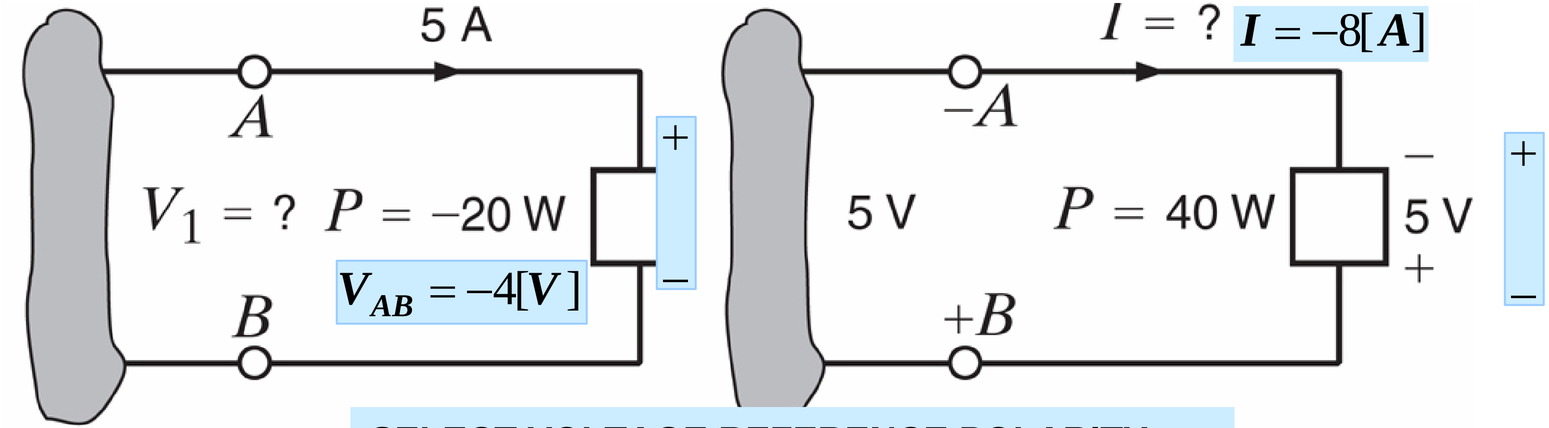
Determine the amount of power absorbed or supplied by the elements ?



$V_{12} = 12V\,,\ I_{12} = -4A$



$V_{12} = 4V\,,\ I_{12} = 2A$



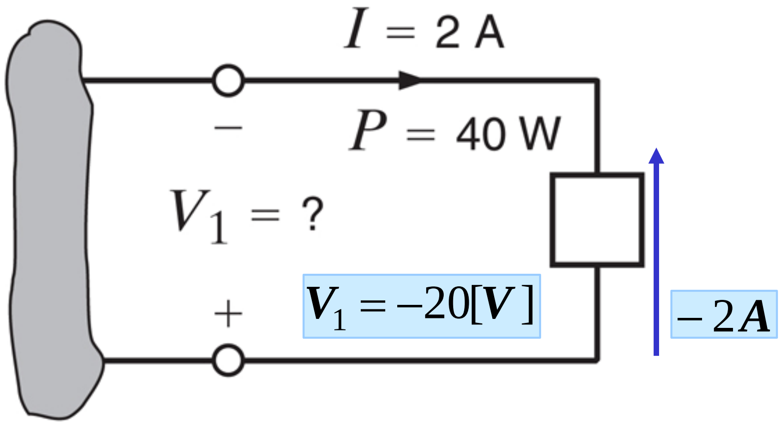
$V_{AB} = -4[V]$

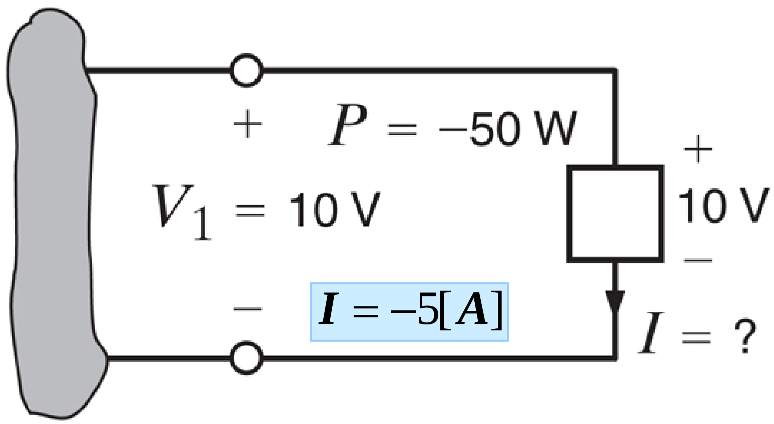
$I = -8[A]$

$-20[W] = V_{AB} \times (5A)$

SELECT VOLTAGE REFERENCE POLARITY BASED ON CURRENT REFERENCE DIRECTION

$40[W] = (-5V) \times I$





$40[W] = V_1 \times (-2A)$

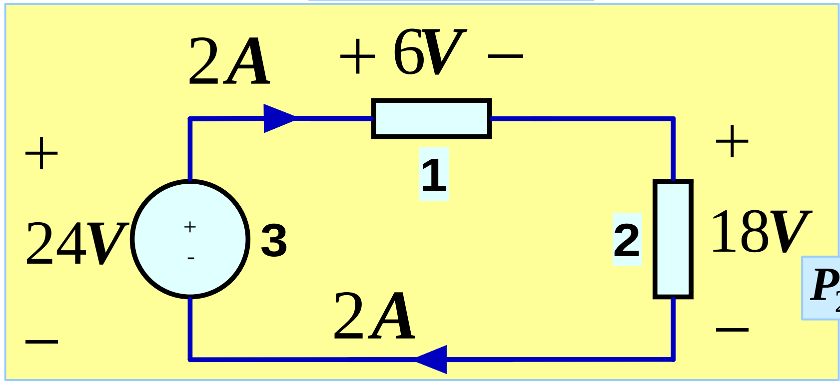
SELECT HERE THE CURRENT REFERENCE DIRECTION BASED ON VOLTAGE REFERENCE POLARITY

$-50[W] = (10[V]) \times I$

WHICH TERMINAL HAS HIGHER VOLTAGE AND WHICH IS THE CURRENT FLOW DIRECTION

COMPUTE POWER ABDORBED OR SUPPLIED BY EACH ELEMENT

$$P_1 = (6V)(2A)$$



$$P_2 = (18V)(2A)$$

$$P_3 = (24V)(-2A) = (-24V)(2A)$$

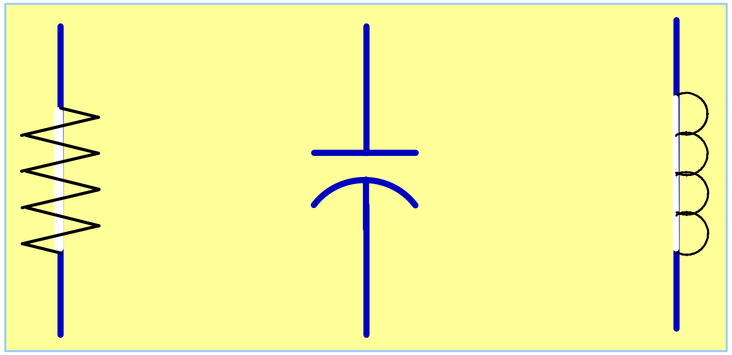
P1 = 12W
P2 = 36W
P3 = -48W

Tellegen's theorem: the sum of the powers absorbed by all elements in an electrical network is zero. Another statement of this theorem is that the power supplied in a network is exactly equal to the power absorbed.

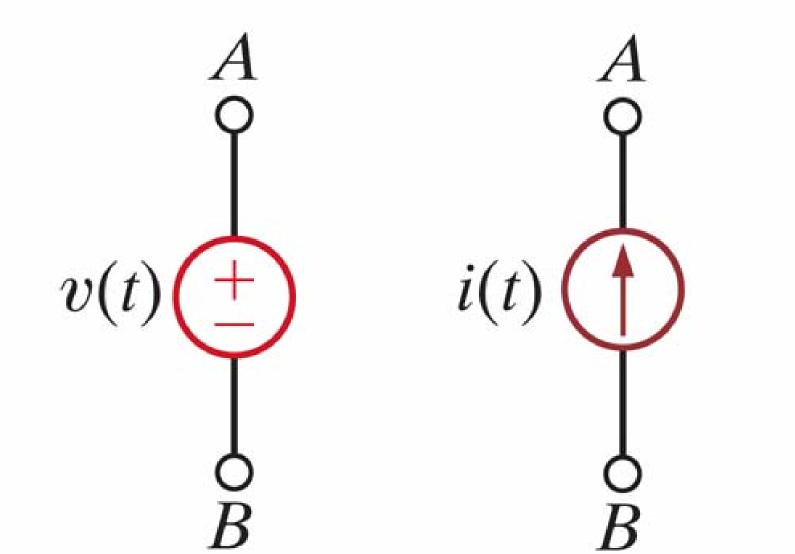
IMPORTANT: NOTICE THE POWER BALANCE IN THE CIRCUIT

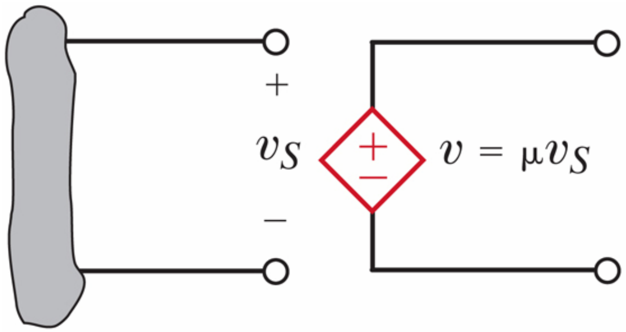
CIRCUIT ELEMENTS

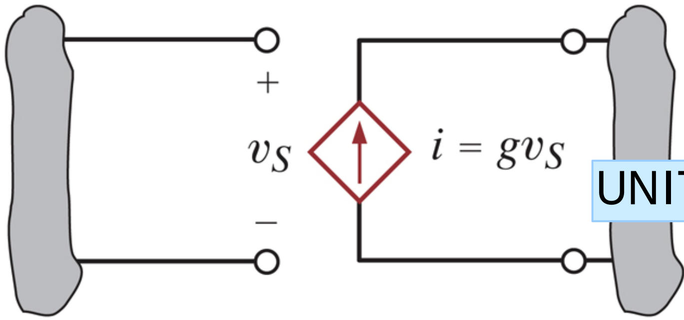
PASSIVE ELEMENTS



INDEPENDENT SOURCES

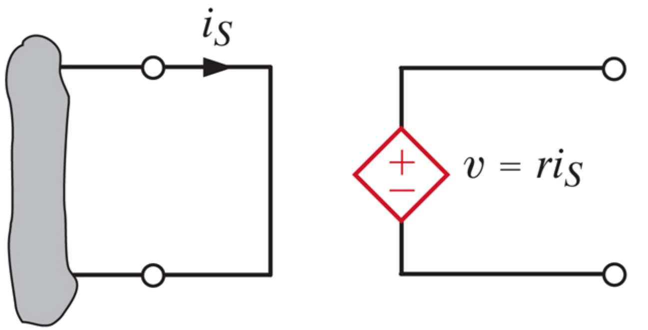


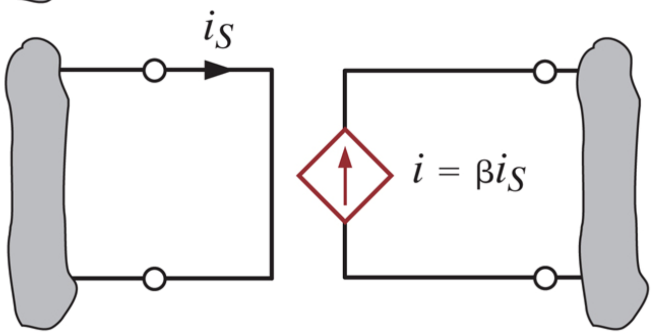




VOLTAGE DEPENDENT SOURCES

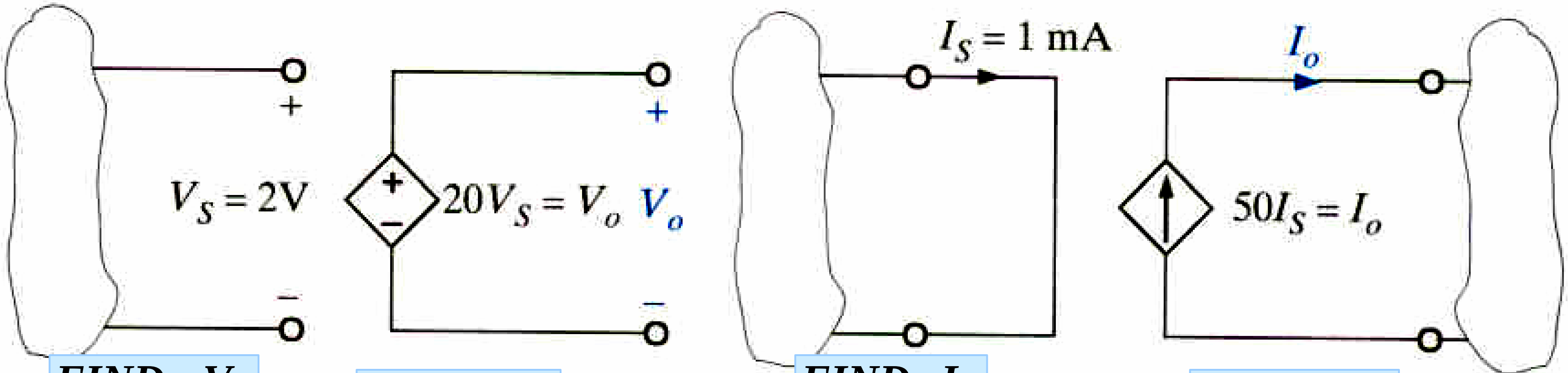
UNITS FOR μ, g, r, β?





CURRENT DEPENDENT SOURCES

EXERCISES WITH DEPENDENT SOURCES



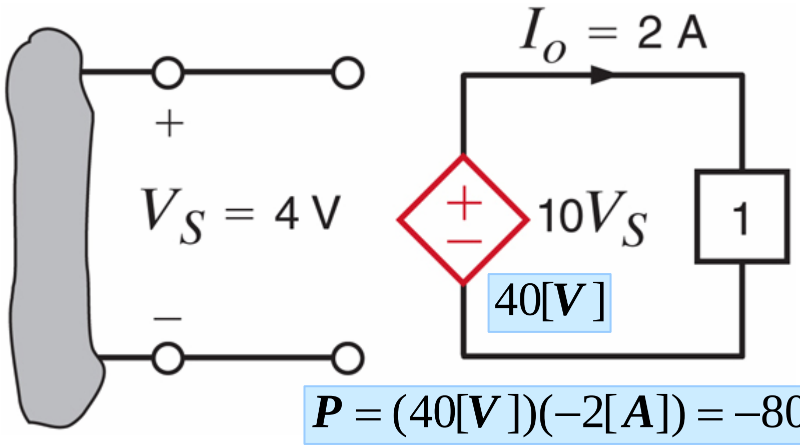
FIND V_O

$V_O = 40[V]$

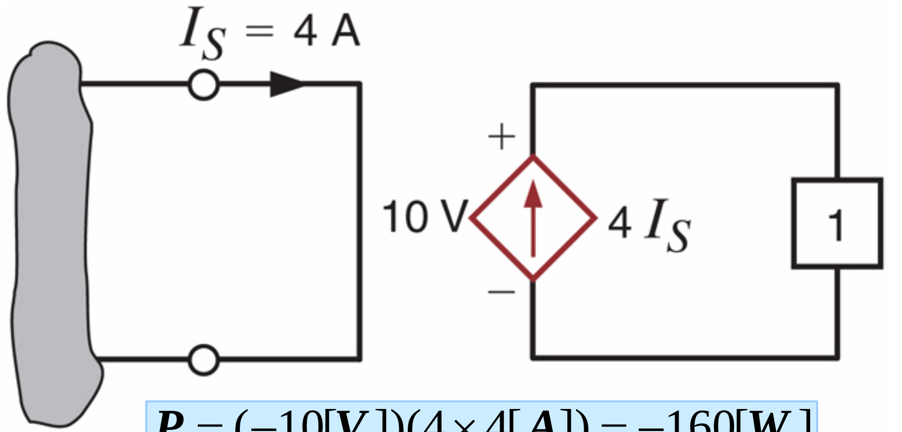
FIND I_O

$I_O = 50mA$

DETERMINE THE POWER SUPPLIED BY THE DEPENDENT SOURCES



$$P = (40[V])(-2[A]) = -80[W]$$

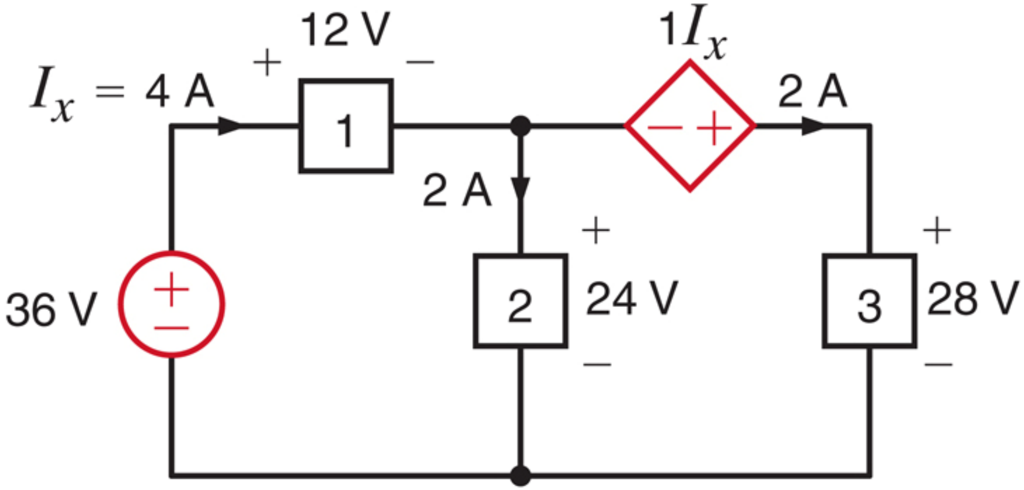


$$P = (-10[V])(4 \times 4[A]) = -160[W]$$

TAKE VOLTAGE POLARITY REFERENCE

TAKE CURRENT REFERENCE DIRECTION

POWER ABSORBED OR SUPPLIED BY EACH ELEMENT



$$P_1 = (12V)(4A) = 48[W]$$

$$P_2 = (24V)(2A) = 48[W]$$

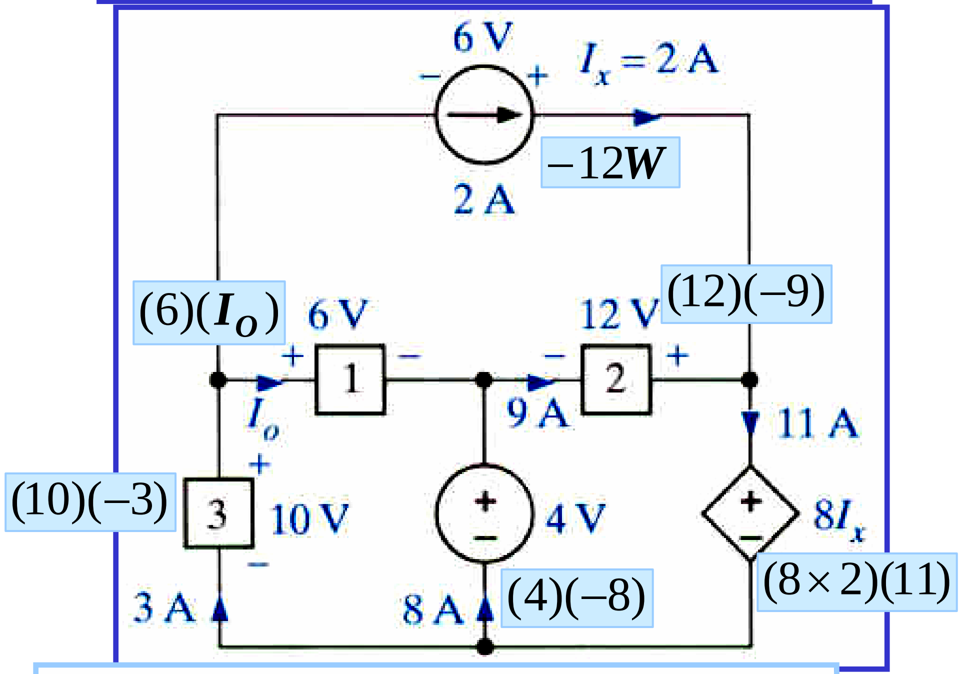
$$P_3 = (28V)(2A) = 56[W]$$

$$P_{DS} = (1I_x)(-2A) = (4V)(-2A) = -8[W]$$

$$P_{36V} = (36V)(-4A) = -144[W]$$

NOTICE THE POWER BALANCE

USE POWER BALANCE TO COMPUTE Io



$$P_{2\,A} = (6)(-2) = -12 \text{ W}$$

$$P_1 = (6)(I_o) = 6I_o \text{ W}$$

$$P_2 = (12)(-9) = -108 \text{ W}$$

$$P_3 = (10)(-3) = -30 \text{ W}$$

$$P_{4\,V} = (4)(-8) = -32 \text{ W}$$

$$P_{DS} = (8I_x)(11) = (16)(11) = 176 \text{ W}$$

POWER BALANCE

$$-12 + 6I_o - 108 - 30 - 32 + 176 = 0$$

$$I_O = 1[A]$$