Chapter 1
Basic Electric Circuit 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
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>
<thead>
<tr>
<th>Base quantity</th>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>meter</td>
<td>m</td>
</tr>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>electric current</td>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>thermodynamic temperature</td>
<td>kelvin</td>
<td>K</td>
</tr>
<tr>
<td>amount of substance</td>
<td>mole</td>
<td>mol</td>
</tr>
<tr>
<td>luminous intensity</td>
<td>candela</td>
<td>cd</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Unit of length</th>
<th>meter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit of mass</th>
<th>kilogram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit of time</th>
<th>second</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit of electric current</th>
<th>ampere</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>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 x 10^-7 newton per meter of length.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit of thermodynamic temperature</th>
<th>kelvin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit of amount of substance</th>
<th>mole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>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 &quot;mol.&quot;</td>
</tr>
</tbody>
</table>
The 20 SI prefixes used to form decimal multiples and submultiples of SI units are given in Table 5.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Name</th>
<th>Symbol</th>
<th>Factor</th>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{24}$</td>
<td>yotta</td>
<td>Y</td>
<td>$10^{-1}$</td>
<td>deci</td>
<td>d</td>
</tr>
<tr>
<td>$10^{21}$</td>
<td>zetta</td>
<td>Z</td>
<td>$10^{-2}$</td>
<td>centi</td>
<td>c</td>
</tr>
<tr>
<td>$10^{18}$</td>
<td>exa</td>
<td>E</td>
<td>$10^{-3}$</td>
<td>milli</td>
<td>m</td>
</tr>
<tr>
<td>$10^{15}$</td>
<td>peta</td>
<td>P</td>
<td>$10^{-6}$</td>
<td>micro</td>
<td>μ</td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>tera</td>
<td>T</td>
<td>$10^{-9}$</td>
<td>nano</td>
<td>n</td>
</tr>
<tr>
<td>$10^{9}$</td>
<td>giga</td>
<td>G</td>
<td>$10^{-12}$</td>
<td>pico</td>
<td>p</td>
</tr>
<tr>
<td>$10^{6}$</td>
<td>mega</td>
<td>M</td>
<td>$10^{-15}$</td>
<td>femto</td>
<td>f</td>
</tr>
<tr>
<td>$10^{3}$</td>
<td>kilo</td>
<td>k</td>
<td>$10^{-18}$</td>
<td>atto</td>
<td>a</td>
</tr>
<tr>
<td>$10^{2}$</td>
<td>hecto</td>
<td>h</td>
<td>$10^{-21}$</td>
<td>zepto</td>
<td>z</td>
</tr>
<tr>
<td>$10^{1}$</td>
<td>deka</td>
<td>da</td>
<td>$10^{-24}$</td>
<td>yocto</td>
<td>y</td>
</tr>
<tr>
<td>Physical量</td>
<td>Unit</td>
<td>Symbol</td>
<td>Equivalent</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>------</td>
<td>--------</td>
<td>------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>Power, radiant flux</td>
<td>watt</td>
<td>W</td>
<td>J/s</td>
<td>m²·kg·s⁻³</td>
<td></td>
</tr>
<tr>
<td>Electric charge, quantity of electricity</td>
<td>coulomb</td>
<td>C</td>
<td>-</td>
<td>s·A</td>
<td></td>
</tr>
<tr>
<td>Electric potential difference, electromotive force</td>
<td>volt</td>
<td>V</td>
<td>W/A</td>
<td>m²·kg·s⁻³·A⁻¹</td>
<td></td>
</tr>
<tr>
<td>Capacitance</td>
<td>farad</td>
<td>F</td>
<td>C/V</td>
<td>m⁻²·kg⁻¹·s⁻⁴·A²</td>
<td></td>
</tr>
<tr>
<td>Electric resistance</td>
<td>ohm</td>
<td>Ω</td>
<td>V/A</td>
<td>m²·kg·s⁻³·A⁻²</td>
<td></td>
</tr>
<tr>
<td>Electric conductance</td>
<td>siemens</td>
<td>S</td>
<td>A/V</td>
<td>m⁻²·kg⁻¹·s³·A²</td>
<td></td>
</tr>
<tr>
<td>Magnetic flux</td>
<td>weber</td>
<td>Wb</td>
<td>V·s</td>
<td>m²·kg·s⁻²·A⁻¹</td>
<td></td>
</tr>
<tr>
<td>Magnetic flux density</td>
<td>tesla</td>
<td>T</td>
<td>Wb/m²</td>
<td>kg·s⁻²·A⁻¹</td>
<td></td>
</tr>
<tr>
<td>Inductance</td>
<td>henry</td>
<td>H</td>
<td>Wb/A</td>
<td>m²·kg·s⁻²·A⁻²</td>
<td></td>
</tr>
<tr>
<td>Current in amperes (A)</td>
<td>Voltage in volts (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^6$</td>
<td>$10^8$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lightning bolt</td>
<td>Lightning bolt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^4$</td>
<td>$10^6$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large industrial motor current</td>
<td>High voltage transmission lines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^2$</td>
<td>$10^4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical household appliance current</td>
<td>Voltage on a TV picture tube</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^0$</td>
<td>$10^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Causes ventricular fibrillation in humans</td>
<td>Large industrial motors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$10^0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human threshold of sensation</td>
<td>AC outlet plug in U.S. households</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>$10^{-2}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated Circuit memory cell current</td>
<td>Car battery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>$10^{-4}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage across human chest produced by the heart (EKG)</td>
<td>Voltage on integrated circuits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-8}$</td>
<td>$10^{-6}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synaptic current (brain cell)</td>
<td>Voltage between two points on human scalp</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-10}$</td>
<td>$10^{-8}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antenna of a radio receiver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>$10^{-10}$</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
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 \( q(t) \)?

**PROBLEM SOLVING TIP**

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

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

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

\[ i(t) = 0.480\pi \cos(120\pi t)\text{[mA]} \]

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

\[ q = \int_{0}^{1} e^{-2x} dx = -\frac{1}{2} e^{-2x} \bigg|_{0}^{1} = -\frac{1}{2} e^{2} - (-\frac{1}{2} e^{0}) \]

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

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

To determine current we must take derivatives. PAY ATTENTION TO UNITS

\[
m = \frac{-10 \times 10^{-12} - 10 \times 10^{-12}}{2 \times 10^{-3} - 0} \frac{C}{s} = -10 \times 10^{-9} \text{ (C/s)}
\]
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

\[ I_{ab} = 5 \text{ A} \]

\[ I_{ba} = 3 \text{ A} \]

\[ I_{ab} = -3 \text{ A} \]

\[ I_{ba} = 3 \text{ A} \]

\[ I_{ab} = -I_{ba} \]
This example illustrates the various ways in which the current notation can be used.

\[ I = -2A \]
\[ I_{cb} = 4A \]
\[ I_{ab} = \]
**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**

\[ \text{VOLT} = \frac{\text{JOULE}}{\text{COULOMB}} = \frac{N \cdot m}{A \cdot s} \]

**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.

\[ V_1 = 2\, \text{V} \]
Point A has 2V more than Point B

\[ V_2 = -5\, \text{V} \]
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

\[ V_{AB} = 2V \]

\[ V_1 = 2V \]

\[ V_{AB} = -5V \]

\[ V_2 = -5V \]

\[ V_{BA} = 5V \]

\[ V_2 = 5V \]
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

BASIC FLASHLIGHT

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

EQUIVALENT CIRCUIT

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 CAMCORDER 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

\[ Q = 2700 \times 10^{-3} \left( \frac{C}{S} \right) \times 3600 \frac{s}{Hr} \times 1Hr \]
\[ = 9.72 \times 10^3 [C] \]

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

\[ W = Q[C] \times V \left( \frac{J}{C} \right) = 9.72 \times 10^3 \times 7.2 [J] \]
\[ = 6.998 \times 10^4 [J] \]

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

\[ P = VI \]

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

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.

<table>
<thead>
<tr>
<th>Voltage(V)</th>
<th>Current A - A'</th>
<th>S1</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>positive</td>
<td>positive</td>
<td>supplies</td>
<td>receives</td>
</tr>
<tr>
<td>positive</td>
<td>negative</td>
<td>receives</td>
<td>supplies</td>
</tr>
<tr>
<td>negative</td>
<td>positive</td>
<td>receives</td>
<td>supplies</td>
</tr>
<tr>
<td>negative</td>
<td>negative</td>
<td>supplies</td>
<td>receives</td>
</tr>
</tbody>
</table>

For S1:
- ON S1: \( V_{AB} > 0, I_{AB} < 0 \)

For S2:
- ON S2: \( V_{A'B'} < 0, I_{A'B'} > 0 \)

\[
P_{S1} = V_{AB}I_{AB} \\
P_{S2} = V_{A'B'}I_{A'B'}
\]
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.

\[ I_{ab} = 4 \, \text{A} \]
\[ V_{ab} = -2 \, \text{V} \]
\[ P = -8 \, \text{W} \text{ SUPPLIES POWER} \]

\[ I_{ab} = -2 \, \text{A} \]
\[ V_{ab} = 2 \, \text{V} \]
\[ P = -4 \, \text{W} \text{ ABSORBS POWER} \]
Determine the amount of power absorbed or supplied by the elements?
SELECT VOLTAGE REFERENCE POLARITY BASED ON CURRENT REFERENCE DIRECTION

\[ V_{AB} = -4\text{[V]} \]

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

\[ 40\text{[W]} = (-5\text{[V]}) \times I \]
SELECT HERE THE CURRENT REFERENCE DIRECTION BASED ON VOLTAGE REFERENCE POLARITY

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

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

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

\[ v(t) \] 
\[ i(t) \]
EXERCISES WITH DEPENDENT SOURCES

- $V_S = 2\text{V}$
  - **FIND** $V_o$
  - $V_o = 40[\text{V}]$

- $20V_S = V_o$

- **FIND** $I_o$
  - $I_S = 1 \text{mA}$
  - $50I_S = I_o$
  - $I_o = 50 \text{mA}$
DETERMINE THE POWER SUPPLIED BY THE DEPENDENT SOURCES

TAKE VOLTAGE POLARITY REFERENCE

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

TAKE CURRENT REFERENCE DIRECTION

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

\[ P_{2A} = (6)(-2) = -12 \, \text{W} \]
\[ P_1 = (6)(I_o) = 6l_o \, \text{W} \]
\[ P_2 = (12)(-9) = -108 \, \text{W} \]
\[ P_3 = (10)(-3) = -30 \, \text{W} \]
\[ P_{AV} = (4)(-8) = -32 \, \text{W} \]
\[ P_{DS} = (8I_x)(11) = (16)(11) = 176 \, \text{W} \]

POWER BALANCE

\[ -12 + 6l_o - 108 - 30 - 32 + 176 = 0 \]

\[ I_o = \frac{1}{l}[A] \]