Chapter 1

Basic components and electric circuits

Objectives

To be familiarized with

- Basic electrical quantities and associated units
- Current direction and voltage polarity
- The passive sign convention for calculating power
- Ideal voltage and current sources
- Dependent sources
- Resistance and Ohm’s law

Units and scales

Six basic units

Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	Kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

Units and scales

- The derived units commonly used in electric circuit theory

Quantity	Unit	Symbol
electric charge	coulomb	C
electric potential	volt	V
resistance	ohm	Ω
conductance	siemens	S
inductance	henry	H
capacitance	farad	F
frequency	hertz	Hz
force	newton	N
energy, work	joule	J
power	watt	W
magnetic flux	weber	Wb
magnetic flux density	tesla	T

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Decimal multiples and submultiples of SI units

Charges

الشحنة

- Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).
- The charge e on one electron is negative and equal in magnitude to 1.602×10^{-19} C which is called as electronic charge.
- Q for constant charge and q(t) if time variant.
- Coulomb is a large unit and in 1C of charge there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}$ electrons.
- The charges that occur in nature are integral multiples of the electronic charge

charge = Number of electron × charge of electron

$C = n e$ $e = 1{,}602 \times 10^{-19}$

$1 = n \dfrac{1{,}602 \times 10^{-19}}{1{,}602 \times 10^{-19}}$

$\dfrac{1}{1{,}602 \times 10^{-19}}$

$n = 6{,}24 \times 10^{18}$ electron

electron $= -1{,}602 \times 10^{-19}$

proton $= +1{,}602 \times 10^{-19}$

→ إشارة $\pm$

example

- How much charge represented by 4600 electrons?
- Solution: each electron has -1.602 x 10^{-19} C. hence 4600 electrons will have – 1.602 x 10^{-19} C/electron x 4600 electrons =

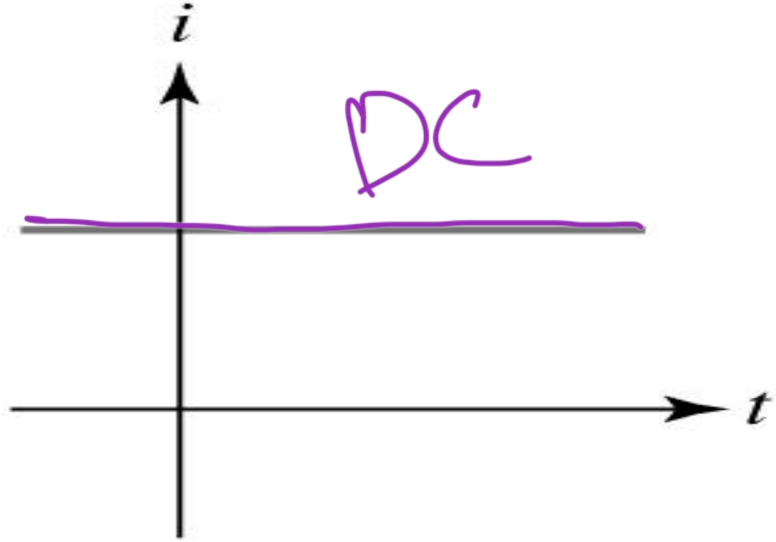
- 7.369 x 10^{-16} C

$c = ne \Rightarrow -4600 \times 1.602 \times 10^{-19}$

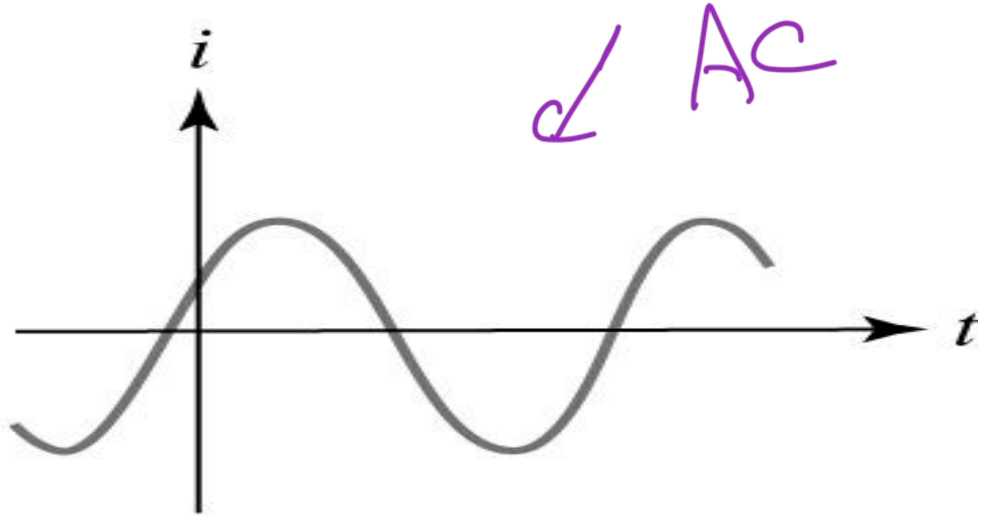
Current

- Is the time rate of change of charge measured in ampere(A)
- Electric current $i = dq/dt$. The unit of ampere can be derived as $1\ A = 1C/s$.
- A direct current (dc) is a current that remains constant with time.
- An alternating current (ac) is a current that varies sinusoidally with time. (reverse direction)

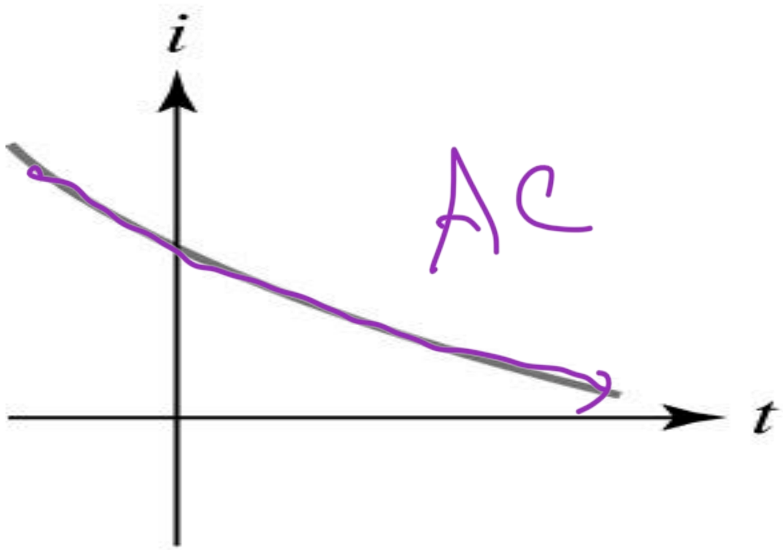
$$i = \frac{\Delta q}{\Delta t} = \frac{\partial q}{\partial t}$$



(a)



(b)



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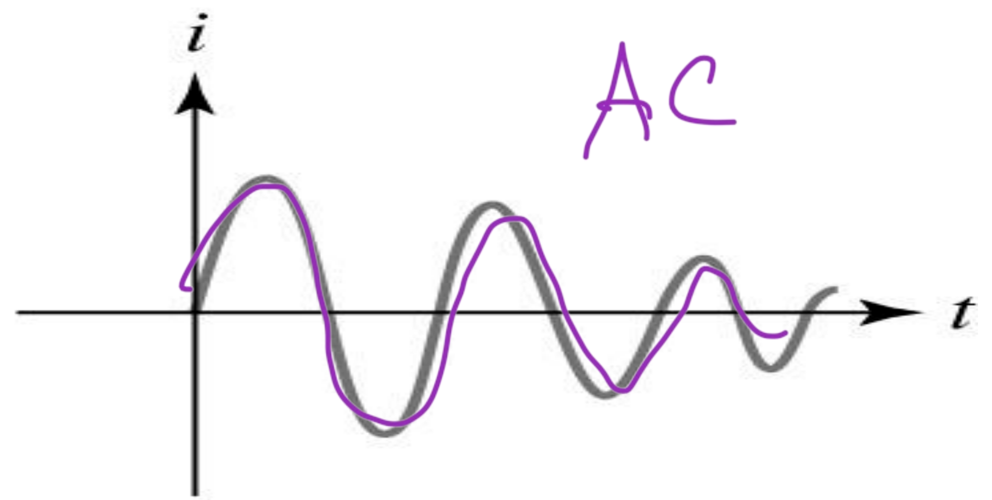
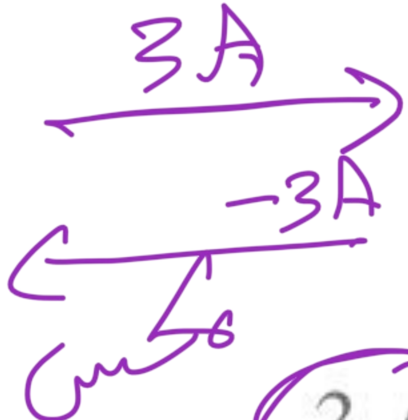
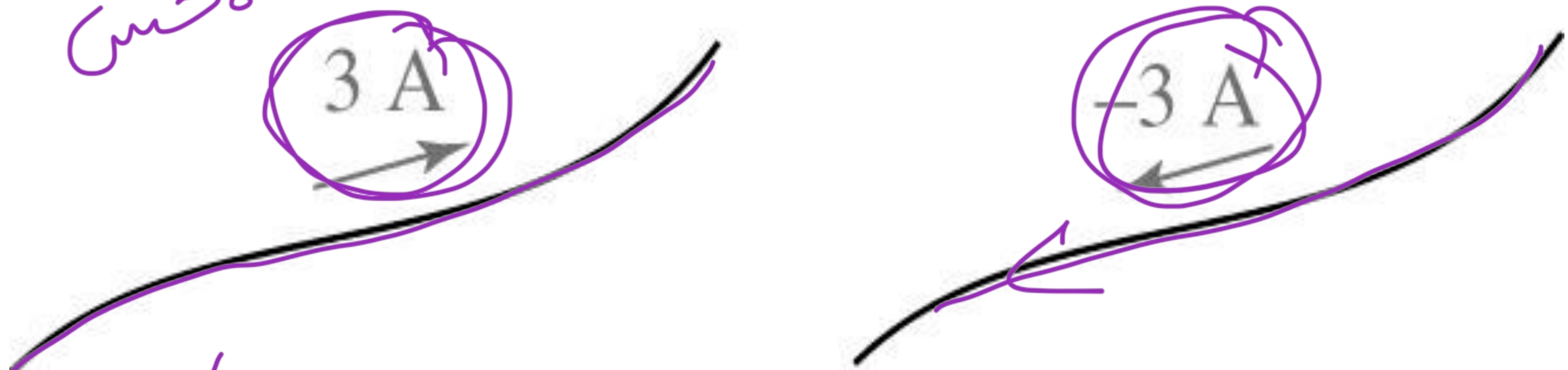


(d)

Current





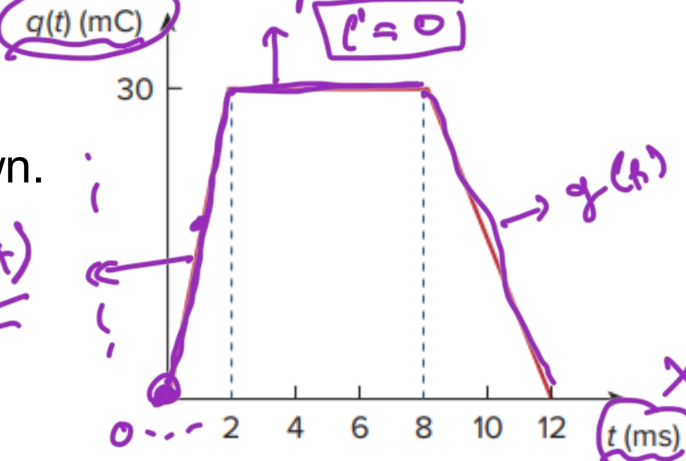
لما تطلع الإشارة سالب ⇐ معناها عكس

(a) (b)

الاتجاه لا أكثر.

Example

Q. The charge entering a certain element is shown.
Find the current at t = 1 ms.



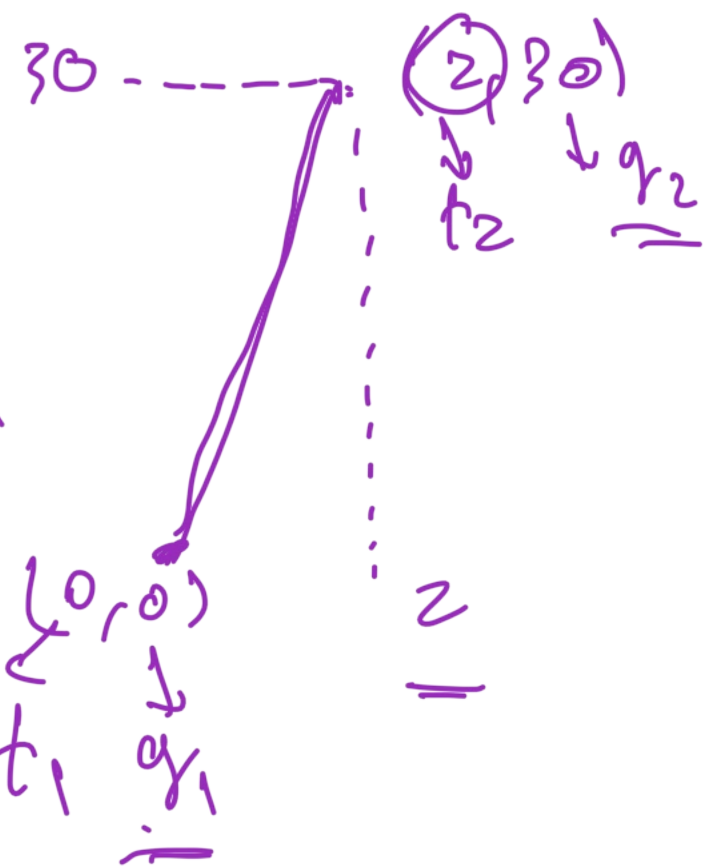
Solution:

Slope of the line ($t = 0\,\text{ms}$ to $t = 2\,\text{ms}$):

$$\text{slope} = \frac{\Delta q}{\Delta t} = \frac{30\,\text{mC} - 0\,\text{mC}}{2\,\text{ms} - 0\,\text{ms}} = \frac{30\,\text{mC}}{2\,\text{ms}} = 15\,\text{mA}.$$

Since t=1 ms lies within the linear region (t=0 to t=2ms), the current i(t) is equal to the slope of this line:
Thus i(1ms)=15 mA.

$$\Rightarrow q(t) - q_1 = m(t - t_1)$$



$$\Rightarrow m = \text{slope} = \frac{\Delta q}{\Delta t} = \frac{q_2 - q_1}{t_2 - t_1}$$

$$m = \frac{30 - 0}{2 - 0} = \frac{30}{2}$$

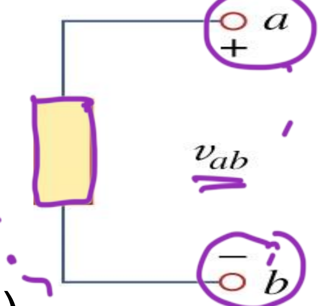
$$\boxed{m = 15\,A}$$

$$q(t) - 0 = 15(t - 0) \rightarrow \boxed{q(t) = 15t}$$

$$i(t) = \frac{dq}{dt} = \boxed{15\,A} \checkmark$$

Voltage

- Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).



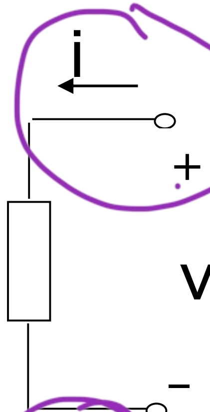
- Mathematically, $v_{ab} = dw/dq$ (volt)
  - w is energy in joules (J) and q is charge in coulomb (C).

- Electric voltage, v_{ab}, is always across the circuit element or between two points in a circuit.
  - $v_{ab} > 0$ means the potential of a is higher than potential of b.
  - $v_{ab} < 0$ means the potential of a is lower than potential of b.

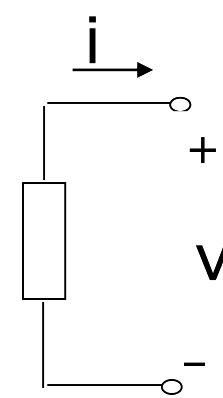
1.5 Power

- Power is the time rate of expending or absorbing energy, measured in watts (W).
- Mathematical expression: $p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$

Passive sign convention:



P = +vi
absorbing power

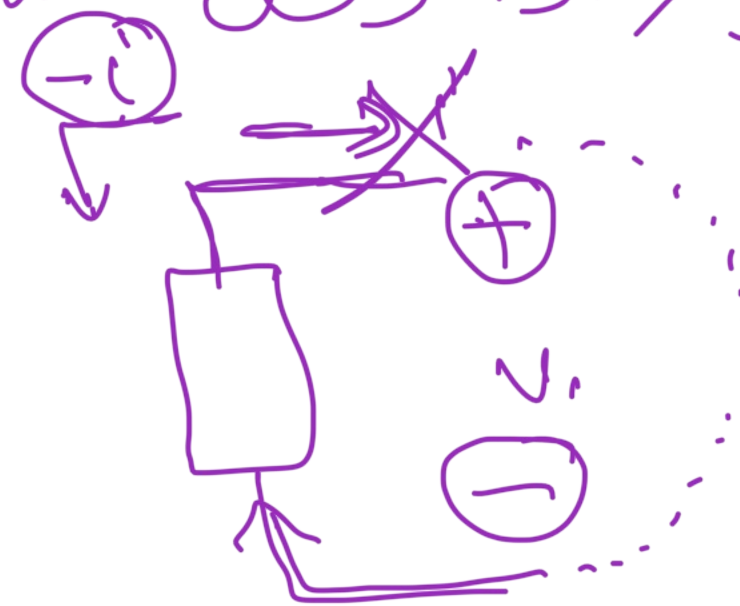


p = −vi
supplying power

+power absorbed= - power supplied

التيار اذا دخل من + ⇐ $P = +iV$

التيار اذا دخل من − ⇐ $P = -iV$

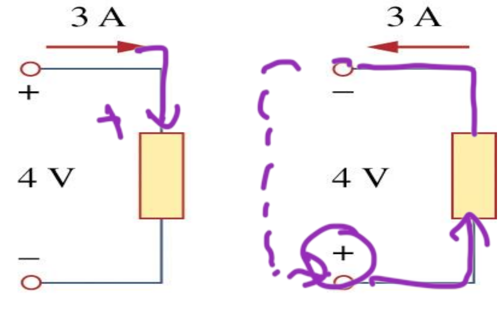


$P = iV$

$P = -iV$

examples

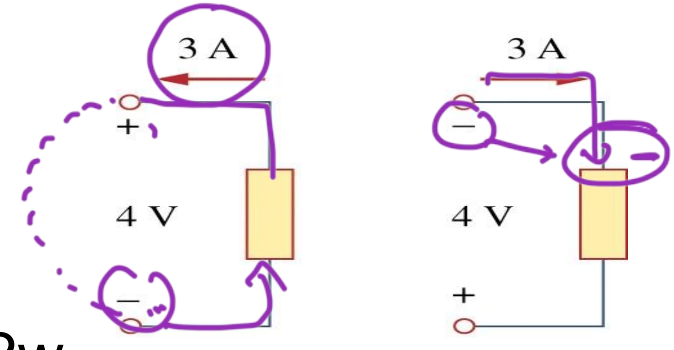
- (a) p= 4x3=12W
- (b) p= 4x3=12W



(a) (b)

Both are absorbing power as + current enters + terminal

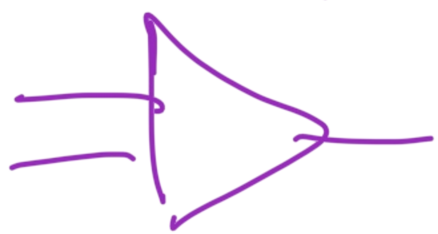
- (a) p= -4 x 3= - 12W
- (b) p= -4 x 3 = -12W
- Both are supplying power of 12w
- Absorbing power of +12W is equivalent to a supplying power of -12W.



(a) (b)

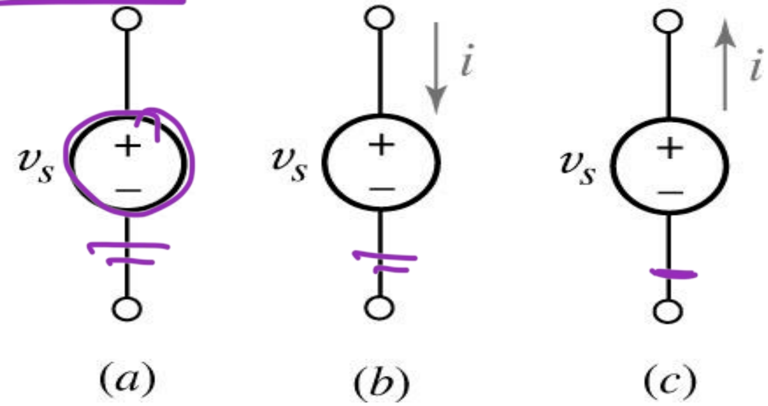
Circuit elements

- Two types passive and active elements
- Active is capable of generating energy while a passive element is not.
- Passive elements: resistors, capacitors and inductors.
- Active elements: generators, batteries and amplifiers

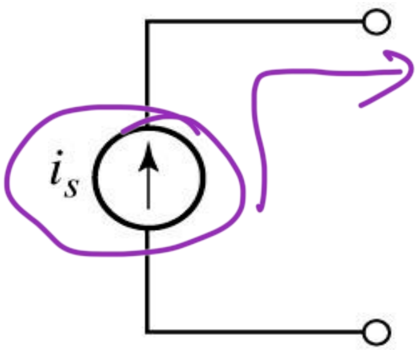


Voltage and current sources

- Ideal independent sources: voltage is completely independent of the current or the current is completely independent of the voltage.



Independent voltage source

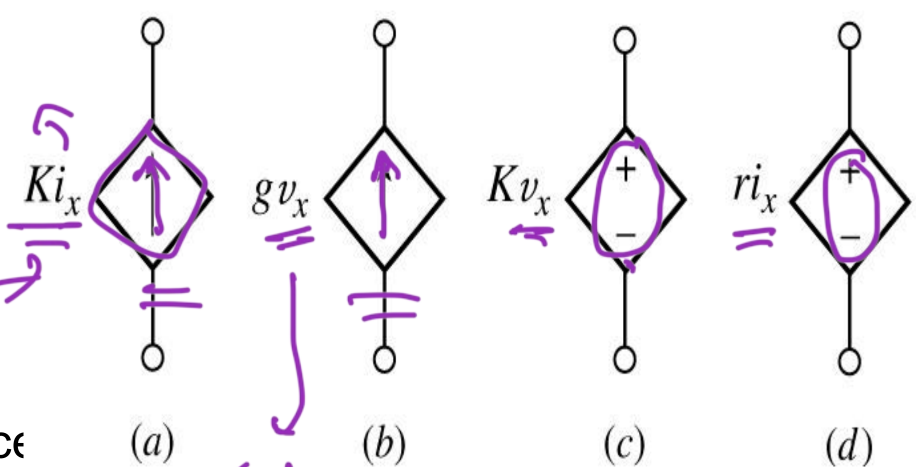


Independent current source

Batteries and generators may be regarded as approximations to ideal voltage sources.

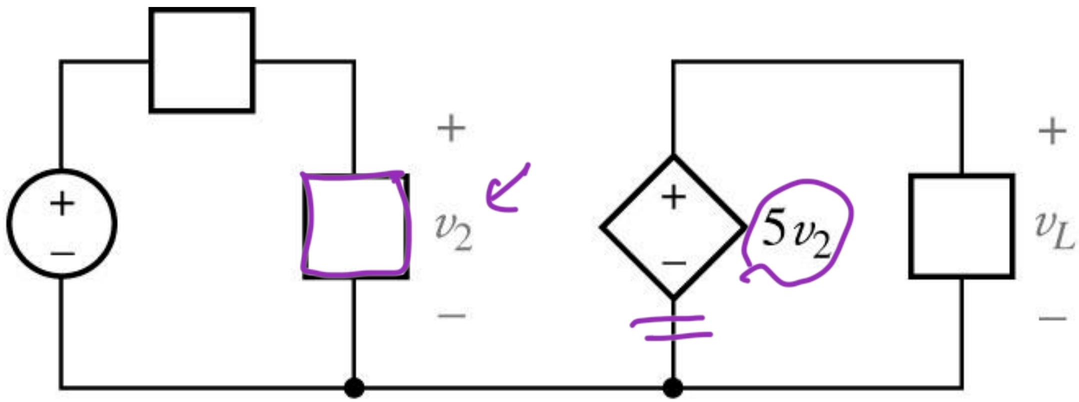
Voltage and current sources

- Ideal dependent (or controlled) sources: the source quantity is controlled by another voltage or current. It is mainly used in modeling electronic devices such as transistor.

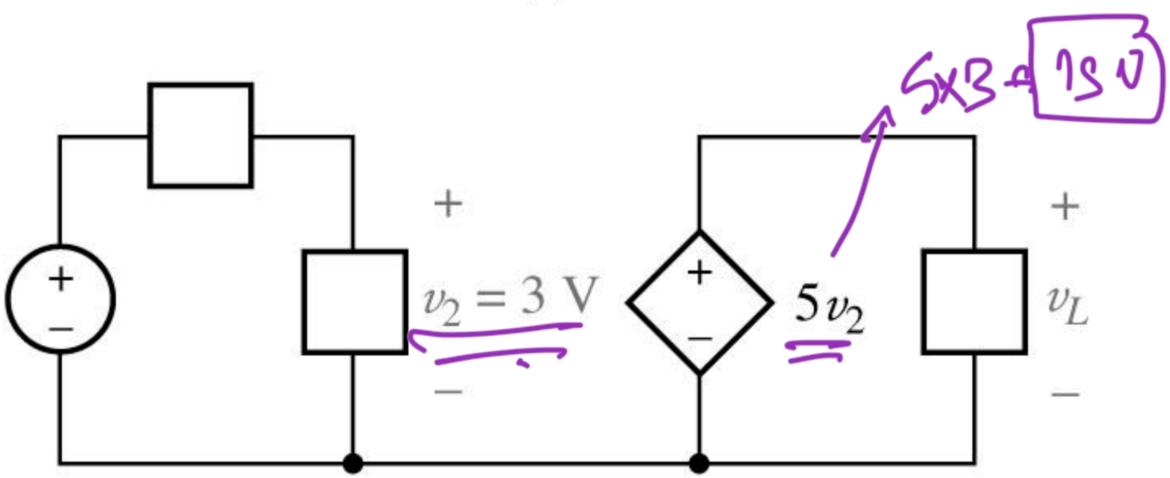


a) Current controlled current source
b) Voltage controlled current source
c) Voltage controlled voltage source
d) Current controlled voltage source

Dependent sources



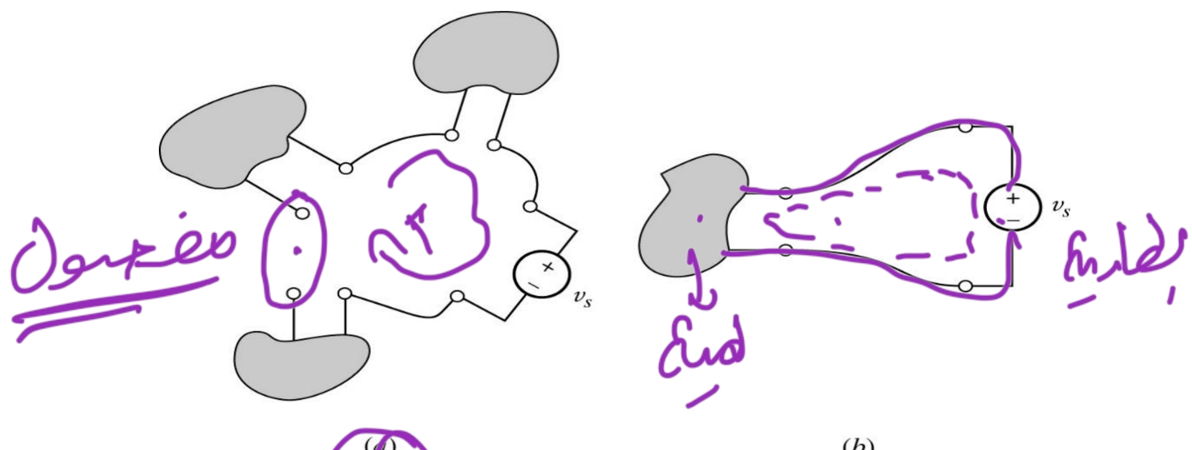
(a)



(b)

Networks and circuits

- The interconnection of two or more simple elements forms an electrical network
- If the network contains at least one closed path, it is also an electric circuit. Note that every circuit is a network but not all networks are circuits.



(a) A network that is not a circuit

(b) a network that is a circuit

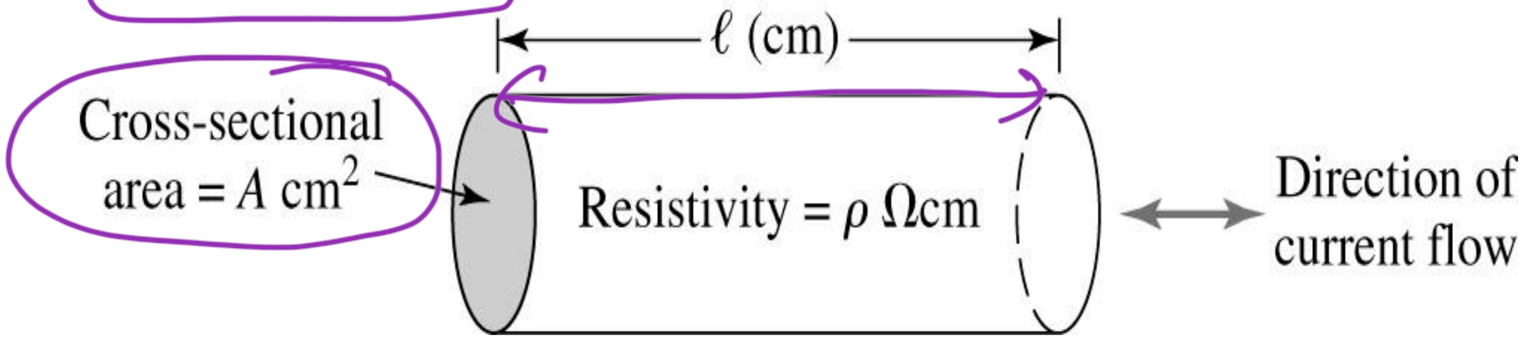
Resistance

- Resistance (R) is the ability to resist current
- Resistivity (ρ) is the measure of a material's natural resistance to current flow. For a a wire with length ℓ, cross-section area A then

$$R = \rho \frac{l}{A}$$

Resistance unit is Ohm or Ω

Resistivity unit is Ohm.meter or Ωm



Resistivities of common materials

TABLE 2.1

Material	Resistivity (Ω·m)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
Silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}	Insulator
Glass	10^{12}	Insulator
Teflon	3×10^{12}	Insulator

Wire gauge

TABLE **2.4** Some Common Wire Gauges and the Resistance of (Soft) Solid Copper Wire.*

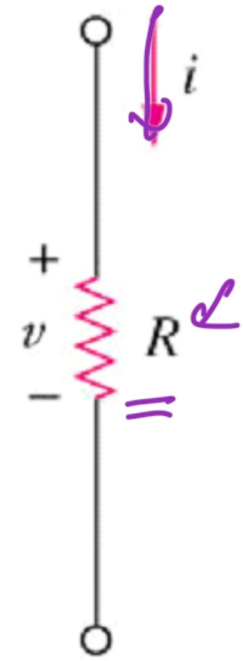
Conductor Size (AWG)	Cross-Sectional Area (mm^2)	Ohms per 1000 ft at 20°C
28	0.0804	65.3
24	0.205	25.7
22	0.324	16.2
18	0.823	6.39
14	2.08	2.52
12	3.31	1.59
6	13.3	0.3952
4	21.1	0.2485
2	33.6	0.1563

* C. B. Rawlins, et al., *Standard Handbook for Electrical Engineering*, 13th ed., D. G. Fink and H. W. Beaty, eds. New York: McGraw-Hill, 1993, p. 4-47.

AWG: American wire gauge which is a standard system of specifying wire size

Ohm's Law

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

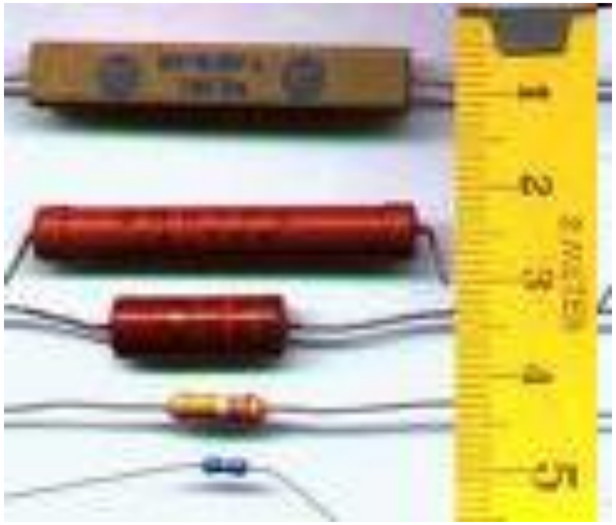


- Mathematical expression for Ohm's Law is as follows:

$$v = iR$$

- Two extreme possible values of R: **0 (zero)** and **∞ (infinite)** are related with two basic circuit concepts: short circuit and open circuit.

Resistors



Ohm's law

$V = IR$

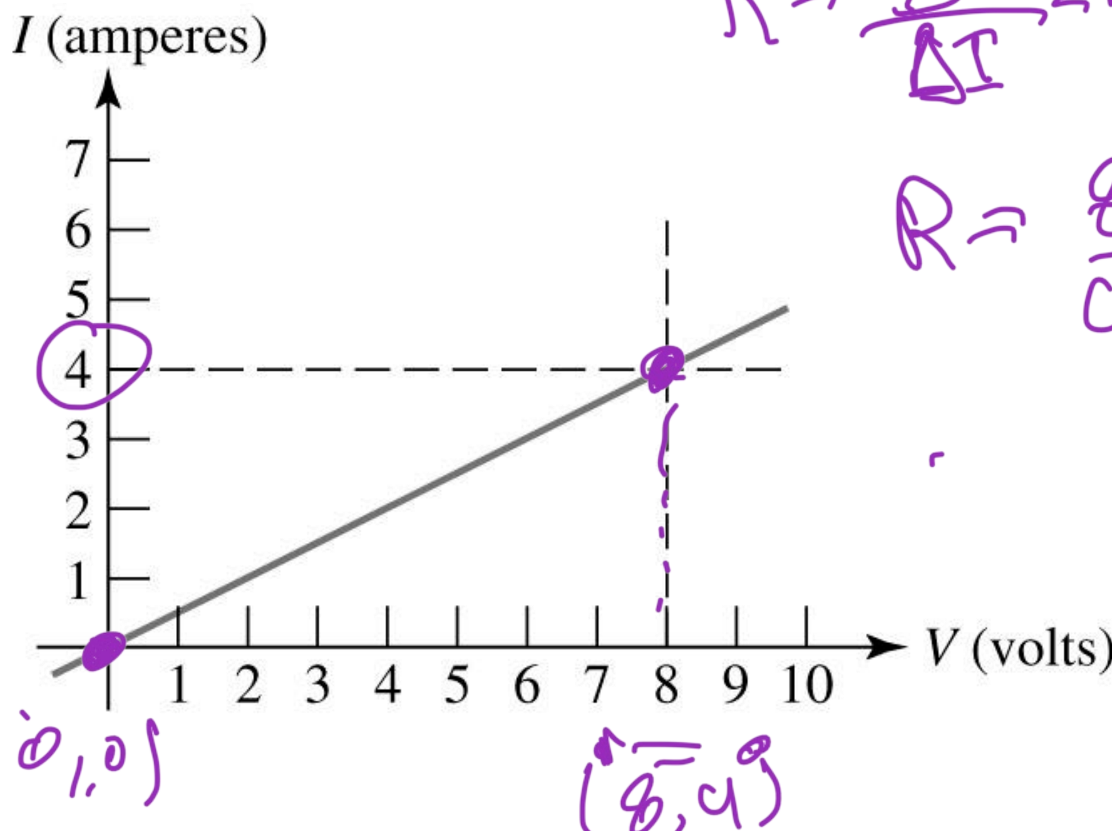
$R = \frac{\Delta V}{\Delta I}$

- Current and voltage relationship for 2 Ω linear resistor

$R = \frac{\Delta V}{\Delta I} = m = \frac{V_2 - V_1}{I_2 - I_1}$

$R = \frac{8 - 0}{4 - 0} = \frac{8}{4}$

$= 2\ \Omega$



Ohm's law

- *Conductance* is the ability of an element to conduct electric current; it is the reciprocal of resistance R and is measured in mhos or siemens.

$$G = \frac{1}{R} = \frac{i}{v}$$

- The unit of conductance is mho ℧, or siemens S
- Power = VI = I^2R = V^2/R

$P = i\,V$ → للبطارية والتيار

$P = i^2 R$

$P = \dfrac{V^2}{R}$

⟹ للمقاومات

Examples

1. An electric iron draws 2 A at 120V. Find its resistance.

Solution:

From Ohm’s law R = V/I= 120/2 = 60Ω

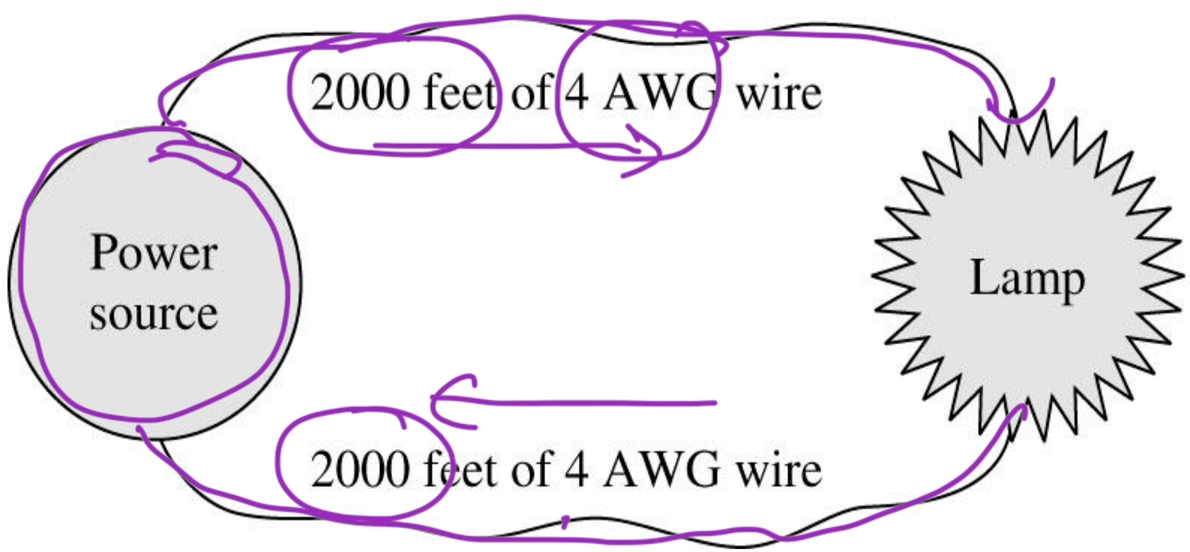
$V = IR$

$R = \frac{V}{I}$

$R = \frac{120}{2} = 60\,\Omega$

example

- A wire is run across a 2000 ft span to a high power lamp that draws 100 A. if 4 AWG wire is used, how much power is dissipated(lost or wasted) within the wire?



4000 ft $\qquad i = 100 A$

$P = iV = i^2 R$

$R = 4\not{000} \times \frac{0,2485}{1\not{000}} = 4 \times 0,2485$

$= 0,994 \, \Omega$

$P = (100)^2 \times 0,994 = 9940 \, W$

Eng

$= 9,94 \times 10^3 \, W$

$= 9,94 \, kW$

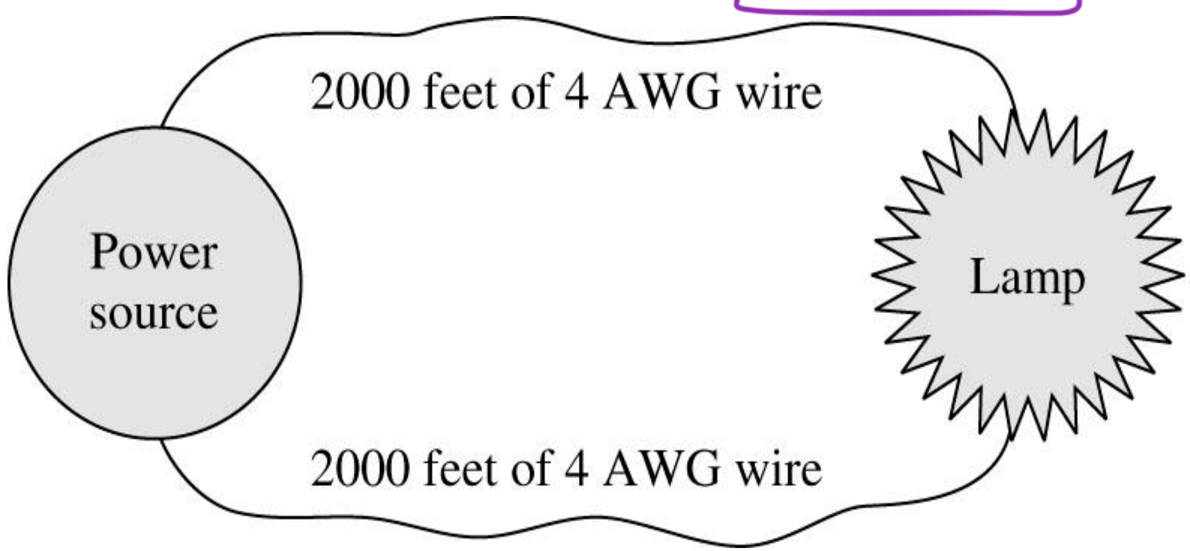
From table 2.4 that 4 AWG wire is 0.2485 Ω per 1000 ft. the total wire is 2000 + 2000= 4000 ft.

Wire resistance = 4000ft x0.2485 Ω/ 1000ft

= 0.994 Ω

Power dissipation in the wire= I^2R

= $(100)^2$x 0.994= 9940 W = 9.94kW



Example of Electricity Bills

A homeowner consumes 700 kWh in January. Determine the electricity bill for the month using the following residential rate schedule:

Base monthly charge of \$12.00.

First 100 kWh per month at 16 cents/kWh.

Next 200 kWh per month at 10 cents/kWh.

Over 300 kWh per month at 6 cents/kWh.

نظام الشرائح

Solution:

We calculate the electricity bill as follows.

Base monthly charge	= \$12.00
First 100 kWh @ \$0.16/kWh	= \$16.00
Next 200 kWh @ \$0.10/kWh	= \$20.00
Remaining 400 kWh @ \$0.06/kWh	= \$24.00
Total charge	= \$72.00

~~700~~ ~~600~~ ~~500~~

400

0 → 100 فل → 1 × 100 = 100

+

100 → 200 فل → 2 × 100 = 200

+

200 → 300 فل → 3 × 100 = 300

+

300 → 5 × 400 = 2000

2600 ريال

1 ريال ← $\frac{100}{100}$ هللة

هللة ← $\frac{1}{100}$ ريال

الشركة السعودية للكهرباء
Saudi Electricity Company
طاقة مثمرة

فاتورة إستهلاك الطاقة الكهربائية

القطاع الشرقي
إدارة كهرباء الدمام
مكتب خدمات الخبر

المشترك	مجمع المها السكني
العنوان	ص.ب. ٠٠١٦٦٤ الخبر ٣١٩٥٢ ٠٠٠١

رقم الفاتورة	٢٣٤٠٠١٢٩٨٠٨١
بداية الفترة	١٤٣٧/٠١/٢٠ ٢٠١٥/١١/٠٢
نهاية الفترة	١٤٣٧/٠٢/١٩ ٢٠١٥/١٢/٠١

هاتف الاستفسار	٩٢٠٠٠١١٠٠
هاتف الطوارئ	٩٣٣
موقع الشركة	www.se.com.sa

شرائح الاستهلاك
يتم إحتساب الاستهلاك على أساس ٣٠ يوم
سكني

ك.و.س	هللة
٢٠٠٠	٥
١٤١٩	١٠

2000×5/100 + 1419×10/100
100 + 141,9
241,9 ريال
+15
256,9 ريال

رقم الحساب	١٠٠٠٠٠٨١٩٢٢١	تاريخ الفاتورة	١٤٣٧/٠٢/٢١
المبلغ المطلوب	٢٥٦.٩٠	تاريخ التوزيع	١٤٣٧/٠٢/٢٤
آخر موعد للسداد	١٤٣٧/٠٣/١٣	تاريخ فصل الكهرباء	
رقم الإشتراك	٣١٠١٠٩٩٦٩٧٣	قيمة الإستهلاك	٢٤١.٩٠
رقم العداد	٧١٩٣٦٤٦٥	خدمة العداد	١٥.٠٠
سعة القاطع	١٠٠	إستحقاق الفترة	٢٥٦.٩٠
القراءة الحالية	٢٤٦٩١٧	رصيد سابق	٠.٠٠
القراءة السابقة	٢٤٣٤٩٨		
معامل الضرب	١.٠٠		
كمية الإستهلاك	٣٤١٩	عدد الأيام	٣٠
إجمالي الإستهلاك	٣٤١٩	رصيد دائن	٠.٠٠
رقم المنطقة	٣١٢٠-٠٣ ١٢٠-١٠١٢ ٠٠٣٠٧٤٥	المبلغ المطلوب	٢٥٦.٩٠

فاتورة بريدية

ALKAHRABA

رقم الحساب	رقم الفاتورة	تاريخ الفاتورة
١٠٠٠٠٠٨١٩٢٢١	٢٣٤٠٠١٢٩٨٠٨١	١٤٣٧/٠٢/٢١
المبلغ المطلوب	٢٥٦.٩٠	

السادة بنك ....
أرجو حسم قيمة هذه الفاتورة من حسابي لديكم رقم ....
التوقيع

الشركة السعودية للكهرباء
Saudi Electricity Company
طاقة مثمرة

رقم الحساب	رقم الفاتورة	تاريخ الفاتورة
١٠٠٠٠٠٨١٩٢٢١	٢٣٤٠٠١٢٩٨٠٨١	١٤٣٧/٠٢/٢١
المبلغ المطلوب	٢٥٦.٩٠	

الشركة السعودية للكهرباء
Saudi Electricity Company
طاقة مثمرة

10000819221262501219489000000000256900

CONSUMPTION TARIFFS

Table shows the New Electricity Tariffs for all categories of consumption as approved by the Council of Ministers' Decree dated 12/12/2017,which has been applied since 1/1/2018 :

<table>
<tr><th>Consumption categories
(Kwh)</th><th>Residential
(Halalah / kwh)</th><th>Commercial
(Halalah / kwh)</th><th>Agricultural & Charities
(Halalah / kwh)</th><th>Governmental
(Halalah / kwh)</th><th>Industrial
(Halalah / kwh)</th><th>Private educational facilities, private medical facilities
(Halalah / kwh)</th></tr>
<tr><td>1-6000</td><td>18</td><td>20</td><td>16</td><td rowspan="2">32</td><td rowspan="2">18</td><td rowspan="2">18</td></tr>
<tr><td>More than 6000</td><td>30</td><td>30</td><td>20</td></tr>
</table>

Examples

How much energy does a 100-W electric bulb consume in two hours?

Example 1.6

Solution:

$$w = pt = 100\ (\text{W}) \times 2\ (\text{h}) \times 60\ (\text{min/h}) \times 60\ (\text{s/min})$$
$$= 720{,}000\ \text{J} = 720\ \text{kJ}$$

This is the same as

$$w = pt = 100\ \text{W} \times 2\ \text{h} = 200\ \text{Wh}$$

$w = pt$

$w = J, Wh$

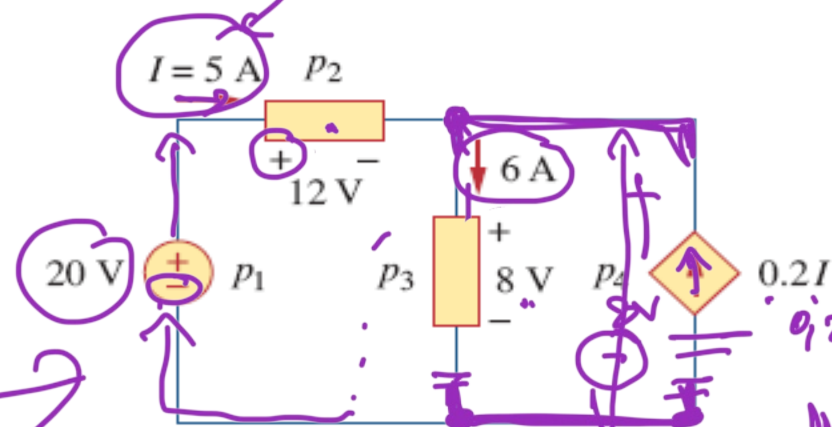
=

watt hour

$100 \times 2 \times 60 \times 60\ s$

Example 1.7

Calculate the power supplied or absorbed by each element in Fig.



$p_1 = 20(-5) = -100$ W Supplied power

$p_2 = 12(5) = 60$ W Absorbed power

$p_3 = 8(6) = 48$ W Absorbed power

$p_4 = 8(-0.2I) = 8(-0.2 \times 5) = -8$ W Supplied power

$$p_1 + p_2 + p_3 + p_4 = -100 + 60 + 48 - 8 = 0$$