CHAPTER – 1 :

BASIC CONCEPS

1.0 INTRODUCTION

All branches of electrical engineering are based on electric circuit theory and electromagnetic theory. Several branches of electrical engineering such as power systems, control systems, electric machines, instrumentation, electronics, communications are based on electric circuit theory. Therefore, basic electric circuit theory course is very importantcourse for an electrical engineering student and of course an excellent starting point for a first semester student in electrical engineering education. Circuit theory course is also very important to students specializing in other branches of the physical sciences because of the applied mathematics, physics and topology involved and also circuits are a good model for the study of energy systems.

In electrical engineering, we are often interested in transfering energy from one point to another. To do this, we require an interconnection of electrical devices and such interconnection is known as an electric circuit. Each component of the electric circuit is known as an element. Therefore, an electric circuit is an interconnection of electrical elements.

Fig. 1.1 shows a simple electrical circuit. It consists of four basic elements: a battery a switch, a lamp and connecting wires. such a simple circuit has several applications such as a torch light, a search light, etc.

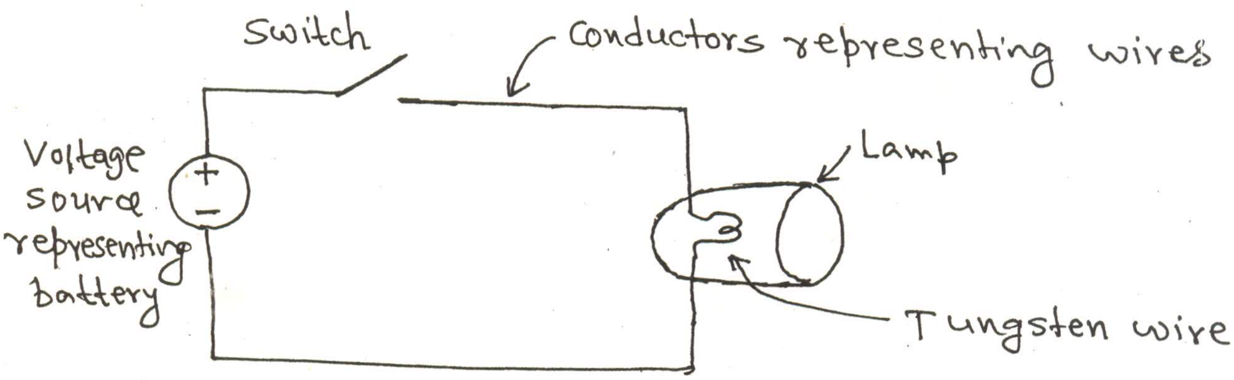


Fig. 1.1: A simple electric circuit

Electrical charge (electrons) will flow through the circuit due to chemical forces in the battery. The charge gains energy from the chemicals in the battery and delivers energy to the lamp. The battery voltage is a measure of the energy gained by a unit of charge as it moves through the battery.

The wires are made of copper conductor and are insulated from one another by electrical insulation coating the wires. Electrons readily moves through the copper conductor but not through the plastic insulation.

The switch is used to allow or disallow the flow of current through the circuit. Current will flow through the circuit when the conducting metallic parts of the switch make contact and we say that the switch is closed. On the other hand, when the conducting parts ~~parts~~ of the switch do not make contact, current does not flow through the circuit and we say that switch is open.

The lamp contains tungsten wire that can withstand high temperature. Tungsten is not as good an electrical conductor as copper, and the electrons experience collisions with the atoms of the tungsten wires, resulting in heating of the tungsten. We can say that tungsten wire has electrical resistance. Thus energy is transferred by the chemical action in the battery to the electrons and then to the tungsten where it appears as heat. The tungsten becomes hot enough so that light is emitted.

1.1 SYSTEMS OF UNITS

We all electrical engineers deal with several measurable quantities. However, our measurement must be communicated in a standard language such that all engineering professionals can understand, irrespective of the country where the measurement is ~~conducted.~~ conducted. Such an international measurement language is the International System of Units (SI), adopted by the General Conference on Weights and Measures in 1960. In this International system, there are six principal units from which the units of all other physical quantities can be obtained. Table 1.1 shows the six principal units and their symbols. The SI units are used throughout the world.

One major advantage of the SI unit is that it uses prefixes based on the power of 10 to relate smaller and larger units to the basic unit. Table 1.2 shows the SI prefixes and their symbols.

TABLE-1.1: The six basic SI units

Quantity	Basic Unit	Symbol
Luminous intensity	candela	cd
Thermodynamic temperature	Kelvin	K
Length	meter	m
Mass	Kilogram	Kg.
Time	Second	S
Electric current	ambere	A

TABLE-2.2: The SI prefixes

Multiplier	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

1.2: CHARGE AND CURRENT

The concept of electric charge is the underlying principle for explaining all electrical phenomena. The most basic quantity in an electric circuit is the electric charge. Here we will review some important characteristics of electric charge.

1. The charge is bipolar, meaning that electrical effects are described in terms of positive and negative charges

2. According to experimental observations, the only charges that occur in nature are integral multiples of the electronic charge $e = -1.602 \times 10^{-19}$ coulomb.

3. Electrical effects are attributed to both the separation of charge and charges in motion.

4. The law of conservation of charge states that charge can neither be created nor destroyed, only transferred. Thus the algebraic sum of the electric charges in a system does not change.

Effect of electric charge can be experienced when we try to remove our woollen sweater and have it stick to our body or walk across a carpet and receive a shock.

Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).

Now consider the flow of electric charges. A unique feature of electric charge is that it can be transferred from one place to another, that means it is mobile, where it can be converted to another form of energy. The motion of charge creates an electric fluid (current).

We know that a conducting wire consists of several atoms and a battery is a source of electromotive force. When a conducting wire is connected to a battery, the charges are compelled to move. positive charges move in one direction while negative charges move in the opposite direction. This motion of charges creates electric current. Convention is to take the current flow as the movement of positive charges, that is, opposite to the flow of negative charges as shown in Fig. 1.2.

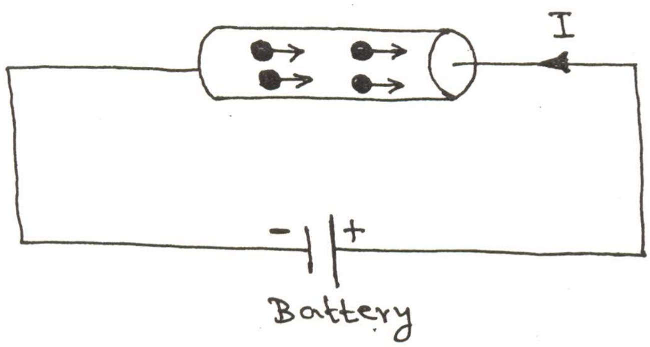


Fig. 1.2: Electric current due to flow of charge through a cross section of a conductor or circuit element.

The electrical effects caused by charges in motion depend on the rate of charge flow. The rate of charge flow is known as the electric current.

Mathematically, the relationship between current, charge and time is

$$i = \frac{dq}{dt} \quad \text{---- (1.1)}$$

Where

$i =$ the current in Amp.

$q =$ the charge in coulombs.

$t =$ the time in seconds.

Note that 1 Amp = 1 coulomb/second.

The charge transferred between time t_0 and t is obtained by integrating both sides of ~~eqn~~ Eqn.(1.1), we get,

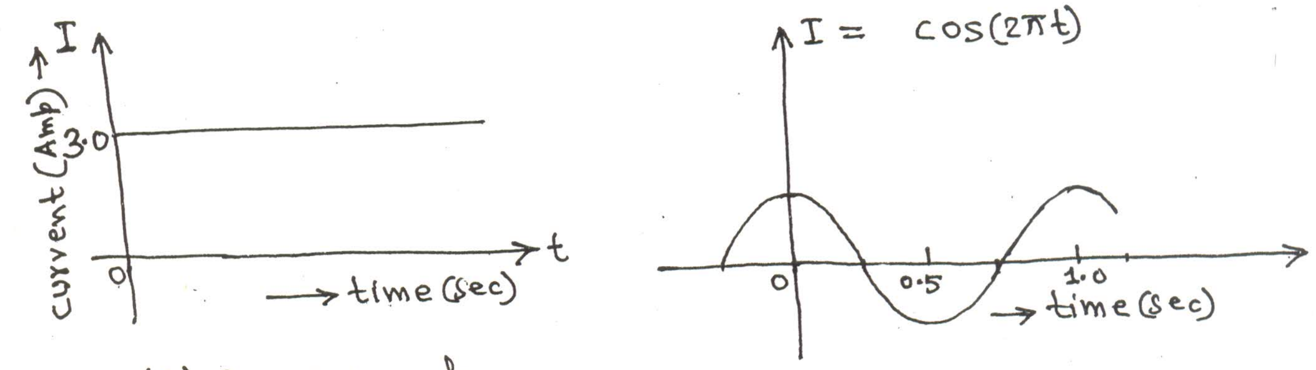
$$q = \int_{t_0}^{t} i\,dt \quad \text{---- (1.2)}$$

Eqn.(1.1) suggests that current need not be a constant - valued function. As we will see later, there can be several types of current; that is charge can vary with time in several ways.

When a current is constant with time, we say that we have direct current (dc). Thus, a direct current (dc) is a current that remains constant with time.

On the other hand, a current that varies with time, reversing direction periodically, is called alternating current (ac). Thus, an alternating current (ac) is a current that varies with time periodically. Alternating current is used in our household, to run the refrigerator, toaster, air conditioner and other electrical appliances.

Fig. 1.3 shows the values of a dc current and a sinusoidal ac current versus time.

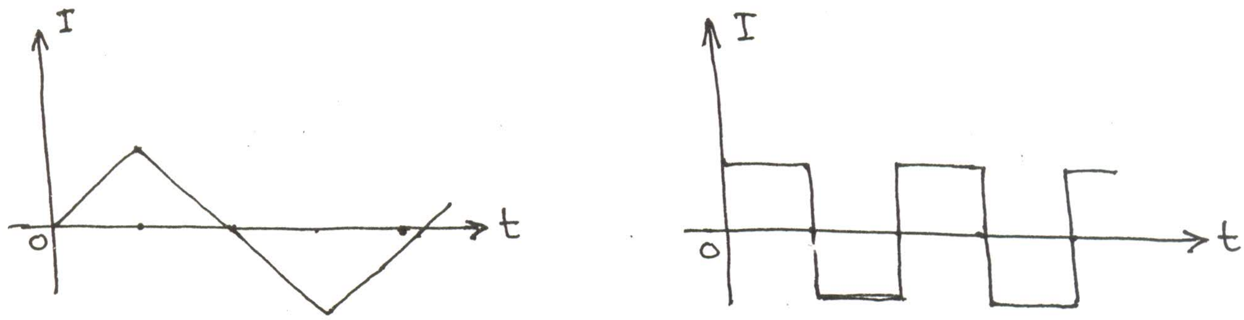


(a) Dc current

(b) Ac current

Fig. 1.3: Examples of dc and ac currents versus time.

Fig. 1.4 shows the other types of time-varying currents such as the triangular and square wave forms.



(a) Triangular wave form

(b) Square wave form.

Fig. 1.4: Two different types of Ac waveforms.

As mentioned earlier, direction of current flow is conventionally taken as the direction of positive charge movement. Based on this convention, a current of 4 Amp may be represented positively or negatively. This is shown in Fig. 1.5, where a lamp is connected in series with a battery.

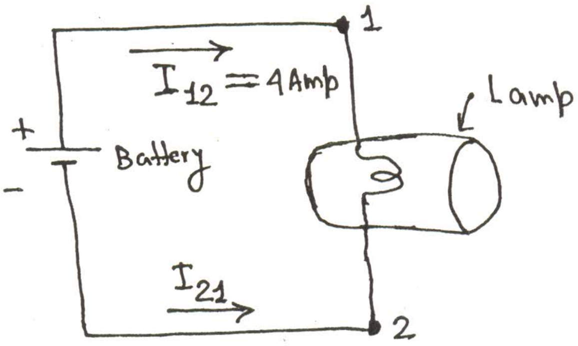


Fig. 1.5: A lamp in series with battery: positive and negative current flow.

In Fig. 1.5, $I_{12} = 4$ Amp, this means the current through the lamp with its reference direction pointing from 1 to 2. Similarly, I_{21} is the current with its reference directed from 2 to 1. Of course, I_{12} and I_{21} are the same in magnitude and opposite in sign, because they denote the same current but with opposite direction. Thus, we have,

$$I_{12} = -I_{21} = 4 \text{ Amp} \quad \cdots \quad (1.3)$$

1.3: VOLTAGE

As explained in the previous section, to move the electron in a conductor in a particular direction requires some work or energy transfer. This work is done by an external electromotive force (emf), typically represented by the battery in Fig. 1.2. This emf is also known as potential difference or voltage. Actually whenever positive and negative charges are separated, energy is expanded. Voltage is the energy per unit charge created by the separation. Thus the voltage V_{12} between two points 1 and 2 in an electric circuit is the energy or work needed to move a unit charge from 1 to 2. We express this ratio in differential form as:

$$v = V_{12} = \frac{dw}{dq} \quad \text{- - - -} \quad (1.4)$$

where

w = the energy in joules.

q = the charge in coulombs.

$v = V_{12}$ = the voltage in volts.

From eqn.(1.4), it is evident that

1 volt = 1 joule/coulomb = 1 newton-meter/coulomb.

Thus, Voltage or potential difference is the energy required to move a unit charge through an element

Fig.1.6 shows the voltage across a lamp connected between points 1 and 2. The plus (+) and minus (−)

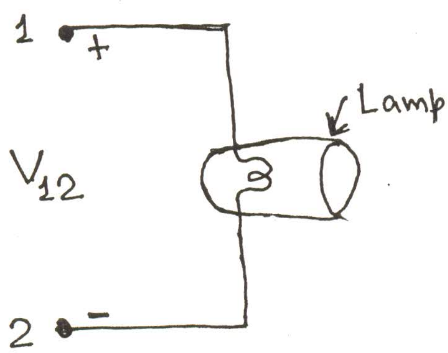


Fig. 1.6: Polarity of voltage V_{12}

signs are used to represent reference direction or voltage polarity. The voltage V_{12} can be interpreted in two ways:

1. Point 1 is at a potential of V_{12} Volts higher than point 2.

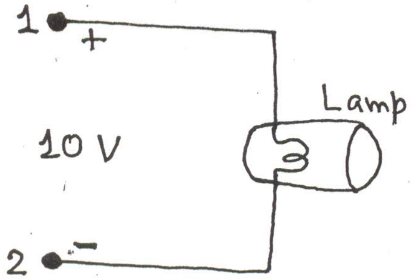
OR

2. The potential at point 1 with respect to point 2 is V_{12}.

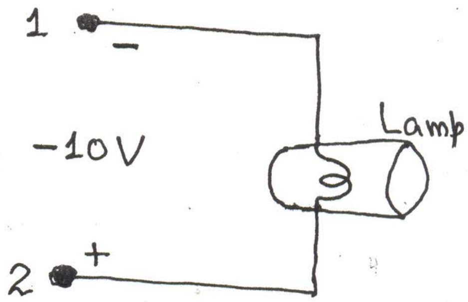
Therefore, Logically it follows that

$$V_{12} = -V_{21} \quad \text{------} \quad (1.5)$$

For the purpose of further explanation, Fig. 1.7 shows two representations of the same voltage.



(a) point 1 is 10 V above point 2



(b) Point 2 is − 10 V above point 1

Fig. 1.7: Two equivalent representations of the same voltage V_{12}.

In Fig. 1.7(a), point 1 is + 10 V above point 2; in Fig. 1.7(b), point 2 is −10 V above point 1. We can say that in Fig. 1.7(a), there is a 10 V voltage drop from point 1 to 2 or equivalently a 10 V voltage rise from point 2 to 1. In general, a voltage drop from

1 to 2 is equivalent to a voltage rise from 2 to 1. (12)

1.4: POWER AND ENERGY

Power and energy calculations are very important in circuit analysis. Although voltage and current are useful variables in an electric circuit, they are not sufficient by themselves. One reason is that the useful output of the system often is nonelectrical, and this output is conveniently expressed in terms of power and energy. Another reason is that all practical devices have limitations on the amount of power that they can handle. For example, we all know from our ~~experience~~ experience that a 60-watt bulb gives more light than a 40-watt bulb. We also know that when we pay our electricity bills, we are paying for the electric energy (watt-hour) consumed over a certain period of time.

We now relate power and energy to voltage and current, we recall from physics that: Power is the time rate of expanding or absorbing energy. Power is measured in Watts (W). Mathematically, we write this relationship as

$$p = \frac{dw}{dt} \quad \text{----} \quad (1.6)$$

13

where

$p =$ the power in watts

$w =$ the energy in joules

$t =$ the time in seconds.

Thus $\quad 1$ watt $= 1$ joule/sec.

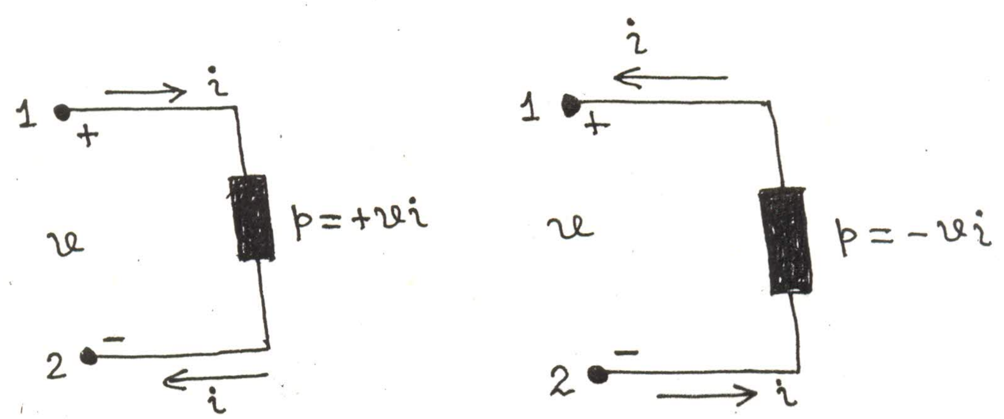
From Eqns. (1.1), (1.4) and (1.6), it follows that

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$$

$$\therefore \quad p = vi \quad \text{- - - -} \quad (1.7)$$

Eqn. (1.7) shows the power associated with a basic circuit element is simply the product of the current in the element and the voltage across the element. Therefore, power is a quantity associated with a pair of terminals, and we have to be able to tell from our calculation whether power is being delivered to the element or supplied by the element. If the power has a + sign, power is being delivered to or absorbed by the element. If, on the other hand, the power has a − sign, power is being supplied by the element. But how do we know when the power has a positive or a negative sign?

Polarity of voltage and direction of current play a major role in determining the sign of power. It is therefore important



(a) Absorbing power (b) supplying power.

Fig. 1.8: Reference polarities for power using the passive sign convention.

In order to power have a positive sign, the direction of current and polarity of voltage must conform with those shown in Fig. 1.8(a). By the passive sign convention, current enters through the positive polarity of the voltage and in this case, $p = +vi$ or $vi > 0$ implies that the element is absorbing power. But if $p = -vi$ or $vi < 0$, as in Fig. 1.8(b), the element is releasing or supplying power. Throughout the text, we will follow the passive sign convention.

Passive sign convention is satisfied when the current enters through the positive terminal of an element and $p = +vi$. However, if the current enters through the negative terminal, $p = -vi$.

In general we can write

+ Power absorbed = − Power supplied.

Fig. 1.9 shows two cases of an element with absorbing power.

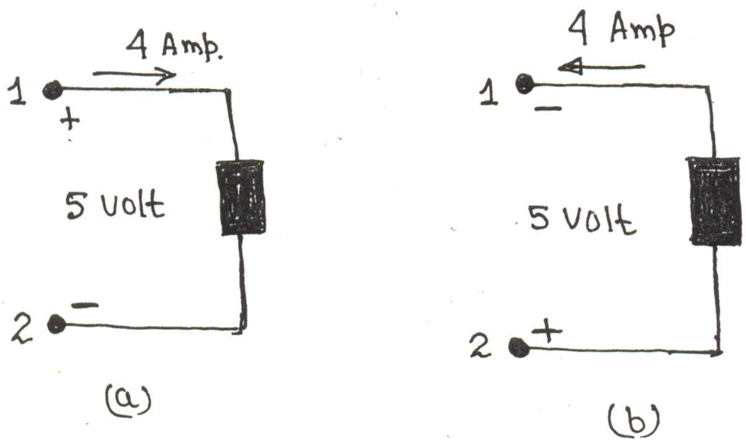


Fig. 1.9: Two cases of an element with an absorbing power of 20W

(a) $p = 5 \times 4 = 20\,W$ (b) $p = 5 \times 4 = 20\,W$

Fig. 1.10 shows two cases of an element with a supplying power.

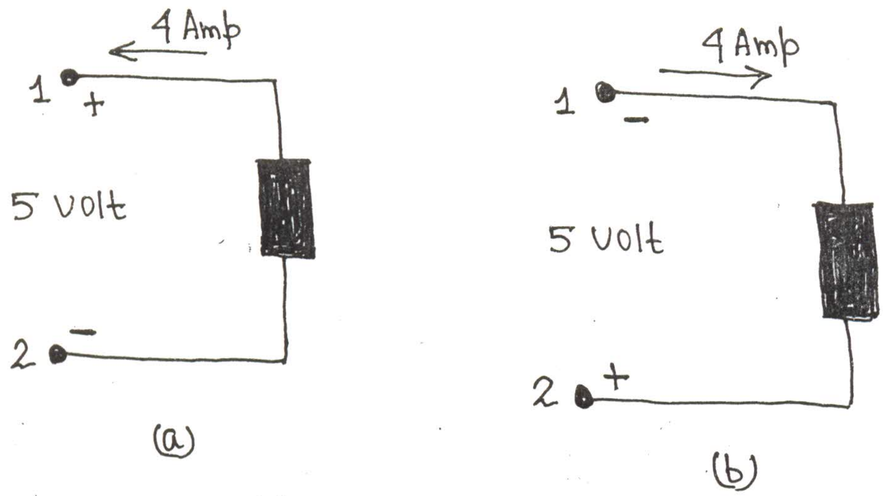


Fig. 1.10: Two cases of an element with a supplying power of 20 W.

(a) $p = 5 \times (-4) = -20\,W$ (b) $p = 5 \times (-4) = -20\,W$.

In any electric circuit, law of conservation of energy must be obeyed. For this reason, at any instant of time, the algebraic sum of power in a circuit must be zero. Therefore, we can write

$$\sum p = 0 \quad ----- (1.8)$$

Eqn. (1.8) confirms the fact that the total power supplied to the circuit must balance the total power absorbed.

To calculate the energy w ~~delivered~~ supplied or absorbed by a circuit element between time instants t_0 and t, we integrate power. Therefore,

$$w = \int_{t_0}^{t} p\,dt = \int_{t_0}^{t} v i\,dt \quad ---- (1.9)$$

Thus, Energy is the capacity to do work. Energy is measured in joules.

The electric power utility companies measure energy in watt-hours (Wh).

Where 1 Wh = 3600 joules.

EX- 1.1: How much charge is represented by 5524 electrons?

Solution:

Each electron has $e = -1.602 \times 10^{-19}$ coulomb.

Hence 5524 electrons will have

-1.602×10^{-19} coulomb/electron $\times$ 5524 electrons

$= 8.849 \times 10^{-16}$ coulomb

EX-1.2 : The total charge entering a terminal is given by $q = 3t\sin(2\pi t)$ mC. Determine the current at $t = 0.4$ sec.

Solution:

We know

$$i = \frac{dq}{dt} = \frac{d}{dt}\left[3t\sin(2\pi t)\right]$$

$$\therefore \quad i = \left[3\sin(2\pi t) + 6\pi t\cos(2\pi t)\right] \text{ mA}$$

at $t = 0.3$ sec,

$$i = \left[3\sin(2\pi \times 0.3) + 6\pi \times 0.3\cos(2\pi \times 0.3)\right] \text{mA}$$

$$\therefore \quad i = 1.106 \text{ mA}$$

EX-1.3 : Determine the total charge entering a terminal between $t = 2$ sec and $t = 4$ sec. Current passing the terminal is $i = (2t^2 - t)$ A.

Solution

By using Eqn.(1.2),

$$q = \int_{t_0}^{t} i\,dt = \int_{2}^{4}(2t^2 - t)\,dt = \left(\frac{2}{3}t^3 - \frac{t^2}{2}\right)\Bigg|_{2}^{4}$$

$$\therefore \quad q = 31.33 \text{ C.}$$

EX-1.4 : charge versus time for a given circuit element is given by

$$q(t) = 0 \quad \text{for } t < 0$$

and

$$q(t) = 2 - 2e^{-100t} \quad \text{for } t > 0$$

Plot $q(t)$ and $i(t)$ versus time.

Solution:

We know

$$i(t) = \frac{dq(t)}{dt}$$

$$= 0 \quad \text{for } t < 0$$

$$= 200\, e^{-100t} \quad \text{for } t > 0$$

Plots of $q(t)$ and $i(t)$ are shown in Fig. 1.11.

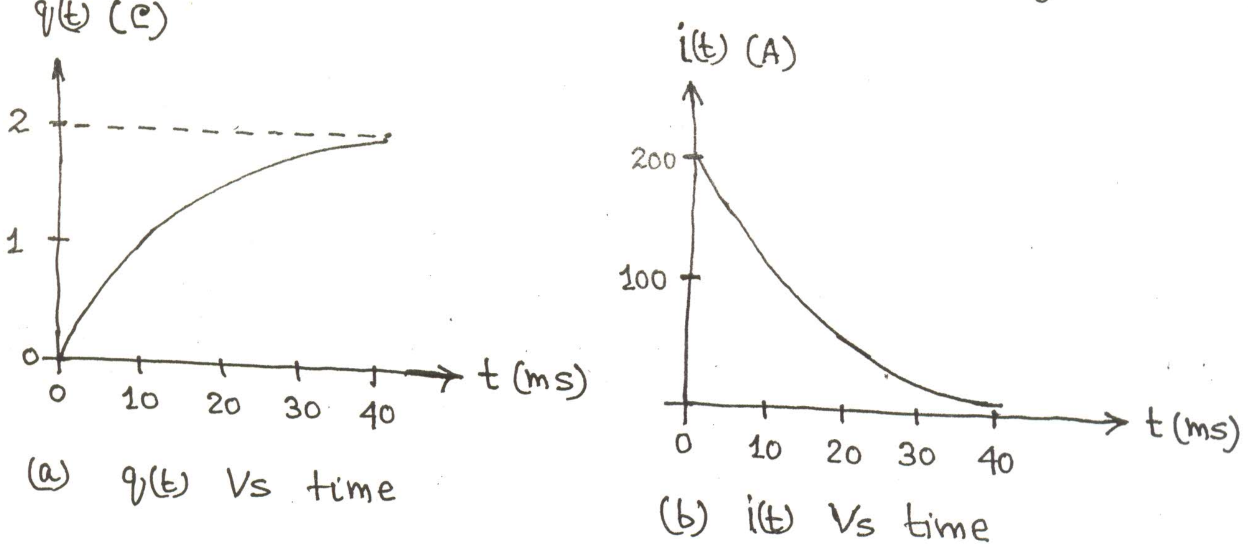


Fig. 1.11: Plots of charge and current versus time of Example – 1.4.

EX-1.5 The current flowing through an element is

$$i = \begin{cases} 1\text{ A}, & \text{for } 0 < t < 1 \\ 3t^2\text{ A}, & \text{for } t > 1 \end{cases}$$

Determine the charge entering the element from $t = 0$ sec to $t = 2$ sec.

Solution

We know

$$q = \int_{t_0}^{t} i\,dt = \int_{t_0}^{t_1} i\,dt + \int_{t_1}^{t} i\,dt = \int_{0}^{1} 1.dt + \int_{1}^{2} 3t^2 dt$$

$$\therefore q = (1+7)\,C = 8\,C.$$

EX-1.6 : Electrical energy is converted to heat at the rate of 8 kJ/min in a resistor and charge flowing through it at the rate of 300 C/min. What is the voltage difference across the resistor terminals?

Soln

We know

$$v = \frac{p}{i} = \frac{8 \times 10^3 \text{ J/min}}{300 \text{ C/min}} = 26.67 \text{ J/C}$$

$\therefore$ $v = 26.67$ Volt.

EX-1.7: An energy source forces a constant current of 4 Amp for 6 sec to flow through a lamp. If 4 kJ is given off in the form of light and heat energy, determine the voltage drop across the lamp.

Solution

Total charge is

$$\Delta q = i \Delta t = 4 \times 6 = 24 \text{ C}$$

The voltage drop is

$$v = \frac{\Delta w}{\Delta q} = \frac{4 \times 10^3}{24} = 166.67 \text{ Volt}$$

EX-1.8 : Compute the power delivered to an element at $t = 4$ ms if the current entering its positive terminal is $i = 4\cos(100\pi t)$ Amp and the voltage is (a) $v = 3i$ (b) $v = 3\frac{di}{dt}$

Soln.

(a) $v = 3i = 3 \times 4\cos(100\pi t) = 12\cos(100\pi t)$

Hence the power is

$p = vi = 12\cos(100\pi t) \times 4\cos(100\pi t)$

$\therefore p = 48\cos^2(100\pi t)$

At $t = 4\,ms = 4 \times 10^{-3}$ sec

$p = 48\cos^2(100\pi \times 4 \times 10^{-3}) = 4.603\ W$

(b) Given that

$v = 3\frac{di}{dt} = 3\frac{d}{dt}[4\cos(100\pi t)]$

$\therefore v = -1200\pi \sin(100\pi t)$

$p = vi = -1200\pi \sin(100\pi t) \times 4\cos(100\pi t)$

$\therefore p = -4800\pi \sin(100\pi t)\cos(100\pi t)$

$\therefore p = -2400\pi \sin(200\pi t)$

At $t = 4\,ms = 4 \times 10^{-3}$ sec

$p = -2400\pi \sin(200\pi \times 4 \times 10^{-3})$ W

$\therefore p = -4431.8\ W = -4.4318\ kW$

Ex-1.9: How much energy does a 200 W electric lamp consume in 2 hours.

Soln.: Expression for energy is given as

$w = pt = 200 \times 2 = 400\ Wh$

Also

$w = 200 \times 2 \times 60 \times 60 = 720,000\ J = 720\ kJ.$

Ex-1.10: Derive an expression for the power for the voltage source shown in Fig.1.12. Also compute the energy for the interval $t=0$ to $t=\infty$.

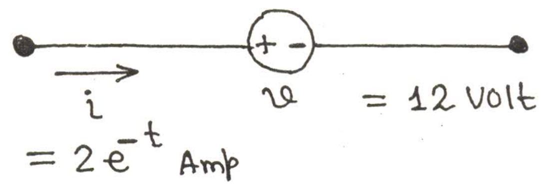


Fig.1.12: Circuit element of Ex-1.10

Soln.

Current enters the positive polarity. Hence, we compute power as

$$p = vi = 12 \times 2e^{-t} = 24e^{-t} \text{ W}$$

Expression for energy transferred is given by

$$w = \int_0^\infty p\,dt = \int_0^\infty 24e^{-t}\,dt \quad \text{Joule}$$

$$\therefore w = \left[-24e^{-t}\right]_0^\infty = 24 \text{ Joule.}$$

1.5: ACTIVE AND PASSIVE CIRCUIT ELEMENTS

An electric circuit is simply an interconnection of the elements. Circuit analysis is the process of determining the currents through the elements or voltages across the elements of the circuit.

There are two types of elements found in electric circuits: Active elements and Passive elements, by considering the energy delivered to or by them.

A circuit element is said to be passive if the total energy delivered to it from the rest of the circuit is always nonnegative, i.e., 22 a

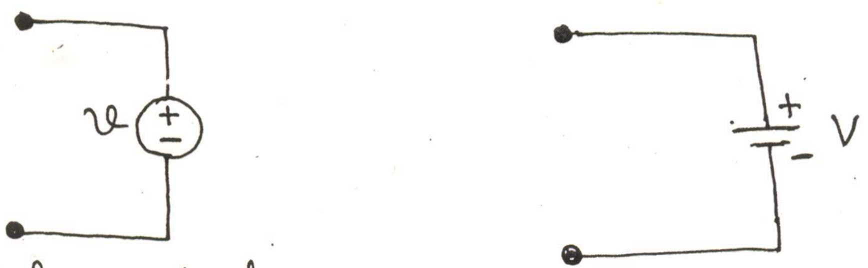
$$w = \int_{t_0}^{t} p\,dt = \int_{t_0}^{t} v i\,dt \geqslant 0 \quad \text{- - - -} \quad (1.10)$$

Of course, an active element is one that is not passive. That is Eqn. (1.10) does not hold for all time. In general, an active element is capable of generating energy while a passive element is not. Examples of passive elements are resistors, inductors and capacitors. Examples of active elements are generators, batteries and operational amplifiers. In this section, we will be familiar with some important active elements.

The most important active elements are voltage or current sources that generally deliver power to the circuit connected them. There are two types of sources: independent and dependent sources.

An independent voltage source is a two-terminal element that maintains a specified voltage between its terminals. The voltage is completely independent of the current through the element. Physical sources such as generators and batteries may be regarded as approximations to ideal voltage source. (22-b)

Fig. 1.13 shows the symbols for independent voltage sources.



(a) Used for constant or time-varying voltage

(b) Used for constant voltage (dc)

Fig. 1.13: symbols for independent voltage sources.

Note that both symbols of Fig. 1.13 can be used to represent dc voltage source, but the symbol of Fig. 1.13(a) can be used for a time-varying voltage source.

An independent current source is a two-terminal element that provides a specified current completely independent of the voltage across the source. Fig. 1.14 shows the symbol for an independent current source

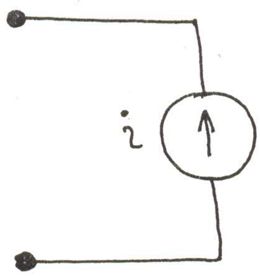
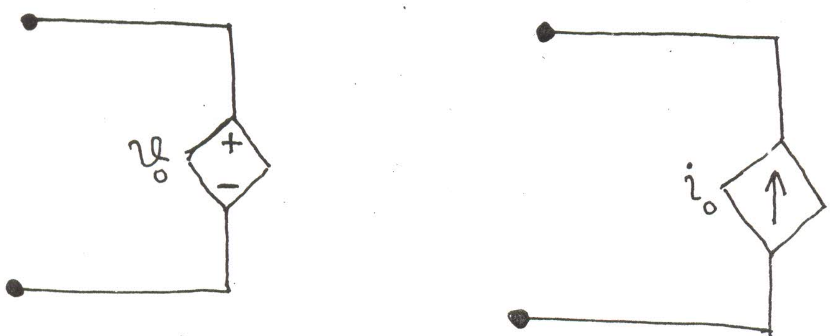


Fig. 1.14: Symbol for an independent current source.

Independent sources are usually meant to deliver power to the external circuit. Symbol of Fig. 1.14 is true for both dc and ac current source. For example, $i = 2$ Amp is dc current source and $i = 2\sin(100\pi t)$ is ac current source.

Dependent sources are usually designated by diamond-shaped symbols. Fig. 1.15 shows the dependent sources.



(a) Dependent voltage source

(b) Dependent current source

Fig. 1.15: Symbols for dependent sources.

A dependent or controlled voltage source is similar to an independent source except that the voltage across the source terminals is a function of other voltages or currents in the circuit. Two examples of dependent sources are shown in Fig. 1.16.

(a) Voltage-controlled voltage source

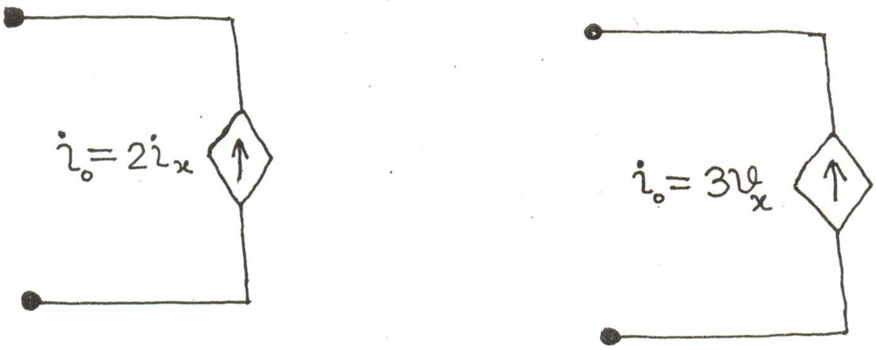
(b) Current-controlled voltage source

Fig. 1.16: Dependent voltage sources or Controlled voltage sources.

A voltage-controlled voltage source is a voltage source having a voltage equal to a constant times the voltage across a pair of terminals elsewhere in the network. This is shown in Fig. 1.16(a)

A current-controlled voltage source is a voltage source having a voltage equal to a constant times the current through some other element in the circuit. This is shown in Fig. 1.16(b). The factor multiplying the current is called the gain parameter.

The current flowing through a dependent current source is determined by a current or voltage elsewhere in the circuit. Two examples of controlled current sources are shown in Fig. 1.17.



(a) Current-controlled current source

(b) Voltage-controlled current source

Fig.1.17: Dependent current sources

A current-controlled current source is shown in Fig.1.17(a). In this case it is assumed that current through the source is 2 times the value of i_x.

A voltage-controlled current source is shown in Fig.1.17(b). The current through the source is 3 times the voltage v_x. The factor multiplying the voltage is called the gain parameter.

Controlled-voltage sources and controlled-current sources are useful in constructing circuit models for many types of real-world devices, such as transistors, transformers, electrical machines and electronic amplifiers. In summary, there are four kinds of controlled sources:

1. Voltage-controlled voltage sources (VCVS)
2. Current-controlled voltage sources (CCVS)
3. Current-controlled current sources (CCCS)
4. Voltage-controlled current sources. (VCCS)

Ex-1.11: Determine the power absorbed or supplied by each element in Fig. 1.18.

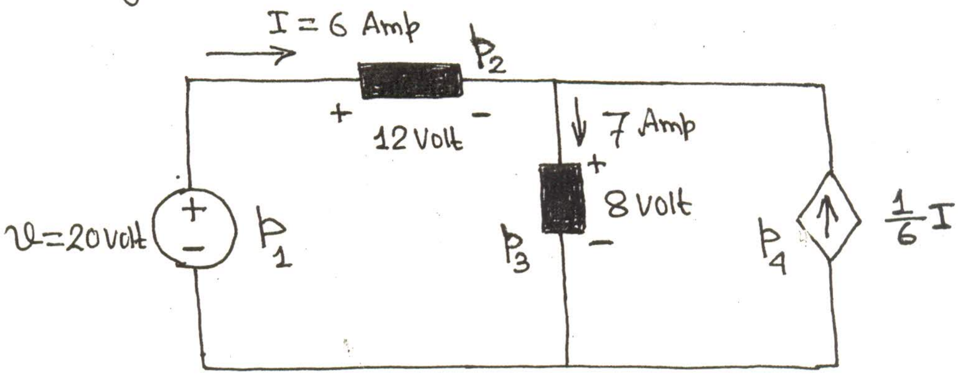


Fig. 1.18: Circuit diagram of Ex-1.11.

Soln.

Fig. 1.18 is an example of a circuit having current-controlled current source.

We apply the sign convention for power shown in Figs. 1.8, 1.9 and 1.10. For p_1, the 6 Amp current is out of the positive terminal (or into the negative terminal); Hence,

$$p_1 = 20 \times (-6) = -120 \text{ Watt} \quad \text{(Supplied power)}$$

For p_2 and p_3, the current flows into the positive terminal of the element in each case:

$$p_2 = 12 \times (6) = 72 \text{ Watt} \quad \text{(Absorbed power)}$$

$$p_3 = 8 \times (7) = 56 \text{ Watt} \quad \text{(Absorbed power)}$$

For p_4, note that the voltage is 8 volt (+ at the top), the same as the voltage for p_3, since both the passive elements and the dependent source are connected to the same terminals. Since the current flows out of the positive terminal,

$$p_4 = 8 \times \left(-\frac{1}{6} I\right) = 8 \times \left(-\frac{1}{6} \times 6\right)$$

$\therefore p_4 = -8.0$ Watt (supplied power)

We can observe that 20 volt independent voltage source and $\frac{1}{6} I$ current-controlled current source are supplying power to the rest of the network, while the two passive elements are absorbing power.

By using Eqn. (1.8),

$$p_1 + p_2 + p_3 + p_4 = -120 + 72 + 56 - 8 = 0$$

This means, total power supplied equals the total power absorbed.

Ex-1.12 : A residential consumer consumes 800 kWh in March. Determine the electricity for the month using the following rate schedule:

Base monthly charge = Rs. 12
First 100 kWh per month at Rs. 1.5/kWh
Next 200 kWh per month at Rs. 2.0/kWh
Over 200 kWh per month at Rs. 2.5/kWh

Soln:

We calculate the electricity bill as follows:

Base monthly charge = Rs. 12.0
First 100 kWh @ Rs. 1.5/kWh = Rs. 150.0
Next 200 kWh @ Rs. 2.0/kWh = Rs. 400.0
Remaining 500 kWh @ Rs. 2.5/kWh = Rs. 1250.0

Total charge = Rs. 1812

$$\text{Average cost} = \frac{1812}{800} = \text{Rs. } 2.265/\text{kWh}$$

Ex- 1.13: Determine the power absorbed or supplied by each component of the circuit as shown in Fig. 1.19

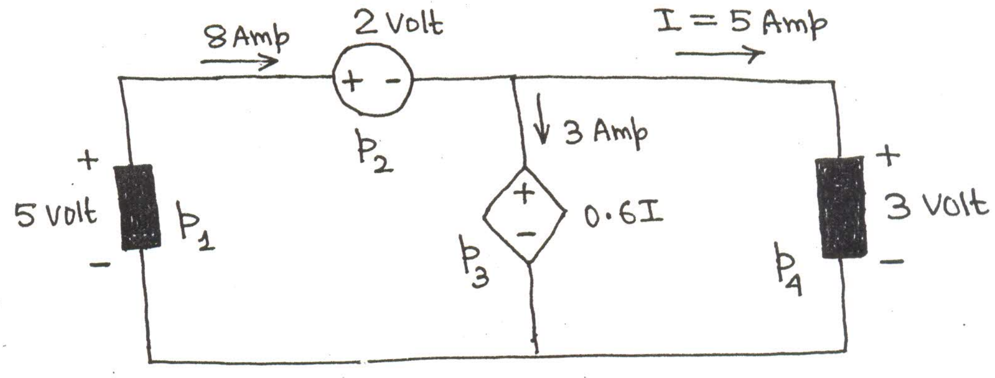


Fig. 1.19: Circuit diagram of Ex- 1.13

Soln.

8 Amp current is out of the + terminal of p_1.

Hence,

$$p_1 = 5 \times (-8) = -40 \text{ Watt.} \quad \text{(Power supplied)}$$

8 Amp current is entering the + terminal of p_2.

$$\therefore p_2 = 2 \times (8) = 16 \text{ Watt} \quad \text{(Power absorbed)}$$

3 Amp current is entering the + terminal of p_3

$$\therefore p_3 = 0.6I \times (3) \text{ Watt}$$

$$\therefore p_3 = 0.6 \times 5 \times 3 = 9 \text{ Watt} \quad \text{(Power absorbed)}$$

5 Amp current is entering the + terminal of p_4.

$$\therefore p_4 = 3 \times (5) = 15 \text{ Watt} \quad \text{(Power absorbed)}.$$

Ex-1.14: State which interconnections in Fig. 1.20 are valid and which are invalid.

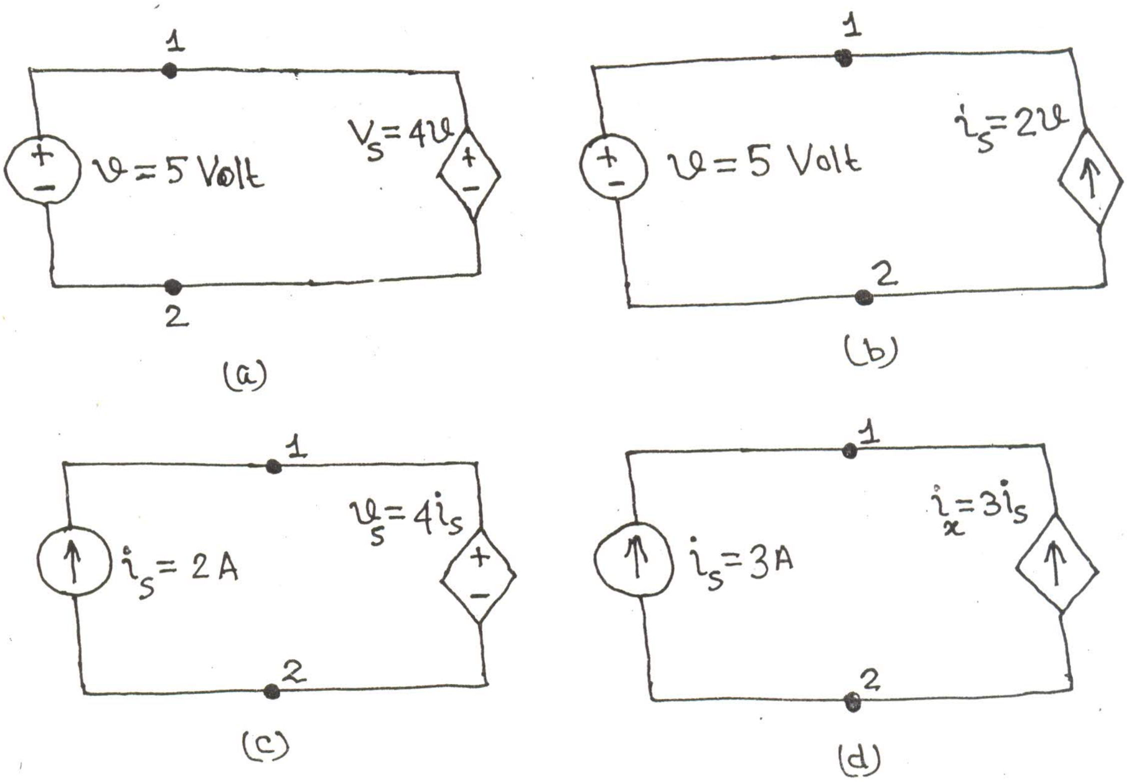


Fig. 1.20: Circuit diagrams of Ex-1.14.

Soln.

Connection (a) is invalid. Both independent source and dependent source supply voltage across the same pair of terminals 1 & 2. This needs that each source supply the same voltage with the same polarity. The independent source supplies 5 Volt, but the dependent source supplies 20 Volt.

Connection (b) is valid. The independent voltage source supplies voltage across the pair of terminals 1 & 2. The dependent current source supplies current through the same pair of terminals. Because an ideal voltage source supplies the same voltage regardless of current and an ideal current source supplies the same current regardless of voltage. This is an allowable connection.

Connection (c) is valid. The independent current source supplies current through the pair of terminals

1 & 2. The dependent votage source supplies voltage across the same of pair of terminals. Because an ideal current source supplies the same current regardless of voltage, and an ideal voltage source supplies the same voltage regardless of current, This is an allowable connection.

Circuit connection (d) is invalid. Both the independent source and the dependent source supply current through the same pair of terminals 1 & 2. This needs that each source supply the same current in the same reference direction. The independent source supplies 3 Amp, lead the dependent source supplies 9 Amp in the opposite direction.

EX-1.15 : Determine the power supplied or absorbed by each component in Fig. 1.21.

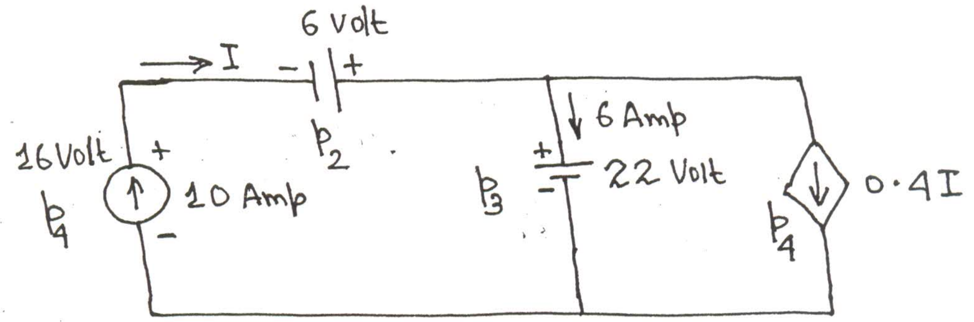


Fig. 1.21: Circuit diagram of EX-1.15

Soln.

For 10 Amp current source, the current flows out of the + terminal, hence

$p_1 = 16 \times (-10) = -160$ W (Power supplied)

For 6 volt source, 10 Amp current flows into the negative terminal, i.e.

$p_2 = 6 \times (-10) = -60$ W (Power supplied)

For the 22 Volt source, 6 Amp currents enters the positive terminal, hence,

$$p_3 = 22 \times 6 = 132\ W \qquad \text{(Power absorbed)}$$

Voltage across dependent source is 22 volt, since this voltage source is connected across it. Therefore, top of this dependent source is positive. Hence,

$$p_4 = 22 \times (0.4I)$$

$$\therefore p_4 = 22 \times (0.4 \times 10)$$

$$\therefore p_4 = 88\ W \qquad \text{(power absorbed)}$$

EX-1.16: Fig. 1.22 shows a circuit diagram. Determine the power supplied or absorbed by the voltage source for

(a) $V = 1$ volt, $I = 2$ Amp

(b) $V = 6$ Volt, $I = -4$ Amp

(c) $V = -12$ Volt, $I = -16$ Amp

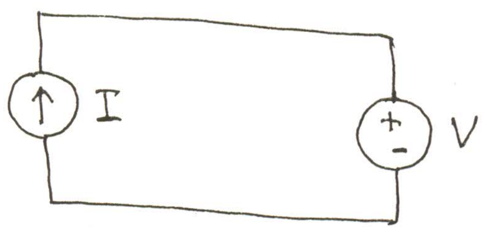


Fig. 1.22: Circuit diagram of EX-1.16

Soln.

For current source, ~~refererence~~ reference arrow for I is into the positively referenced terminal for V. Here simply we use $p = VI$ relationship.

(a) $P = VI = 1 \times 2 = 2W$ (Power absorbed)

(b) $P = VI = 6 \times (-4) = -24 W$ (Power supplied)

(c) $P = VI = (-12)(-16) = 192 W$ (Power absorbed)

Ex-1.17: Fig. 1.23 shows a circuit diagram. Determine p_1 and p_2 for (a) $I = 4$ Amp (b) $I = -3$ Amp.

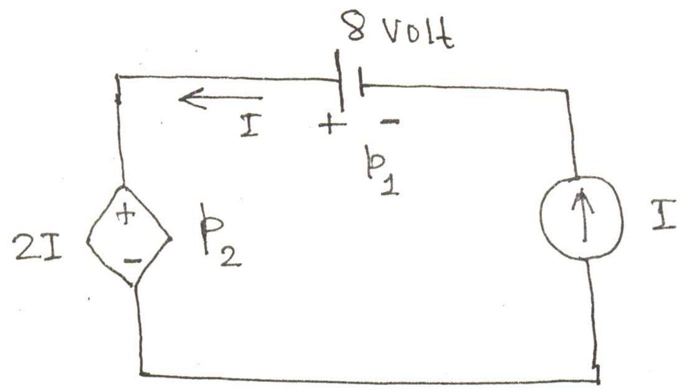


Fig. 1.23: circuit diagram of EX-1.17.

Soln.

~~Current~~

(a) when $I = 4$ Amp, current I flows out of the + terminal of 8 Volt source and enters the + terminal of dependent voltage source; Hence

$p_1 = 8 \times (-4) = -32$ W (Power supplied)

$p_2 = (2I) \times I = 2 \times 4 \times 4$.

$\therefore p_2 = 32$ W (power absorbed)

(b) when $I = -3$ Amp, ~~It is just opposite of case (a)~~

~~[illegible]~~

$p_1 = (-8)(-3) = 24\ W$ (Power absorbed)

$p_2 = (2I) \times I = 2\times(-3)^2 = 18\ W$ (Power absorbed)

EX-1.18: State which circuit connections are valid and which are invalid in Fig. 1.24.

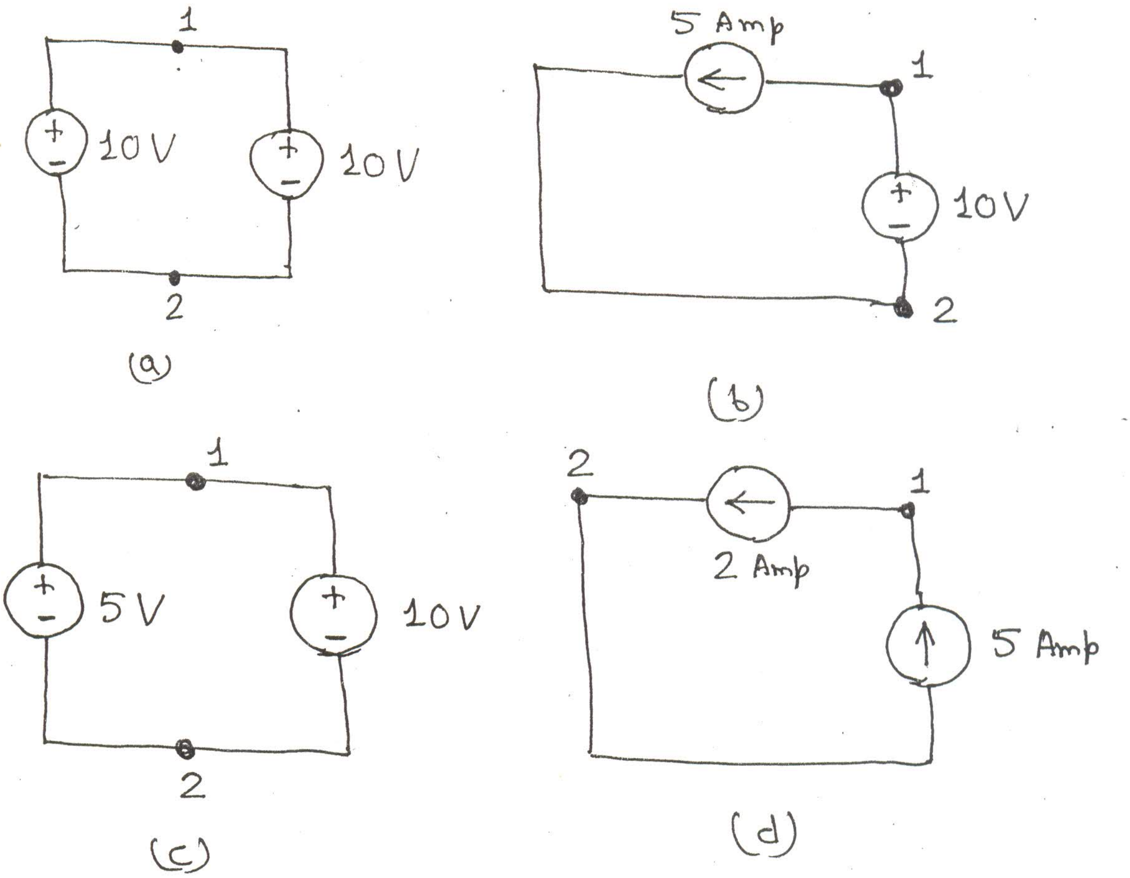


Fig. 1.24: Circuit diagrams of EX-1.18

Soln.

Connection (a) is valid. Each source supplies voltage across the same pair of terminals, marked 1 & 2. This requires that each source supply the same voltage with the same polarity, which they do.

Connection (b) is valid. The voltage source supplies voltage across the terminals 1 & 2. The current source supplies the current through the same pair of terminals.

Connection (c) is invalid. Each source supplies voltage across the same pair of terminals, marked 1 & 2. This requires that each source supply the same voltage with the same polarity, which they do not.

Connection (d) is invalid. Each source supplies the current through the same pair of terminals. This requires that each source supply the same current in the same direction, which they do not.

EXERCISE- 1

1.1: For $t \geq 0$, $q = 0.4(1 - e^{-250t})$ mC. Determine the current at $t = 3$ ms.

Ans: 47.2 mA

1.2: A certain circuit element has the current voltage

$i = 10 e^{-5000t}$ A and $v = 50(1 - e^{-5000t})$ Volt,

Find the total energy transferred during $t \geq 0$.

Ans: 50×10^{-3} J

1.3: For the circuit of Fig. 1.25, determine (a) the power, P_x, delivered to element X and (b) the voltage V_x, across element X.

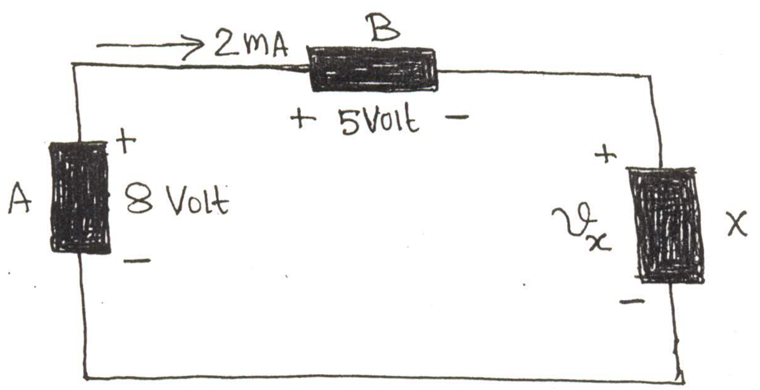


Fig. 1.25: Circuit for Problem 1.3

Ans: (a) 6 mW

(b) 3 Volt

1.4: The current at the terminals of an element is

$$i = 0, \text{ for } t < 0$$

$$i = 20\, e^{-5000t} \text{ Amp}, \text{ for } t \geq 0$$

Determine the total charge entering the element

Ans: 4000×10^{-6} C

1.5: Assume that a 20 Volt voltage drop occurs across an element from terminal 2 to terminal 1 and that a current of 4 Amp enters terminal 2.

(a) Specify the values of v and i for the polarity references shown in Fig. 1.26.

(b) State whether the circuit inside the box is absorbing or supplying power.

(c) How much power is the circuit absorbing?

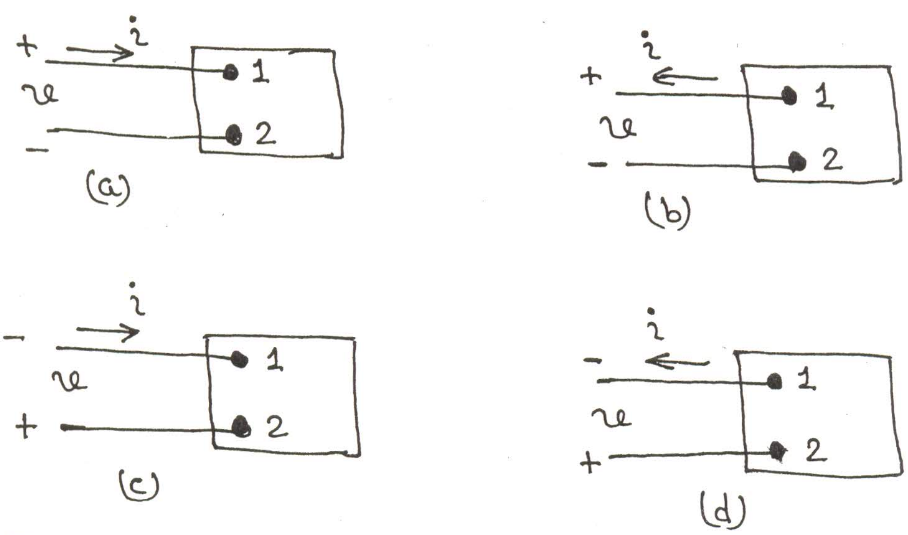


Fig. 1.26: Circuit diagram of Problem 1.5.

Ans: (a) Circuit 1.21(a); $v = -20V$, $i = -4A$

Circuit 1.21(b); $v = -20V$, $i = 4A$

Circuit 1.21(c); $v = 20V$, $i = -4A$

Circuit 1.21(d); $v = 20V$, $i = 4A$

(b) absorbing

(c) 80 Watt.

1.6: Assume that the voltage at the terminals of an element corresponding to the current in Problem 1.4 is

$$v = 0, \quad \text{for } t < 0$$

$$v = 10e^{-5000t} \text{ kV} \quad \text{for } t \geq 0$$

Determine the total energy delivered to the circuit element.

Ans: 20 joule

1.7: State which interconnection in Fig. 1.27 are valid and which violate the constraints imposed by the ideal sources.

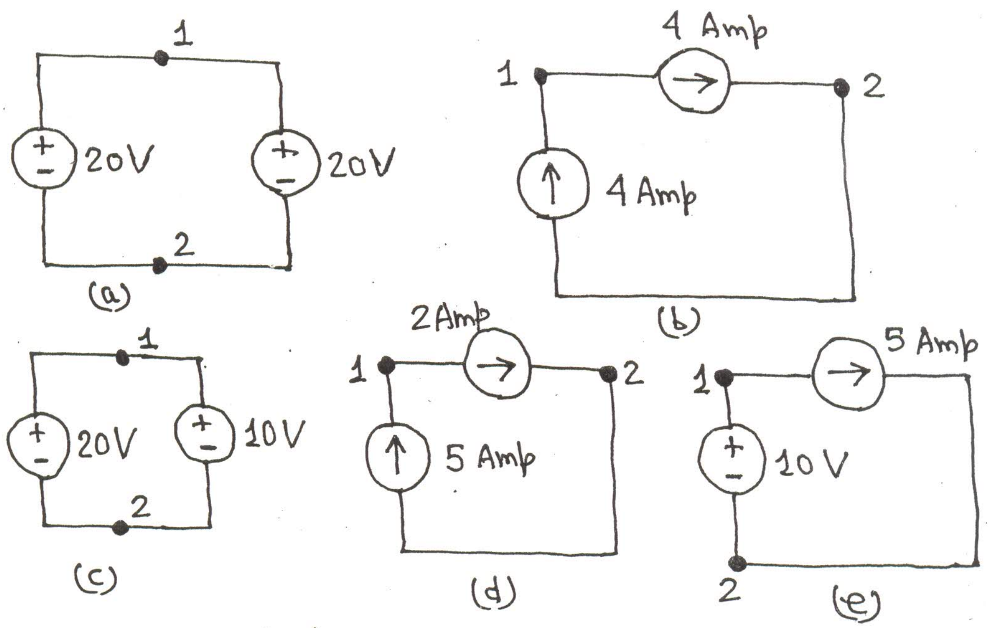


Fig. 1.27: circuit diagrams of Problem-1.7

Ans: (a) Valid (b) Valid (c) Not Valid
(d) Not Valid (e) Valid

1.8: A certain electrical element draws the current $i(t) = 10\cos(4t)$ Amp at a voltage $v(t) = 120\cos(4t)$ Volt. Find the energy absorbed by the element in 2.0 sec.

Ans: -2486 J.

1.9: A stove element draws 15 Amp when connected to a 120 V line. How long does it take to consume 30 000 J.

Ans: 16.67 Sec.

1.10: The current through an element is shown in Fig. 1.28. Compute the total charge that passed through the element at: (a) $t = 1$ sec, (b) $t = 3$ sec (c) $t = 5$ sec.

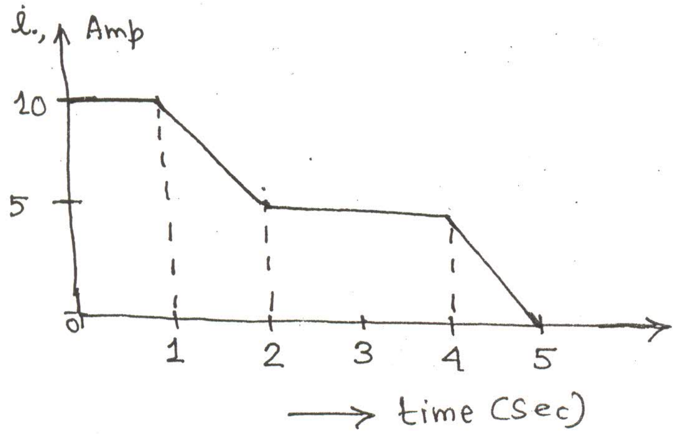


Fig. 1.28: For problem 1.10

Ans: (a) 10 C
(b) 22.5 C
(c) 30 C.

1.11: Two electric circuits represented by two boxes A and B are connected as shown in Fig. 1.29. For each of the following sets of numerical values, determine the power and state whether the power is flowing from A to B or B to A.

(a) $i = 5$ Amp, $v = 120$ Volt

(b) $i = -8$ Amp, $v = 250$ Volt

(c) $i = -10$ Amp, $v = -480$ Volt

(d) $i = 16$ Amp, $v = -150$ Volt

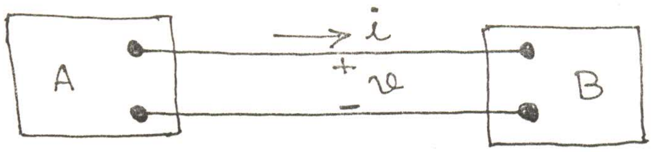


Fig.1.29: Circuit connection for problem 1.11

Ans: (a) 600 W, A to B

(b) −2000 W, B to A

(c) 4800 W, A to B

(d) −2400 W, B to A.

1.12: The voltage and current at the terminals of the circuit shown in Fig. 1.30 are zero for $t < 0$. For $t \geq 0$, $v = 100e^{-50t}\sin(150t)$ Volt and $i = 20e^{-50t}\sin(150t)$ Amp.

(a) Find the power absorbed by the element at $t = 0.02$ sec

(b) Find the total energy absorbes by the element.

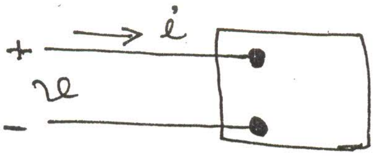


Fig. 1.30: circuit element of problem 1.12.

Ans: (a) 5.39 W (b) 9 J

1.13: For the circuit connection of Fig. 1.31, determine p_1, p_2 and p_3 for (a) I = 2 Amp (b) I = −3 Amp

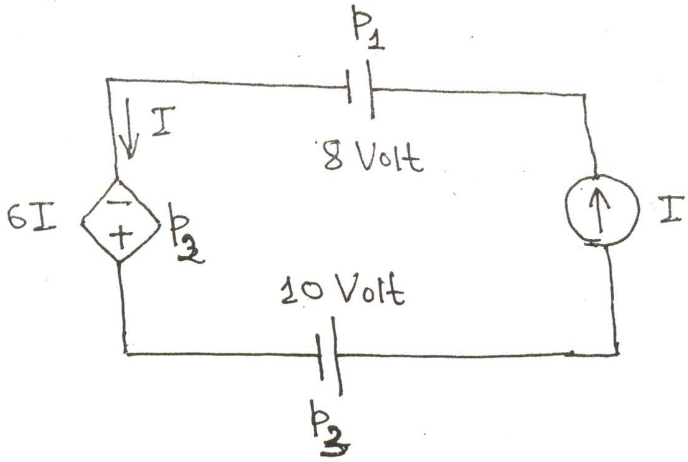
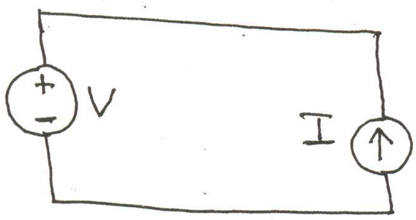


Fig. 1.31: circuit diagram for problem 1.13.

Ans: (a) p_1 = 16 Watt, p_2 = −24 Watt, p_3 = −20 Watt

(b) p_1 = −24 Watt, p_2 = −54 Watt, p_3 = 30 Watt.

1.14: For the circuit of Fig. 1.32, compute the power absorbed or supplied by the current source for (a) V = 4 volt, I = 2×10^{-3} Amp (b) V = 10 volt, I = −15 Amp.



Ans: (a) − 0.008 Watt

(b) 150 Watt.

Fig. 1.32: Circuit diagram for problem 1.14

1.15: The current entering the positive terminal of a device is $i(t) = 3e^{-2t}$ Amp and the voltage across the device is $v(t) = 5\frac{di}{dt}$ Volt. Determine

(a) the charge delivered to the device between $t = 0$ and $t = 2$ sec.

(b) the power absorbed (c) the energy absorbed in 3 sec.

Ans: (a) 1.297 C (b) $-90e^{-4t}$

(c) -22.5 Joule

1.16: Determine the power consumed or supplied by each component in the circuit of Fig. 1.33.

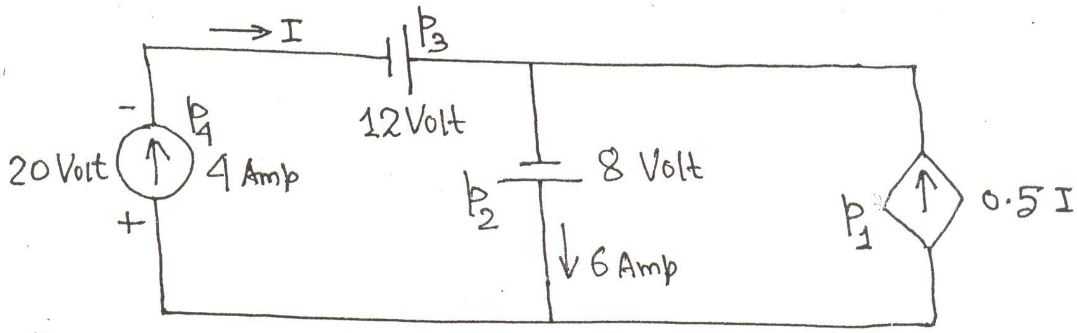


Fig. 1.33: circuit connection of Problem 1.16

Ans: $P_1 = 16$ Watt, $P_2 = -48$ Watt.

$P_3 = -48$ Watt, $P_4 = 80$ Watt.

1.17: Fig. 1.34 shows a circuit connection with five elements. If $P_1 = -205$ Watt, $P_2 = 60$ Watt, $P_3 = 70$ Watt, $P_5 = 30$ Watt. Determine the power P_4 received or supplied by element P_4.

Ans: 45 Watt.

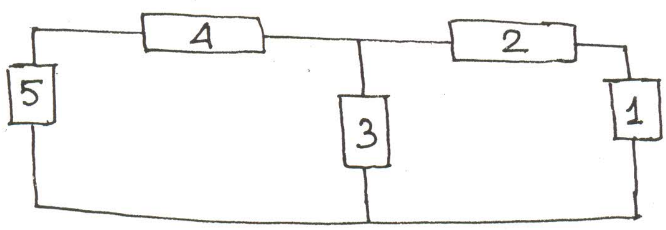


Fig. 1.34: Circuit connection for Problem 1.17.

1.18: Determine I_s in the circuit of Fig. 1.35.

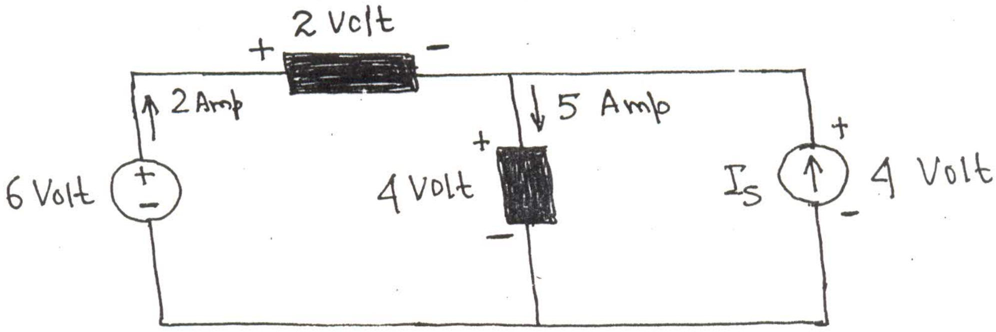


Fig. 1.35 : Circuit connection for Problem 1.18

Ans: $I_s = 3$ Amp.

1.19 The charge flowing in a conductor is plotted in Fig. 1.36. Sketch the current wave form.

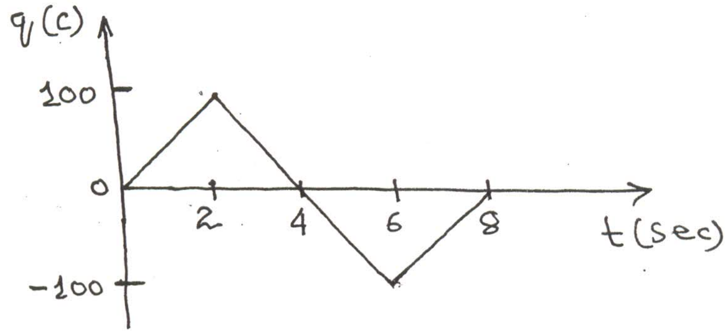


Fig. 1.36: Wave form for Problem 1.19.

$$\text{Ans:} \quad i = \begin{cases} 50 \text{ A}, & 0 < t < 2 \\ -50 \text{ A}, & 2 < t < 6 \\ 50 \text{ A}, & 6 < t < 8 \end{cases}$$

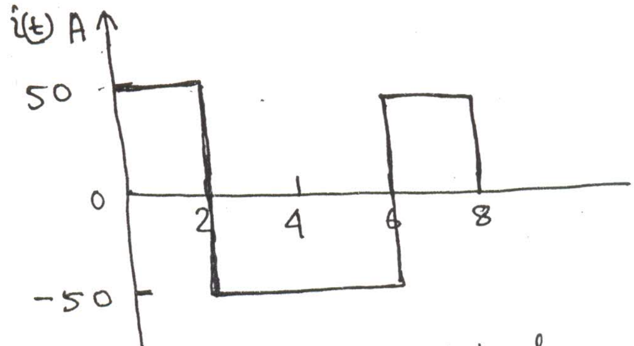


Fig. A1.19: Sketch of current wave form

1.20: Which of the devices of Fig. 1.37 are sources?

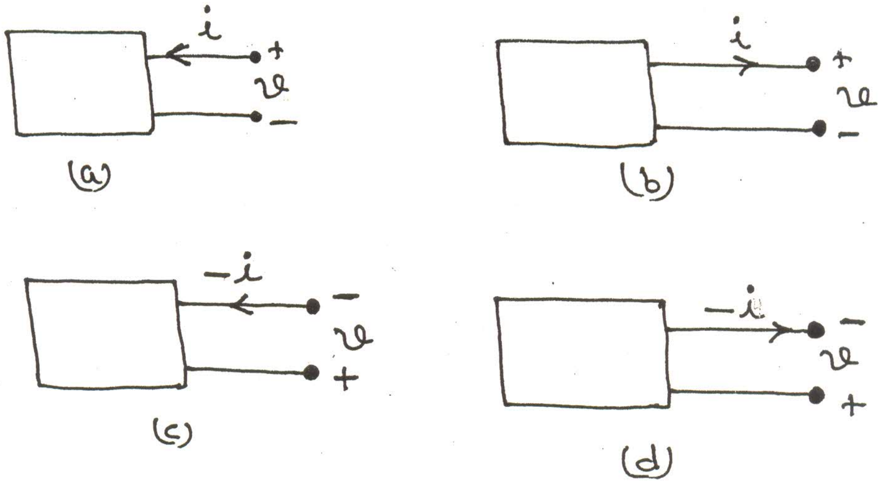


Fig. 1.37: Circuits connections of Problem 1.20

Ans : (b) and (d)

1.21: How much power is delivered by a 10 Amp current source (a) if it is open circuited? (b) if it is short circuited? (c) if a voltage source of 1 Volt is placed across it so that the current enters at the negative terminal of the voltage source?

Ans: (a) infinity (b) none
(c) −10 Watt.

1.22: How much power is delivered by a 10 Volt Voltage source (a) if it is open circuited? (b) if it is short circuited? (c) if it is connected in parallel with a current source of value 1 Amp and direction such that the current enters the positive terminal of the voltage source?

Ans: (a) none (b) infinity
(c) −10 Watt.

1.23: In moving from 1 to 2, a Coulomb of charge changes its energy by 10 Joules. Give the voltage of point 1 with respect to point 2 if (a) the charge is positive and the energy is lost (b) the charge is positive and the energy is gained (c) the charge is negative and the energy is lost and (d) the charge is negative and the energy is gained.

Ans: (a) 10 Volt (b) −10 Volt (c) −10 Volt
(d) 10 Volt.

1.24: In a certain two-terminal device a positive current of 10 Amp enters at terminal 1 and leaves from terminal 2. What is the power absorbed in the device when (a) the voltage at 1 is 10 Volts positive with respect to 2? (b) the voltage at 2 is 10 Volts positive with respect to 1? (c) the voltage at 1 is −10 Volt positive with respect to 2?

Ans: (a) 100 Watt (b) −100 Watt
(c) −100 Watt.