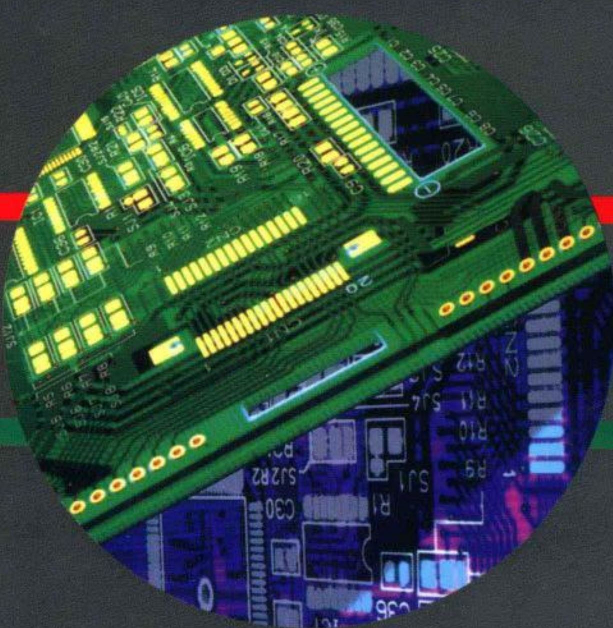
电 工 学

Electrical Engineering

（英文版）

主编 孙凡金



大连海事大学出版社

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内容简介

《电工学（英文版）》内容包括：概述、电路理论、暂态电路、正弦交流电路、三相电路、半导体二极管和晶体管、理想运算放大器、数字电路，共8章。本书采用国际通用的图形符号、名词与术语体系，各章配有深浅度适中的习题，附录添加了电工常用英文词汇及数学运算英文注释，帮助读者在较短时间内理解并掌握书中内容。本书内容简明扼要、深入浅出、语言准确、流畅，适用于工科各专业本（专）科英语或双语教学，特别适合开设双语电工学课程的院校使用。此外，本书亦可作为职业大学、成人教育大学和网络教育等同类专业的教材，以及工程技术人员的学习参考资料。

前　言

《论语》道“工欲善其事，必先利其器”，而时至今日，随着自然科学与社会科学的紧密结合与长足发展，“器”者，不应局限于生产工具和操作技能等基本手段，个人的“思维创新”与民族的“科学发展”方为国之大器。创新性思维和综合能力的培养来源于先进的教育体制和科学的教育手段。

自我国加入WTO后，标志中国进入世界多边贸易机制，为适应经济全球化和科技革命的挑战，高等教育的发展正趋向于教育方式的国际化和人才培养的综合化。其中，国内各高等院校先后在不同专业对相关课程开设了“双语教学”，并不断推广与普及，积累经验，探索合理的教学方法和教学手段，已取得一定的成果。在我国，所谓双语教学是指用汉语以外的一门外语（多指英语）作为课堂主要用语，进行非语言学科的教学，培养学生专业知识的同时，加强和提高英语水平。仅开设基础外语科目，只能使学生掌握有限的外语，很难达到精通的程度，由此双语教学被普遍认为是提高英语综合运用能力的重要途径之一。

开展双语教学的目标是使学生在掌握该学科的专业知识和技能的基础上，逐步掌握该学科知识的外语表达和专业术语，提高用外语进行各种学术交流的能力，锻炼学生用英语进行学习和思考的能力。双语教学因非母语授课，在教学资源上和教学手段上严重匮乏。“预则立，不预则废”，为不断提高双语教学质量，作者认为下列教学环节应不断加强，师生共进。

（1）师资是教育之本，教育之魂

“师者，传道授业解惑者也”，作者认为“己惑者，授惑于众，则众惑；己明者，授明于众，则众明”。双语教学不但要求教师有良好的外语水平，更为重要的是专业授课能力，只有在丰富的专业授课经验的前提下，知识的外语讲解才能有的放矢。因此，对从事双语授课的教师，要进行必要的培训，阶段性培养，分层次考核。若揠苗助长，形式主义，只能所授非所长。例如，授课外语比例可为30%、50%、70%、90%进行逐层提高，切勿急于求成、好高骛远。

（2）教材应以人为本，以业授道

因国外与国内教学体制的严重差异，双语教学对教材的要求应人性化、科学化，为所授专业学生量身设计。若无合适的国外原版教材，可自行编写满足教学大纲的讲义或

教材。不根据授课专业和教学大纲而盲目选择原版教材只能导致资源浪费。以《电工学》课程为例，国内高校教学大纲通常包含电路基础、电磁理论、数字电路、模拟电路4部分内容，主要针对非电类专业开设的基础课。而国外教材选取比较困难，由此，作者通过参阅大量国外教材，根据专业培养要求和教学大纲编写了此书，尽量做到知识点清晰、深入，应用实例新颖、丰富，语言准确、生动，使学生在掌握电工技术英文表达和专业术语的基础上，逐渐培养中文与英文交叉思考的能力和习惯，为未来的专业发展打下良好的基础。

（3）课堂要温水煮蛙，循序渐进

在授课的初期，建议以中文讲授为主，不断引入外语专业术语，随教学内容的推进，逐步增大英语比例，最终过渡到以外语授课为主的双语模式。将教学内容根据难易程度不同加以划分，易于理解的内容采用全外语讲解，在一些重点、难点和比较容易产生歧义的地方用汉语进行解释或重复强调，可避免学生因语言滞后而造成的思维障碍。比如电工学中，讲解晶体管内部载流子的运动过程和外部电流生成方式，以及三极管小信号模型时，应关注中文的解释。最后，让学生在自然轻松状态下接受外语授课，达到温水煮蛙的效果。

在本人的教学过程中发现，部分学生由于英语水平较低，会产生消极的学习心态，由此利用课堂英语交流和多媒体来丰富授课内容，从而激发学习兴趣，培养学习热情，进入良性学习状态中。例如，在电工学的双语授课中，可多向学生介绍国内外电气技术的发展现状和趋势，大型电气公司的产品及技术组成。

总之，双语教学是高等院校培养创新型和综合性人才的一种重要途径，而我国双语教学的实践改革正在探索前进，作者愿与从事此项工作的同仁互勉互励，为我国的教育事业和人才培养尽微薄之力。

本书第2、3、4、6、7章由孙凡金编写，第1、5章由刘彦呈编写，第8章由赵友涛编写。王川老师与陈洋老师对书中图文做了修订工作，在此深表感谢。

由于编者能力有限，本书内容难免有不完善之处，殷切期望读者给予批评和指正，以便今后修订提高。

孙凡金

2012年11月于大连海事大学

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Chapter 1 Introduction

CHAPTER OUTLINE

1.1 Circuit Diagrams [电路图]
1.2 Voltage and Current Direction [电压与电流方向]
1.3 Voltage and Current Source [电压源与电流源]
1.4 Ohm's Law [欧姆定律]
1.5 Nodes, Loops and Branches [结点、回路与支路]
1.6 Kirchhoff's Law [基尔霍夫定律]
1.7 Series and Parallel Circuits [串联与并联电路]

WORDS AND KEY TERMS

- circuit [电路]
- resistor [电阻]
- inductor [电感]
- current [电流]
- node [结点]
- battery [电池]
- capacitor [电容]
- amplifier [放大器]
- electron [电子]
- branch [支路]
- switch [开关]
- transistor [晶体管]
- voltage [电压]
- positive polar [正极]
- negative polar [负极]

1.1 Circuit Diagrams [电路图]

Electrical systems can not only gather, store, process, transport, and present information, but also distribute, store, and convert energy between various forms. For example, in electrical power plant, energy is converted from various sources to electrical form. Electrical distribution systems transport the energy to virtually every factory, home, and business in the world, where it is converted to a multitude of useful forms, such as mechanical energy, heat, and light.

Electric circuits are constructed using components such as batteries, switches, resistors, capacitors, transistors, interconnecting wires, etc. The diagrams are used to represent these circuits on paper, and diagrams generally include three types: block diagrams, schematic diagrams, and pictorial diagrams.

1.1.1 Block diagrams [结构图]

Block diagrams describe a circuit or system in simplified form. The overall problem is broken into blocks, each representing a portion of the system or circuit. Blocks are labeled to indicate what they do or what they contain, and then interconnected to show their relationship to each other. General signal flow is usually from left to right and top to bottom. Fig. 1.1, for example, represents an audio amplifier. Although the detail circuits are not presented in this block diagrams, you should be able to follow the general idea quite easily—sound is picked up by the microphone, converted to an electrical signal, amplified by a pair of amplifiers, then output to the speaker, where it is converted back to sound. A power supply energizes the system. The advantage of a block diagram is that it gives you the overall picture and helps you understand the general nature of a problem. However, it does not provide detail.

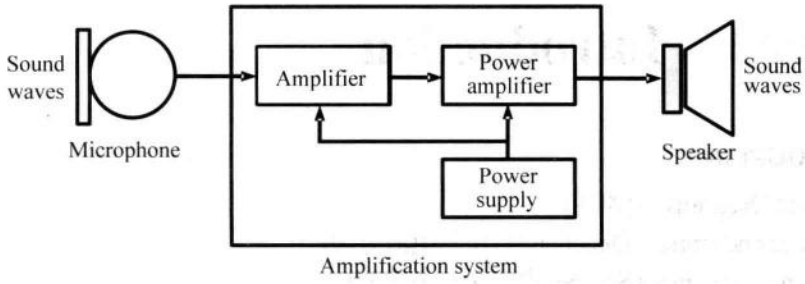


Fig. 1.1 A block diagram of an audio amplification system

1.1.2 Pictorial diagrams [实物图]

Pictorial diagrams are one of the types of diagrams that provide detail. They help you visualize circuits and their operation by showing components as they actually appear. For example, the circuit of Fig. 1.2 consists of a battery, a switch, and an electric lamp, all interconnected by wire. When the switch is closed, the battery causes current in the circuit, which lights the lamp. The battery is referred to as the source and the lamp as the load.

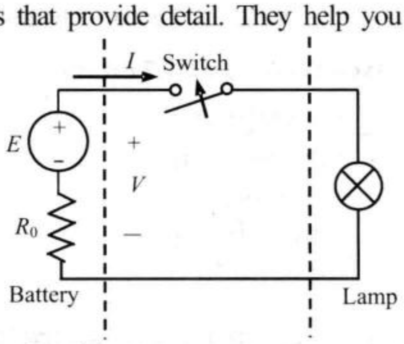


Fig. 1.2 Circuit based on pictorial

1.1.3 Schematic diagrams [原理图]

While pictorial diagrams help you visualize circuits, they are cumbersome to draw. ***Schematic diagrams*** get around this by using simplified, standard symbols to represent components. In Fig. 1.3, for example, we have used some of these symbols to create a schematic for the circuit of Fig. 1.2. Each component has been replaced by its corresponding circuit symbol. Consider the lamp of Fig. 1.3, the lamp possesses a property called *resistance* that causes it to resist the passage of charge. When you wish to emphasize this property, use the resistance symbol rather than the lamp symbol.

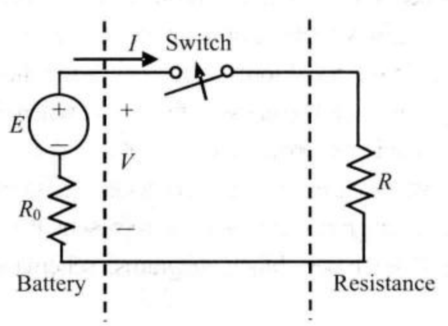


Fig. 1.3 Circuit based on schematic diagram

1.2 Voltage and Current Direction [电压与电流方向]

In order to figure out how circuit work, we will first examine some of the different components that can be used in a circuit: voltage and current sources, batteries, and resistors. We also need to understand the concepts of voltage, current, and power, since these are the quantities we usually need to find. One word of advice before we begin: pay close attention to the role of "+" and "–" signs when labeling voltages, and the significance of the arrow in defining current; They often make the difference between wrong and right answers.

1.2.1 Charge [电荷]

One of the most fundamental concepts in electric circuit analysis is that of charge conservation. We know from basic physics that two types of charge: positive (corresponding to a proton), and negative (corresponding to an electron). For the most part, this text is concerned with circuits in which only electron flow is relevant. There are many devices (such as batteries, diodes, and transistors) in which positive charge motion is important to understanding internal operation, but external to the device we typically concentrate on the electrons which flow through the connecting wires. Although we continuously transfer the charges between different parts of a circuit, we do nothing to change the total amount of charge. In other word, we neither create nor destroy electrons (or protons) when running electric circuit. Charge in motion represents a current.

In the SI (international system of units) system, the fundamental unit of charge is the ***Coulomb*** (C). It is defined in terms of the ampere by counting the total charge that passes through an arbitrary cross section or a wire during an internal of one second; one coulomb is measured each second for a wire carrying a current of 1 ampere (Fig. 1.4). In this system of units, a single electron has a charge of -1.602×10^{-19} C and a single proton has a charge of $+1.602\times10^{-19}$ C.

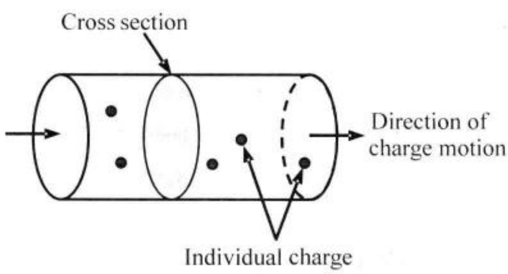


Fig. 1.4 Charge flowing through a wire, illustrating the definition of the coulomb

A quantity of charge that does not change with time is typically represented by Q. The instantaneous amount of charge (which may or may not be time-invariant) is represented by $q(t)$. or simply q. This convention is used throughout the remainder of the text: capital letters are reserved for constant (time-invariant) quantities, whereas lowercase letters represent the more general case. Thus, a constant charge may be represented by either Q or q, but an amount of charge that changes over time must be represented by the lowercase letter q.

Electrical circuits are analogous to fluid-flow systems. The battery is analogous to a pump, and charge is analogous to the fluid. Conductors (usually copper wires) correspond to frictionless pipes through which the fluid flows.

1.2.2 Current [电流]

The idea of "transfer of charge" or "charge in motion" is of vital importance to us in studying electric circuits because, in moving a charge from place to place, we may also transfer energy from one point to another. The familiar cross-country power transmission line is a practical example of a device that transfers energy. Of equal importance is the possibility of varying the rate at which charge is transferred in order to communicate or transfer information. This process is the basis of communication systems such as radio, television, and telemetry.

The current present in a discrete path, such as a metallic wire, has both a numerical value and a direction associated with it; it is a measure of the rate at which charge is moving past a given reference point in a specified direction.

Once we have specified a reference direction, we may let $q(t)$ be the total charge that has the reference point since an arbitrate time $t=0$, moving in the direction. A contribution to this total charge will be negative if negative charge is moving in the reference direction, or if positive charge is moving in the opposite direction. As an example, Fig. 1.5 shows a history of the total charge $q(t)$ that has passed a given reference point in a wire (such as the one shown in Fig. 1.4).

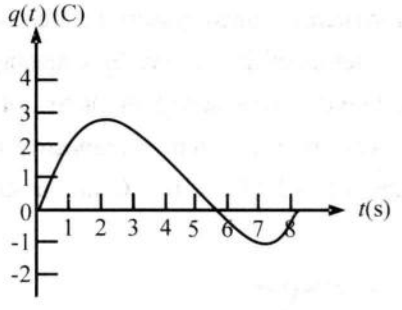


Fig.1.5 A graph of the instantaneous value of the total charge $q(t)$ that has passed a given reference point since $t=0$

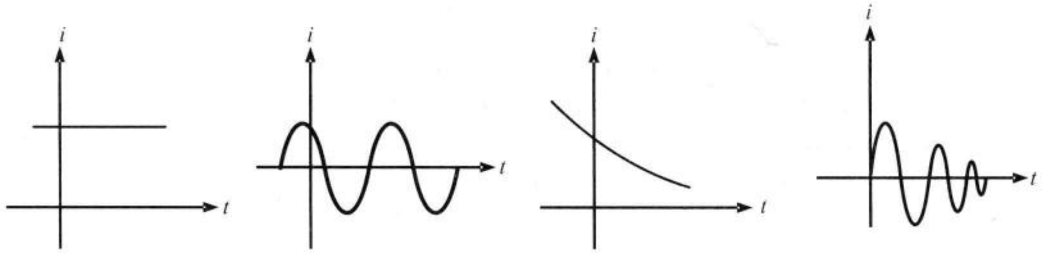
We define the current at a specific point and flowing in a specified direction as the instantaneous rate at which net positive charge is moving past that point in the specified direction. This, unfortunately, is the historical definition, which came into popular use before it was appreciated that current in wires is actually due to negative, not positive charge motion. Current is symbolized by I or i, and so

$$i=\frac{\mathrm{d}q}{\mathrm{d}t} \tag{1-1}$$

The unit of current is the ampere (A), named after A. M. Ampere, a French physicist. It is commonly abbreviated as an "amp", this is unofficial and somewhat informal.

Using Eq. (1-1), we can compute the instantaneous current. The use of the lowercase letter i is again to be associated with an instantaneous value; an uppercase I would denote a constant (i.e., time-invariant) quantity.

Several different types of current are illustrated in Fig. 1.6. A current that is constant in time is termed a direct current, or simply DC, and is shown by Fig. 1.6 (a). We will find many practical examples of currents that vary sinusoidal with time (Fig. 1.6 (b)); currents of this form are present in normal household circuit. Such a current is often referred to as alternating current, or AC. Exponential currents and damped sinusoidal currents are shown in Fig. 1.6 (c) and Fig. 1.6 (d).



(a) Direct current (dc) (b) Sinusoidal current (ac) (c) Exponential current (d) Damped sinusoidal current

Fig. 1.6 Several types of current

We establish a graphical symbol for current by placing an arrow next to the conductor. Thus, in Fig. 1.7 (a) the direction of the arrow and the value 5 A indicate either that a net positive charge of –5 C/s is moving to the right or that a net negative charge of +5 C/s is moving to the left each second. In Fig. 1.7(b) there are again two possibilities: either +5 A is flowing to left or –5 A is flowing to the right. All four statements and both figures represent currents that are equivalent in their electrical effects, and we say that they are equal. A non electrical analogy that may be easier to visulize is to think in terms of a personal saving account: e.g., a deposit can be viewed as either a negative case flow out of your account or a positive flow into your account.

Fig.1.7 Two methods of representation for the exact same current

It is convenient to think of current as the motion of positive charge, even though it is known that current in metallic conductors results from electron motion. In ionized gases, in some semiconductor materials, positively charged elements in motion constitute part or all of the current. Thus, any definition of current can agree with the physical nature of conduction only part of the time. The definition and symbolism we have adopted are standard.

It is essential that we realize that the current arrow does not indicate the "actual" direction flow but is simply part of a convention that allows us to talk about "the current in the wire" in an unambiguous manner. The arrow is a fundamental part of the definition of a current! Thus, to talk about the value of a current $i(t)$ without specifying the arrow is to discuss an undefined entity.

So far we have used arrows alongside circuit elements or conductors to indicate reference directions for currents. Another way to indicate the current and reference direction for a circuit element is to label the ends of the element and use double subscripts to define the reference direction for the current. For example, consider the resistance of Fig. 1.8. The current denoted by i_{ab} is the current through the element with its reference direction pointing from a to b. Similarly, i_{ba} is the current with its reference directed from b to a. of course, i_{ab} and i_{ba} are the same in magnitude and opposite in sign, because they denote the same current but with opposite reference directions. Thus, we have $i_{ab} =-i_{ba}$.

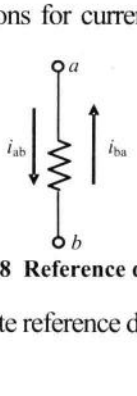


Fig.1-8 Reference direction

1.2.3 Voltage [电压]

We must now begin to refer to a circuit element, something best defined in general terms to begin with. Such electrical devices as fuse, light bulbs, resistors, batteries, capacitors, generators, and spark coils can be represented by combinations of simple circuit elements. We begin by showing a very general circuit element as a shapeless object possessing two terminals at which connections to other elements may be made (Fig. 1.9).

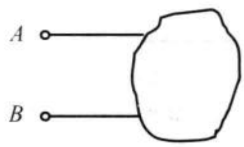


Fig.1.9 A two-terminal circuit element

There are two paths by which current may enter or leave the element. In subsequent discussions we will define particular circuit elements by describing the electrical characteristics that may be observed at their terminals.

In Fig. 1.9, let us suppose that a dc current is sent into terminal *A*, through the general element, and back out of terminal *B*. Let us also assume that pushing charge through the element requires an expenditure of energy. We then say that an electrical voltage (or a potential difference) exists between the two terminals, or that there is a voltage "across" the element. Thus, the voltage across a terminal pair is a measure of the work required to move charge through the element. The unit of voltage is the volt, and 1 volt is the same as 1 J/C. Voltage is represented by V or v.

A voltage can exist between a pair of electrical terminals whether a current is flowing or not. An automobile battery, for example, has a voltage of 12 V across its terminals even if nothing whatsoever is connected to the terminals.

According to the principle of conservation of energy, the energy that is expended in forcing charge through the element must appear somewhere else. When we later meet specific circuit elements, we will note whether that energy is stored in some form that is readily available as electric energy or whether it changes irreversibly into heat, acoustic energy, or some other no-electrical form.

We must now establish a convention by which we can distinguish between energy supplied to an element, and energy that is supplied by the element itself. We do this by our choice of sign for the voltage of terminal *A* with respect to terminal *B*. If a positive current is entering terminal *A* of the element and an external source must expend energy to establish this current, then terminal *A* is positive with respect to terminal *B*. Alternatively, we may say that terminal *B* is negative with respect to terminal *A*.

The sense of the voltage is indicated by a plus-minus pair of algebraic signs. In Fig. 1.10 (a), for example, the placement of the "+" sign at terminal *A* indicates that terminal *A* is v volts positive with respect to terminal *B*. If we later find that v happens to have a numerical value of -5 V, then we may say either that *A* is -5 V positive with respect to *B* or that *B* is 5 V positive with respect to A. Other cases are shown in Fig. 1.10 (b), Fig. 1.10 (c), and Fig. 1.10 (d).

Just as we noted in our definition of current, it is essential to realize that the plus-minus pair of algebraic signs does not indicate the "actual" polarity of the voltage but is simply part of a convention that enables us to talk unambiguously about "the voltage across the terminal pair." Note: The definition of any voltage must indicate a plus-minus sign pair.

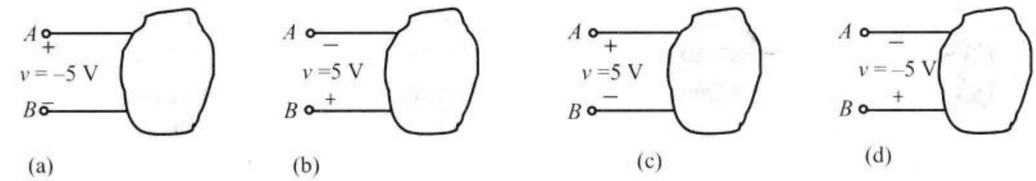


Fig. 1.10 (a, b) Terminal *B* is 5 V positive with respect to terminal *A*; (c, d) terminal *A* is positive with respect to terminal *B*

(1) Double subscripts

As you have already seen, voltages are always expressed as the potential difference between two points. In a 9V battery, there is a 9 V rise in potential from the negative terminal to the positive terminal. Current through a resistor results in a voltage drop across the resistor such that the terminal from which charge leaves is at a lower potential than the terminal into which charge enters. We now examine how voltages within any circuit may be easily described as the voltage between two points. If we wish to express the voltage between two points (say points *a* and *b* in a circuit), then we express such a voltage in a subscripted form (e.g., V_{ab}), where the first term in the subscript is the point of interest and the second term is the point of reference.

Consider the series circuit of Fig. 1.11. If we label the points within the circuit *a, b, c,* and *d,* we see that point *b* is at a higher potential than point *a* by an amount equal to the supply voltage. We may write this mathematically as V_{ba}= +50 V. Although the plus sign is redundant, we show it here to indicate that point *b* is at a higher potential than point *a.* If we examine the voltage at point *a* with respect to point *b,* we see that *a* is at a lower potential than *b.* This may be written mathematically as $V_{ab} = -50$ V.

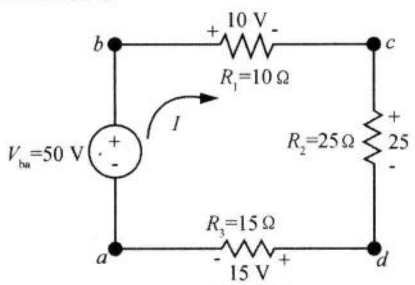


Fig. 1.11

From the above illustration, we make the following general statement:

$$V_{ab}=-V_{ba} \tag{1-2}$$

for any two points *a* and *b* within a circuit.

Current through the circuit results in voltage drops across the resistors as shown in Fig. 1.11. If we determine the voltage drops on all resistors and show the correct polarities, then we see that the following must also apply:

V_{bc}= +10 V V_{cb}= −10 V; V_{cd}= +25 V V_{dc}= −25 V; V_{da}= +15 V V_{ad}= −15 V

If we wish to determine the voltage between any other two points within the circuit, it is a simple matter of adding all the voltages between the two points, taking into account the polarities of the voltages. The voltage between points *b* and *d* would be determined as follows:

$$V_{bd}= V_{bc} + V_{cd} =10\text{ V}+25\text{ V}= +35\text{ V}$$

Similarly, the voltage between points *b* and *a* could be determined by using the voltage drops of the resistors:

$$V_{ba} = V_{bc} + V_{cd} + V_{da} = 10\text{ V} + 25\text{ V} + 15\text{ V} = +50\text{ V}$$

(2) Single Subscripts（electric potential）

In a circuit which has a reference point (or ground point), most voltages will be expressed with respect to the reference point. In such a case it is no longer necessary to express a voltage using a dual subscript. Rather if we wish to express the voltage at point *a* with respect to ground, we simply refer to this as V_a. Similarly, the voltage at point *b* would be referred to as V_b. Therefore, any voltage which has only a single subscript is always referenced to the ground point of the circuit.

Example 1-1: For the circuit of Fig. 1.12, determine the electric potentials V_a, V_b, V_c, and V_d.

Solution: Applying the voltage divider rule, we determine the voltage across each resistor as follows:

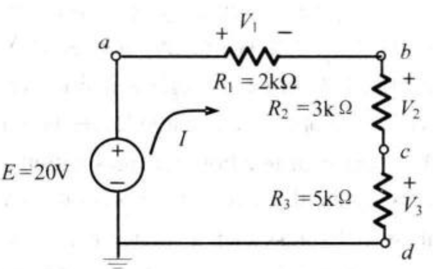


Fig. 1.12

$$V_1 = \frac{2\text{ k}\Omega}{2\text{ k}\Omega + 3\text{ k}\Omega + 5\text{ k}\Omega}(20\text{ V}) = 4\text{ V}$$

$$V_2 = \frac{3\text{ k}\Omega}{2\text{ k}\Omega + 3\text{ k}\Omega + 5\text{ k}\Omega}(20\text{ V}) = 6\text{ V}$$

$$V_3 = \frac{5\text{ k}\Omega}{2\text{ k}\Omega + 3\text{ k}\Omega + 5\text{ k}\Omega}(20\text{ V}) = 10\text{ V}$$

Now we solve for the voltage at each of the points as follows:

$$V_a = 4\text{ V}+6\text{ V}+10\text{ V}=+20\text{ V}=E\text{ ; } V_b = 6\text{ V}+10\text{ V}=+16\text{ V ; } V_c = +10\text{ V ; } V_d = 0\text{ V}$$

If the voltage at various points in a circuit is known with respect to ground, then the voltage between the points may be easily determined as follows:

$$V_{ab} = V_a - V_b \tag{1-3}$$

Example 1-2: For the circuit of Fig. 1.13, determine the voltages V_{ab} and V_{cb} given that V_a=+5 V, V_b=+3 V, and V_c=−8 V.

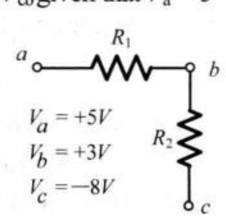


Fig. 1.13

Solution: V_{ab}= +5 V−(+3 V)= +2 V; V_{cb}=−8 V−(+3 V)=−11 V

The idea of voltages with respect to ground is easily extended to include voltage sources. When a voltage source is given with respect to ground, it may be simplified in the circuit as a ***point source.*** Point sources are often used to simplify the representation of circuits. We need to remember that in all such cases the corresponding points always represent voltages with respect to ground (even if ground is not shown).

Example 1-3: Determine the current and direction in the circuit of Fig. 1.14.

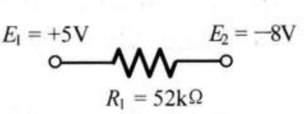


Fig. 1.14

Solution: The circuit may be redrawn showing the reference point and converting the voltage point sources into the more common schematic representation. The resulting circuit is shown in Fig. 1.15.

Now, we easily calculate the current in the circuit as

$$I = \frac{E_1 - E_2}{R_1} = \frac{5\ \text{V} - (-8\ \text{V})}{52\ \text{k}\Omega} = 0.25\ \text{mA}$$

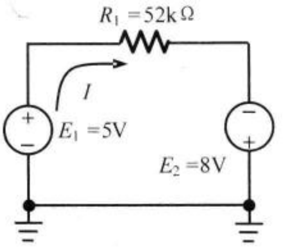


Fig. 1.15

1.2.4 Power [功率]

We now need to determine an expression for the power being absorbed by a circuit element in terms of a voltage across it and current through it. Voltage has already been defined in terms of energy expenditure, and power is the rate at which energy is expended.

We have already defined power, and we will represent it by P or p. If one joule of energy is expended in transferring one coulomb of charge through the device in one second, then the rate of energy transfer is one watt. The absorbed power must be proportional both to the number of coulombs transferred per second (current), and to the energy needed to transfer one coulomb through the element (voltage). Thus, $p = vi$. The physical unit of the power is watt.

Consider the circuit element shown in Fig. 1.16. Because the current is the rate of flow of charge and the voltage v is a measure of the energy transferred per unit of charge, the product of the current and the voltage is the rate of energy transfer.

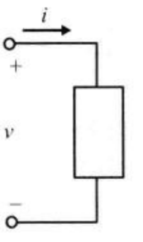


Fig. 1.16

Now we may ask whether the power calculated represents energy supplied or absorbed by the element. Refer to Fig.1.16 and notice that the current reference enters the positive polarity of the voltage. We call this arrangement the passive reference configuration. Provided that the references are picked in this manner, a positive result for the power calculation implies that energy is being absorbed by the element. On the other hand, a negative result means that the element is supplying energy to other parts of the circuit.

If the current reference enters the negative end of the reference polarity, a positive value for p indicates the energy is supplied by the element, and a negative value shows that energy is absorbed by the element.

Example 1-4: Consider the circuit elements shown in Fig. 1.17. Calculate the power for each element.

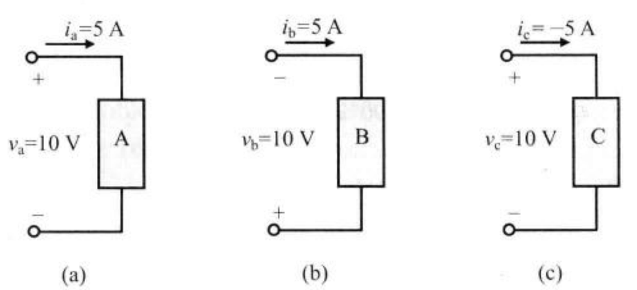


Fig.1.17 Circuit elements for Example 1-4.