# Introduction +
# Lecture 1: Circuit Theory Basics

Makerspace - MS 101

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# Objective and Major Components of the EE Syllabus

- To give students sufficient background in Electronic Circuits - to design and implement their final project
- Major components of the EE Syllabus (Lectures: 12)
  - KCL, KVL, Passive Components, Transformer
  - Electronic devices: pn junction diode, Zener diode, LED, Photodiode, solar cell.
  - Diode circuits – half-wave, full-wave, bridge
  - Operational amplifiers, feedback amplifiers, oscillators, comparators and Schmitt trigger
  - BJT switches
  - Electromechanical devices: relays, DC motors, Servo motors
  - Logic gates and digital circuits, digital-to-analog converter (DAC), and analog-to-digital converter (ADC)
  - Microprocessors, microcontrollers, memory and I/O devices
  - Sensors, actuators, interfacing
  - Microcontroller board (Arduino) with real-word interfacing

# Lab Experiments

1) Familiarization with basic measuring instruments and other lab equipment (DMM, DSO, AFG); measurement of frequency response of an RC high-pass filter.
2) a) Unregulated DC power supply using transformer and rectifiers (Bridge Rectifier); measurement of ripple voltage for a few $R_L$ and C values.
   b) Familiarization with the Keithley DC Power Supply
   c) Regulated DC power supply using a 3-pin regulator IC; measurement of line and load regulations.
3) Op-amp based inverting amplifier and a low-pass filter: frequency response measurements.
4) Familiarization with the Arduino Board. Interfacing relay using BJT.
5) Arduino board in battery mode: interfacing DC motor and other sensors.

# Reference Books

- W H Hayt, J E Kemmerly, and S M Durbin, Engineering Circuit Analysis, 8th ed., Mc Graw-Hill, (Indian Edition), 2013.
- A.S. Sedra and K.C. Smith, Microelectronic Circuits, Oxford University Press, 7th ed. (Indian edition), 2017.
- MA Mazidi, S Naimi, S Naimi, AVR Microcontroller and Embedded Systems: Using Assembly and C, Pearson India, 1st edition 2013.

- *Note: No need to busy these books. E-copies of the required portions will be uploaded on Moodle*

# Lecture 1: Circuit Theory Basics

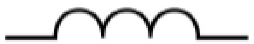
# Lecture 1: Circuit Theory Basics

- Part A: Passive electrical devices: R, L, C, and transformer.
- Part B: Independent and dependent sources
- Part C: Kirchhoff’s current and voltage laws

# Part A: Passive Electrical Devices - R, L, C and Transformer

# R (Resistor), L (Inductor), C(Capacitor)

- *R*, *L* and *C* are used in electronic circuits
- They are **two-terminal** devices (or **single-port** devices)
  - Can be fully described by their *V-I* characteristic

| | | |
|---|---|---|
| Resistor |  | $V = IR$ |
| Inductor |  | $v = L\frac{di}{dt}$ |
| Capacitor |  | $v = \frac{1}{C}\int i\,dt$ |

# Resistors

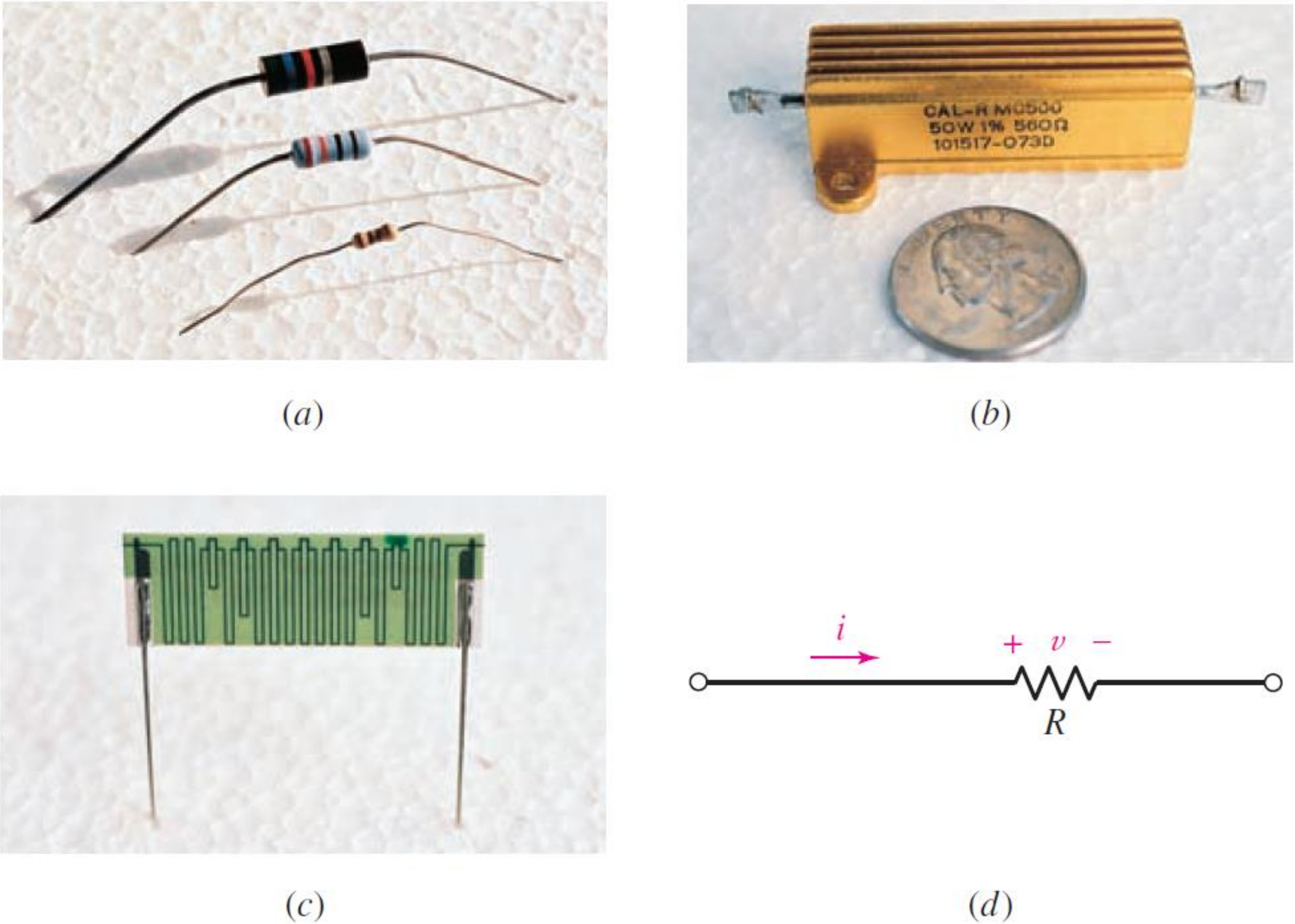



**FIGURE 2.24** (*a*) Several common resistor packages. (*b*) A 560 Ω power resistor rated at up to 50 W. (*c*) A 5% tolerance 10-teraohm (10,000,000,000,000 Ω) resistor manufactured by Ohmcraft. (*d*) Circuit symbol for the resistor, applicable to all of the devices in (*a*) through (*c*).

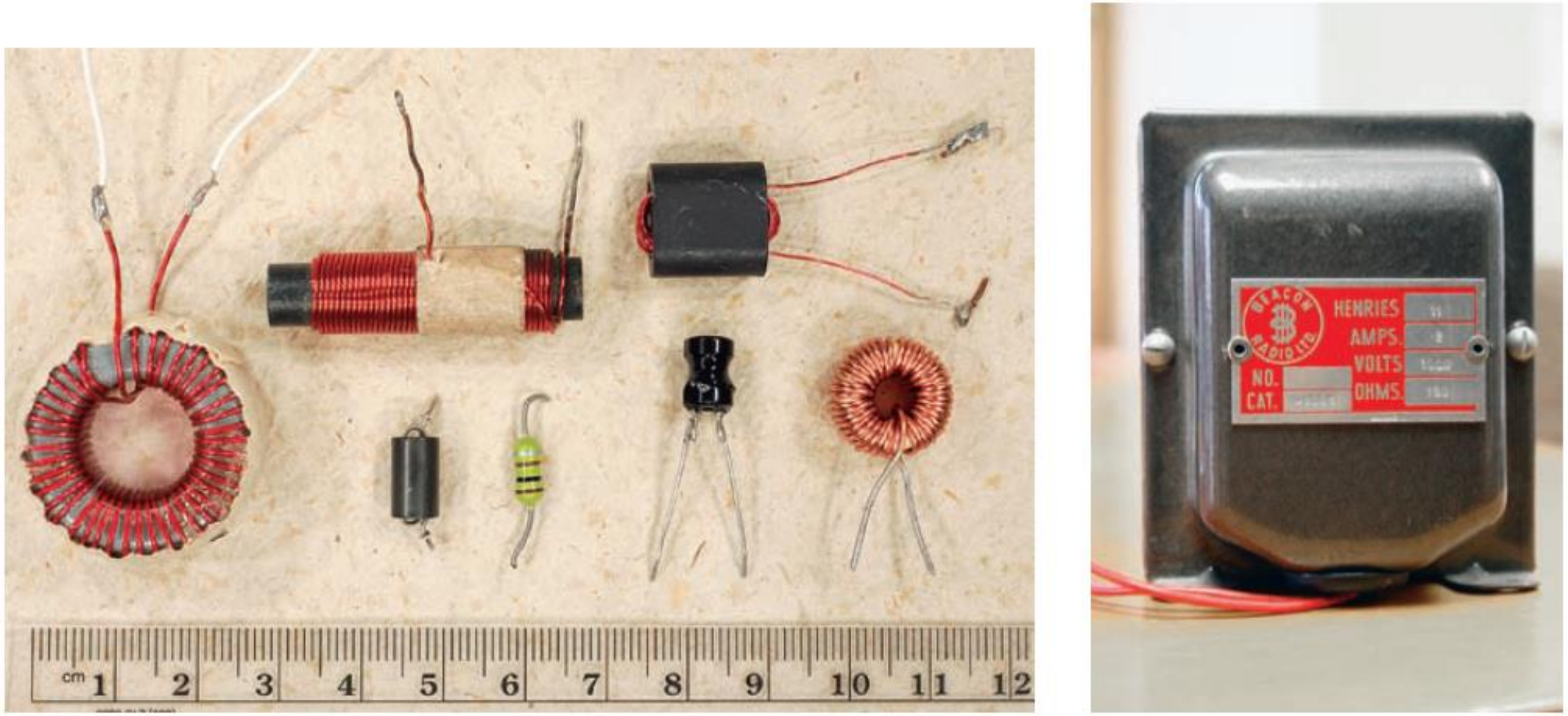
Source: Chapter 2, Sec 2.4: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8th ed., McGraw-Hill Company, 2012

# Resistors: Common Applications in Electronic Circuits

- Extensively used in all electronic circuits (different values and wattages)
- Comes in various sizes (based on the power dissipation capability)

- Most electronic circuits, except DC power supplies require only small wattage (say 1/8 watt) resistors
- Values and tolerance are generally indicated through colour codes
- Potentiometers (variable resistors) also used in many applications

# Inductors




(a) (b)

**FIGURE 7.11** (*a*) Several different types of commercially available inductors, sometimes also referred to as "chokes." Clockwise, starting from far left: 287 $\mu$H ferrite core toroidal inductor, 266 $\mu$H ferrite core cylindrical inductor, 215 $\mu$H ferrite core inductor designed for VHF frequencies, 85 $\mu$H iron powder core toroidal inductor, 10 $\mu$H bobbin-style inductor, 100 $\mu$H axial lead inductor, and 7 $\mu$H lossy-core inductor used for RF suppression. (*b*) An 11 H inductor, measuring 10 cm (tall) $\times$ 8 cm (wide) $\times$ 8 cm (deep).

Source: Chapter 7, Sec 7.2: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8$^{th}$ ed., McGraw-Hill Company, 2012

# Inductors: Common Applications in Electronic Circuits

- **Inductor property**: current through it cannot change instantaneously; but the voltage can.
- Inductors are very seldom used in general purpose electronic circuits, except for special applications
- Typical Applications:
  - Switched-Mode Power Supplies (SMPS) – in the μH range
  - RF circuits: small valued inductors (in the nH to μH range)
  - Compact Fluorescent Tube (CFL) supply – μH to mH range

Inductor 

$$v = L\frac{di}{dt}$$

- Major disadvantages:
  - large size, especially when used as chokes (used in fluorescent tubes)
  - Can create disturbance (EMI) in sensitive circuits
- Large valued inductors occasionally used in Electric Power circuits

# Capacitors

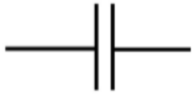
(a) (b) (c)

**FIGURE 7.2** Several examples of commercially available capacitors. (*a*) Left to right: 270 pF ceramic, 20 $\mu$F tantalum, 15 nF polyester, 150 nF polyester. (*b*) Left: 2000 $\mu$F 40 VDC rated electrolytic, 25,000 $\mu$F 35 VDC rated electrolytic. (*c*) Clockwise from smallest: 100 $\mu$F 63 VDC rated electrolytic, 2200 $\mu$F 50 VDC rated electrolytic, 55 F 2.5 VDC rated electrolytic, and 4800 $\mu$F 50 VDC rated electrolytic. Note that generally speaking larger capacitance values require larger packages, with one notable exception above. What was the tradeoff in that case?

Source: Chapter 7, Sec 7.1: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8$^{th}$ ed., McGraw-Hill Company, 2012

# Capacitors: Common Applications in Electronic Circuits

- **Capacitor property**: voltage across a capacitor cannot change instantaneously; but the current can.
- Typical uses:

Capacitor  $v = \frac{1}{C}\int i dt$

  - C connected in series
    - To block DC voltage and couple only an ac voltage to a circuit, such as an amplifier circuit
  - C connected in parallel
    - As a filter capacitor at the output of a rectifier circuit (typ 100 to 1000 μF) for reducing ripple voltages
    - As bypass capacitors (100 to 220 μF) across emitter resistor in BJT amplifier circuits
    - As de-coupling capacitors (10 nF to 100 nF) across the power supply pins of ICs to smoothen the power supply voltage
  - C used for timing applications in oscillator and other waveform generators (typ small valued capacitors, say 10 nF to 200 nF)

# Transformer

- Transformer:
  - Two coils of wire separated by a small distance, and coupled magnetically through an iron core
- Has two ports, primary and secondary
  - Primary: the input end (left side), to which the ac voltage source $V_1$ is connected
  - Secondary: the port on the right side to which the load $Z_L$ is connected
- Turns ratio = $N_2/N_1$, the ratio of the number of secondary turns to the primary turns.
  - $V_2/V_1 = N_2/N_1$
  - $V_2/V_1 < 1$ : step-down transformer
  - $V_2/V_1 > 1$ : step-up transformer
- DC power supplies and most other common electronic applications use step-down transformers.
  - input $V_1$ is 230 V rms, and $V_2$ is typically 12 to 20 V rms.

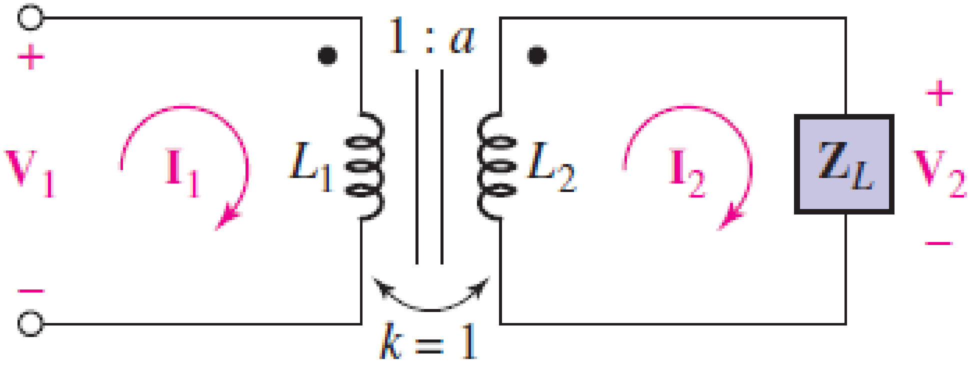



**FIGURE 13.25** An ideal transformer is connected to a general load impedance.

Ref: Chapter 13, Sec 13.4: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8th ed., McGraw-Hill Company, 2012


**FIGURE 13.15** A selection of small transformers for use in electronic applications; the AA battery is shown for scale only.

Source: Chapter 13, Sec 13.3: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8$^{th}$ ed., McGraw-Hill Company, 2012

# Part B: Active Devices - Independent and Dependent Sources

# Independent Voltage Source

- Terminal voltage is completely independent of the current through it.
- We may call this an 'Ideal Voltage Source'

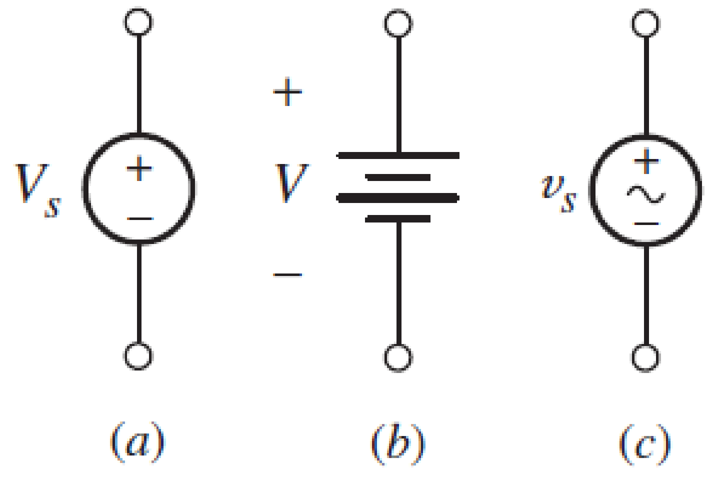



Fig.1 Independent voltage source symbols

(a) DC source symbol,

(b) Battery symbol,

(c) AC source symbol

# Independent Current Source

- Current supplied is completely independent of its terminal voltage.

- We may call this an ‘Ideal Current Source’

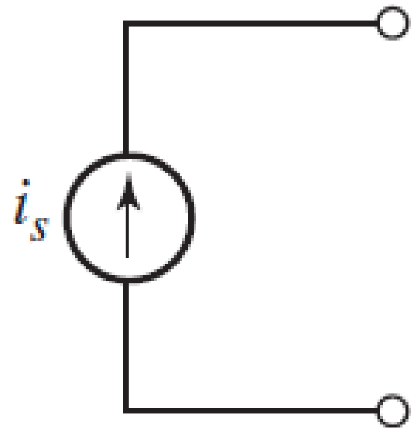



Fig. 2 Circuit symbol for the independent current source

# Practical Voltage Sources

- Practical voltage sources are non-ideal.
- As the current supplied by it to a load increases, its terminal voltage progressively decreases (see Fig.3).
- This is due to the non-zero internal resistance present in all practical voltage sources.
- The terminal voltage of a practical voltage source equals that of an ideal one, only when current supplied is zero (or when the voltage source is open-circuited).

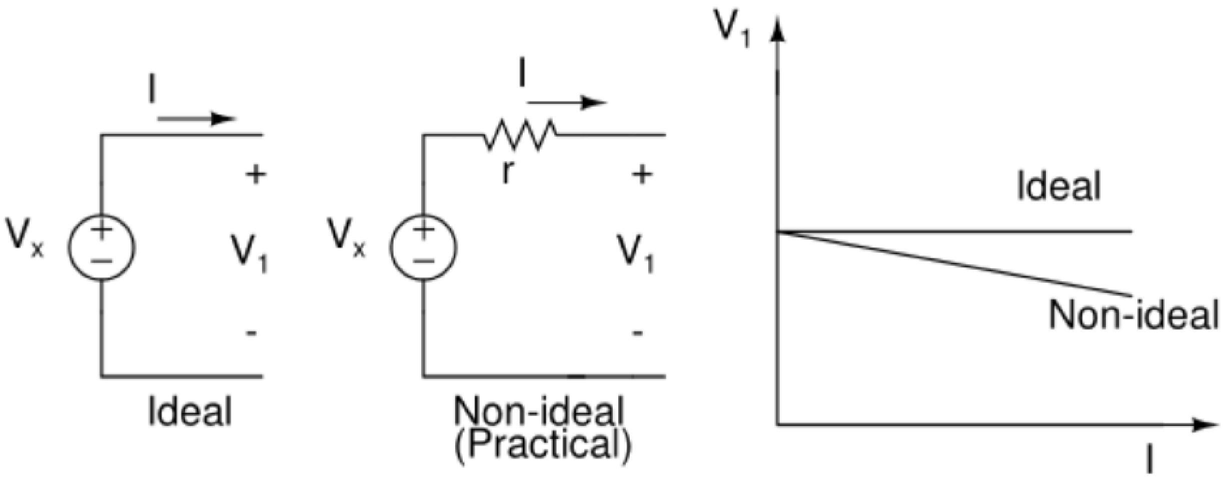



Fig. 3

# Practical Current Sources

- In a practical (or non-ideal) current source, as the terminal voltage across the load increases, the current supplied by it progressively decreases (see Fig.4).
- This is due to lower internal shunt resistance in a practical current source.
- The current supplied by a practical current source equals that of an ideal one only when the load across its terminals is zero (or when the current source is short-circuited).

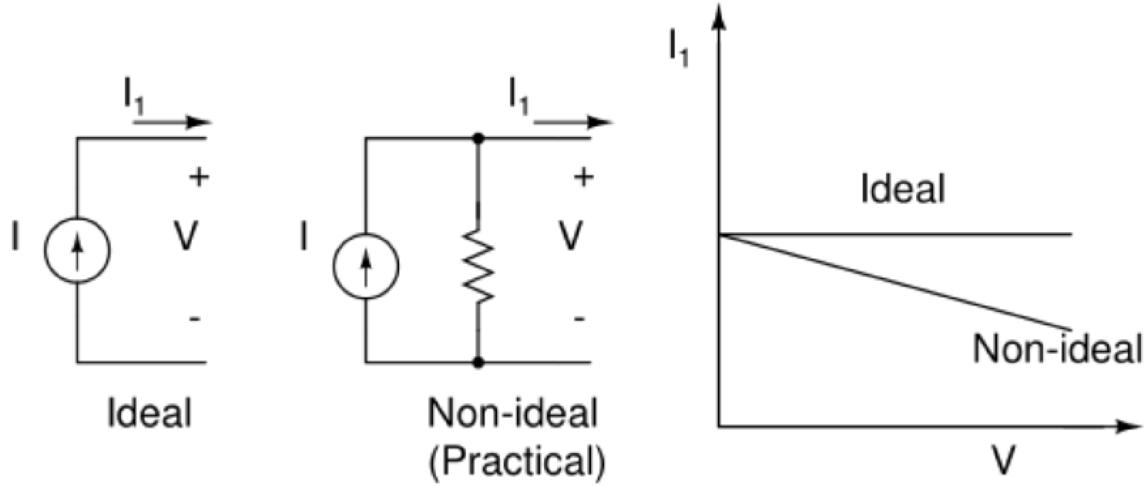



Fig. 4

# Dependent Sources

- **Independent sources**
  - the value of the source quantity is not affected in any way by activities in the remainder of the circuit.

- **Dependent (or controlled) sources**
  - The source quantity (voltage or current) is determined by a voltage or current existing at some other location in the system being analyzed.
  - Used in the equivalent electrical models for many electronic devices, such as transistors, operational amplifiers, and integrated circuits.
  - Shown with diamond symbols

# Dependent Sources

- Four types as shown
- In Fig 4(a) and (c), *K* is a dimensionless scaling constant.
- In Fig 4(b), *g* is a scaling factor with units of A/V
- Fig. 4(d), *r* is a scaling factor with units of V/A
- The controlling current $i_x$ and the controlling voltage $v_x$ must be defined in the circuit.

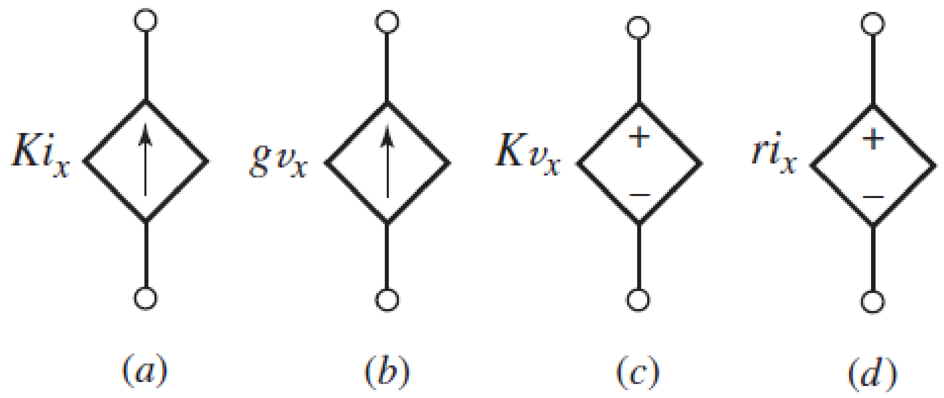



Fig. 4 Circuit symbols for the four different types of dependent sources:

(a) current-controlled current source;

(b) voltage-controlled current source;

(*c*) voltage-controlled voltage source;

(*d*) Current controlled voltage source

# Part C: Kirchhoff’s Current and Voltage Laws

# Kirchhoff's Current and Voltage Laws (KCL and KVL)

- With reference to Fig 5,
- **Node**:
  - 1, 2 and 3 are nodes
- **Path** (moving from node to node without encountering a node more than once):
  - Node 1 to node 3 to node 2 is a path
- **Loop** (when the node at which we started is the same as the node on which we ended, the path is called a closed path or a loop):
  - Node 1 to node 3 to node 2 and then back to node 1 is a loop or a closed path

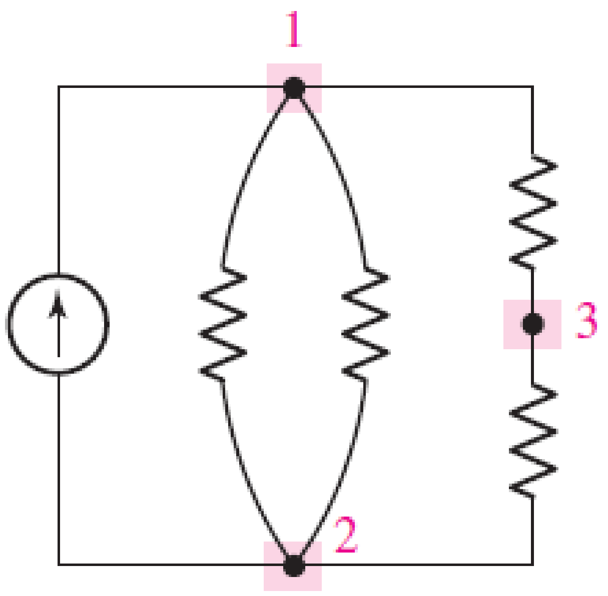



Fig. 5

# Kirchhoff's Current Law (KCL)

- Statement: *The algebraic sum of the currents entering any node is zero.*
- (charge cannot accumulate at a node)
- $i_A + i_B + (-i_C) + (-i_D) = 0$

- Or, $i_A + i_B = i_C + i_D$
- i.e. the sum of the currents going in must equal the sum of the currents going out.
- A compact expression for Kirchhoff's current law is: $$\sum_{n=1}^{N} i_n = 0$$

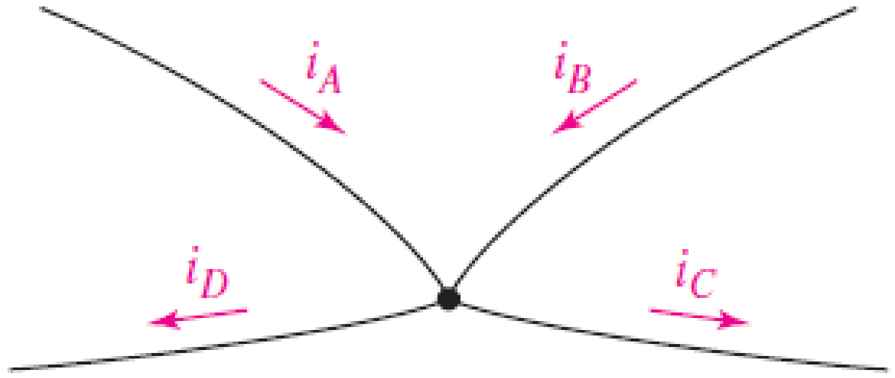



Fig. 6 Example node to illustrate the application of Kirchhoff's current law.

# Kirchhoff's Voltage Law (KVL)

- Statement: *The algebraic sum of the voltages around any closed path is zero.*
- i.e. in a closed path, $$\sum_{n=1}^{N} v_n = 0$$
- Method: Move around the closed path in a clockwise direction and write down directly the voltage of each element whose (+) terminal is entered, and write down the negative of every voltage first met at the (−) sign.
- For the example in Fig. 7, we have

$$-v_1 + v_2 - v_3 = 0$$

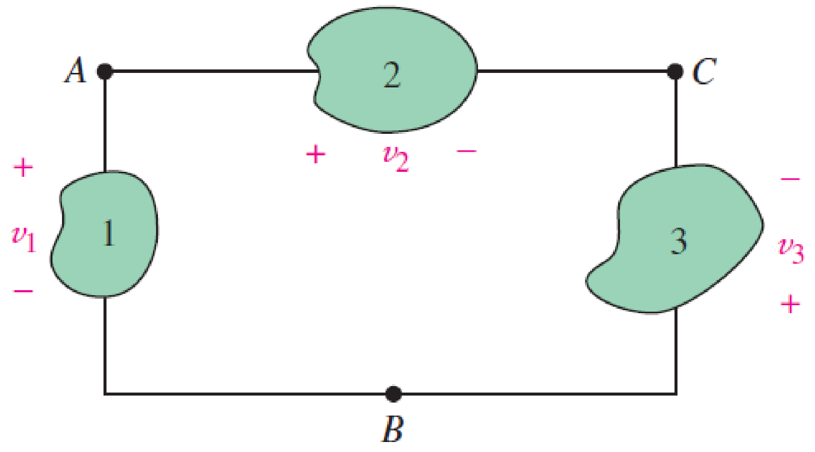



Fig. 7 The potential difference between points A and B is independent of the path selected.