Circuit Analysis and Design

Academic year 2025/2026 – Lecture 1

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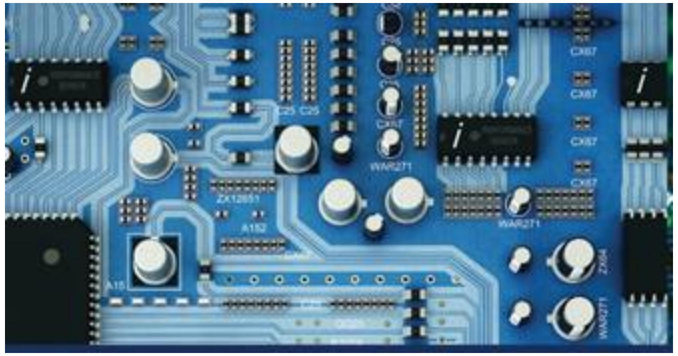
"A good student never steal or cheat"

Agenda



- Introduction
- Logistics
- Syllabus / policies
- What is this course all about and course outcomes?
- International System of Units (SI)
- Charge, voltage, current, and power
- Independent sources
- Summary

Acknowledgement: We would like to thank Cenange learning. These slides are modified version of Cenange learning. J. S Kang, Cengage Learning, 2016

Contact Info

Course instructors:

Dr. Muhammad Aslam,

Dr. Masood Ur Rahman,

Prof. Ali Imran

Contact: Office hours/through Email/Moodle chat

The course has **Lectures/Tutorials** and mandatory **Laboratory** sessions per week → please refer to your own timetable

GTA's for the course

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Course Material

Recommended textbooks:

- **James S Kang, Electric circuits, Cengage Learning, 2016.**
  (we mostly follow this book)

- Robert Boylestad, Introductory Circuit analysis, 13th Edition, Pearson, 2015.
- Neil Storey, Electronics a System Approach , 5th Edition, Pearson, 2013.
- Artilce M. Davis, Linear Circuit Analysis, Cengage Learning, 2013.
- J David Irwin, R Mark Nelms, (Basic) Engineering Circuit Analysis (10 ed), Wiley, 2011.
- A R Hambley, Electrical Engineering (6 ed), Prentice Hall, 2014.
- J Nilsson and S Riedel, Electric Circuits (10 ed), Pearson, 2014.
- R C Dorf and J A Svoboda, Introduction to Electric Circuits (9 ed), Wiley, 2014.
- Giorgio Rizzoni, Fundamentals of Electrical Engineering, McGraw-Hill, 2009.

However numerous books deal with electrical circuit theory, analysis and design, with similar coverage, and you can choose one with a style that you prefer.

This list has been provided by the colleague teaching the ‘mirror’ course in Glasgow
http://readinglists.glasgow.ac.uk/lists/83D94E61-49DE-0916-8244-8019129BE4D4.html

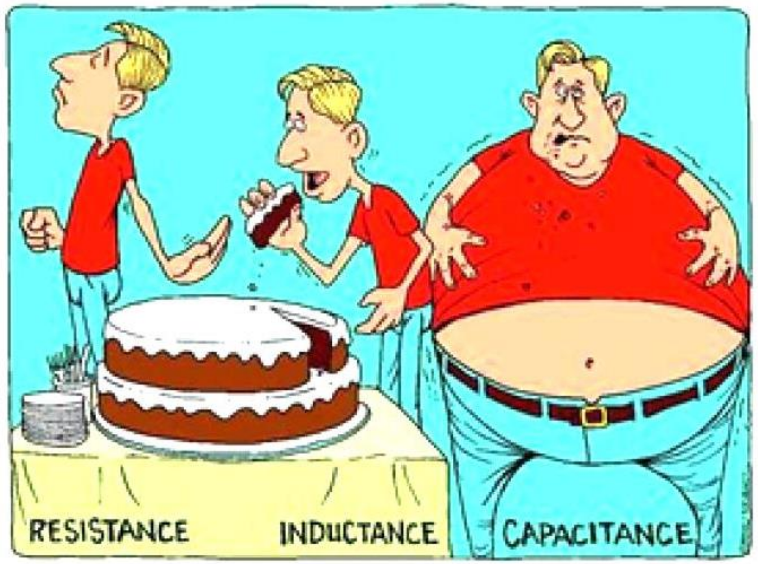
Additional material (lab scripts, lecture notes, exercises) provided in **Moodle** website

Course Description

Provide a basic understanding of the **behaviour of electrical circuits** containing **inductance**, **capacitance** and **resistance** and the **circuits response to DC, steady-state AC, and transient DC voltages and currents**. Establish the concept of **impedance and frequency response** of a circuit. Present and design, through simulations and practical experiments, simple circuit systems such as **filters and operational amplifiers**.

Course outcome: By the end of this course students will be able to:

- **define** the fundamental electrical properties of charge, current, voltage, power and their units;
- **apply** the fundamental laws of circuits analysis, including Ohm’s law, Kirchhoff’s laws for current and voltages, and Thévenin's and Norton’s theorems, to circuits containing resistors, capacitors, inductors, and operational amplifiers;
- **employ** the concepts of phasors and impedances in the analysis of linear steady-state AC electrical circuits;
- **analyse** the behaviour at transients of 1st order and 2nd order DC electrical circuits;
- **design** and characterise passive and active filters; and
- **practice** and apply the concepts acquired in class to laboratory experiments involving the use of basic equipment such as multimeters, DC power supplies, digital oscilloscopes, and waveform generators



(Tentative) Lectures and Lab Plan

Lecture Topics	Laboratory Topics
Nomenclature and basic introduction of circuit and signals	Familiarise with lab and its equipment
Ohm's and Kirchhoff's laws, voltage dividers, series and parallel components	Design of DC circuits and Thevenin theorem
Mesh and nodal analysis, calculation of the bias point of a circuit, Equivalent circuits (Thevenin and Norton),	Transients and time constants
Review of part 1, transients (1st and 2nd order)	AC circuits and filters
Review of transients, AC circuit analysis (phasors and impedance), Application to filter analysis	Operational Amplifiers
concept of RMS values for power calculations, Operational amplifiers, final review pre-exam	Lab Report Work

Assessment and Requirements

- Formative assessment (helping you check your progress and understanding)
  - Exercises in class at lectures
  - GTAs formative comments at the end of each laboratory session and tutorials

- Summative assessment (contributing to your final grade)
  - 75% final written **examination**
  - 25% **laboratory** activities
    - There are 6 laboratory sessions to attend (we would encourage you to read the lab script before attending the lab if possible)
    - An individual laboratory report on an open problem to be written and submitted on Moodle

- Students **must attend** the timetabled classes, including the laboratory sessions. If you attend less than 75% you will be awarded a CW (Credit Withheld). This will prevent to progress in your degree until cleared.
- Any student who misses an assessment or a significant number of classes because of illness or other good cause should **report** these to teaching office (counsellor) and adviser of study as soon as possible.

Let us start!

First of all some quick reference words…

The list in the next slide tries to provide the translation of a few words used in the course from English to Chinese characters… It is intended to be a reference for the students for quick checking.

Many thanks to Dr Keliang Zhou, whose slides provided the inspiration for this, and to Dr Bo Tan and Qingchao Chen for their help.

If you spot any mistake, please let me know ☺

行为 or 性能	behaviour
电感值	inductance value
电容值	capacitance value
电阻值	resistance value
瞬态响应	transient response
微分方程	differential equations
时域	time domain
频域	frequency domain
稳态响应	steady-state response
相量	phasor
阻抗	impedance
运算放大器 / 运算放大器	operational amplifier
开关	switch
电源	power supply/source
叠加原理	superposition principle
无源的	passive
有源的	active
耗能元件	dissipative element
储能元件	energy storage element
基氏电流定律	Kirchhoff current law
基氏电压定律	Kirchhoff voltage law
等效	equivalent
元件串并联 / 串并联元件	series and parallel components
戴维宁 定理	Thevenin’s theorem
诺顿 定理	Norton’s theorem

线性电路	linear circuit
电荷	electric charge
电势	potential -> voltage
连续性	continuity
n-阶常微分方程	N-order differential equation
单位阶跃函数	unit step function
特征方程	characteristic equation
过阻尼	over-damped
临界阻尼	critically damped
欠阻尼	under-damped
强迫响应 / 强制响应	forced response
自然响应	natural response
欧拉等式	Euler’s equation
导纳	admittance
电阻	resistance
电抗	reactance
电导	conductance
电纳	susceptance
倒数	reciprocal
分贝	decibel
共轭	conjugate

Introduction Chapter

- **International System of Units (SI)**:
  - Seven base units of SI along with derived units relevant to electrical and computer engineering are presented.
- Charge, Electric Field, **Voltage**, **Current**, **Power**
- **Voltage source:** with voltage V_s provides
  - Constant potential difference to circuit connected between the positive terminal and the negative terminal.
  - If voltage from voltage source is constant with time, voltage source is a direct current (dc) source.
  - If voltage from the voltage source is a sinusoid, voltage source is an alternating current (ac) voltage source.
- **A current source** with current I_s provides
  - Constant current of I_s amperes to the circuit connected to the two terminals.
  - If current from current source is constant with time, current source is a direct current (dc) source.
  - If current from current source is a sinusoid, current source is an alternating current (ac) current source.
- Voltage or current on the **dependent sources** depends solely on the **controlling voltage** or **controlling current.**
- **Elementary signals** that are useful throughout the text are introduced.

International System of Units (SI)

- **SI system** is founded on **seven base units** for seven quantities assumed to be mutually independent.

Base Units	What it is?
Meter (m)	**Length** of a path traveled by light in a vacuum during a time interval of 1/299,792,458 ($\approx 1/(3 \times 10^8)$) of a second.
Kilogram (kg)	Equal to the **mass** of the international prototype of the kilogram.
Second (s)	**Duration** of **9,192,631,770 periods/vibrations/ticks of radiation** corresponding to **transition** between **two hyperfine levels** of ground state of the **cesium 133 atom.**
Ampere (A)	Constant **current** which, if maintained in **two straight parallel conductors of infinite length**, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to **2 x 10^{-7} newtons** per meter of length.

International System of Units (Continued)

Base Units	What it is?
Kelvin (K)	It is fraction 1/273.16 of the thermodynamic **temperature** of the triple point of water.
Mole (mol)	▪ It is **amount of substance** of a system which contains as many elementary entities as there are atoms in **0.012 kilogram of carbon 12.** ▪ When mole is used, **elementary entities must** be specified and may be **atoms, molecules, ions, electrons**, other particles, or specified groups of such particles
Candela (cd)	it is **luminous intensity (brightness),** in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} Hertz and that has the radiant intensity in that direction of 1/683 watt per steradian.

SI Derived Units with Special Names and Units

Derived Quantity	Name	Symbol	Expression in terms of other SI units
Frequency	hertz	Hz	$1/s$
Energy	joule	J	N·m
Power	watt	W	J/s
Electric charge	coulomb	C	–
Electric potential difference	volt	V	W/A
Capacitance	farad	F	C/V
Electric resistance	ohm	Ω	V/A
Electric conductance	siemens	S	A/V
Magnetic flux	weber	Wb	V·s
Magnetic flux density	tesla	T	Wb/m^2
Inductance	henry	H	Wb/A

From Electric Circuits by James S. Kang (Cenange Learning)

SI Prefixes

Prefix	Symbol	Magnitude	Example
pico	p	10^{-12}	1 pF = 10^{-12} F
nano	n	10^{-9}	1 nF = 10^{-9} F, 1 ns = 10^{-9} s
micro	μ	10^{-6}	1 μF = 10^{-6} F, 1 μs = 10^{-6} s
milli	m	10^{-3}	1 mA = 10^{-3} A, 1 mm = 10^{-3} m
centi	c	10^{-2}	1 cm = 0.01 m
deci	d	10^{-1}	1 dB = 0.1 Bel
deka	da	10	1 dam = 10 m, 1 daL = 10 L
hecto	h	10^{2}	1 hL = 100 L
kilo	k	10^{3}	1 kHz = 1000 Hz, 1 kΩ = 1000 Ω
mega	M	10^{6}	1 MHz = 10^{6} Hz
giga	G	10^{9}	1 GHz = 10^{9} Hz
tera	T	10^{12}	1 THz = 10^{12} Hz

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Electric Charge

- **Atoms** are the basic building blocks of matter. **Nucleus** of atoms consists of **protons** and **neutrons**. **Electrons** orbit around the nucleus.

  - The protons are positively charged and the electrons are negatively charged. The neutrons are electrically neutral.

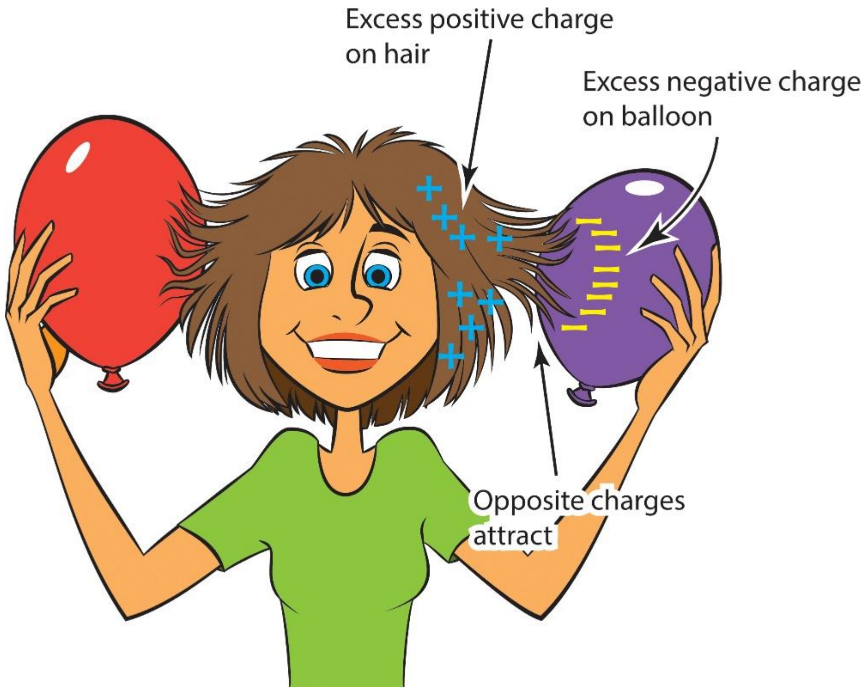
  - The amount of **charge** on a **proton** is given by

    $$\mathbf{e = 1.60217662 \times 10^{-19}\ C}$$

  - The amount of **charge** on an **electron** is given by

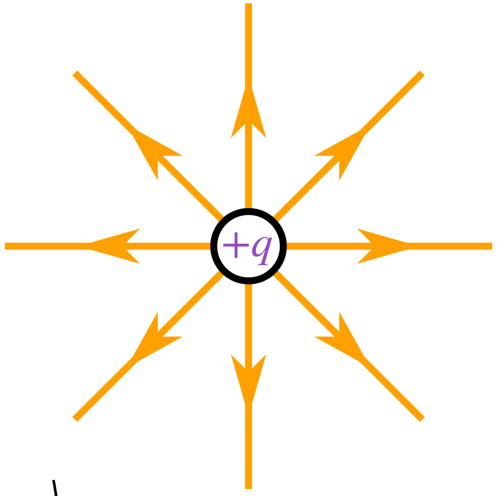
    $$\mathbf{-e = -1.60217662 \times 10^{-19}}$$

- Note: Charge is quantized as the integral multiple of e. Since there are equal number of protons and electrons per atom, the atoms are electrically neutral.

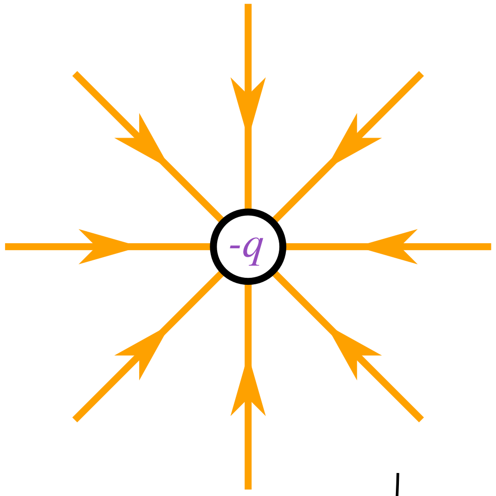


Electric Field

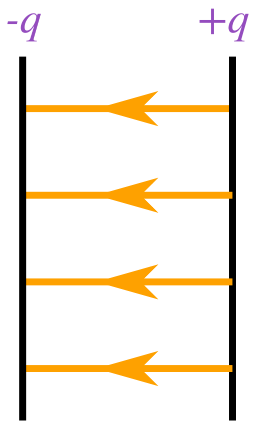
E field around
a positive charge



E field around a
negative charge

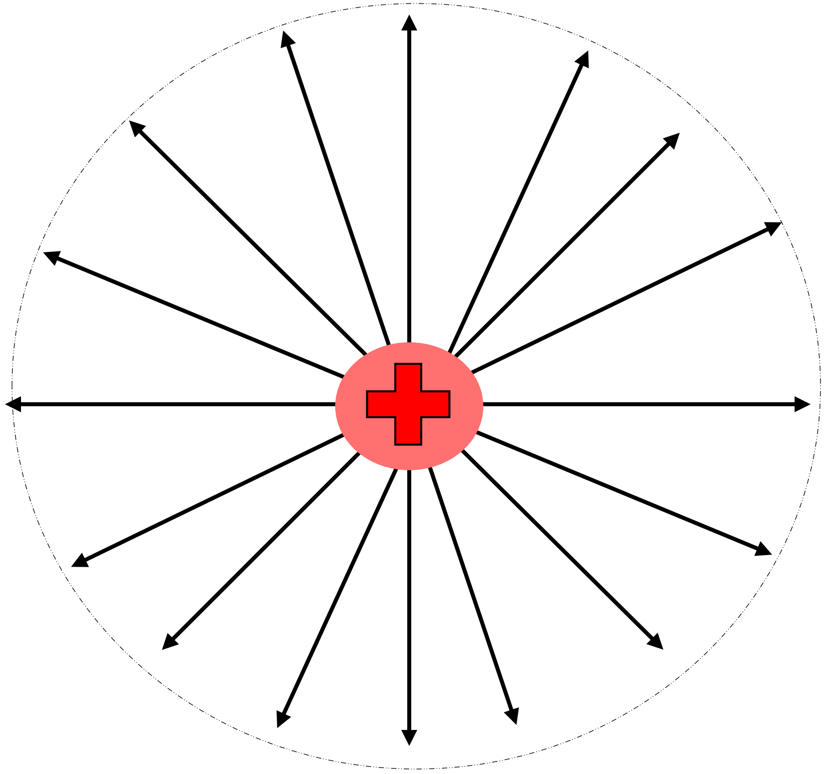


E field inside a
parallel plate
capacitor



Field is constant
between plats

Electric Field of a greater +ve charge

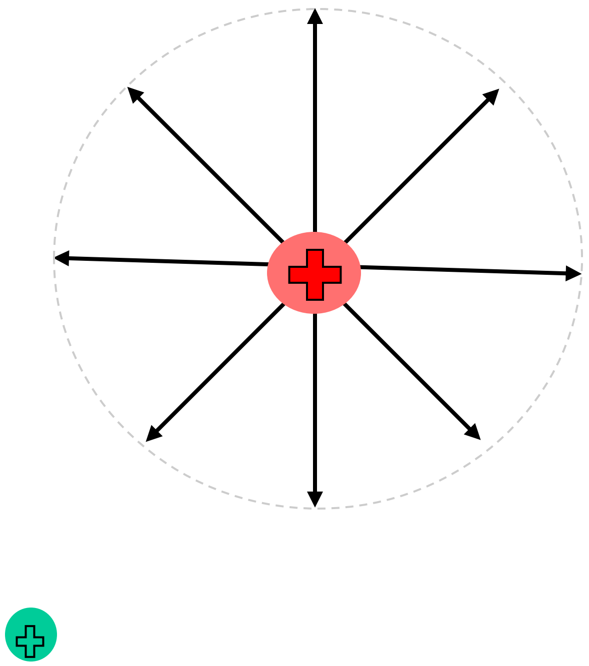


As Charge is increased
Field becomes stronger

- ❑ Field becomes stronger near charge
- ❑ Field becomes weaker away from charge

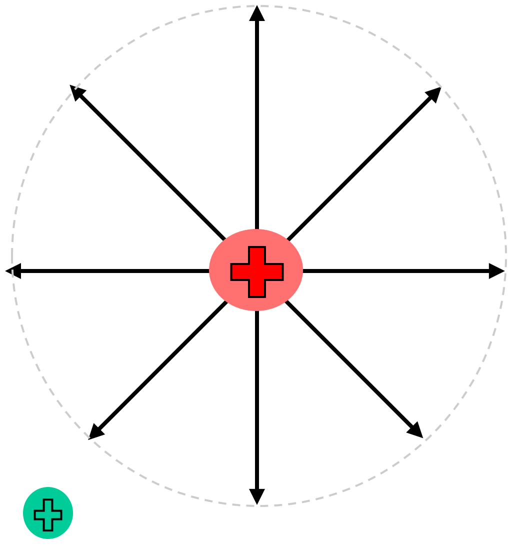
Lets Bring a Test Charge inside Electric Field

Test charge outside of field



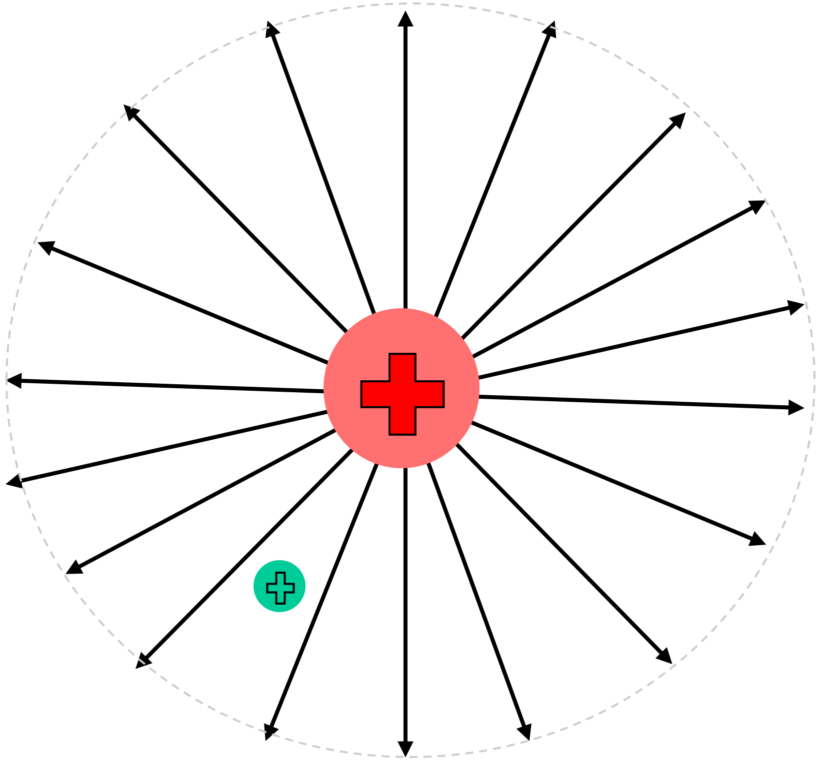
- ❑ Zero force between charges
- ❑ No work done

Test charge inside of field



- ❑ Repulsive force starts between like charges when inside field
- ❑ Need Energy/work to bring charge inside

Electric Field of a greater +ve charge



- ❑ As distance decrease and charge size increases
- ❑ Force becomes stronger
- ❑ More Energy/work required

Coulomb's Law

- According to Coulomb's law, magnitude of **force between** two charged bodies is proportional to the **charges Q and q** and inversely proportional to the **distance squared**:

$$\boxed{F \propto \frac{Qq}{r^2}} \quad \Rightarrow \quad \boxed{F = \frac{1}{4\pi\varepsilon}\frac{Qq}{r^2}}$$

where ε is permittivity of the medium. The permittivity of free space, ε_0, is given by

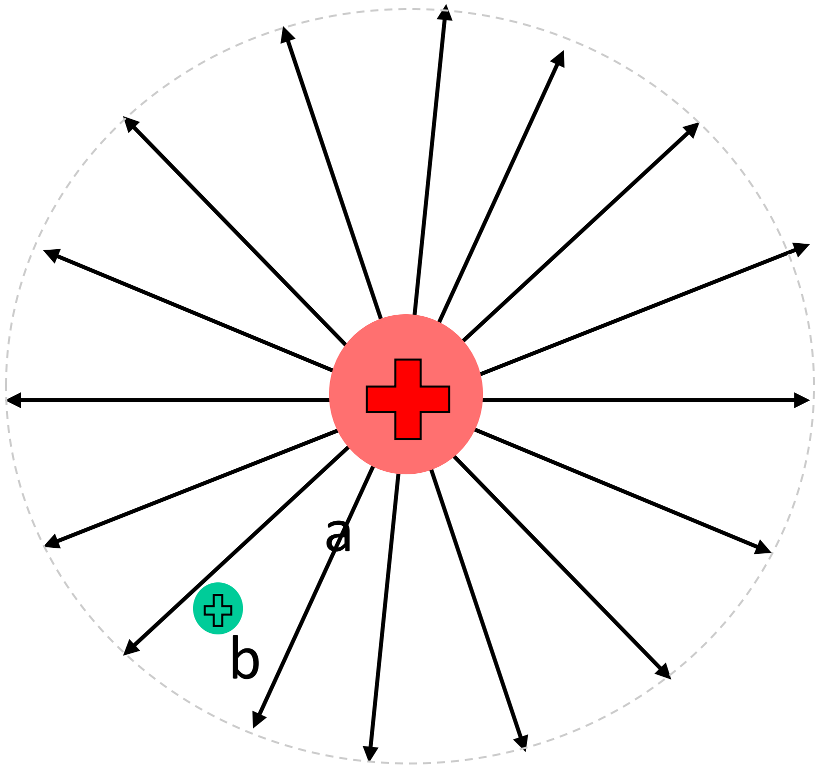
$$\boxed{\varepsilon_0 = \frac{1}{4\pi c^2 10^{-7}}\left(F/m\right) = 8.8541878176\times10^{-12}\left(F/m\right)}$$

where c is the speed of light in the vacuum, given by c = 299,792,458 m/s ≈ 3 x 10^8 m/s.

- Unit for the permittivity is farads per meter (F/m). Direction of force coincides with the line connecting the two bodies. If the charges are of the same polarity, the two bodies repel each other. On the other hand, if the charges are of the opposite polarity, they attract each other.

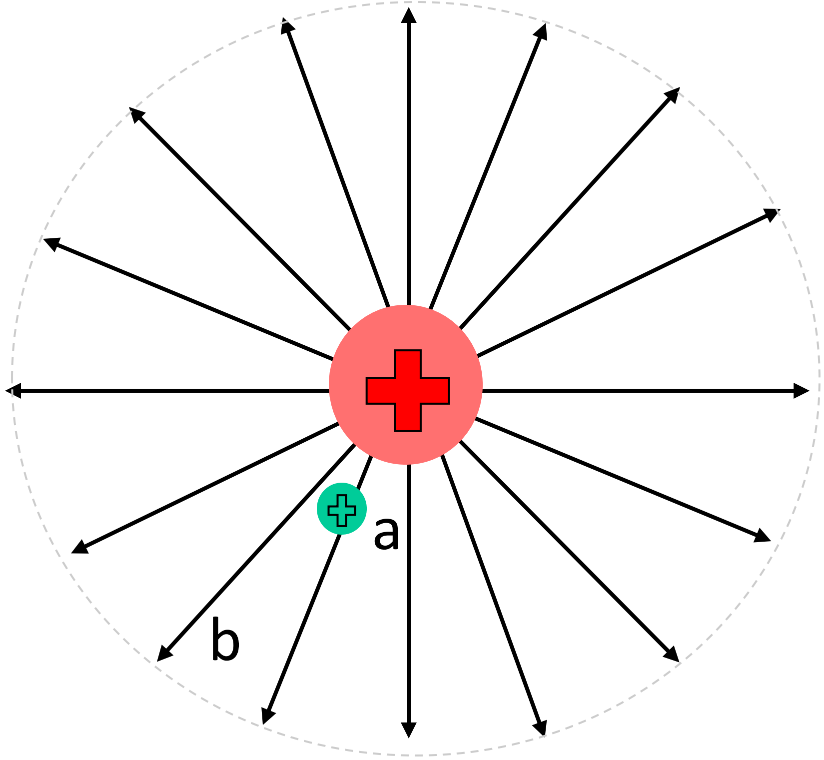
Work on a Unit Charge/ Potential Difference (Voltage)

- Work against the Field low potential energy to higher



- Use external energy to move from low to high potential
- Example: Active elements (Source/Battery) provide energy to charges
- Potential of charge increases, Potential of a > b,

- Moving down the field from high potential energy to low



- Consumes its own energy to from high to low potential
- Example: Passive elements (Resistors) consumes energy of charges
- Potential of charge decreases, Potential of b<a

- **Voltage** is work done on **unit charge (1 C)**, **1J work on 1 C charge in a field = potential difference is 1 volt**

Electric Field and Voltage

- The presence of the point charge creates a field around it where charged particles experience force. This field is called an **electric field**.
- If an object with charge q is placed in the presence of electric field E, the object will experience a force

$$F = qE \rightarrow E = \frac{F}{q}$$

- For a positive point charge Q, E is as below (where ar indicates the direction of the field)

$$\boldsymbol{E} = \frac{1}{4\pi\varepsilon}\frac{Q}{r^2}\boldsymbol{a}_r$$

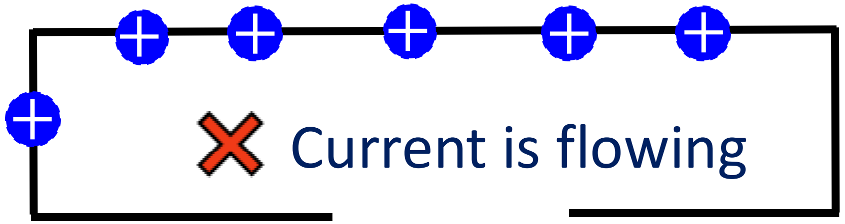
- We then define **voltage** the work to do per unit of charge in order to move this from one point to another in the presence of an electric field. This is measured in **Volt (V).** 1 V = 1 Joule / 1 Coulomb

$$v = \frac{dw}{dq}$$

Current

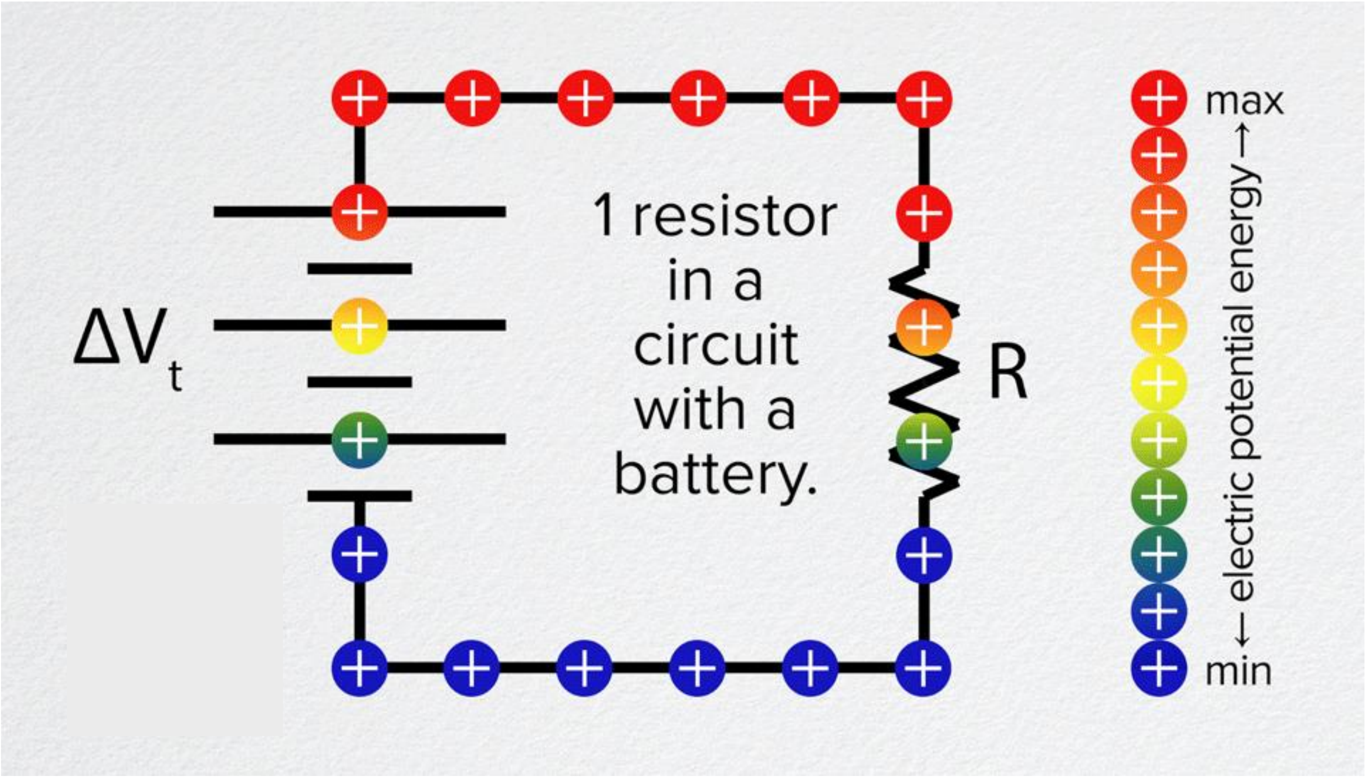
- ❑ If there is No Voltage Source, there will be No Potential difference and hence No current will flow

Incomplete is Circuit



- No source/battery is connected

Complete is Circuit



- ❑ Voltage Source provides potential difference to charges and **Current starts to flow in the circuit**

Current

- In the absence of electric field, the free electrons in the conduction band of conductors such as copper wire make random movements. When an electric field is applied along the copper wire, the negatively charged electrons will move toward the direction of higher potential.
- The **current** is defined as the **flow of charge through a cross-sectional area as a function of time**, or **the time rate of change of the charge**. The formula is given below. The unit for the current is coulombs per second or **amperes (A).**
- If the amount of charge crossing the area changes with time, the current is defined as

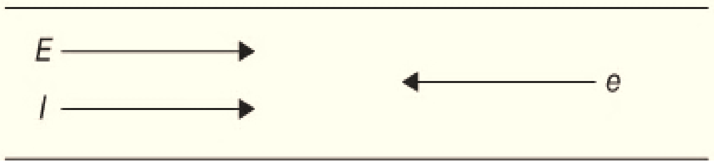
$$i(t) = \frac{dq(t)}{dt}$$

- **Sign Convention:** The direction of current is defined as the direction of positive charges. **Figure 1.2** shows the direction of the electric field, current, and electron inside a conductor.
- The charge transferred between time t_1 and t_2 can be obtained by integrating the current from t_1 and t_2, that is,

$$q = \int_{t_1}^{t_2} i(\lambda)\, d\lambda$$

FIGURE 1.2

The directions of E, I, and e.



Example 1.1

The charge flowing into a circuit element for $t \geq 0$ is given by

$$q(t) = 2 \times 10^{-3}\left(1 - e^{-1000t}\right)\ coulomb$$

Find the current flowing into the element for $t \geq 0$

Solution:

Current is rate of change of charge

$$i(t) = \frac{dq(t)}{dt} = \frac{\mathrm{d}\left(2\times 10^{-3}\left(1-e^{-1000t}\right)\right)}{dt}$$

$$i(t) = 0 - 2 \times 10^{-3}\frac{de^{-1000t}}{dt}$$

$$i(t) = 2 \times 10^{-3} \times 1000\, e^{-1000t}$$

$$i(t) = 2\, e^{-1000t}\mathrm{A}\ \ for\ t \geq 0$$

Class Task

Multiple Choice ?

P1.1 Find the current flowing through an element if the charge flowing through the element is given

$$q(t) = \begin{cases} 0.002t, \ \mathrm{C} & t \geq 0 \\ 0, & t < 0 \end{cases}$$

Answers

A. 1mA
B. 2mA
C. 3mA

Homework: Exercise P1.6 to P1.6

Example 1.2

Current flowing into a circuit element is given by $i(t) = 5\sin(2\pi 10t)\, mA\ for\ t > 0$. Find the charge flowing into the device for t ≥ 0. Also find the total charge entered into the device at t = 0.05 s

?

$$q(t) = \int_{-\infty}^{\infty} i(t)dt$$

$$q(t) = \int_{0}^{t} 5\sin(2\pi 10t)dt\ \ mA\ for\ t \geq 0$$

$$q(t) = -\frac{5\times 10^{-3}}{2\pi 10} cos(2\pi 10t)\Big|_{0}^{t}$$

$$q(t) = \frac{10^{-3}}{4\pi}(1\ - cos(2\pi 10t))$$

Charge at **0.05 s**

$$q(0.05) = \frac{10^{-3}}{4\pi}(1\ - cos(2\pi 10(0.05))\,)$$

$$q(0.05) = 1.591531.5915 \times 10^{-4}\ \ \text{coulombs}$$

Home Exercise

?

P 1.7 Find the total charge passing through an element at one cross section over the time interval $0 < t < 5s$ if the current through the same cross section is given by $i(t) = 5\,mA$

Options

A. 5 mC

B. 15 mC

C. 25 mC

Home Task: P1.8 ~ P1.12

Power

- Power is the change in energy as a function of time, defined as below.
- Or Rate of change in energy

$$p = \frac{dw}{dt} = \boxed{\frac{dw}{dq}}\,\boxed{\frac{dq}{dt}} = \mathrm{v}i$$

Power

- If the voltage and the current are time-varying, the power is also time-varying. Thus, we have **p(t) instantaneous power**:

$$p(t) = i(t)v(t)$$

- Energy is the capacity to do work, so the integration of power over time

$$w = \int_{t_1}^{t_2} p\, dt = \int_{t_1}^{t_2} \mathrm{v}\, i\, dt$$

- Units for energy are **kWatt-hour**, which is what the electric company measures on your electric meter to send you a bill (1kWh = 3.6 MJ).

Passive Sign Convention

- In the passive sign convention, if the **direction of current** is **from the positive terminal** of a device, through the device, **to the negative terminal of the device** as shown in Figure 1.3(a), the **power is positive**. The device **absorbs/consumes/dissipates power**.

- On the other hand, if the **current leaves the positive terminal** of a device, flows through the rest of the circuit, and **enters the negative terminal** of the device as shown in Figure 1.3(b), the **power is negative**. The device **releases/generates power**.

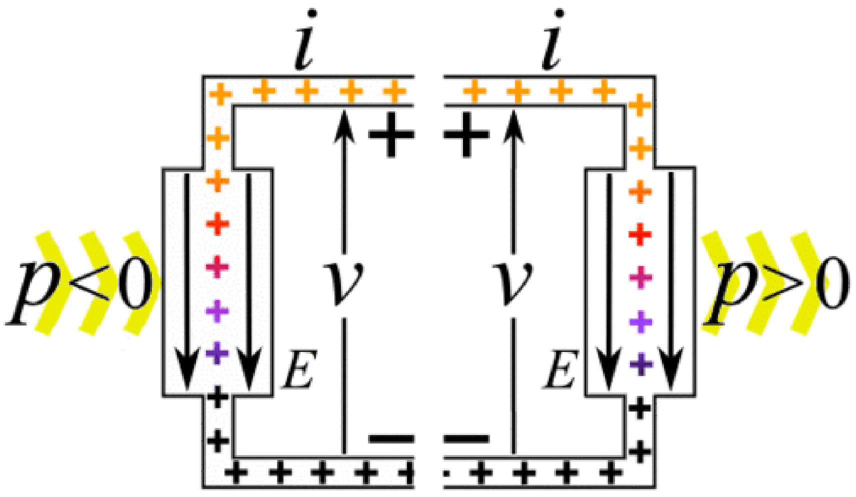


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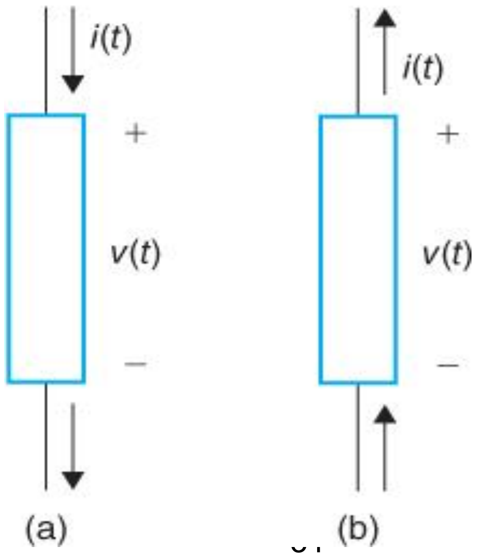
FIGURE 1.3

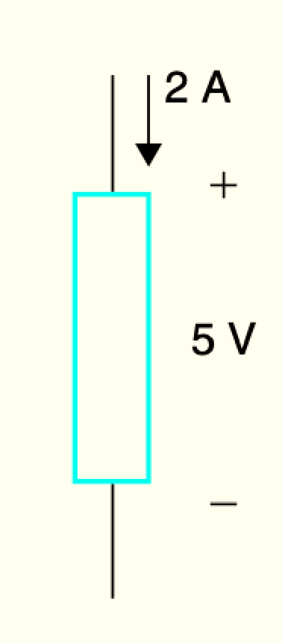
(a) Power is positive.
(b) Power is negative.



Example

?

1.12 Find the power in the circuit element shown in Figure P1.12 and state whether the element is absorbing power or delivering power.



$P = IV$
$P = (+5)(+2)$
$P = 10\ W$

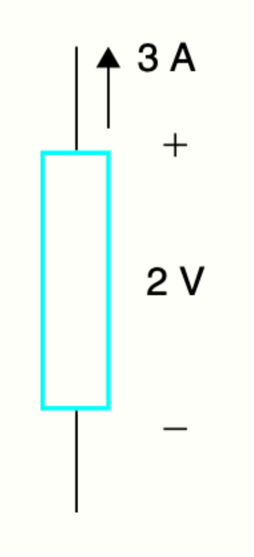
As current is entering positive terminal of the element
The element is absorbing the power
It is passive circuit element

Class Task

Multiple Choice

?

1.13 Find the power in the circuit element shown in Figure P1.12 and state whether the element is absorbing power or delivering power.



Options

$A.\ \ 5$

$B.\ \ -6$

$C.\ \ 6$

Homework: Problem 1.13 ~ 1.15

Exercise 3:

Let the voltage across an element be **$v(t) = 100\cos(2\pi 60t)$ V** and the current though the element from positive terminal to negative terminal be **$i(t) = 5\cos(2\pi 60t)$** A for $t \geq 0$. Find the instantaneous power $p(t)$ and plot $p(t)$.

EXAMPLE 1.3 (Solution)

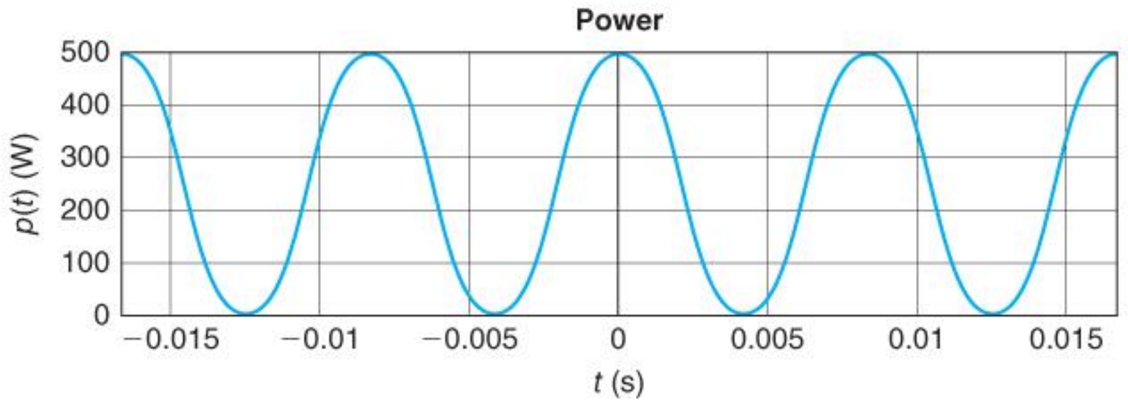
- Let the voltage across an element be v(t) = 100 cos(2π60t) V and the current though the element from positive terminal to negative terminal be i(t) = 5 cos(2π60t) A for t ≥ 0. Find the instantaneous power p(t) and plot p(t).

$p(t) = i(t)v(t) = 5\cos(2\pi 60t) \times 100\cos(2\pi 60t) = 500\cos^2(2\pi 60t) = 250 + 250\cos(2\pi \times 120t)$ W.

- The instantaneous power p(t) is shown in Figure 1.4. Since p(t) ≥ 0 for all t, the element is not releasing power any time. One the average, the element absorbs 250 W of power.

FIGURE 1.4

Plot of $p(t)$.



Homework:
1.17 ~ 1.21

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Exercise 1.3

- Let the voltage across an element be

$$v(t) = 100\, cos(2\pi 60t)\, V$$

- Current though the element from positive terminal to negative terminal be

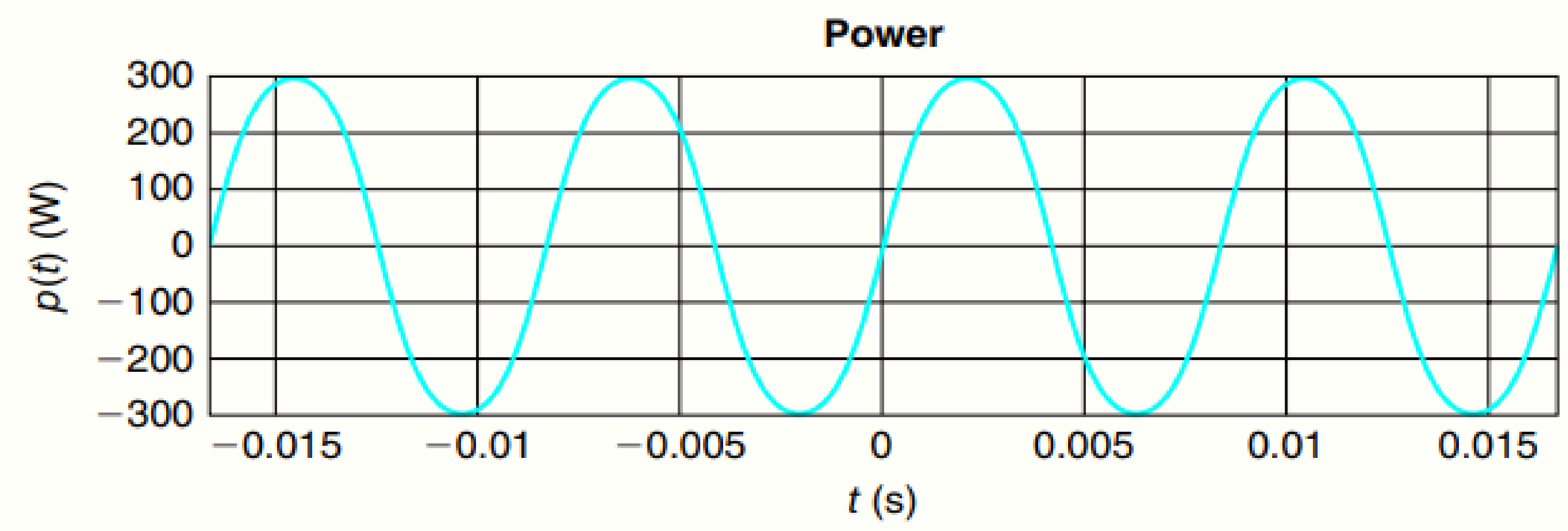
$$i(t) = 6\, sin(2\pi 60t)\, A\ for\ t \geq 0.$$

- Find the instantaneous power p(t) and plot p(t).???

Exercise 1.3 (Continued)

- The Answer should be

$$p(t) = i(t)\,v(t) = 6\sin(2\pi 60t) \times 100\cos(2\pi 60t) = 300\sin(2\pi 120t)\ \text{W}.$$



Independent Sources

- These source **directly convert energy** from another form to electrical energy
- A **voltage source** with voltage V_s **provides** a **constant potential difference** to the circuit connected between the positive terminal and the negative terminal. The circuit notations for voltage source are shown in Figure 1.6.
- If a positive charge Δq is moved from the negative terminal to the positive terminal through the voltage source, the potential energy of the charge is increased by ΔqV_s.
- If a negative charge with magnitude Δq is moved from the positive terminal to the negative terminal through the voltage source, the potential energy of the charge is increased by ΔqV_s.
- A **current source** with **current I_s** provides a **constant current of I_s** amperes to the circuit connected to the two terminals. The circuit notation for current source is shown in Figure 1.7.

FIGURE 1.6

Circuit symbols for voltage sources.

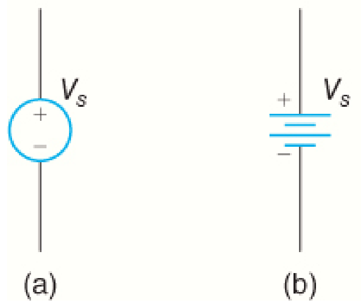
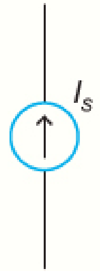


FIGURE 1.7

A circuit symbol for the current source.



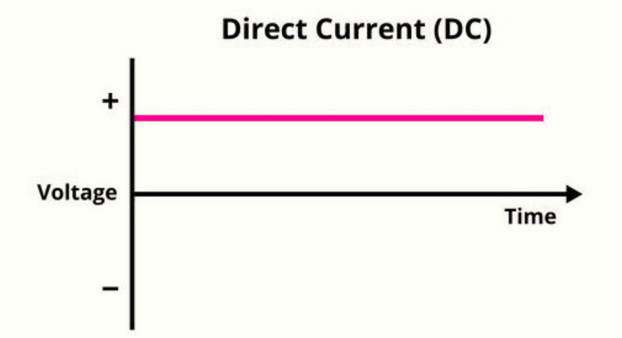
Remember that:

- **Current can flow in and out of an independent voltage source**, but the **polarity of the voltage is determined by the voltage source**.

- There is always a **voltage drop across the independent current source** and **the direction of positive current is determined by the current source.**

DC Sources and AC Sources

- If the **voltage** from the voltage **source is constant with time**, the voltage source is called the **direct current (dc)** voltage source. Likewise, if the **current from** the current source is **constant with time,** the current source is called the **direct current (dc)** current source.
- If the **voltage** from the voltage source is a **sinusoid** as shown in Figure 1.8, the voltage source is called **alternating current (ac)** voltage source. Likewise, if the **current** from the current source is a sinusoid, the **current source** is called **alternating current (ac) current source**.
- A circuit notation for ac voltage source and ac current source are shown in Figure 1.9.



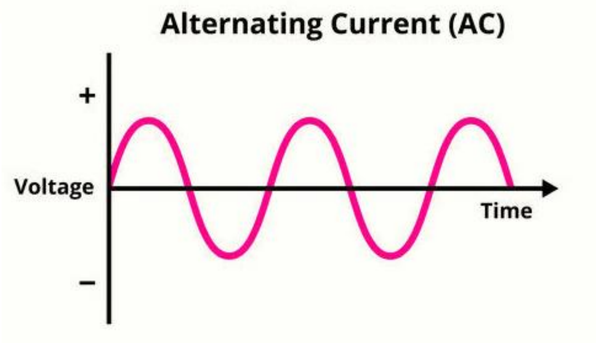


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FIGURE 1.8

Plot of a cosine wave with period T, amplitude V_m, and phase zero.

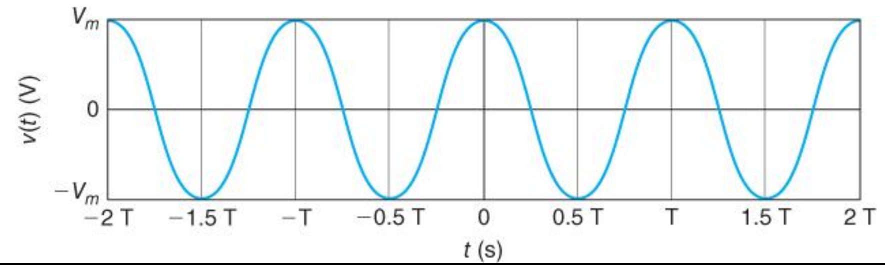
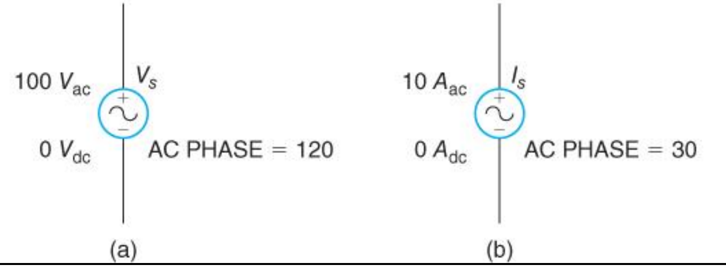
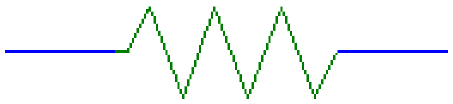
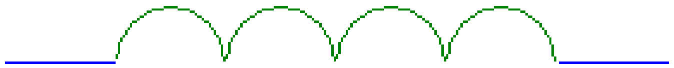
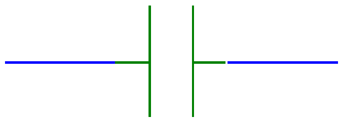


FIGURE 1.9

Circuit symbols for (a) ac voltage source; (b) ac current source.



Passive Components

Component	Symbol	Basic Measure (Unit)
Resistor		Ohm (Ω)
Inductor		Henry (H)
Capacitor		Farad (F)

Passive Elements

- The magnitude of the voltage drop and current flowing through passive devices depends on the voltage and current sources that are present and/or recently attached to the circuit.
  - These components can dissipate power immediately or store power temporarily and later release the stored power back into the circuit.

Summary

- Course contents
- Grading policy
- Course is all about and its outcome
- Introduction
- Si Units
- Voltage, current, electric field, power
- Independent Sources
- Passive elements
- What will we study in next lecture.