EE 209  
Fundamentals of Electrical and Electronics Engineering (3-0)3  

- Basic Principles of Electricity,  
- Circuit Analysis,  
- AC Circuits,  
- AC Power,  
- Phasors,  
- Three Phase Systems,  
- Transformers,  
- Magnetic Circuits,  
- Electrical Safety  

(Offered to non-EE students only)  
Prerequisite: PHYS 106 or consent of the department.
Basic Principles of Electricity

Book for the Course

Principles and Applications of Electrical Engineering, 4/e

Giorgio Rizzoni
The Ohio State University

Mc. Graw Hill Book Company,

ISBN: 0072463473
Copyright year: 2003
999 Pages

Available in Reserve Division of the
Middle East Technical University
Central Library
Basic Principles of Electricity

Course Syllabus

Chapters to be Covered

- Basic Principles of Electricity,
- Circuit Analysis,
- AC Circuits,
- AC Power,
- Phasors,
- Three Phase Systems,
- Transformers,
- Magnetic Circuits,
- Electrical Safety
## Basic Principles of the Course

### Examinations

Two midterm examinations and a final exam

<table>
<thead>
<tr>
<th>Examination</th>
<th>Questions</th>
<th>Credits</th>
<th>Duration</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midterm Exam 1</td>
<td>Three</td>
<td>Equal</td>
<td>90 min</td>
<td>20 %</td>
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<tr>
<td>Midterm Exam 2</td>
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<tr>
<td>Final Exam</td>
<td>Four</td>
<td>Equal</td>
<td>120 min</td>
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</table>

Attendance 30 %

Total 100 %
Basic Principles of Electricity

Homework

No homeworks will be assigned

You are advise to examine;
• the homeworks in the book,
• examination questions that will be distributed
Examinations

- **Midterm examinations** will cover all the material taught until the examination date,
- **Final Examination** will cover the overall course material,
- Announced exam schedule can neither be changed nor discussed after it has been settled,
- Duration of the examination will never be extended,
- Questions will never be allowed during the examination
**Basic Principles of the Course**

**Make-up Examinations**

- Will be given only to those students with valid documented excuse,
- Requests for make-up exam that does not include a valid documented excuse will be rejected,
- A single make-up exam will be given to all students with legitimate rights for the exam,
- Exam will be carried out in an officially settled date and hour,
- Exam will not be repeated, i.e. Make-up of make-up will not be performed,
- Students will be responsible for answering the questions only from the parts covered in the exam that they have missed
Questions and Solutions of the Previous Examinations

Exam Questions and Solutions

- A file including all exam questions and solutions is available,
- A file including the questions and solutions of all the previous examinations will be submitted to a student who is elected by the class for photocopying and distributing this file to the class,
- This student will be responsible for the toll collection and distribution activity

In case that there is no volunteer for the job, the task will be cancelled!
Yahoo Group for the Course

http://groups.yahoo.com/group/ee209/

Yahoo Group for the course is;

http://groups.yahoo.com/group/ee209/

This group is intended to be the main communication medium for information exchange and storage for the course.

Enrollment to this group is compulsory ---

All students are obliged to subscribe to this group by using the procedure described in the next page.
Basic Principles of Electricity

E-mail Group

Enrollment

To subscribe from the group, send an email to:
ee209-subscribe@yahoogroups.com

To unsubscribe from the group, send an email to:
ee209-unsubscribe@yahoogroups.com
Nicknames (User Ccodes)

Nicknames
Please choose nicknames that reflect your personal identity, i.e. your surname and/or name and/or you name and surname augmented.

Please do NOT choose improper or annoying nicknames, such as; “Arizona Tigers”, “diabolic, “best friend”, “miserable(68)” etc. that does not reflect your personal identity
Basic Principles of Electricity

E-mail Group

Communication

All questions, suggestions, complaints, demands, requests and other communication concerning the course should be directed to the e-mail communication address of the group:

ee209@yahoogroups.com

The Course Instructor keeps the right of not answering some or all of the questions, suggestions, complaints, demands, requests forwarded in this mail group, in case that it is not necessary, or not relevant, or not possible.
In your e-mails:

- Be polite,
- Start your letter with; “Dear Group Members” or “Dear Friends” and end with; “With best regards”
- Do not use disturbing abbreviations, such as “slm” for “selam”,
- Do not discuss your own personal, social or academic problems,
- Do not be aggressive to the Group members and to Course Instructor,
- Do not discuss subjects not relevant to the course, (such as last match of Fenerbahçe)

People who violate the above rules will be deleted from the group
E-mail Group

Course Instructor is the Main Moderator of the e-mail Group.

Assistant Moderator

An assistant moderator who is familiar with the management of yahoogroups activities, will be elected and appointed for managing the group from volunteer candidates in the class during the first hour. Moderators have identical authorities in group management in all respects.
Basic Principles of Electricity

Problems

Complaints and Expressions

Complaints and expressions concerning your;

- **personal,**
- **Social,**
- **Academic**

Problems will never be listened, nor be appreciated nor be interested.

- Your personal, social and academic problems will **never** be an influencing factor in grading,
- Your personal, social and academic problems will not be taken into account at all

This course is **NOT** a proper platform for expressing your own problems, negative or positive human feelings, such as, crying, complaining, hating, admiring, or any other physiologic, psychological expressions
Unfortunately, there will not be any chance for office hour

- Please do not refer my office for any reason,
- and do not blame for that.
My GSM No: 0 532 384 78 65

Telephone calls for concerning your personal, social and academic problems will neither be listened, nor be appreciated nor be interested.
# Basic Principles of Electricity

## E-mail Group

### Weekly Course Schedule (Three hours/week)

<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
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<tr>
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<td>10:40</td>
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<td>(ME), G-203</td>
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</tbody>
</table>

Announced schedule can be discussed
**Basic Principles of Electricity**

**Atom**

<table>
<thead>
<tr>
<th>Structure of atom</th>
<th>Helium Atom</th>
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</thead>
<tbody>
<tr>
<td>Electron is assumed to be negatively charged</td>
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<tr>
<td>Proton is assumed to be positive charged</td>
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</tbody>
</table>

Electron  
Proton  
Neutron

---

IBM Research/Peter Arnold, Inc.
**Basic Principles of Electricity**

### Electrical Charge

#### Definition

<table>
<thead>
<tr>
<th>Unit of Electrical Charge</th>
<th>Coulomb</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3 x 10^{18} electrons</td>
<td>1</td>
</tr>
<tr>
<td>or</td>
<td></td>
</tr>
<tr>
<td>Electrical charge / electron</td>
<td>1/ (6.3 x 10^{18})</td>
</tr>
<tr>
<td>Coulomb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>= 1.602 x 10^{-19} Coulomb</td>
</tr>
</tbody>
</table>
Basic Principle of Circuit

Mechanical Example

Inclined Surface

Gravitational force

\[ \Delta h = h_2 - h_1 \]
Basic Principles of Electricity

**Water Circuit**

- Water Current (I)

Water Current = Volume (m$^3$) / sec
Basic Principles of Electricity

Water Circuit

\[ \Delta P = P_2 - P_1 \]

Gravitational force

Water Current (I)
Basic Principles of Electricity

Electrical Circuit

Electrical Current (I)

Electrical Current = No. of electrons / sec
= 1 Coulomb / sec

6.3 x 10^{18} electrons / sec = 1 Amper
Basic Principles of Electricity

Electrical Circuit

Electrical Current (I)

Electromotive force

Current (I)

Voltage (V)

Consumer (Load)
Basic Principles of Electricity

Voltage Difference

Pressure Difference

\[ \Delta P = P_2 - P_1 \]

Pump

Gravitational force

Voltage Difference

\[ \Delta V = V_2 - V_1 \]

Current (I)

METU
**Ground Node (Earth Point)**

**Definition**

*Ground Node* is the point (junction) at which the voltage is assumed to be zero.

All other voltages take their references with respect to this ground node.

**Representation**

\[ \Delta V = V_2 - V_1 = V_2 \]

\[ V_1 = 0 \]
**Ground Node (Earth Point)**

**Definition**

*Ground Node* is the point (junction) at which the voltage is assumed to be zero.

*All other voltages take their references with respect to this ground node.*

**Ground Node** (Black Terminal)

**Measured Node** (Red Terminal)
Current = no. of electrons transferred / time duration

\[ I = \frac{\Delta Q}{\Delta t} \]

1 Amp = 1 Coulomb / 1 Seconds

Charge = Current $\times$ Time duration

\[ \Delta Q = I \times \Delta t \]
Basic Principles of Electricity

Traffic Current

Cars Flowing in a Highway

Traffic Current = Cars / minute
Basic Principles of Electricity

Water Current

Birecik Dam (672 MW)

Water Current = \( \frac{\text{Volume (m}^3\text{)}}{\text{sec}} \)

Water Current = 500 m\(^3\)/sec
Basic Principles of Electricity

Example: Electrical Current

A cylindrical conductor is 1 m long and 2 mm in diameter and contains $10^{29}$ free carriers per cubic meter.

1. Find the total charge of the carriers in this wire.
2. If the wire is used in a circuit, find the current flowing in the wire if the average velocity of the carriers is $19.9 \times 10^{-6}$ m/s.
Basic Principles of Electricity

Example: Electrical Current

Solution:

1. In order to compute the total charge contributed by the electrons, we first need to compute the volume of the conductor.

\[
Volume = Length \times Cross-sectional area = \pi r^2 L = \pi \left( \frac{2 \times 10^{-3}}{2} \right)^2
\]

Next we compute the charge by determining the total number of charge carriers in the conductor as follows:

\[
Charge = Volume \times \frac{Charge}{Unit \, volume}
\]

\[
Q = \pi \left( \frac{2 \times 10^{-3}}{2} \right)^2 \left(1 \times 1.602 \times 10^{-19} \, C \right) \left(10^{29} \, \frac{carriers}{m^3} \right)
\]

\[
= -50.33 \times 10^3 \, C
\]
2. If the carriers move with an average velocity of $19.9 \times 10^{-6}$ m/s, the magnitude of the total current flow in the wire can be computed by considering that current is the flow of charge per unit time:

$$\text{Current} = \text{Charge density per unit length} \times \text{Carrier velocity}$$

$$= \frac{50.33 \times 10^3}{1} \times 19.9 \times 10^{-6}$$

$$= 1 \text{ A}$$
Basic Principles of Electricity

Electrical Current - Basic Principle

Electrons

Electromotive force

Current

$\Delta V = V_2 - V_1$
Basic Principles of Electricity

Electrical Current
DC (Direct Current) Sources

\[ \Delta V = V_2 - V_1 \]

\[ V_1 = 0 \]

\[ V_2 \]

Battery

Battery
Basic Principles of Electricity

Simple AC Circuit

Generator

Current (I)

Customer
Kirchoff’s Current Law (KCL)

Basic Principle

\[ \sum \text{Cars entering} = \sum \text{Cars leaving} \]

Balance

- **Cars entering:** 370
- **Cars leaving:**
  - 120
  - 65
  - 55
  - 130
  - 370

**Cars entering:** 370 cars/min
- 120 cars/min
- 65 cars/min
- 130 cars/min
- 55 cars/min
Kirchoff’s Current Law (KCL)

Charges entering
\[ Q_1 + Q_2 + Q_{n-1} + Q_{in} = Q_{out} \]

Balance
\[ Q_{in} = Q_{out} \quad \text{or} \quad Q_{in} - Q_{out} = 0 \]
\[ \sum Q = 0 \]
Kirchoff’s Current Law (KCL)

Kirchoff’s First Law

or
\[ \sum \Delta Q = 0 \]

or
\[ \sum \frac{\Delta Q}{\Delta t} = 0 \]

or
\[ \sum_{i=1}^{n} I_i = 0 \]
Mechanical Force

**Definition**

Force needed to accelerate 1 kg of mass to 1 meter / sec$^2$ is defined as 1 Newton.

1 Newton = 1 kg x 1 meter / sec$^2$
1000 Newton = 1000 kg x 1 meter / sec$^2$

**Wagon**
Mass = 1000 kg

Force = 1000 Newton

Acceleration = 1 m/sec$^2$
Mechanical Energy

**Definition**

1 Joule is the energy needed to move a mass 1 meter by using 1 Newton force

- 1 Joule = 1 Newton \( \times \) 1 Meter

![Diagram](image)
### Power

**Definition**

Power is the work done within a certain unit of time, i.e. one second or one hour.

\[ \text{Power} = \frac{\text{Energy}}{\text{Duration}} \]

\[ = 1 \text{ Joule} / \text{sec} \]

**Please note that force (and hence power) of the weak horse shown below is half of the first, but the work done (energy spent) is the same, i.e.**

\[ \text{Energy} = 2 \text{ seconds} \times 0.5 \text{ Newton} \times 1 \text{ meter} \]

Energy = 1 Joule, Power = 1 Joule / sec.

Energy = 1 Joule, Power = 1 Joule / 2 sec.
Basic Principles of Electricity

Mechanical Energy vs Electrical Energy

**Equivalence**

Mechanical Energy = Electrical Energy

Mechanical Work = Electrical Work

The same amount of energy may be spent out by using electricity

Mechanical Energy (Work) = 1 Joule

Electrical Energy (Work) = 1 Joule

1 Joule

Current (I)

Voltage (V)
Basic Principles of Electricity

Electrical Power

Definition

Similar to mechanical power, electrical power is the work done within a certain unit of time, i.e. one second or one hour.

Electrical Power = Electrical Energy / Duration

= 1 Joule / sec

1 sec

1 Meter

1 Newton

Wagon

Wagon

Mechanical Power = 1 Joule / sec.

Wagon

Electrical Power = 1 Joule / sec.

(1 sec)

Current (I)

Voltage (V)
Basic Principles of Electricity

Equivalence of Mechanical and Electrical Powers

**Equivalence**

**Mechanical Power = Electrical Power**

Mechanical Power = 1 Joule / sec.

Electrical Power = 1 Joule / sec.
Basic Principles of Electricity

Electrical Power

**Definition**

\[ 1 \text{ Joule} / \text{second} = 1 \text{ Watt} \]

(1 Joule energy is spent within 1 second)

\[ 1 \text{ Joule} = 1 \text{ Watt \times second} \]

\[ 1 \text{ Horse Power} = 746 \text{ Watts} = 0.746 \text{ kWatt} \]

**Diagram**

1 Meter
1 Newton
1 sec
Wagon
Wagon

**Mathematical Representation**

\[ \text{Electrical Power} = 1 \text{ Joule} / \text{sec.} = 1 \text{ Watt} \]

\[ \text{Current (I)} \]

\[ \text{Voltage (V)} \]
**Basic Principles of Electricity**

**Electrical Power**

**Definition**

\[ P = V \times I \]

(Watt) = (Volt) x (Amp)

**Power = Voltage x Current**

![Diagram of electrical power circuit](image)
**Basic Principles of Electricity**

**Voltage**

**Definition**

*Power = Voltage x Current*

\[ P = V \times I \]

*Voltage = Power / Current*

\[ V = \frac{P}{I} \]

![Diagram showing voltage, current, and power.](image)
Voltage

Definition

\[ \text{Power} = \text{Voltage} \times \text{Current} \]

or

\[ \text{Voltage} = \frac{\text{Power}}{\text{Current}} \]

or

\[ V = \frac{P}{I} \]

1 Volt = 1 Watt / 1 Amp

Current (1 Amp)

DC Voltage (1 Volt)

Power (1 Watt)
Basic Principles of Electricity

Electrical Energy

Definition

Energy = Power \times Time
(Watt-sec) \times (Watt) \times (second)

Energy = Power \times Time
Unit of Electrical Energy

**Definition**

\[ \text{Energy} = \text{Power} \times \text{Time} \]

- \(\text{Power} = \text{Watt} = 1000 \text{ Watts}\)
- \(\text{Time} = \text{second} = 1 \text{ second}\)

\[ \text{Energy} = \text{Power} \times \text{Time} \]

- \(\text{Power} = \text{KiloWatt} = 1000 \text{ Watts}\)
- \(\text{Time} = \text{hour} = 1 \text{ hour}\)

\[ \text{1 KiloWatt - hour} = 1000 \times 3600 \text{ Watt} \times \text{seconds} = 3,600,000 \text{ Joules} \]
Basic Principles of Electricity

Electrical Energy

Example

Calculate the monthly payment for the energy consumed by the lamp shown on the RHS.

Source voltage is 220 Volt
Current drawn by the lamp is 5 Amp
Price of electrical energy is 12 Cents / kWh

\[
\text{Power} = \text{Voltage} \times \text{Current} \\
P = V \times I \\
P = 220 \times 5 = 1100 \text{ Watts} \\
\text{Energy} = P \times \Delta t \\
= 1100 \text{ Watts} \times (24 \text{ hours /day} \times 30 \text{ days/month}) \\
= 792000 \text{ Watt hours} = 790.2 \text{ kWh} \\
\text{Monthly payment} = 790.2 \times 12 \text{ Cents / month} \\
= 90.504 \text{ USD} = 122.1 \text{ YTL / month}
\]
**Alternative Definition of Voltage**

1 Volt = 1 Watt / 1 Amp
= (1 Joule / sec) / 1 Amp
= 1 Joule / (1 Amp x sec)
= 1 Joule / 1 Coulomb (*)

(*) Remember that 1 Amp = 1 Coulomb / 1 sec

1 Volt is the voltage needed:
- to move 1 Coulomb of electrical charge,
- to spend 1 Joule of energy for this movement in a conductor
Basic Principles of Electricity

Alternative Definition of Voltage

1 Volt = 1 Joule / 1 Coulomb

Please note that the time parameter does not appear in the above equation, implying that it is arbitrary.

Case 1
Let \( t = 1 \) sec
Then, \( I = \frac{1 \text{ Coulomb}}{1 \text{ sec}} = 1 \text{ Amp} \)
\( P = V \times I = 1 \text{ Volt} \times 1 \text{ Amp} = 1 \text{ Watt} \)
Energy = \( P \times t = (1 \text{ Joule/ sec}) \times \text{ sec} = 1 \text{ Joule} \)

Case 2
Let now \( t = 2 \) sec
Then, \( I = \frac{1 \text{ Coulomb}}{2 \text{ sec}} = 0.5 \text{ Amp} \)
\( P = V \times I = 1 \text{ Volt} \times 0.5 \text{ Amp} = 0.5 \text{ Watt} \)
\( = \text{ Energy} / 2 = 0.5 \text{ Joule/ sec} \)
Energy = \( P \times t = 0.5 \times 2 = 1 \text{ Joule} \) again
**Resistance**

**Definition**

Resistance is the reaction of a pipe against water flow.

- Resistance $R_1$\[R_1 > R_2\] Resistance $R_2$
- Current $I_1$\[I_2 > I_1\] Current $I_2$
**Basic Principles of Electricity**

**Resistance**

**Definition**

Resistance is the reaction of a conductor against electrical current.

- Resistance $R_1$ with current $I_1$
- Resistance $R_2$ with current $I_1$

$R_1 > R_2$

$I_1 < I_2$
Basic Principles of Electricity

**Ohm Law**

\[ I = \frac{V}{R} \]

- **Voltage** \((V)\)
- **Current I** \((Amp)\)
- **Resistance** \((R)\)

Unit of resistance is Ohm

1 Ohm is the resistance that allows 1 Amper to pass at 1 Volts voltage;

1 Ohm = 1 Volt / 1 Amper

**Basic Principles**

Current flowing in the circuit is;
- proportional to voltage,
- inversely proportional to resistance

Hence

or

\[ V = R \times I \]

\[ I = \frac{V}{R} \]

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**Basic Principles of Electricity**

**Ohm Law**

Two circuits with different Resistances, identical voltage sources

Resistance $R_1$ \( R_1 > R_2 \) Resistance $R_2$

Current \( I_1 \) \( I_1 < I_2 \)

\[
\frac{V}{R_1} = I_1
\]

\[
\frac{V}{R_2} = I_2
\]
Basic Principles of Electricity

Ohm Law

V-I Characteristics

\[ V = R \times I \]

(Volt) (Ohm) (Amp)

Current I (Amp)

Voltage (Volt)

Residence (R)

\[ \text{Slope} = \frac{\Delta V}{\Delta I} = R \]

V varies linearly with I

V-I Characteristics graph with voltage varying linearly with current.
Ohm Law - Example

Question

Calculate the current flowing in the circuit shown on the RHS

\[ V = R \times I \]
\[ (\text{Volt}) = (\text{Ohm}) \times (\text{Amp}) \]

\[ I = \frac{V}{R} \]
\[ = \frac{220}{5} = 44 \text{ Amps} \]
### Basic Principles of Electricity

#### Ohm Law

Nonlinear V-I Characteristics

\[
V = R \times I
\]

(Volt) (Ohm) (Amp)

- \( R = R_0 (1 + \alpha \Delta t) \)
- \( \Delta t = T - 23^\circ C \)
- \( R_0 = \text{Resistance at } 23^\circ C \)
- \( \alpha = \text{The temperature coeff. of the metal} \)

Note that resistance increases with temperature, hence current is reduced.

\[ R = R_0 (1 + \alpha \Delta t) \]

\( \Delta t = T - 23^\circ C \)

\( R_0 = \text{Resistance at } 23^\circ C \)

\( \alpha = \text{The temperature coeff. of the metal} \)

---

**Example:**

\( V = 220 \text{ V} \)

\( I = 5 \text{ Amp} \)

**Graph:**

- **Slope** = \( \Delta V / \Delta I = R \)

**Temperature coefficients of resistance or resistivity of some metals (10^-3/°C):**

- Silver: 3.8
- Copper: 3.9
- Gold: 3.4
- Aluminum: 3.9
- Iron: 5.0
- Tungsten: 4.5
- Nichrome: 0.4
- Platinum: 3.92
Resistance Formula

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

where, $R$ is the resistance of conductor,
$\rho$ is the resistivity coefficient,
$\rho = \frac{1}{56} \text{Ohm-mm}^2/\text{m (Copper)}$
$1/32 \text{Ohm-mm}^2/\text{m (Aluminum)}$
$l$ (m) is the length of the conductor
$A$ (mm$^2$) is the cross sectional area of the conductor

ACSR Conductor
(Aluminum Conductor Steel Reinforced)
Resistivity Coefficient

\[ R = \frac{\rho \, l}{A} \]

where, \( R \) is the resistance of conductor, \( \rho \) is the resistivity coefficient, \( l \) (m) is the length of the conductor, and \( A \) (mm\(^2\)) is the cross sectional area of the conductor.

- For Copper: \( \rho = \frac{1}{56} \text{ Ohm-mm}^2/\text{m} \)
- For Aluminum: \( \rho = \frac{1}{32} \text{ Ohm-mm}^2/\text{m} \)
Resistance Formula

Example
Calculate the resistance of a copper cable with length 3200 meters and cross section 240 mm$^2$

Solution
$R = \frac{1}{56} \times \frac{3200}{240} = 0.238$ Ohms
# Basic Principles of Electricity

## Resistance Formula

### Example
Calculate the resistance of a copper cable with length 3200 meters and cross section 240 mm$^2$.

### Solution
\[
R = \frac{1}{56} \times \frac{3200}{240} = 0.238 \text{ Ohms}
\]

![ACSR Conductor (Aluminum Conductor Steel Reinforced)](image)

<table>
<thead>
<tr>
<th>$l$</th>
<th>3200 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>240 (mm$^2$)</td>
</tr>
</tbody>
</table>
Basic Principles of Electricity

Resistivity Coefficients of Various Metals

**Formula**

\[ R = \rho \frac{l}{A} \]
where, \( R \) is the resistance of conductor, \( \rho \) is the resistivity coefficient, \( l \) (m) is the length of the conductor, and \( A \) (mm\(^2\)) is the cross-sectional area of the conductor.

**Resistivity Coefficients**

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity Coefficient</th>
<th>Resistance</th>
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<tbody>
<tr>
<td></td>
<td>Ohm-mm(^2)/m</td>
<td>Ohms/feet</td>
</tr>
<tr>
<td>Silver</td>
<td>0.0162</td>
<td>0.00094</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0172</td>
<td>0.00099</td>
</tr>
<tr>
<td>Gold</td>
<td>0.0244</td>
<td>0.00114</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.0282</td>
<td>0.00164</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.9580</td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td>0.0700</td>
<td>0.00406</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.7800</td>
<td>0.00452</td>
</tr>
<tr>
<td>Iron</td>
<td>0.1000</td>
<td>0.00579</td>
</tr>
<tr>
<td>Platinium</td>
<td>0.1000</td>
<td>0.00579</td>
</tr>
<tr>
<td>Steel</td>
<td>0.1180</td>
<td>0.00684</td>
</tr>
<tr>
<td>Lead</td>
<td>0.2200</td>
<td>0.01270</td>
</tr>
</tbody>
</table>
Basic Principles of Electricity

Color Codes for Resistances

Rule

RESISTOR COLOUR CHART

1st Digit 2nd Digit 3rd Digit Multiplier tol

0 black 1 brown 2 red 3 orange 4 yellow 5 green 6 blue 7 purple 8 silver 9 white

5 band code

5 6 0 2 1

47K 2% 56K 1%

47K 2%
Insulator is a material with almost infinite resistance.

**Insulators are used to support HV lines and conductors**

In practice, all materials have resistances. Hence, they conduct a certain amount of current when a voltage is applied to the terminals. Insulator are materials that conduct only a very small amount of current, even when an extremely high voltage is applied to the terminals.
Basic Principles of Electricity

Power dissipation in a Resistance

\[ V = R \times I \]

(Volt) = (Ohm) (Amp)

On the other hand, it was shown in this lecture that;

\[ \text{Power} = \text{Voltage} \times \text{Current} \]

or

\[ P = V \times I \]

Hence, power dissipation in resistance \( R \) is

\[ \text{Power} = R \times I \times I \]

\[ = R \times I^2 \text{ Watt} \]
Let $A_1 = A_2$

Hence;

$$l_{\text{total}} = l_1 + l_2$$

$$R_{\text{total}} = \frac{\rho \ l_{\text{total}}}{A} = \frac{\rho \ (l_1 + l_2)}{A} = \frac{\rho \ l_1}{A} + \frac{\rho \ l_2}{A} = R_1 + R_2$$
Series Connected Resistances

Equivalent Resistance Formula

\[ R_{\text{total}} = R_1 + R_2 \]

Series connected resistances are added

\[ R_{\text{total}} = R_1 + R_2 + \ldots + R_k \]
Basic Principles of Electricity

Ohm Law for Series Resistances

\[ V = R_{\text{total}} \times I \]  
\[ V = R_1 \times I + R_2 \times I \]

- Voltage (Volt)
- Current (Amp)
- Resistance (Ohm)

Diagram on the left:
- Voltage (Volt)
- Current (Amp)
- Resistance (R_{total})

Diagram on the right:
- Voltage (Volt)
- Current (Amp)
- Resistance (R_1)
- Resistance (R_2)
Ohm Law for Series Resistances

\[ V = R_1 \times I + R_2 \times I \]

\[ = V_1 + V_2 \]
## Basic Principles of Electricity

### Admittance

#### Definition

Inverse of resistance is called **“Admittance”**

\[ g = \frac{1}{R} \quad \text{(Siemens)} \quad \text{or} \quad \frac{1}{\text{Ohm}} \]

Unit of **“Admittance”** is Siemens

#### Example

Calculate the admittance of 10 kΩ resistance shown on the RHS

\[ g = \frac{1}{10^4} = 10^{-4} \text{ Siemens} \]
Basic Principles of Electricity

Shunt Connected Resistances

Equivalent Resistance Formula

\[ V = V_T / R_{1} = V_T \times g_1 \]

\[ I_1 = V_T / R_{1} = V_T \times g_1 \]

\[ I_2 = V_T / R_{2} = V_T \times g_2 \]

\[ I_k = V_T / R_k = V_T \times g_k \]
Shunt Connected Resistances

Equivalent Resistance Formula

\[ R_{\text{equiv}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_k}} \]

\[ I_1 = \frac{V_T}{R_1} \]
\[ I_2 = \frac{V_T}{R_2} \]
\[ I_k = \frac{V_T}{R_k} \]
\[ I_{\text{total}} = V_T \left( \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_k} \right) = V_T / R_{\text{equiv}} \]
**Example**

Find the equivalent resistance of the following connection:

\[
R_1 = 1 \text{ Ohm} \quad R_2 = 2 \text{ Ohms} \quad R_k = 4 \text{ Ohms}
\]

\[
V = V_T
\]

\[
I_1 \quad I_2 \quad I_{\text{Total}}
\]

\[
R_{\text{equiv}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_k}}
\]

\[
\frac{1}{1/1 + 1/2 + 1/4} = \frac{1}{(7/4)} = \frac{4}{7} = 0.5714 \text{ Ohm}
\]
Shunt Connected Resistances

**Example**

Find the equivalent admittance of the following connection:

\[
g_{\text{equiv}} = \frac{1}{g_1 + g_2 + \ldots + g_k}
\]

\[
R_{\text{equiv}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_k}}
\]

1. \(g_1 = \frac{1}{1}\) Siemens
2. \(g_2 = \frac{1}{2}\) Siemens
3. \(g_k = \frac{1}{4}\) Siemens

\[
\frac{1}{g_{\text{equiv}}} = \frac{1}{g_1 + g_2 + \ldots + g_k}
\]

\[
g_{\text{equiv}} = g_1 + g_2 + g_3 = \frac{1}{1} + \frac{1}{2} + \frac{1}{4}
\]

\[
= \frac{7}{4}
\]

\[
= 1.75\ \text{Siemens}
\]
**Basic Principles of Electricity**

**Voltages on Series Connected Elements**

Voltages on series connected elements are added

\[ V = V_1 + V_2 \] (Volt)  
\[ V = V_1 + \ldots + V_{n-1} \] (Volt)

Current I (Amp)

\[ V_s \] (Volt)

\[ V_1 \] (Volt)

\[ V_2 \] (Volt)

\[ V \] (Volt)

\[ V_{n-1} \] (Volt)
Basic Principles of Electricity

Voltages on Series Connected Elements

Voltages on series connected elements are added

\[ V = V_1 + \ldots + V_{n-1} \]  
\[ V = \sum_{i=1}^{n-1} V_i \]  
\[ V_n - \sum_{i=1}^{n-1} V_i = 0 \]  
\[ \sum_{i=1}^{n} V_i = 0 \]
Basic Principles of Electricity

Kirchoff’s Voltage Law (KVL)

**Statement**

The above result may be expressed as:

**Sum of voltages in a closed loop is zero**

or

\[ \sum_{i=1}^{n} V_i = 0 \]

**Kirchoff’s Second Law**

or

**Kirchoff’s Voltage Law**
### Kirchoff’s Voltage Law (KVL)

#### Example

<table>
<thead>
<tr>
<th>Expression</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i = n$</td>
<td></td>
</tr>
<tr>
<td>$\sum_{i=1}^{n} V_i = 0$</td>
<td></td>
</tr>
<tr>
<td>$V_s = 220$ Volts</td>
<td>$V_s - V_1 - V_2 = 0$</td>
</tr>
<tr>
<td></td>
<td>$220 - 100 - 120 = 0$</td>
</tr>
</tbody>
</table>

**Diagram:**
- **Current $I$ (Amp):**
  - $V_1 = -100$ (Volt)
  - $V_2 = -120$ (Volt)
- **Voltage $V$:**
  - $220$ V

**Diagram Description:**
- Positive direction for current $I$.
Kirchhoff’s Voltage Law (KVL)

**Simple Rules**

Head (pinpoint) of the arrow is negative, Tail of the arrow is positive

This current is assigned such a direction that it always enters from the ‘+’ side of the resistance

\[ V_1 \text{(Volt)} \]
\[ V_2 \text{(Volt)} \]
\[ V_s \text{(Volt)} \]
A Simple Rule for applying Kirchoff’s Voltage Law (KVL)

- Choose a ground node,
- Assume that current I flows clockwise,
- Starting from the ground node, assign “+” and “-” signs to those passive elements (i.e. those elements other than source) in such a direction that the current enters to “+” side and the leaves from the “-” side,
- Assign “+” sign to the that side of the source from which current is leaving.
A Simple Rule for applying Kirchoff’s Voltage Law (KVL)

**A Simple Rule**

- Then write down the voltages on each element by using Ohm Law on a path in a clockwise direction,
- Assign “+” sign to those voltage terms in the equation that you pass from “-” to “+”,
- Assign “-” sign to those voltage terms in the equation that you pass from “+” to “-”,
- Stop and equate it to zero when you come again to the ground node that you have started

**Example:**

\[ +V_s -V_1 -V_2 = 0 \]

\[ V_s = V_1 + V_2 \]
## Summary of Kirchoff’s Laws

<table>
<thead>
<tr>
<th>Kirchoff’s Current Law (KCL)</th>
<th>Kirchoff’s Voltage Law (KVL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Algebraic sum of currents entering a junction is zero</strong></td>
<td><strong>Algebraic sum of voltages in a closed loop is zero</strong></td>
</tr>
<tr>
<td>[ \sum_{i=1}^{n} I_i = 0 ]</td>
<td>[ \sum_{i=1}^{n} V_i = 0 ]</td>
</tr>
</tbody>
</table>

**Node (Junction):**
- Current \( I_n \)
- Current \( I_1 \)
- Current \( I_2 \)
- Current \( I_{n-1} \)

**Current I (Amp):**
- \( V = 220 \text{ V} \)
- \( V_1 = -100 \text{ (Volt)} \)
- \( V_{n-1} = -120 \text{ (Volt)} \)
Voltage Division Principle

\[ V_1 = R_1 \times I \]
\[ V_2 = R_2 \times I \]
\[ \vdots \]
\[ V_k = R_k \times I \]

\[ V_s = V_1 + V_2 + \ldots + V_k \]
\[ = (R_1 + \ldots + R_k) \times I \]

\[ V_k \div V_s = \frac{R_k}{R_1 + \ldots + R_k} \]

Voltage Division Ratio = \[ \frac{R_k}{R_1 + \ldots + R_k} \]
Potentiometer (Voltage Divider)

Principle

Input voltage is divided and a certain fraction is given to the output.

Current I

\[ V_k = \frac{R_k}{R_1 + \ldots + R_k} V_s \]

Division Ratio = \[ \frac{R_k}{R_1 + \ldots + R_k} \]

Diagram:

- A, B, C
- Current I
- \( V_s \)
- \( V_1 \)
- \( V_2 \)
- \( V_k \)
Potentiometer (Voltage Divider)

Circuit Arrangement

Rotary Potentiometer

Division Ratio = \frac{R_k}{R_1 + \ldots + R_k}

Rotary Potentiometer

Volt. Source

Voltmeter
**Current Division Principle**

\[
V_T \times g_1 = I_1 \\
V_T \times g_2 = I_2 \\
\vdots \\
V_T \times g_k = I_k \\
\frac{V_T (g_1 + \ldots + g_k)}{I_s} = I_1 + \ldots + I_k
\]

or

\[
V_T (g_1 + \ldots + g_k) = I_s \\
I_k / I_s = g_k / (g_1 + \ldots + g_k)
\]

**Division Ratio**

\[
I_k = \frac{g_k}{g_1 + \ldots + g_k}
\]

**Diagram:**

- Source Current \(I_s\)
- \(g_1\), \(I_1 = V_T \times g_1\)
- \(g_2\), \(I_2 = V_T \times g_2\)
- \(g_k\), \(I_k = V_T \times g_k = I_s g_k / (g_1 + \ldots + g_k)\)

\(V = V_T\)
**Basic Principles of Electricity**

**Voltage Sources**

**Definition**
Voltage source is an element which creates a voltage difference at its terminals.

**A simple Rule:**
Current is assigned such a direction that it always leaves the ‘+’ side of the voltage or current source.

---

**Example:**
- Voltage Source: $V = 24$ Volts
- DC Voltage Source: $V = 24$ Volts
**Ideal Voltage Source**

**Definition**

An ideal voltage source is the one that the terminal voltage does not change with the current drawn.

An ideal voltage source has zero internal resistance.

\[ V = 24 \text{ Volts} \]

\[ V_T = \text{constant} \]

\[ V_T = V_s \]

\[ \Delta V = R \times I = 0 \]

Battery

Load Current I

Terminal Voltage (Volts)

Load Current I (Amp)
Non-Ideal (Real) Voltage Sources

Definition

A voltage source always has an internal resistance \( R \) connected in series with the source.

Writing down KVL for the above cct;

\[ V_s - \Delta V - V_T = 0 \]

or

\[ V_T = V_s - \Delta V \]

where,

\[ \Delta V = R \times I \]

is called “internal voltage drop”

Terminal voltage \( V_T \) is reduced by \( \Delta V \)
Non-Ideal (Real) Voltage Sources

**Definition**

Writing down KVL for the above cct:

\[ V_T = V_s - \Delta V \]

\[ = V_s - R \times I \]

- **Battery**
- **Load Current I**
- **Internal resistance**

\[ \Delta V = R \times I \]

\[ V_s = 24 \text{ V} \]

\[ V_T = 24 - \Delta V \]

**Slope**

\[ \text{Slope} = \frac{-\Delta V_T}{\Delta I} = -R \]

- **Terminal Voltage** \( V_T \) depends on \( I \) i.e. it is reduced as \( I \) is increased
An ideal current source is an element providing a constant current from its terminals.

Definition

Terminal Current $I_T$ = Source Current $I_s$

Source Current $I_s$
Non-Ideal (Real) Current Source

**Definition**

A non ideal current source is an element with a current depending on terminal voltage.

**Terminal Current $I_T$**

\[ I_T = I_s - \Delta I \]

\[ I_T = I_s - g \times V_T \]

**Current Source $I_s$**

**Ideal Current Source $I_s$**
Non-Ideal (Real) Current Source

Definition: Non-Ideal Current Source

A non ideal current source is an element with a current depending on terminal voltage.

Terminal Current $I_T$

$I_T = I_s - \Delta I$

$I_T = I_s - g \times V_T$

Non-Ideal Current Source

Ideal Current Source $I_s$

$\Delta I$

$g = 1 / R$

Terminal Voltage (Volts)

Terminal Current ($I_s$, Amp)

$I_T$ depends on $V$ i.e. it is reduced as $V$ is increased

Slope = $\Delta I_T / \Delta V_T = -g$
Controlled (Dependent) Sources

**Definition: Controlled Sources**

A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit.

**Voltage Controlled Current Source**

\[ I_s = A V_x \]

Where:
- \( I_s \) = Terminal Current
- \( A \) = Amplification coefficient
- \( V_x \) = Control Voltage
### Controlled (Dependent) Sources

#### Definition: Controlled Sources

A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit.

**Controlled Source: Current**

\[ I_s = A \times I_x \]

#### Current Controlled Current Source

**Terminal Current:**

\[ I_T = I_s + I_x \]

\[ I_T = I_s + I_x \]

**Current Controlled Current Source**

\[ I_s = A \times I_x \]
Controlled (Dependent) Sources

**Definition: Controlled Sources**
A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit.

**Controlled Source: Voltage** \( V_s = A \, V_x \)
**Definition: Controlled Sources**

A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit.

**Controlled Source: Voltage** $V_s = A I_x$

**Current Controlled Voltage Source**

Current Controlled Voltage Source

$V_s = A I_x$

Terminal Current: $I_T = I_s$

$I_t = I_s$

$V_s$

$I_x$

$+/

$I_s$
# Basic Principles of Electricity

## Example

### Question

Solve the circuit on the RHS for current $I_x$

### Solution

Write down KVL;

\[
V_s - 10 - 2I_x = 0
\]

\[
10I_x - 10 - 2I_x = 0
\]

\[
8I_x = 10 \rightarrow I_x = 10 / 8 = 1.25 \text{ Amp}
\]
An ammeter is a measuring instrument used to measure the flow of electric current in a circuit. Electric currents are measured in amperes, hence the name "ammeter" is commonly misspelled or mispronounced as "ampmeter" by some. The earliest design is the D'Arsonval galvanometer. It uses magnetic deflection, where current passing through a coil causes the coil to move in a magnetic field. The voltage drop across the coil is kept to a minimum to minimize resistance in any circuit into which the meter is inserted.
An ammeter is always series connected in the circuit measured.
Measuring Devices - Ammeter

An ammeter is always series connected in the circuit measured.

Internal Resistance of Ammeter

\[ R_{\text{amp}} \]

\[ I_{\text{load}} \]

\[ R_L \]

\[ \text{Battery} \]

\[ \text{Lamp} \]
An ideal ammeter is the one with zero internal resistance (Short Circuit)

- An ideal ammeter behaves as a short circuit, i.e. $R_{amp} \approx 0$.
- An ideal ammeter has zero resistance so that the measured current is not influenced.

No ammeter can ever be ideal, and hence all ammeters have some internal resistance.
An ammeter should not influence the current measured.

\[ I = \frac{V_s}{R + R_{\text{amp}}} \]

\[ R_{\text{amp}} \approx 0 \]

Hence,

\[ I = \frac{V_s}{R + R_{\text{amp}}} \approx \frac{V_s}{R} \]
Non-Ideal (Real) Ammeter

Definition

No ammeter can ever be ideal, and hence all ammeters have some internal resistance

A real (non-ideal) ammeter has always an internal resistance in series

• A non ideal ammeter behaves as a series resistance with: $R_{amp} \neq 0$
• Hence the measured current is influenced (reduced)

\[
I_{load} = \frac{V_s}{R + R_{amp}} < \frac{V_s}{R} = I_{ideal}
\]
Sometimes the electrical service carried out by the circuit may be so vital that it can not be interrupted by breaking the line for a series connection of the ammeter. Ammeter shown on the RHS is a particular design for such circuits to measure current flowing in the circuit as well as resistance without breaking the circuit.
A voltmeter has a high internal resistance so that it passes only a small current.

An ideal voltmeter has a very large resistance so that the circuit in which it has been placed is not disturbed.

An ideal voltmeter is an open circuit.

However, no voltmeter can ever be ideal, and therefore all voltmeters draw some small current.

Voltmeter is always parallel connected to the terminals measured.
A voltmeter has a high internal resistance so that it passes only a small current. A voltmeter is always shunt (parallel) connected in the circuit that it measures. Measured voltage:

\[ V_o = V_s \quad \frac{R_L}{R_1 + R_L} \]
Ideal Voltmeter

Definition

An ideal voltmeter is the one with infinite internal resistance (Open circuit)

An ideal voltmeter has a very large resistance, $R_m \approx \infty$. i.e. it behaves as an open circuit, so that the measured circuit is not influenced.

However, no voltmeter can ever be ideal, and therefore all voltmeters draw some current.

A real voltmeter has a certain internal resistance so that it passes a certain current.
No voltmeter can ever be ideal, and therefore all voltmeters draw some current.

\[
R_m \approx \infty \quad \text{i.e.} \quad R_m \gg R_L
\]
\[
I_m \ll I_{\text{Load}}
\]
\[
I_{\text{Source}} = I_{\text{Load}} + I_m \equiv I_{\text{Load}}
\]
\[
V_o = R_L (I_{\text{source}} - I_m)
\]
\[
= R_L I_{\text{Source}} - R_L I_m
\]
\[
\approx R_L I_{\text{Source}}
\]

Negligible
**Example**

**Problem**

Calculate the internal admittance $g_m$ of a voltmeter, if it reads 11.81 Volts when connected to a 0.48 mA current source with an internal admittance of $g_s = 4 \times 10^{-5}$ Siemens.

**Ideal Voltmeter**

$I_m \approx 0$

**Non-ideal Voltmeter**

$I_m$ (negligible)

$V_{\text{read}} = 11.81 \text{ V}$

$I_s = 0.48 \text{ mA}$

$g_s = 4 \times 10^{-5} \text{ S}$

$g_m = 1/R_m$

**Siemens = 1/Ω**
Example

**Problem**

\[ R_s = \frac{1}{g_s} = \frac{1}{(4 \times 10^{-5}) \text{ Siemens}} = \frac{10^5}{4} = 25 \text{ k}\Omega \]

\[ I_s \times R_{eq} = V_{read} = 11.81 \text{ Volts} \]

Hence,

\[ R_{eq} = \frac{V_{read}}{I_s} = \frac{11.81}{(0.48 \times 10^{-3})} = 24607.17 \Omega \]

**Ideal Voltmeter** \( I_m \approx 0 \)

\[ R_{eq} = \frac{R_s \times R_m}{R_s + R_m} = 24607.17 \Omega \]

**Non-ideal Voltmeter**

\[ I_g \approx 0 \]

\[ I_g = I_s = 0.48 \text{ mA} \]

\[ V_{read} = 11.81 \text{ V} \]

\[ g_s = 4 \times 10^{-5} \text{ S} \]

\[ g_m = \frac{1}{R_m} \]

\[ R_m = 155.39 \text{ M}\Omega \]
Basic Principles of Electricity

Advanced Measuring Devices

Power Quality Analyzer

GÜÇ KALİTESİ ANALİZÖRÜ

Fluke 43Basic
Fluke 43B
Fluke 43Kit

Power Quality Analyzer
Power Quality Analyzer
Power Quality Analyzer
The **Wheatstone Bridge** is an electrical circuit used to determine an unknown resistance $R_x$ by adjusting the values of known resistances, so that the current measured in the line connecting the terminals C and D is zero.
Adjust the resistances $R_1$, $R_2$, and $R_b$ such that the ammeter connected between the terminals C and D reads zero current.

Hence, the voltage difference between the terminals C and D is zero.

$\Delta V_{CD} = 0$

or

$V_C = V_D$
**Wheatstone Bridge**

**Principle**

\[ V_C = V_D \]
\[ V_C = V_s \frac{R_b}{(R_x + R_b)} \]
\[ V_D = V_s \frac{R_2}{(R_1 + R_2)} \]
\[ V_s \frac{R_b}{(R_x + R_b)} = V_s \frac{R_2}{(R_1 + R_2)} \]

or

\[ \frac{R_b}{(R_x + R_b)} = \frac{R_2}{(R_1 + R_2)} \]
\[ R_b (R_1 + R_2) = R_2 (R_x + R_b) \]
\[ R_b R_1 + R_b R_2 = R_2 R_x + R_2 R_b \]

or

\[ R_x = \frac{R_b R_1}{R_2} \]
Basic Principles of Electricity

Wheatstone Bridge

Basic Rule

Cross multiplication branch resistances must be equal at balance condition

\[ R_x \times R_2 = R_b \times R_1 \]

Please note that voltage \( V_s \) is neither used, nor needed in the above equation, i.e. its value is arbitrary.
**Example**

Calculate the value of unknown resistance $R_x$ in the balanced Wheatstone Bridge shown on the RHS.

Cross multiplication of branch resistances must be equal at balance condition:

$$R_x \times R_2 = R_b \times R_1$$

$$R_x = \frac{R_b \times R_1}{R_2}$$

$$= \frac{100 \times 100}{20} = 500 \text{ Ohm}$$
Switch or circuit breaker is a device used to open an electrical circuit manually or automatically by an electronic relay system.

Switch or Circuit Breaker

Switch - Circuit Breaker

Open “Off”  
Closed “On”

\[ \begin{align*}
V_s & \quad \text{Source Voltage} \\
R_1 & \quad \text{Resistance}
\end{align*} \]
## Basic Principles of Electricity

### Meaning of “Open” and “Closed” (Highly Important)

<table>
<thead>
<tr>
<th>Breaker</th>
<th>Open Circuit or Switch</th>
<th>Closed Circuit or Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open (On), Closed (Off)</td>
<td>Open Circuit</td>
<td>Open (Off) Switch</td>
</tr>
</tbody>
</table>

#### Open Circuit or Switch

- **Open Circuit**: $I_{Load} = 0$
- **Open (Off) Switch**: $I_{Load} = 0$

#### Closed Circuit or Switch

- **Closed Circuit**: $I_{Load}$
- **Closed (On) Switch**: $I_{Load}$

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“Closed Switch (On)” does NOT mean that there is no voltage (current) in the circuit!
Thermal-Magnetic Circuit Breaker

220 Volt, 63 Amp. Thermal-Magnetic (Molded-Case) Breaker

“Closed Switch (On)” does NOT mean that there is no voltage (current) in the circuit!
Medium Voltage (36 kV) Vacuum Circuit Breaker

Open Circuit

\[ V_s \]

\[ R_1 \]

\[ I_{\text{Load}} = 0 \]

Vacuum tube enclosing breaker poles

Tripping buttons

Spring handle (taken off)
Basic Principles of Electricity

Did everybody understand the Basic Principles of Electricity?