Lecture PowerPoints

Chapter 19

Physics: Principles with Applications, 7th edition
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Chapter 19
DC Circuits
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19-1 EMF and Terminal Voltage

Electric circuit needs battery or generator to produce current—these are called sources of emf (electromotive force). We will use the letter $E$ to denote the emf.

Battery is a nearly constant voltage source, but does have a small internal resistance, which reduces the actual voltage from the ideal emf:

$$V_{ab} = E - Ir. \quad (19-1)$$

This resistance behaves as though it were in series with the emf.
19-2 Resistors in Series

When two or more resistors are connected end to the end along a single pass, they are connected in series. A series connection has a single path from the battery, through each circuit element in turn, then back to the battery.

Resistors: any elements that have resistance (light bulbs, heating elements, etc)
19-2 Resistors in Series

The current in a series circuit goes through every component in the circuit. Therefore, all of the components in a series connection carry the same current. There is only one path in a series circuit in which the current can flow. The current through each resistor is the same.

According to the Ohm’s law, $V=IR \rightarrow$

The voltage across each resistor depends on the resistance. The sum of the voltage drops across the resistors equals the battery voltage.

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \quad (19-2)$$
19-2 Resistors in Series

From this we get the equivalent resistance (that single resistance that gives the same current in the circuit).

\[ R_{eq} = R_1 + R_2 + R_3. \]  (19-3)
Example 1:

• When an external resistor of resistance $R_1 = 14 \, \Omega$ is connected across the terminals of a battery, a current of 6.0 A flows through the resistor. When a different external resistor of resistance $R_2 = 64 \, \Omega$ is connected instead, the current is 2.0 A. Calculate (a) the emf of the battery and (b) the internal resistance of the battery.

• Answer: (a) 150 V (b) 11 \, \Omega
If two or more components are connected in parallel they have the same potential difference (voltage) across their ends. The potential differences across the components are the same in magnitude, and they also have identical polarities. The same voltage is applicable to all circuit components connected in parallel. A parallel connection splits the current; the voltage across each resistor is the same:
19-2 Resistors in Series and in Parallel

The total current is the sum of the currents across each resistor:

\[ I = \frac{V}{R_{eq}} \]

\[ I = I_1 + I_2 + I_3, \]

\[ \frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \]
19-2 Resistors in Series and in Parallel

This gives the reciprocal of the equivalent resistance:

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}. \quad (19-4)
\]
An analogy using water may be helpful in visualizing parallel circuits:
Example 2

• Four resistors are connected across an ideal dc battery with voltage $V$, as shown in the figure. If the total current in this circuit is $I = 1 \text{ A}$, what is the value of the voltage $V$?

• Answer: 4V
Example 3

• Two 100-W light bulbs of fixed resistance are to be connected to an ideal 120-V source. What are the current, potential difference, and dissipated power for each bulb when they are connected
  – (a) in parallel (the normal arrangement)?
  – (b) in series?

• Answer:
  – (a) 0.83 A in each; 120 V for each; 100 W in each (200 W total)
  – (b) 0.42 A in each; 60 V for each; 25 W in each (50 W total)
19-3 Kirchhoff’s Rules

Some circuits cannot be broken down into series and parallel connections.
19-3 Kirchhoff’s Rules

For these circuits we use Kirchhoff’s rules.

Junction rule: The sum of currents entering a junction equals the sum of the currents leaving it.
Loop rule: The sum of the changes in potential around a closed loop is zero.
19-3 Kirchhoff’s Rules

Problem Solving: Kirchhoff’s Rules

1. Label each current.

2. Identify unknowns.

3. Apply junction and loop rules; you will need as many independent equations as there are unknowns.

4. Solve the equations, being careful with signs.
EMFs in series in the same direction: total voltage is the sum of the separate voltages.
19-4 EMFs in Series and in Parallel; Charging a Battery

EMFs in series, opposite direction: total voltage is the difference, but the lower-voltage battery is charged.
EMFs in parallel only make sense if the voltages are the same; this arrangement can produce more current than a single emf.
Example:

• Determine the current in the 4.0-Ω resistor for the circuit shown in the figure. Assume that the batteries are ideal and that all numbers are accurate to two significant figures.

\[
\begin{align*}
I_1 R_1 + I_3 R_3 &= V_1 \\
I_2 R_2 - I_3 R_3 &= V_2 \\
I_3 &= I_1 - I_2
\end{align*}
\]

Solve this system of equations for \( I_3 \)

\[
I_3 = \frac{R_2}{R_1} \left( V_1 - V_2 \right) \frac{R_1}{\frac{R_2}{R_1} (R_1 + R_3) + R_3}
\]

• Answer: 0.28 A
Capacitors in parallel have the same voltage across each one:

\[ V = V_{ab} \]
In this case, the total capacitance is the sum:

\[ Q = C_{eq} V. \]

\[ C_{eq} V = C_1 V + C_2 V + C_3 V = (C_1 + C_2 + C_3)V \]

or

\[ C_{eq} = C_1 + C_2 + C_3. \]  \hspace{1cm} (19-5)
Capacitors in series have the same charge:

\[ V = V_{ab} \]
In this case, the reciprocals of the capacitances add to give the reciprocal of the equivalent capacitance:

\[
V = V_1 + V_2 + V_3.
\]

\[
\frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)
\]

or

\[
\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.
\] (19-6)
19-6 RC Circuits—Resistor and Capacitor in Series

When the switch is closed, the capacitor will begin to charge.
The voltage across the capacitor increases with time:

$$V_c = \mathcal{E}(1 - e^{-t/RC})$$  \hspace{0.5cm} (19-7a)

This is a type of exponential.
19-6 \( RC \) Circuits—Resistor and Capacitor in Series

The charge follows a similar curve:

\[ Q = Q_0 \left(1 - e^{-t/RC}\right) \quad (19-7b) \]

This curve has a characteristic time constant:

\[ \tau = RC \quad (19-7c) \]
If an isolated charged capacitor is connected across a resistor, it discharges:

\[ Q = Q_0 e^{-t/RC} \]
Example

- The RC circuit has $R = 8.7 \, \text{K}\Omega$ and $C=3 \, \mu\text{F}$. The capacitor is at $V_0$ at $t=0$, when switch is closed. How long it take the capacitor to discharge to 0.25% of its initial voltage?

\[
\frac{V}{V_0} = 2.5 \times 10^{-3}
\]

\[
V = V_0 \exp\left(-\frac{t}{RC}\right)
\]

\[
\exp\left(-\frac{t}{RC}\right) = 2.5 \times 10^{-3}
\]

\[
t = 0.16 \, \text{s}
\]
Even very small currents—10 to 100 mA can be dangerous, disrupting the nervous system. Larger currents may also cause burns.

Household voltage can be lethal if you are wet and in good contact with the ground. Be careful!
A person receiving a shock has become part of a complete circuit.
Faulty wiring and improper grounding can be hazardous. Make sure electrical work is done by a professional.
The safest plugs are those with three prongs; they have a separate ground line.

Here is an example of household wiring—colors can vary, though! Be sure you know which is the hot wire before you do anything.
19-8 Ammeters and Voltmeters—Measurement Affects the Quantity Being Measured

An ammeter measures current; a voltmeter measures voltage. Both are based on galvanometers, unless they are digital.

The current in a circuit passes through the ammeter; the ammeter should have low resistance so as not to affect the current.

\[ I = I_{\text{A}} \]

\[ r \]

\[ I_G \]

\[ I_R \]

\[ R_{\text{sh}} \]
A voltmeter should not affect the voltage across the circuit element it is measuring; therefore its resistance should be very large.
19-8 Ammeters and Voltmeters—Measurement Affects the Quantity Being Measured

An ohmmeter measures resistance; it requires a battery to provide a current
If the meter has too much or (in this case) too little resistance, it can affect the measurement.
Summary of Chapter 19

• A source of emf transforms energy from some other form to electrical energy

• A battery is a source of emf in parallel with an internal resistance

• Resistors in series:

\[ R_{\text{eq}} = R_1 + R_2 + R_3. \]

• Resistors in parallel:

\[ \frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}. \]
Summary of Chapter 19

• Kirchhoff’s rules:
  1. sum of currents entering a junction equals sum of currents leaving it
  2. total potential difference around closed loop is zero
Summary of Chapter 19

- Capacitors in parallel:

\[ C_{eq}V = C_1V + C_2V + C_3V = (C_1 + C_2 + C_3)V \]

or

\[ C_{eq} = C_1 + C_2 + C_3. \]

- Capacitors in series:

\[ \frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = Q \left( \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) \]

or

\[ \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}. \]
Summary of Chapter 19

• RC circuit has a characteristic time constant:

\[ \tau = RC \]

• To avoid shocks, don’t allow your body to become part of a complete circuit

• Ammeter: measures current

• Voltmeter: measures voltage