Physics 4B
Chapter 27: Circuits

"It is good to have an end to journey toward; but it is the journey that matters, in the end."
Ursula K. Le Guin

"*Nobody made a greater mistake than he who did nothing because he could only do a little*."
Edmund Burke

Reading: pages 705 - 724

Outline:

⇒ emf and terminal voltage
⇒ combinations of resistors
  series
  parallel
⇒ Kirchoff's rules
  junction rule
  loop rule
⇒ calculating potential difference
⇒ ammeters and voltmeters (PowerPoint)
⇒ RC circuits
  charging and discharging a capacitor
  time constant

Problem Solving Techniques

You should understand the definition of emf in terms of the work done on a charge as it moves through an emf device. You should also know that real emf devices have both emf's and internal resistances and, because they do, the terminal potential difference is not the same as the emf if charge is passing through the device. Be aware in each instance if the current is in the direction of the emf or in the opposite direction. The terminal potential difference depends on the relative direction of the current.

You should be able to write down Kirchhoff's loop equation for a single loop and solve it for an unknown (the current, a resistance, or an emf). If the current is known, you should be able to compute the potential difference between any two points on the circuit. You should also be able to compute the rate with which an emf supplies energy and the rate with which a resistor dissipates energy. Remember that for any electrical device the rate with which energy is transferred to or from the device is the product of the current through it and the potential difference across it.

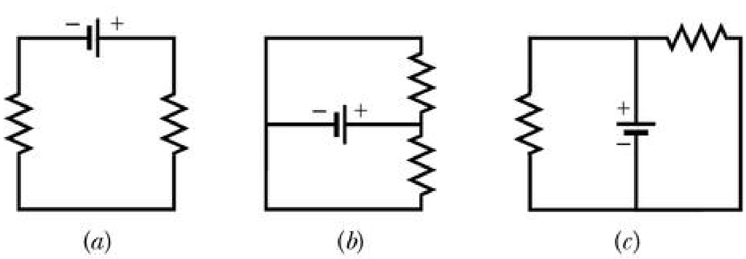
You should know how to write and solve Kirchhoff's junction and loop equations for multiloop circuits. Draw a current arrow in each branch of the circuit and label each arrow with a different symbol. Write the junction equations first. The number of equations will be one less than the number of junctions. Then write the loop equations. The number will be such that the total number of equations is equal to the number of branches in the circuit. Solve the junction and loop equations for the unknowns.

Some problems ask you to calculate the equivalent resistance when two or more resistors are connected in parallel or series. You should also know how to use equivalent resistances to solve circuit problems. Remember that for a series connection, the current is the same in all the resistors and is the same as the current in the equivalent resistor. The potential difference across the equivalent resistor is the sum of the potential differences across the resistors of the combination. For a parallel connection, the potential difference across all the resistors is the same and is the same as the potential difference across the equivalent resistor. The current in the equivalent resistor is the sum of the currents in the resistors of the combination.

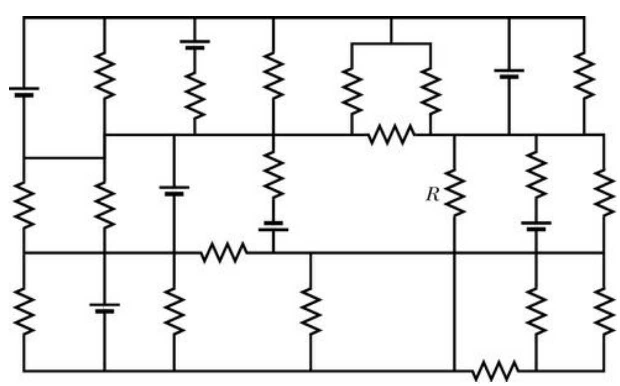
Some problems deal with a resistor and capacitor in a series circuit, with the capacitor either charging or discharging. You should know how to solve problems using the expression for the charge on the capacitor as a function of time: $q(t) = C\mathcal{E}(1 - e^{-t/t})$ for a charging capacitor and $q(t) = q_0e^{-t/t}$ for a discharging capacitor. Here $\tau = RC$ is the capacitive time constant. Also know how to compute the current in the circuit and the potential difference across the capacitor. Some problems ask for the time or the capacitive time constant. If q and q_0 are given, write $q/q_0 = e^{-t/\tau}$ and take the natural logarithm of both sides. The result is $\ln(q/q_0) = -t/\tau$. You can now solve for t or τ.

Questions and Example Problems from Chapter 27

Question 1
For each circuit in the figure below, are the resistors connected in series, in parallel, or neither?

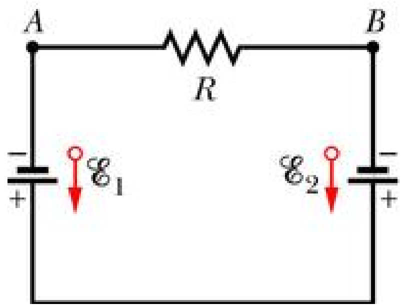


Question 2
Res-monster maze. In the figure, all the resistors have a resistance of 4.0 Ω and all the (ideal) batteries have an emf of 4.0 V. What is the current through resistor R? (If you can find the proper loop through this maze, you can answer the question with a few seconds of mental calculation.)



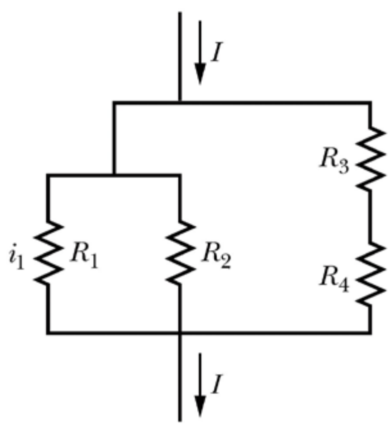
Problem 1

In the figure below, $\mathscr{E}_1$ = 12 V and $\mathscr{E}_2$ = 8 V. (a) What is the direction of the current in the resistor? (b) Which battery is doing positive work? (c) Which point, *A* or *B*, is at the higher potential?



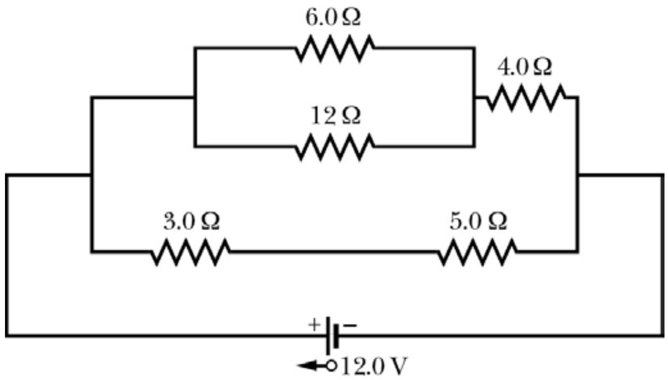
Problem 2

The figure below shows a portion of a circuit through which there is a current I = 6.00 A. The resistances are $R_1 = R_2 = 2.00R_3 = 2.00R_4 = 4.00\ \Omega$. What is the equivalent resistance of the four resistors.



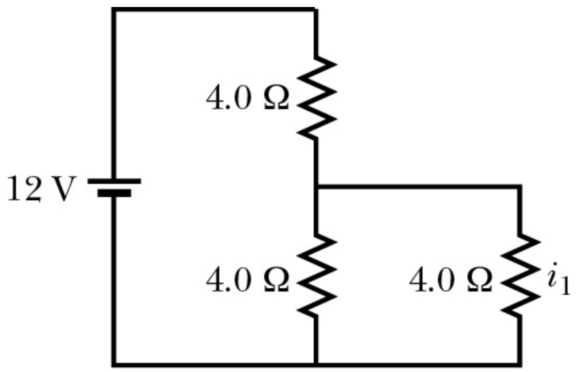
Problem 3

A circuit containing five resistors connected to a battery with a 12.0 V emf is shown in the figure below. (a) What is the equivalent resistance of the five resistors? (b) What is the voltage across and the current through each resistor?



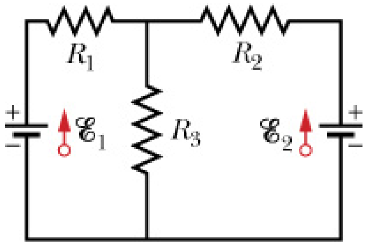
Problem 4

(a) What are the size and direction of current i_1 in the figure below? (Can you answer this making only mental calculations?) (b) At what rate is the battery supplying energy?



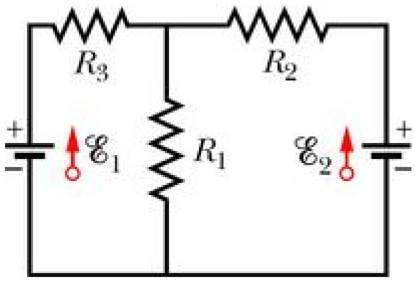
Problem 5

In the figure below, the ideal batteries have emfs $\mathscr{E}_1$ = 10.0 V and $\mathscr{E}_2 = 0.500\mathscr{E}_1$, and the resistances are each 4.00 Ω. What is the current in (a) resistor 2 and (b) resistor 3?



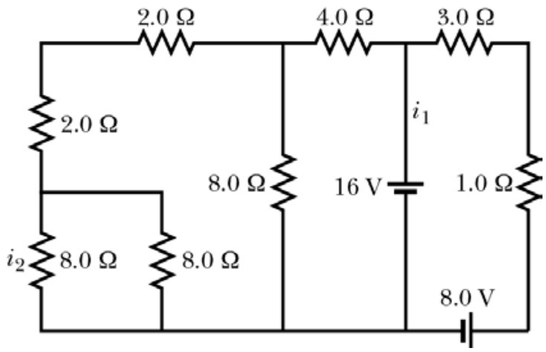
Problem 6

In the figure below, $\mathscr{E}_1$ = 3.00 V, $\mathscr{E}_2$ = 1.00 V, R_1 = 5.00 Ω, R_2 = 2.00 Ω, R_3 = 4.00 Ω, and both batteries are ideal. What is the rate at which energy is dissipated in (a) R_1, (b) R_2, and (c) R_3? What is the power of (d) battery 1 and (e) battery 2?

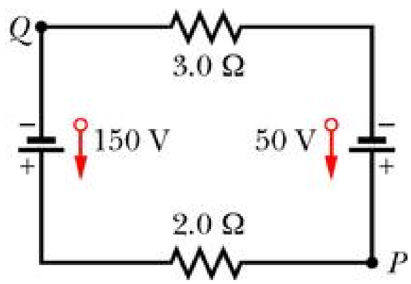


Problem 7

What are the sizes and directions of current (a) i_1 and (b) i_2 in the figure below? At what rate is energy being transferred at (c) the 16 V battery and (d) the 8.0 V battery, and for each, is energy being supplied or absorbed? The batteries are ideal.



Problem 8
In the figure below, if the potential at point P is 100 V, what is the potential at point Q?



Problem 9
In an *RC* series circuit, $\mathcal{E}$ = 12.0 V, *R* = 1.40 MΩ, and *C* = 1.80 μF. (a) Calculate the time constant. (b) Find the maximum charge that will appear on the capacitor during charging. (c) How long does it take for the charge to build up to 16.0 μC?

Problem 10

What multiple of the time constant τ gives the time taken by an initially uncharged capacitor in an RC series circuit to be charged to 99.0% of its final charge?

Problem 11

A 3.00 MΩ resistor and a 1.00 μF capacitor are connected in series with an ideal battery of emf $\mathscr{E}$ = 4.00 V. At 1.00 s after the connection is made, what are the rates at which (a) the charge of the capacitor is increasing, (b) energy is being stored in the capacitor, (c) thermal energy is appearing in the resistor, and (d) energy is being delivered by the battery?