2008-2009 Physics Olympiad Preparation Program

University of Toronto

Problem set 6: Electronics, Circuits

Due: 2009 April 6

Notes:

The 2009 CAP High School Prize Examination will be held on **Monday, 2009 April 6, 2009**.

The POPTOR Weekend takes place from **Friday evening 2009 May 15 to Sunday May 17.**

1. You need to charge a 1.5 V NiCad battery and have a 10 V DC power supply left over from a now unused cordless phone. However, the battery has a warning on it that the charging current should not exceed 50 mA. You decide to use the power supply, but place a resistor in series with the battery to limit the current.

   a) Sketch the circuit that you will use.

   b) When you measure the voltage on the discharged NiCad battery, it is 1.2 V. How big a resistor do you need to limit the charging current to 50 mA?

   c) When you begin the charging how much power is lost in the resistor? How much power goes into the battery?

   d) If you forget to take the charger off after the battery is fully charged, how much power is deposited in the battery. Where does it go?

2. A signal cable, consisting of two insulated copper wires, each 0.8* mm in diameter, twisted together, links two buildings on campus. A short circuit has developed somewhere along the cable and as it is 2 km long, you decide to try to find the location of the problem and repair the cable – the cost of laying a new cable is somewhat more than the price of the cable. The nature of the "short circuit" is an unknown resistance, R_s, connecting the two wires. To narrow your search you make some measurements, after disconnecting both ends of the cable from the signaling equipment. With the pair of wires at the far end not connected, when you attach a 100 V DC power supply at the near end, you measure a current of 370 mA. When you connect both wires at the far end of the cable, you measure 800 mA. Where is the problem located?

** The value in an earlier version, 1.0 mm, was a copy error – it produced imaginary solutions.*

3. For alternating current, the resistance of a wire is complicated by the frequency dependence of the depth to which the alternating electric field can penetrate radially into the conductor. This characteristic depth is called the skin depth, δ and is given by

$$\delta = \sqrt{\frac{2\rho}{2\pi f \mu}}$$

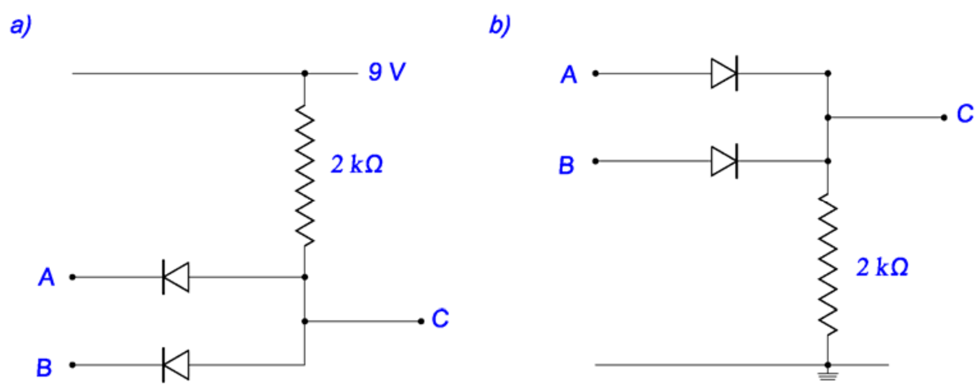
   where ρ is the resistivity and μ is the magnetic permeability of the material and f is the frequency. For a wire which has a large diameter compared with δ, the resistance can be approximate by assuming that the wire is a hollow cylinder with a wall thickness δ.

   a) For an aluminum conductor 5 cm in diameter, calculate the resistance per unit length. For aluminum, $\rho = 2.65 \times 10^{-8}\ \Omega$ m and $\mu = 4\pi \times 10^{-7}$ N A^{-2}.

b) The hydro-electric power station at Churchill Falls, NL produces 5.4 GW of electricity, most of which is sold to Hydro-Québec, transported over 735 kV transmission lines. If the distance from Churchill Falls to Québec City is 1200 km, how many conductors with the capacity of the one in part (a) are required so that the resistive losses are limited to 1% of the total power produced. Assume that the 735 kV is a peak-to-peak measurement; use the equivalent root-mean-square voltage and current for the calculation ($V_{rms} = V_{p\text{-}p} / \sqrt{2}$)

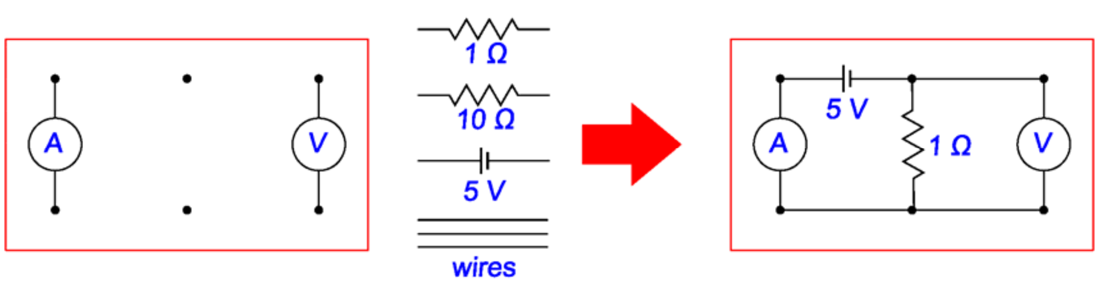
c) The generators at Churchill Falls produce the electricity at 15 kV (assume $V_{p\text{-}p}$). To show the advantage of the stepped up transmission voltage, calculate the number of conductors as in (a) required to transmit the power at the generated voltage. Are there any disadvantages to the higher transmission voltages?

4. For each of the circuits in the figure below, calculate and make a table of the voltage appearing at point C when the voltage at points A and B are either 0 or 5V (four conditions). The diodes have a voltage drop of 0.2 volts when conducting. What logic function do these circuits perform?

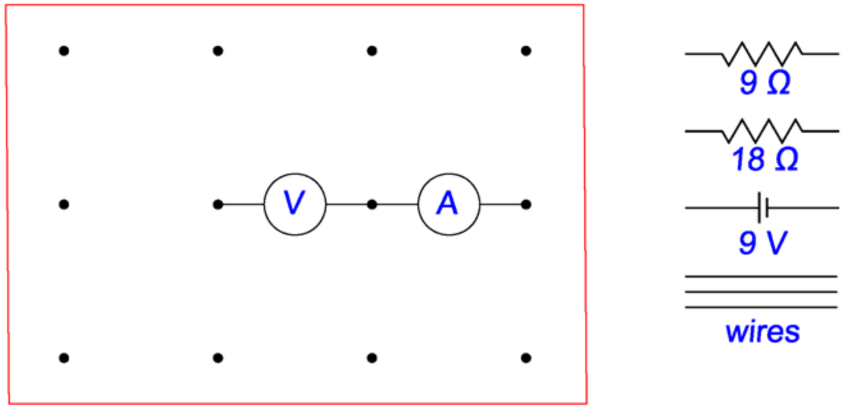


5. On the figures below and on the next page, connect the dots using the components provided so that the voltage and current measurements show the values that would be given by the resulting circuit. You may not need to use all the dots or components, but you may need to use a dot for more than one connection. You also may use a particular component more than once in the circuit. The V and A symbolize ideal voltmeters and ammeters (i.e. the voltmeter draws negligible current and the ammeter causes a negligible voltage drop).

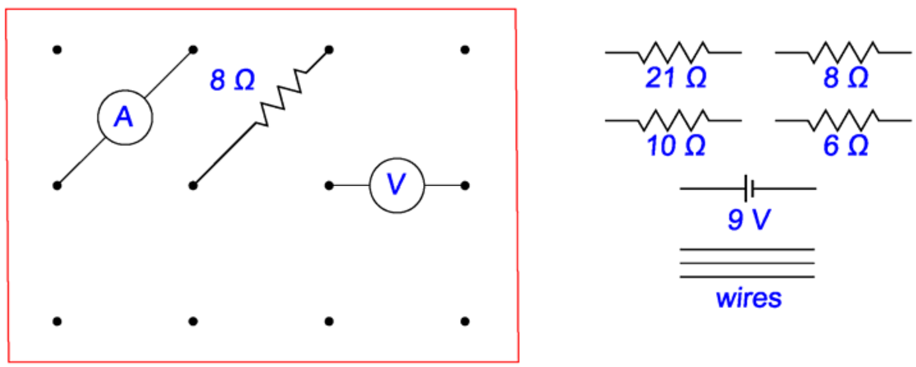
Example: the voltmeter reads 5 V, the ammeter 5 A



a) The voltmeter reads 6 V, the ammeter, 167 mA



b) The voltmeter reads 2 V, the ammeter, 833 mA



c) The voltmeter reads the waveform shown below on the right. (For this one you can pretend you have an oscilloscope.)