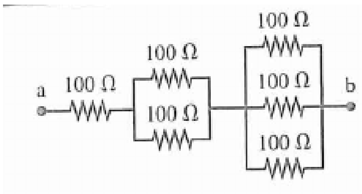
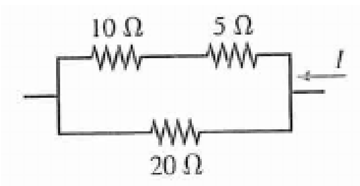
L3 Physics: Questions for 3.1 (Electrodynamics, DC analysis)

The first four questions below are from Knight, chapter 28. Questions 5 to 8 are from past exams. You are reminded that the questions are not necessarily ordered in terms of difficulty.

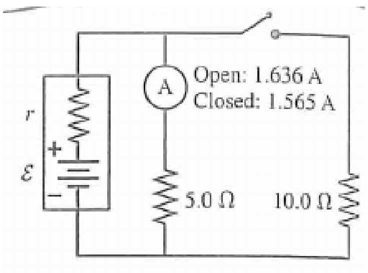
1. (a) What is the equivalent resistance between points a and b in the following circuit fragment?



   (b) The $10\,\Omega$ resistor in the following circuit fragment is dissipating $40\,\mathrm{W}$. How much power is being dissipated by the two other resistors?

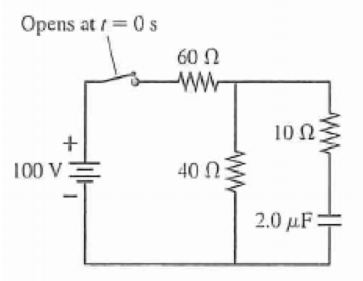


   (c) What are the emf and internal resistance of the battery in the following circuit?



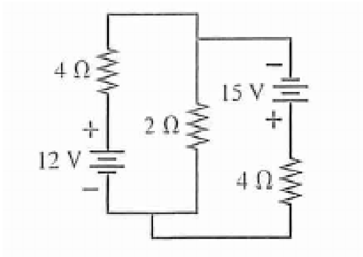
2. (a) What value resistor will discharge a $2.0\,\mu\mathrm{F}$ capacitor to 20% of its initial charge in $4\,\mathrm{ms}$?
   (b) A capacitor is discharged through a $200\,\Omega$ resistor. The discharge current decreases to 20% of its initial value in $2.0\,\mathrm{ms}$. What is the value of the capacitance?

3. The switch in the following circuit has been closed for a very long time.



   (a) What is the charge on the capacitor?
   (b) The switch is opened at time $t = 0\,\mathrm{s}$. At what time has the charge on the capacitor decreased to 10% of its initial value?

4. What power is dissipated by the $2\,\Omega$ resistor in the following circuit?

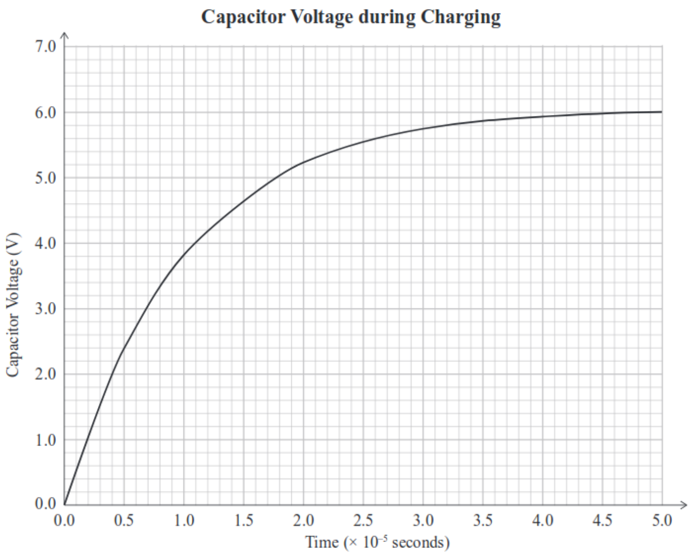


5. Casey sets up a battery, a switch, and a $3.00\,\Omega$ light bulb in series. The battery voltage is measured to be $6.02\,\mathrm{V}$ when the switch is open. However, when the switch is closed, Casey notices that the battery voltage drops to $5.85\,\mathrm{V}$.

   (a) Explain why the battery voltage is less when the switch is closed.

   (b) Casey measures the current through the circuit to be $1.89\,\mathrm{A}$. State the emf, and show that the internal resistance of the battery is approximately $0.09\,\Omega$.

   (c) Casey now adds a capacitor in series with the battery and closes the switch. Casey measures the voltage across the capacitor as it charges.



   Using information from the graph, determine the capacitance of the capacitor.

   (d) Casey discharges the capacitor, removes the light bulb, and begins to charge the capacitor again. Casey predicts that, by removing the light bulb, less energy will be converted to light and heat, and so the capacitor will charge more quickly, and have more stored energy once fully charged. Use physical reasoning to discuss each aspect of Casey's prediction.

   You should discuss, with explanations:

   - whether the capacitor will charge more quickly than before
   - whether less energy will be converted to light and heat during the charging process without the light bulb
   - whether more energy will be stored in the fully charged capacitor.

6. Show that the force of gravitational attraction between a pair of electrons is about 1×10^{-43} times the force of electrostatic repulsion.

   The force of electrostatic repulsion between two charges q_1 and q_2, separated by a distance r, is

$$F = k\frac{q_1 q_2}{r^2}$$

   where k is Coulomb's constant. (Some useful data may be found at the end of this problemset.)

7. A resistance of $4.0\,\Omega$ is connected across a cell of internal resistance r. The $4.0\,\Omega$ resistor dissipates energy at $16\,\mathrm{W}$. The $4.0\,\Omega$ resistor is replaced by a $1.0\,\Omega$ resistor, which also dissipates energy at $16\,\mathrm{W}$. Show that the source voltage must be $12\,\mathrm{V}$.

8. (a) Describe the electrical properties required for a material to act as a dielectric.

   (b) A capacitor containing a dielectric is initially charged and then disconnected from a battery. The capacitor then has its dielectric removed.

      i. Explain why work has to be done to remove the dielectric.

      ii. Show that the minimum work required to remove the dielectric is

$$\frac{1}{2} C_F V_F^2 \left(\frac{\varepsilon_r - 1}{\varepsilon_r} \right),$$

      where C_F is the capacitance of the capacitor with dielectric removed, V_F is the final potential difference, and ε_r is the dielectric constant.

   (c) If the capacitor is still connected to the battery when the dielectric is removed, the energy stored in the capacitor will decrease. Despite this reduction in energy, work must still be done to withdraw the dielectric. Explain this apparent contradiction.

   (d) If the charged capacitor is held just touching the surface of a liquid dielectric, the dielectric will be drawn up into the capacitor.

      i. Explain why the capacitor voltage decreases when this phenomenon takes place.

      ii. Explain why the liquid dielectric is drawn up into the charged capacitor.

Useful data

Mass of an electron	$9.11 \times 10^{-31}\,\mathrm{kg}$
Charge of an electron	$-1.60 \times 10^{-19}\,\mathrm{C}$
Gravitational constant	$6.67 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$
Coulomb's constant	$8.98 \times 10^{9}\,\mathrm{N\,m^2\,C^{-2}}$

This version: August 26, 2019