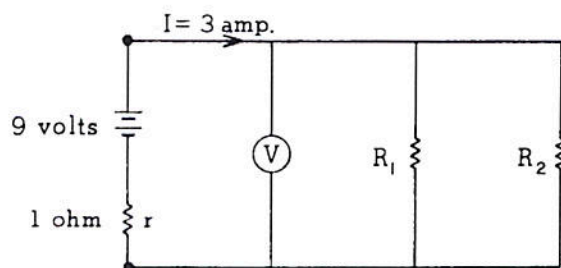
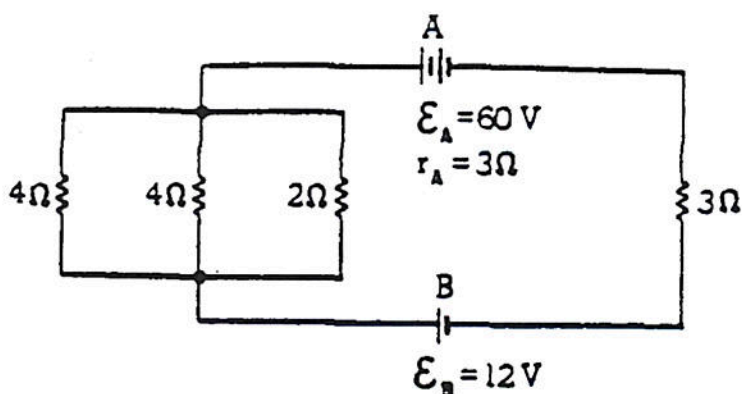


AP Physics Free Response Practice – Circuits



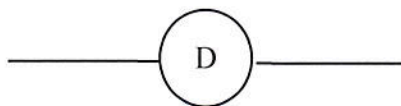
1976B3. In the circuit shown above, the current delivered by the 9-volt battery of internal resistance 1 ohm is 3 amperes. The power dissipated in  $R_2$  is 12 watts.

- Determine the reading of voltmeter  $V$  in the diagram.
- Determine the resistance of  $R_2$ .
- Determine the resistance of  $R_1$ .



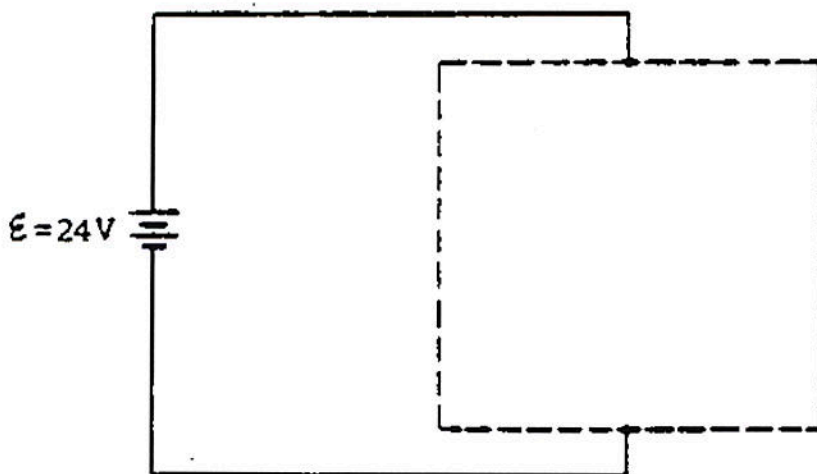
1981B4. A circuit consists of battery A of emf  $\mathcal{E}_A = 60 \text{ volts}$  and internal resistance  $r_A = 3 \text{ ohms}$ ; battery B of emf  $\mathcal{E}_B = 12 \text{ volts}$  and internal resistance  $r_B = 1 \text{ ohm}$ ; and four resistors connected as shown in the diagram above.

- Calculate the current in the 2-ohm resistor.
- Calculate the power dissipated in the 3-ohm resistor.
- Calculate the terminal voltage of battery B.



1980B2. The electrical device whose symbol is shown above requires a terminal voltage of 12 volts and a current of 2 amperes for proper operation.

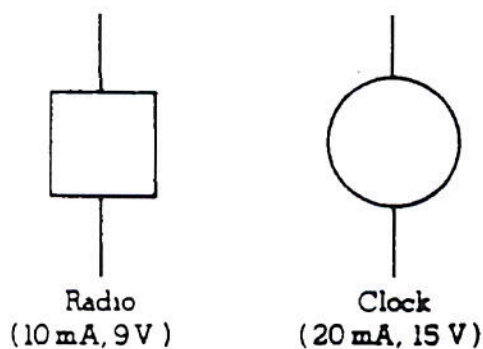
- a. Using only this device and one or more 3-ohm resistors design a circuit so that the device will operate properly when the circuit is connected across a battery of emf 24 volts and negligible internal resistance. Within the dashed-line box in the diagram below, draw the circuit using the symbol for the device and the appropriate symbol for each 3-ohm resistor.



- b. Using only this device and one or more 3-ohm resistors, design a circuit so that the device will operate properly when connected to a source that supplies a fixed current of 6 amperes. Within the dashed-line box in the diagram below, draw the circuit using the symbol for the device and the appropriate symbol.

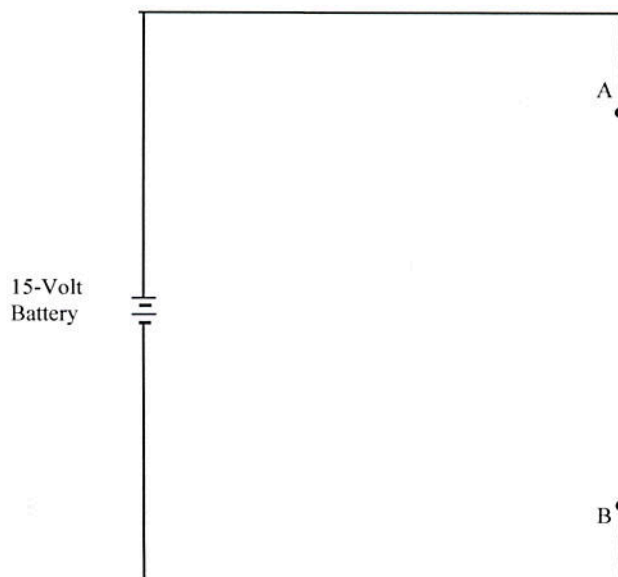


- c. Calculate the power dissipation in each 3-ohm resistor used in the circuit in part b..
-

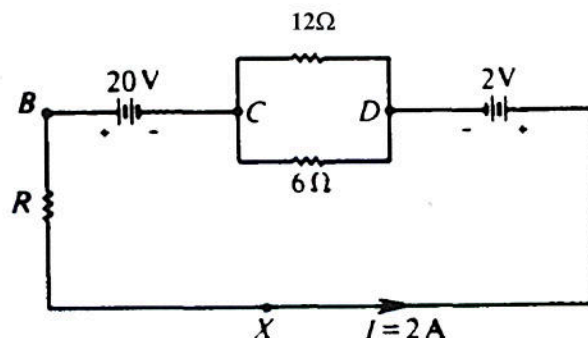


1982B4. A cabin contains only two small electrical appliances: a radio that requires 10 milliamperes of current at 9 volts, and a clock that requires 20 milliamperes at 15 volts. A 15-volt battery with negligible internal resistance supplies the electrical energy to operate the radio and the clock.

- a. Complete the diagram below to show how the radio, the clock, and a single resistor  $R$  can be connected between points A and B so that the correct potential difference is applied across each appliance. Use the symbols in the diagram above to indicate the radio and the clock.

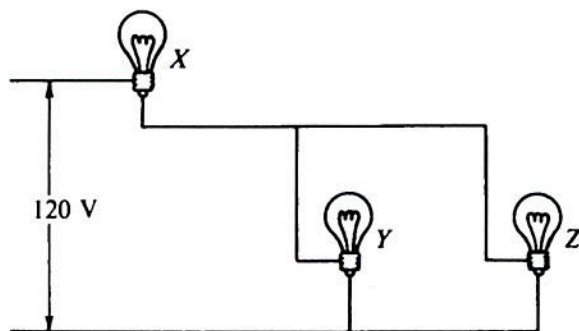


- b. Calculate the resistance of  $R$ .
- c. Calculate the electrical energy that must be supplied by the battery to operate the circuits for 1 minute.



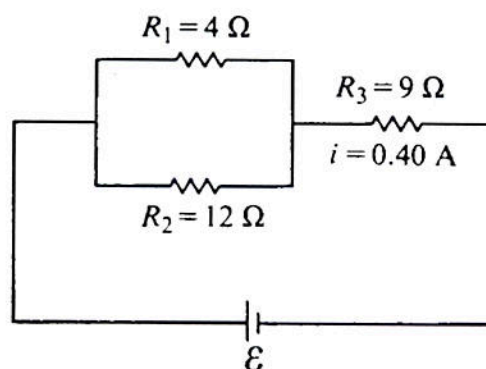
1983B3. The circuit shown above is constructed with two batteries and three resistors. The connecting wires may be considered to have negligible resistance. The current  $I$  is 2 amperes.

- Calculate the resistance  $R$ .
- Calculate the current in the
  - 6-ohm resistor
  - 12-ohm resistor
- The potential at point  $X$  is 0 volts. Calculate the electric potential at points  $B$ ,  $C$ , and  $D$  in the circuit.
- Calculate the power supplied by the 20-volt battery.



1986B3. In the circuit shown above,  $X$ ,  $Y$ , and  $Z$  represent three light bulbs, each rated at 60 watts, 120 volts. Assume that the resistances of the bulbs are constant and do not depend on the current.

- What is the resistance of each bulb?
- What is the equivalent resistance of the three light bulbs when arranged as shown?
- What is the total power dissipation of this combination when connected to a 120-volt source as shown?
- What is the current in bulb  $X$ ?
- What is the potential difference across bulb  $X$ ?
- What is the potential difference across bulb  $Z$ ?

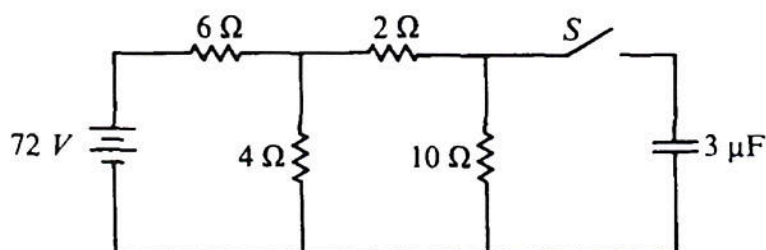


1987B4. Three resistors are arranged in a circuit as shown above. The battery has an unknown but constant emf  $\mathcal{E}$  and a negligible internal resistance.

- Determine the equivalent resistance of the three resistors.

The current  $I$  in resistor  $R_3$  is 0.40 ampere.

- Determine the emf  $\mathcal{E}$  (Voltage) of the battery.
- Determine the potential difference across resistor  $R_1$ .
- Determine the power dissipated in resistor  $R_1$ .
- Determine the amount of charge that passes through resistor  $R_3$  in one minute.



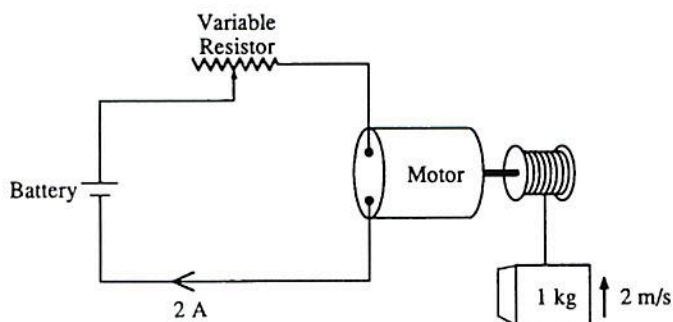
1988B3. The circuit shown above includes a switch  $S$ , which can be closed to connect the 3-microfarad capacitor in parallel with the 10-ohm resistor or opened to disconnect the capacitor from the circuit.

Case I: Switch  $S$  is open. The capacitor is not connected. Under these conditions determine:

- the current in the battery
- the current in the 10-ohm resistor
- the potential difference across the 10-ohm resistor

Case II: Switch  $S$  is closed. The capacitor is connected. After some time, the currents reach constant values. Under these conditions determine:

- the charge on the capacitor
- the energy stored in the capacitor

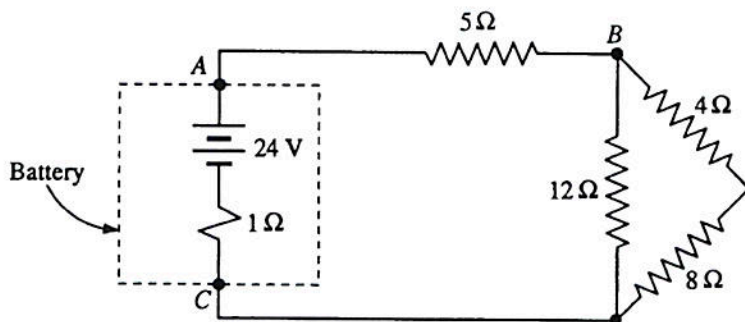


1989B3. A series circuit consists of a battery of negligible internal resistance, a variable resistor, and an electric motor of negligible resistance. The current in the circuit is 2 amperes when the resistance in the circuit is adjusted to 10 ohms. Under these conditions the motor lifts a 1-kilogram mass vertically at a constant speed of 2 meters per second.

- Determine the electrical power that is
  - dissipated in the resistor
  - used by the motor in lifting the mass
  - supplied by the battery
- Determine the potential difference across
  - the resistor
  - the motor
  - the battery

The resistor is now adjusted until the mass rises vertically at a constant speed of 3 meters per second. The voltage drop across the motor is proportional to the speed of the motor, and the current remains constant.

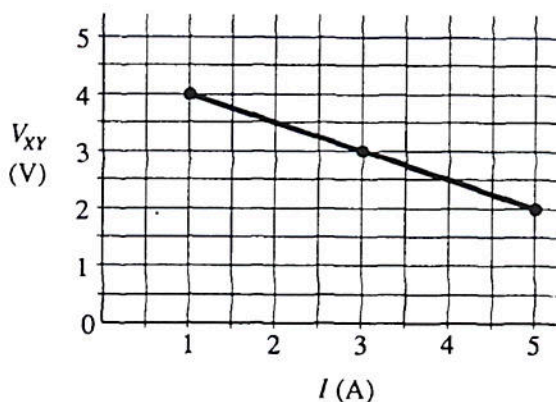
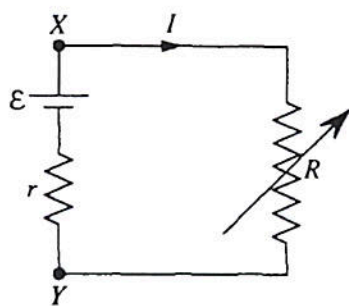
- Determine the voltage drop across the motor.
- Determine the new resistance in the circuit.



1990B3. A battery with an emf of 24 volts and an internal resistance of 1 ohm is connected to an external circuit as shown above. Determine each of the following:



- the equivalent resistance of the combination of the 4-ohm, 8-ohm, and 12-ohm resistors
- the current in the 5-ohm resistor
- the terminal voltage,  $V_{AC}$  of the battery
- the rate at which energy is dissipated in the 12-ohm resistor
- the magnitude of the potential difference  $V_{BC}$
- the power delivered by the battery to the external circuit

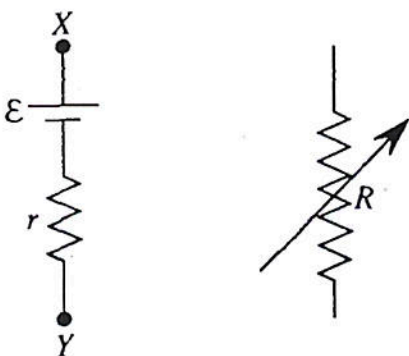




1991B4. A battery with emf  $\mathcal{E}$  and internal resistance  $r$  is connected to a variable resistance  $R$  at points  $X$  and  $Y$ , as shown above on the left. Varying  $R$  changes both the current  $I$  and the terminal voltage  $V_{XY}$ . The quantities  $I$  and  $V_{XY}$  are measured for several values of  $R$  and the data are plotted in a graph, as shown above on the right.

- Determine the emf  $\mathcal{E}$  of the battery.
- Determine the internal resistance  $r$  of the battery.
- Determine the value of the resistance  $R$  that will produce a current  $I$  of 3 amperes.
- Determine the maximum current that the battery can produce.
- The current and voltage measurements were made with an ammeter and a voltmeter. On the diagram

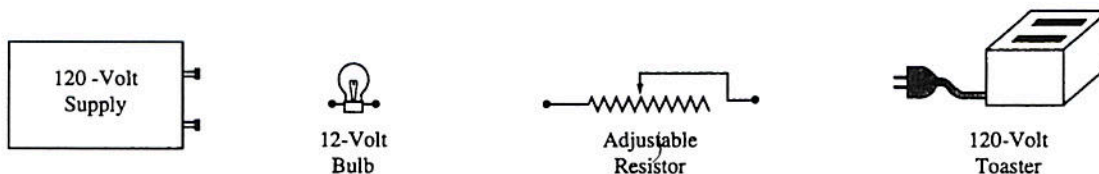
below, show a proper circuit for performing these measurements. Use  to represent the ammeter and  to represent the voltmeter.



- 1995B2. A certain light bulb is designed to dissipate 6 watts when it is connected to a 12-volt source.
- Calculate the resistance of the light bulb.
  - If the light bulb functions as designed and is lit continuously for 30 days, how much energy is used? Be sure to indicate the units in your answer.

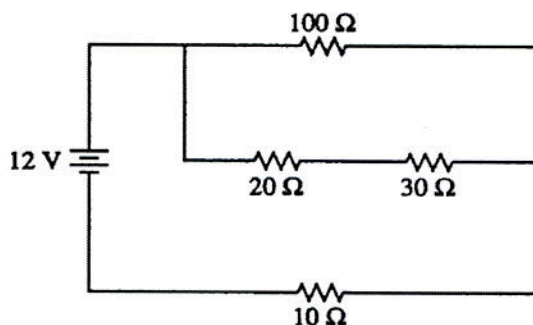
The 6-watt, 12-volt bulb is connected in a circuit with a 1,500-watt, 120-volt toaster; an adjustable resistor; and a 120-volt power supply. The circuit is designed such that the bulb and the toaster operate at the given values and, if the light bulb fails, the toaster will still function at these values.

- On the diagram below, draw in wires connecting the components shown to make a complete circuit that will function as described above.



- Determine the value of the adjustable resistor that must be used in order for the circuit to work as designed.
- If the resistance of the adjustable resistor is increased, what will happen to the following?
  - The brightness of the bulb. Briefly explain your reasoning.
  - The power dissipated by the toaster. Briefly explain your reasoning.

- 1996B4. A student is provided with a 12.0-V battery of negligible internal resistance and four resistors with the following resistances:  $100\ \Omega$ ,  $30\ \Omega$ ,  $20\ \Omega$ , and  $10\ \Omega$ . The student also has plenty of wire of negligible resistance available to make connections as desired.
- Using all of these components, draw a circuit diagram in which each resistor has nonzero current flowing through it, but in which the current from the battery is as small as possible.
  - Using all of these components, draw a circuit diagram in which each resistor has nonzero current flowing through it, but in which the current from the battery is as large as possible (without short circuiting the battery).








The battery and resistors are now connected in the circuit shown above.

- Determine the following for this circuit.
  - The current in the  $10\text{-}\Omega$  resistor
  - The total power consumption of the circuit
- Assuming that the current remains constant, how long will it take to provide a total of 10 kJ of electrical energy to the circuit?

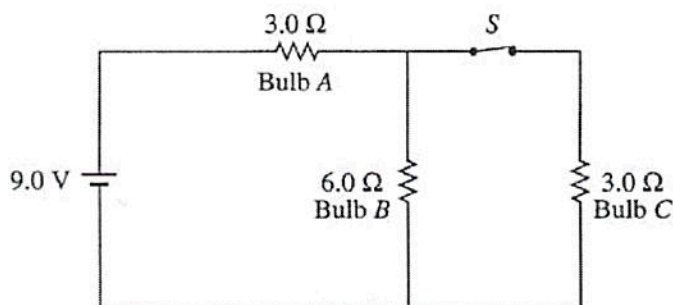
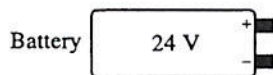


1997B4 (modified) Three identical resistors, each of resistance  $30\ \Omega$  are connected in a circuit to heat water in a glass beaker.  $24\text{ V}$  battery with negligible internal resistance provides the power. The three resistors may be connected in series or in parallel.

- If they are connected in series, what power is developed in the circuit?
  - If they are connected in parallel, what power is developed in the circuit?
- Using the battery and one or more of the resistors, design a circuit that will heat the water at the fastest rate when the resistor(s) are placed in the water. Include an ammeter to measure the current in the circuit and a voltmeter to measure the total potential difference of the circuit. Assume the wires are insulated and have no resistance. Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram.

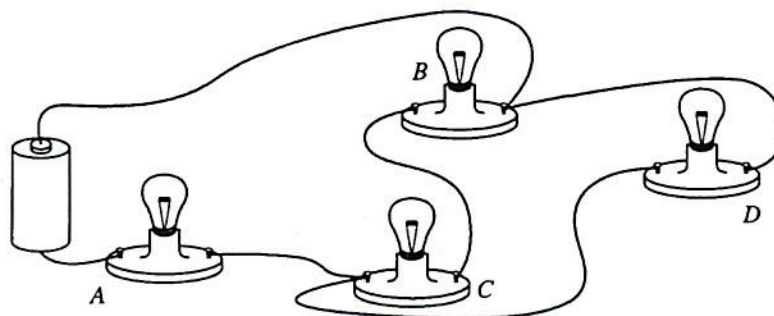
Symbols to be Used:  Resistors   Ammeter  Voltmeter 

Draw your diagram in this box only.



2002B3B. Lightbulbs of fixed resistance  $3.0\ \Omega$  and  $6.0\ \Omega$ , a  $9.0\text{ V}$  battery, and a switch  $S$  are connected as shown in the schematic diagram above. The switch  $S$  is closed.

- Calculate the current in bulb A.
- Which lightbulb is brightest? Justify your answer.
- Switch  $S$  is then opened. By checking the appropriate spaces below, indicate whether the brightness of each lightbulb increases, decreases, or remains the same. Explain your reasoning for each lightbulb.
  - Bulb A: The brightness ☐ increases ☐ decreases ☐ remains the same  
Explanation:
  - Bulb B: The brightness ☐ increases ☐ decreases ☐ remains the same  
Explanation:
  - Bulb C: The brightness ☐ increases ☐ decreases ☐ remains the same  
Explanation:



1998B4 In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

- a. Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B, C, and D to refer to the corresponding lightbulbs.



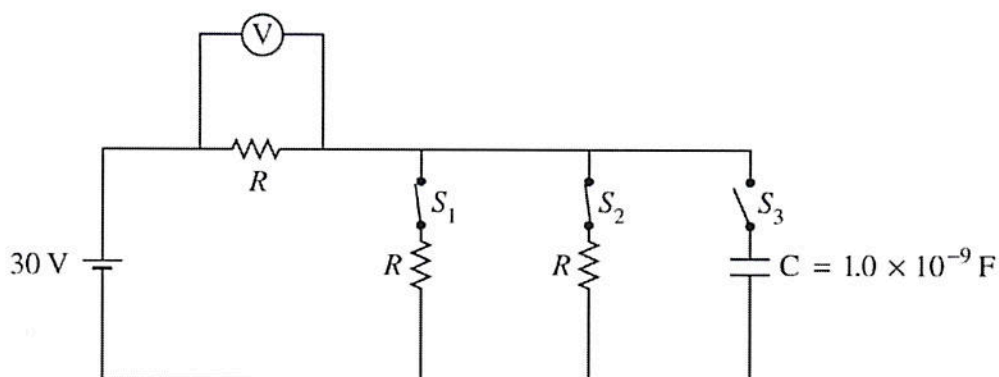
Battery



Resistors

Draw your diagram in this box only.

- b. List the bulbs in order of their brightnesses, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. Justify your answer.
- c. Bulb D is then removed from its socket.
- Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.
  - Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.



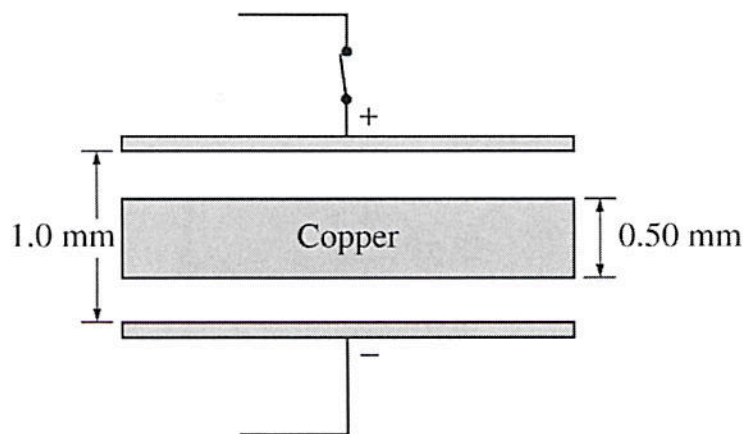
2000B3. Three identical resistors, each with resistance  $R$ , and a capacitor of  $1.0 \times 10^{-9} \text{ F}$  are connected to a  $30 \text{ V}$  battery with negligible internal resistance, as shown in the circuit diagram above. Switches  $S_1$  and  $S_2$  are initially closed, and switch  $S_3$  is initially open. A voltmeter is connected as shown.

- a. Determine the reading on the voltmeter.

Switches  $S_1$  and  $S_2$  are now opened, and then switch  $S_3$  is closed.

- b. Determine the charge  $Q$  on the capacitor after  $S_3$  has been closed for a very long time.

After the capacitor is fully charged, switches  $S_1$  and  $S_2$  remain open, switch  $S_3$  remains closed, the plates are held fixed, and a conducting copper block is inserted midway between the plates, as shown below. The plates of the capacitor are separated by a distance of  $1.0 \text{ mm}$ , and the copper block has a thickness of  $0.5 \text{ mm}$ .



- c. i. What is the potential difference between the plates?  
 ii. What is the electric field inside the copper block?  
 iii. On the diagram above, draw arrows to clearly indicate the direction of the electric field between the plates.  
 iv. Determine the magnitude of the electric field in each of the spaces between the plates and the copper block.

2002B3 Two lightbulbs, one rated 30 W at 120 V and another rated 40 W at 120 V, are arranged in two different circuits.

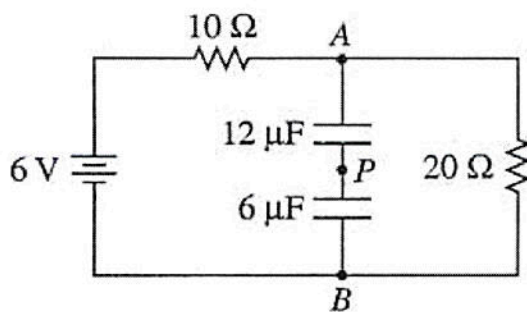
- The two bulbs are first connected in parallel to a 120 V source.
  - Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.
  - Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.
- The bulbs are now connected in series with each other and a 120 V source.
  - Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.
  - Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.
- In the spaces below, number the bulbs in each situation described, in order of their brightness. (1 = brightest, 4 = dimmest)
 

\_\_\_\_ 30 W bulb in the parallel circuit

\_\_\_\_ 40 W bulb in the parallel circuit

\_\_\_\_ 30 W bulb in the series circuit

\_\_\_\_ 40 W bulb in the series circuit
- Calculate the total power dissipated by the two bulbs in each of the following cases.
  - The parallel circuit
  - The series circuit



2003B2 A circuit contains two resistors ( $10\ \Omega$  and  $20\ \Omega$ ) and two capacitors ( $12\ \mu\text{F}$  and  $6\ \mu\text{F}$ ) connected to a 6 V battery, as shown in the diagram above. The circuit has been connected for a long time.

- Calculate the total capacitance of the circuit.
- Calculate the current in the  $10\ \Omega$  resistor.
- Calculate the potential difference between points A and B.
- Calculate the charge stored on one plate of the  $6\ \mu\text{F}$  capacitor.
- The wire is cut at point P. Will the potential difference between points A and B increase, decrease, or remain the same?

\_\_\_\_ increase      \_\_\_\_ decrease      \_\_\_\_ remain the same

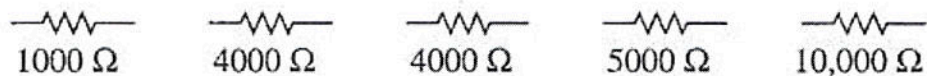
Justify your answer.



2003Bb2. A student is asked to design a circuit to supply an electric motor with 1.0 mA of current at 3.0 V potential difference.

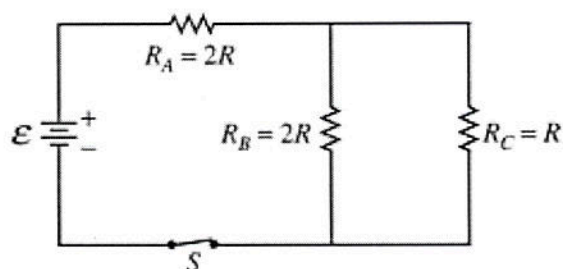
- Determine the power to be supplied to the motor.
- Determine the electrical energy to be supplied to the motor in 60 s.
- Operating as designed above, the motor can lift a 0.012 kg mass a distance of 1.0 m in 60 s at constant velocity. Determine the efficiency of the motor.

To operate the motor, the student has available only a 9.0 V battery to use as the power source and the following five resistors.



- In the space below, complete a schematic diagram of a circuit that shows how one or more of these resistors can be connected to the battery and motor so that 1.0 mA of current and 3.0 V of potential difference are supplied to the motor. Be sure to label each resistor in the circuit with the correct value of its resistance.





2007B3. The circuit above contains a battery with negligible internal resistance, a closed switch  $S$ , and three resistors, each with a resistance of  $R$  or  $2R$ .

- a. i. Rank the currents in the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same current, give them the same ranking.

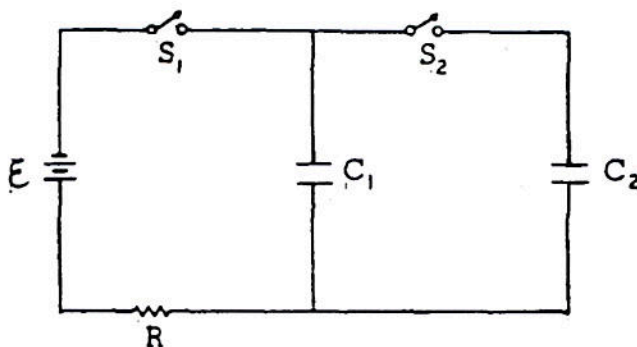
\_\_\_\_\_  $I_A$       \_\_\_\_\_  $I_B$       \_\_\_\_\_  $I_C$   
 ii. Justify your answers.

- b. i. Rank the voltages across the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same voltage across them, give them the same ranking.

\_\_\_\_\_  $V_A$       \_\_\_\_\_  $V_B$       \_\_\_\_\_  $V_C$   
 ii. Justify your answers.

For parts c. through e., use  $\mathcal{E} = 12 \text{ V}$  and  $R = 200 \, \Omega$ .

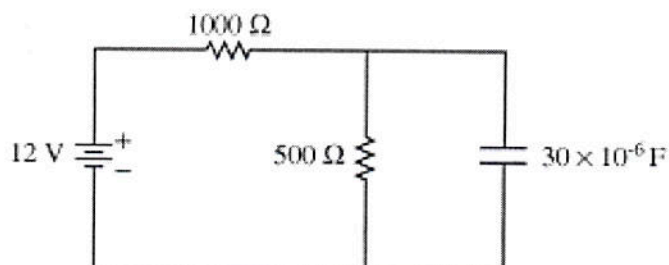
- c. Calculate the equivalent resistance of the circuit.  
 d. Calculate the current in resistor  $R_C$ .  
 e. The switch  $S$  is opened, resistor  $R_B$  is removed and replaced by a capacitor of capacitance  $2.0 \times 10^{-6} \text{ F}$ , and the switch  $S$  is again closed. Calculate the charge on the capacitor after all the currents have reached their final steady-state values.



1975E2. In the diagram above,  $V = 100 \text{ volts}$ ;  $C_1 = 12 \text{ microfarads}$ ;  $C_2 = 24 \text{ microfarads}$ ;  $R = 10 \text{ ohms}$ . Initially,  $C_1$  and  $C_2$  are uncharged, and all switches are open.

- a. First, switch  $S_1$  is closed. Determine the charge on  $C_1$  when equilibrium is reached.  
 b. Next  $S_1$  is opened and afterward  $S_2$  is closed. Determine the charge on  $C_1$  when equilibrium is again reached.  
 c. For the equilibrium condition of part b., determine the voltage across  $C_1$ .  
 d.  $S_2$  remains closed, and now  $S_1$  is also closed. How much additional charge flows from the battery?





B2007b3. In the circuit above, a 12.0 V battery is connected to two resistors, one of resistance 1000  $\Omega$  and the other of resistance 500  $\Omega$ . A capacitor with a capacitance of  $30 \times 10^{-6}$  F is connected in parallel with the 500  $\Omega$  resistor. The circuit has been connected for a long time, and all currents have reached their steady states.

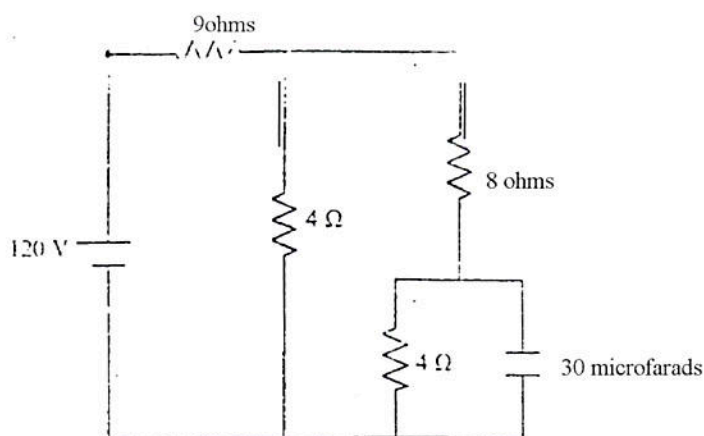
- Calculate the current in the 500  $\Omega$  resistor.
- Draw an ammeter in the circuit above in a location such that it could measure the current in the 500  $\Omega$  resistor. Use the symbol  $\textcircled{A}$  to indicate the ammeter.
  - Draw a voltmeter in the circuit above in a location such that it could measure the voltage across the 1000  $\Omega$  resistor. Use the symbol  $\textcircled{V}$  to indicate the voltmeter.
- Calculate the charge stored on the capacitor.
- Calculate the power dissipated in the 1000  $\Omega$  resistor.
- The capacitor is now discharged, and the 500  $\Omega$  resistor is removed and replaced by a resistor of greater resistance. The circuit is reconnected, and currents are again allowed to come to their steady-state values. Is the charge now stored on the capacitor larger, smaller, or the same as it was in part c.?

\_\_\_\_\_ Larger

\_\_\_\_\_ Smaller

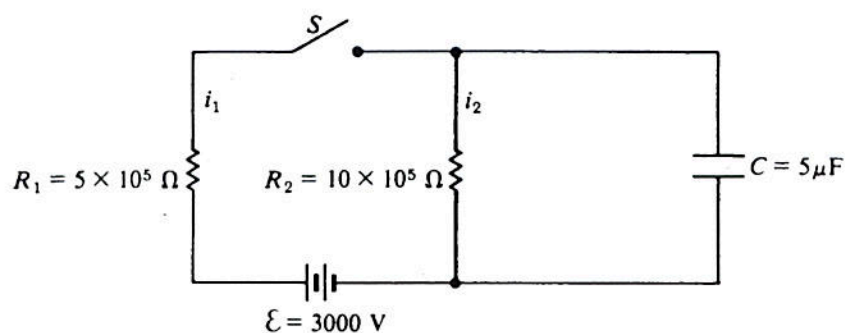
\_\_\_\_\_ The same as

Justify your answer.



1988E2. In the circuit shown above, the battery has been connected for a long time so that the currents have steady values. Given these conditions, calculate each of the following

- The current in the 9-ohm resistor.
- The current in the 8-ohm resistor.
- The potential difference across the 30-microfarad capacitor.
- The energy stored in the 30-microfarad capacitor.

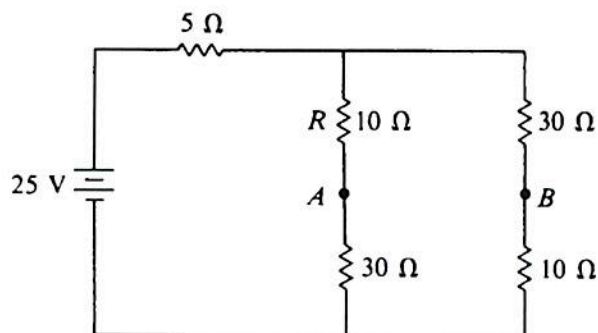


1985E2 (modified) In the circuit shown above,  $i_1$  and  $i_2$  are the currents through resistors  $R_1$  and  $R_2$ , respectively.  $V_1$ ,  $V_2$ , and  $V_c$  are the potential differences across resistor  $R_1$ , resistor  $R_2$ , and capacitor  $C$ , respectively. Initially the capacitor is uncharged.

- Calculate the current  $i_1$  immediately after switch  $S$  is closed.

Assume switch  $S$  has been closed for a long time.

- Calculate the current  $i_2$ .
- Calculate the charge  $Q$  on the capacitor.
- Calculate the energy  $U$  stored in the capacitor.

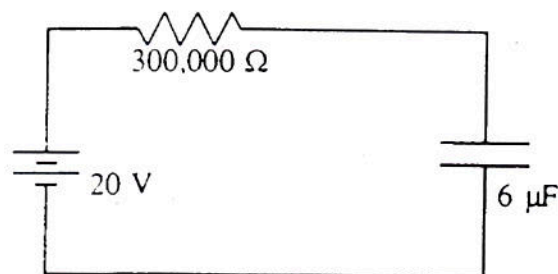


1986E2 (modified) Five resistors are connected as shown above to a 25-volt source of emf with zero internal resistance.

- Determine the current in the resistor labeled  $R$ .

A 10-microfarad capacitor is connected between points  $A$  and  $B$ . The currents in the circuit and the charge on the capacitor soon reach constant values. Determine the constant value for each of the following.

- The current in the resistor  $R$
- The charge on the capacitor



1989E3. A battery with an emf of 20 volts is connected in series with a resistor of 300,000 ohms and an air-filled parallel-plate capacitor of capacitance 6 microfarads.

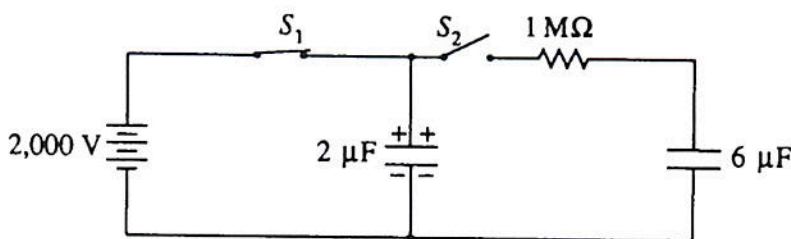
- a. Determine the energy stored in the capacitor when it is fully charged.

The spacing between the capacitor plates is suddenly increased (in a time short enough so the charge does not have time to readjust) to four times its original value.

- b. Determine the work that must be done in increasing the spacing in this fashion.  
c. Determine the current in the resistor immediately after the spacing is increased.

After a long time, the circuit reaches a new static state.

- d. Determine the total charge that has passed through the battery.  
e. Determine the energy that has been added to the battery.



1992E2. The 2-microfarad ( $2 \times 10^{-6}$  farad) capacitor shown in the circuit above is fully charged by closing switch  $S_1$  and keeping switch  $S_2$  open, thus connecting the capacitor to the 2,000-volt power supply.

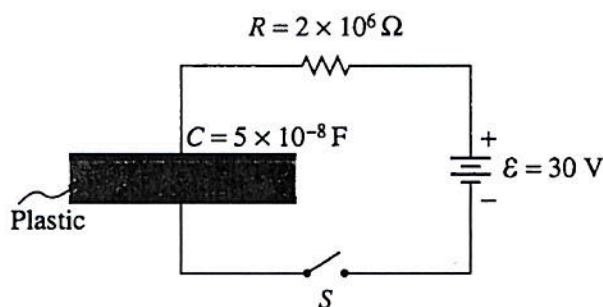
- a. Determine each of the following for this fully charged capacitor.  
i. The magnitude of the charge on each plate of the capacitor.  
ii. The electrical energy stored in the capacitor.

At a later time, switch  $S_1$  is opened. Switch  $S_2$  is then closed, connecting the charged 2-microfarad capacitor to a 1-megohm ( $1 \times 10^6\ \Omega$ ) resistor and a 6-microfarad capacitor, which is initially uncharged.

- b. Determine the initial current in the resistor the instant after switch  $S_2$  is closed.

Equilibrium is reached after a long period of time.

- c. Determine the charge on the positive plate of each of the capacitors at equilibrium.  
d. Determine the total electrical energy stored in the two capacitors at equilibrium. If the energy is greater than the energy determined in part a. ii., where did the increase come from? If the energy is less than the energy determined in part a. ii., where did the electrical energy go?



1995E2 (modified) A parallel-plate capacitor is made from two sheets of metal, each with an area of  $1.0$  square meter, separated by a sheet of plastic  $1.0$  millimeter ( $10^{-3}$  m) thick, as shown above. The capacitance is measured to be  $0.05$  microfarad ( $5 \times 10^{-8}$  F).

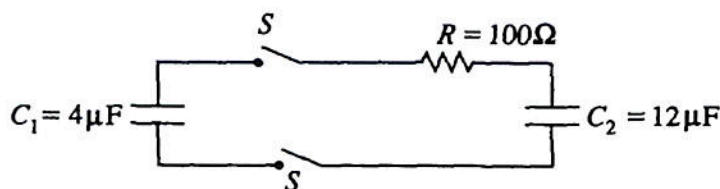
- a. What is the dielectric constant of the plastic?

The uncharged capacitor is connected in series with a resistor  $R = 2 \times 10^6$  ohms, a  $30$ -volt battery, and an open switch  $S$ , as shown above. The switch is then closed.

- b. What is the initial charging current when the switch  $S$  is closed?  
 c. Determine the magnitude and sign of the final charge on the bottom plate of the fully charged capacitor.  
 d. How much electrical energy is stored in the fully charged capacitor?

After the capacitor is fully charged, it is carefully disconnected, leaving the charged capacitor isolated in space. The plastic sheet is then removed from between the metal plates. The metal plates retain their original separation of  $1.0$  millimeter.

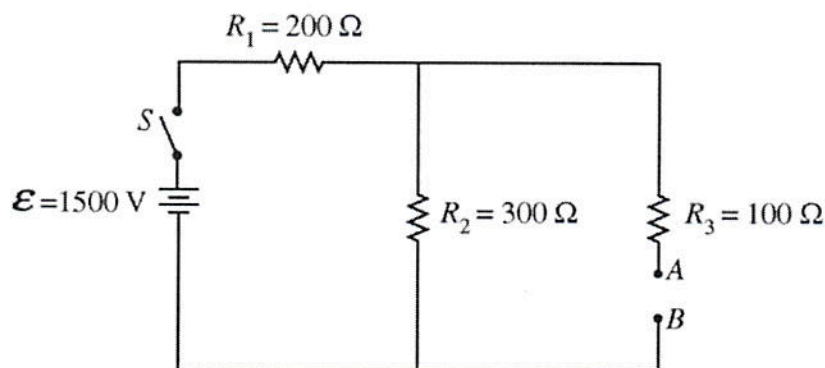
- e. What is the new voltage across the plates?  
 f. If there is now more energy stored in the capacitor, where did it come from? If there is now less energy, what happened to it?



1996E2 (modified) Capacitors 1 and 2, of capacitance  $C_1 = 4\mu\text{F}$  and  $C_2 = 12\mu\text{F}$ , respectively, are connected in a circuit as shown above with a resistor of resistance  $R = 100\ \Omega$  and two switches. Capacitor 1 is initially charged to a voltage  $V_0 = 50$  V and capacitor 2 is initially uncharged. Both of the switches  $S$  are then closed at time  $t = 0$ .

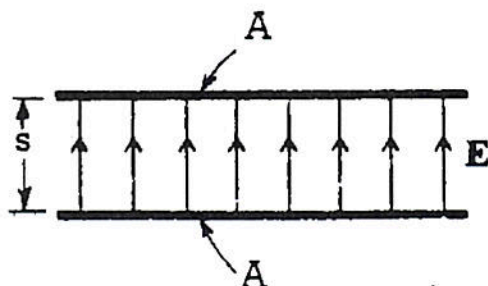
- a. What are the final charges on the positive plate of each of the capacitors 1 and 2 after equilibrium has been reached?  
 b. Determine the difference between the initial and the final stored energy of the system after equilibrium has been reached.





2008E2 (modified) In the circuit shown above, A and B are terminals to which different circuit components can be connected.

- a. Calculate the potential difference across  $R_2$  immediately after the switch S is closed in each of the following cases.
  - i. A  $50 \Omega$  resistor connects A and B.
  - ii. An initially uncharged  $0.80 \mu\text{F}$  capacitor connects A and B.

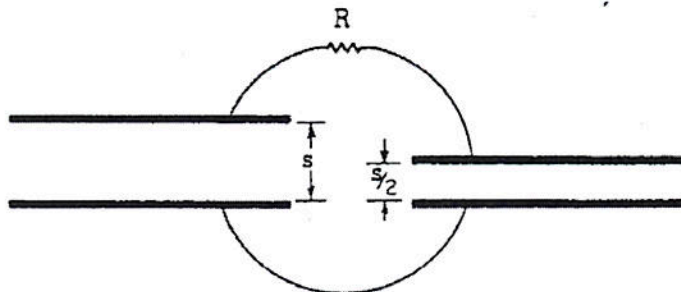


1978B3. A uniform electric field  $E$  is established between two capacitor plates, each of area  $A$ , which are separated by a distance  $s$  as shown above.

- a. What is the electric potential difference  $V$  between the plates?
- b. Specify the sign of the charge on each plate.

The capacitor above is then connected electrically through a resistor to a second parallel-plate capacitor, initially uncharged, whose plates have the same area  $A$  but a separation of only  $s/2$ .

- c. Indicate on the diagram below the direction of the current in each wire, and explain why the current will eventually cease.



- d. After the current has ceased, which capacitor has the greater charge? Explain your reasoning.
- e. The total energy stored in the two capacitors after the current has ceased is less than the initial stored energy. Explain qualitatively what has become of this "lost" energy.

