Chapter 18

Direct-Current Circuits

Outline

18.1. Sources of EMF

18.2. Resistors in series

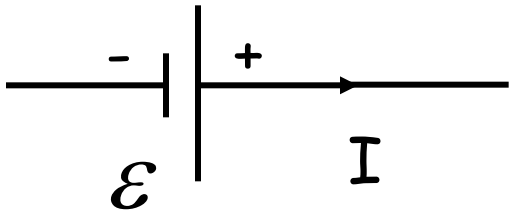
18.3. Resistors in parallel

18.1. Sources of EMF

"Electromotive force ε" (emf)

ε ≡ external work per unit charge

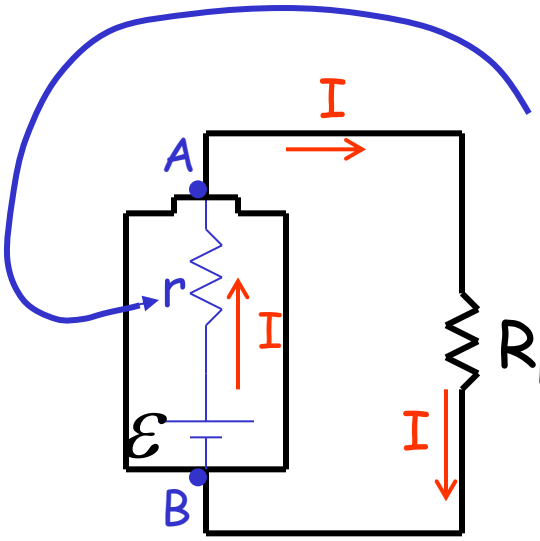
Units: J/C = volts (not actually a force)
but it "pushes" the charges through the circuit.



Eg: Battery
(chemical energy ➔ electrical energy)

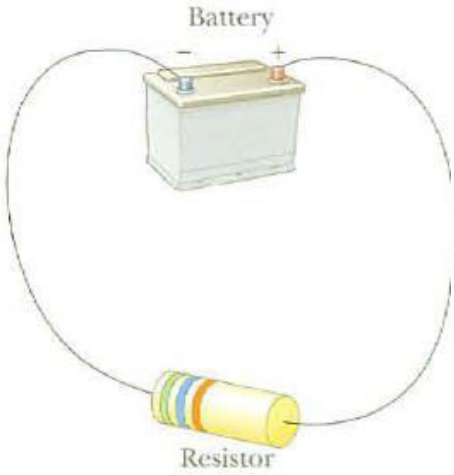
Generator
(mechanical energy ➔ electrical energy)

Real Batteries



r = "internal resistance" of the battery

R_L (external resistance, "load")



$V_B + \mathcal{E} - Ir = V_A$

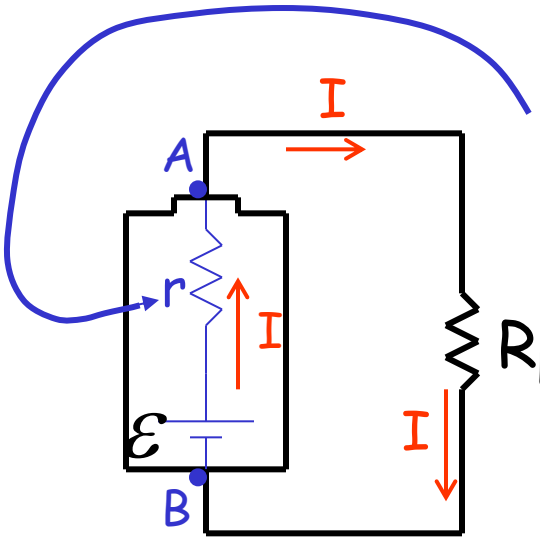
$V_A - V_B = V$ = "terminal voltage" ➔ measured

$$\Rightarrow \quad \mathcal{E} - Ir = (V_A - V_B)$$

$\mathcal{E} - Ir = V$

"Terminal voltage"

Real Batteries



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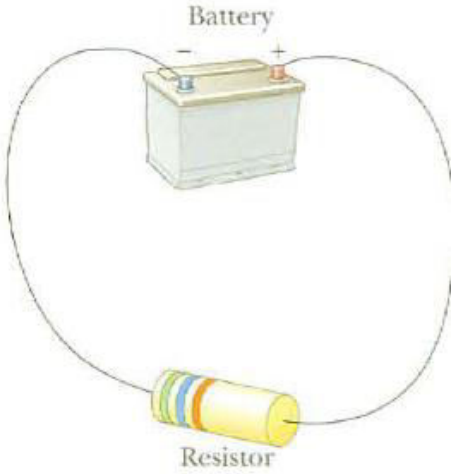


$$\varepsilon = IR + Ir$$

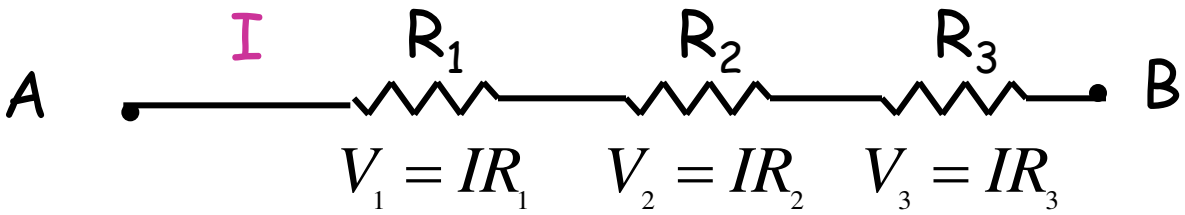
$$I = \varepsilon/(R + r)$$

$$I\mathcal{E} = I^2R + I^2r$$ ← "Power of a battery"

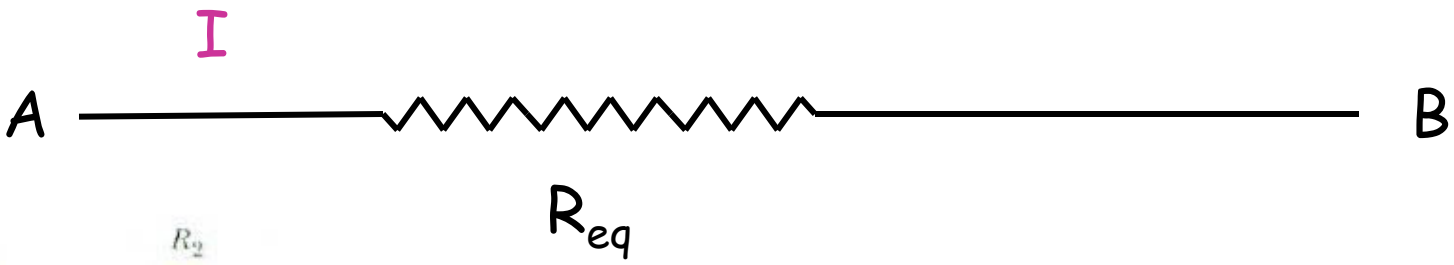
QUICK QUIZ 18.1 True or False: While discharging, the terminal voltage of a battery can never be greater than the emf of the battery.

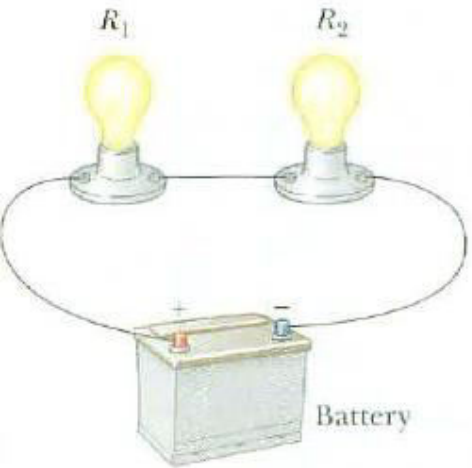
QUICK QUIZ 18.2 Why does a battery get warm while in use?

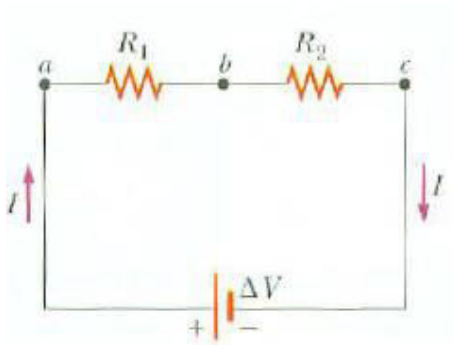
18.2. Resistors in Series



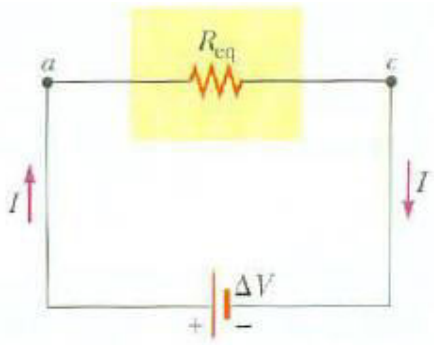
We want to replace this combination by a single resistor with resistance R_{eq}







(b)



(c)

- Same <u>current</u> through all resistors
- Voltages add:

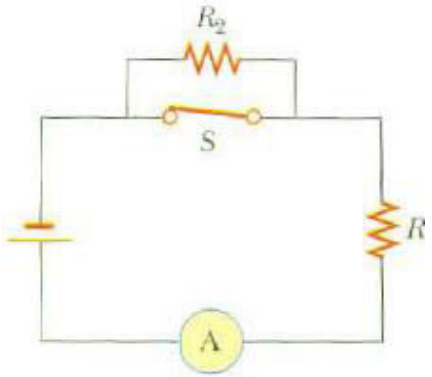
$V_{eq} = V_1 + V_2 + V_3 + \ldots$

$IR_{eq} = IR_1 + IR_2 + IR_3 + \ldots$ *(same current through all)*

So, $R_{eq} = R_1 + R_2 + R_3 + \ldots$

Quiz 18.3

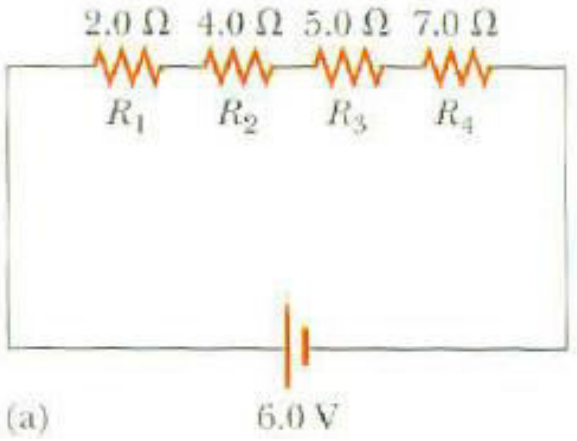
In Figure 18.4 the current is measured with the ammeter at the bottom of the circuit. When the switch is opened, does the reading on the ammeter :
(a) increase, (b) decrease, or (c) not change?



QUICK QUIZ 18.4 The circuit in Figure 18.4 consists of two resistors, a switch, an ammeter, and a battery. When the switch is closed, power $\mathcal{P}_c$ is delivered to resistor R_1. When the switch is opened, which of the following statements is true about the power $\mathcal{P}_o$ delivered to R_1? (a) $\mathcal{P}_o < \mathcal{P}_c$ (b) $\mathcal{P}_o = \mathcal{P}_c$ (c) $\mathcal{P}_o > \mathcal{P}_c$

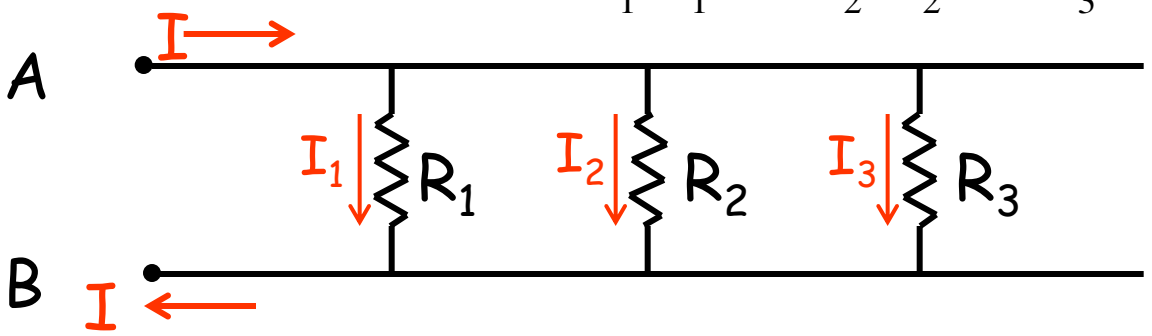
Example18.1

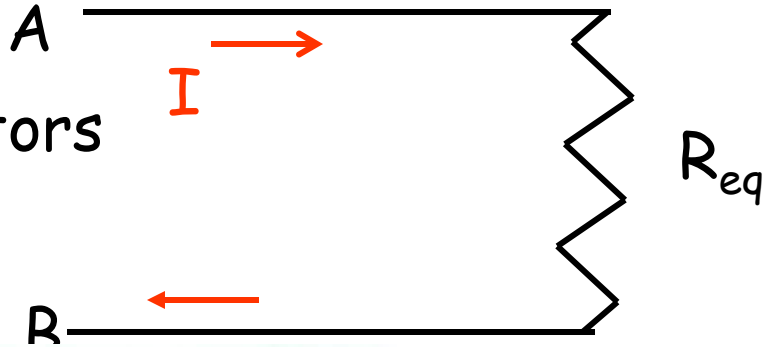
Four resistors are arranged as shown in the Figure
find
(a) the equivalent resistance of the circuit and
(b) the current in the circuit if the emf' of the battery is6.0 V.



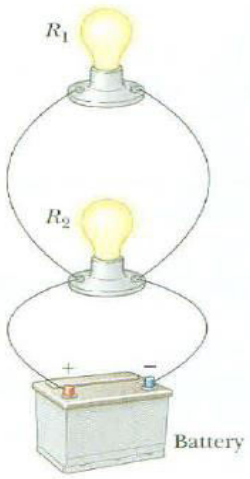
18.3 Resistors in Parallel

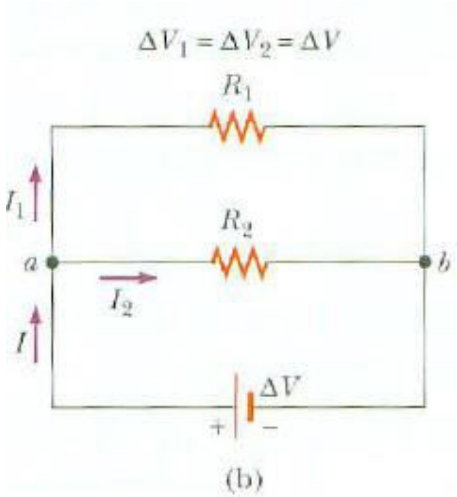
$$V = I_1 R_1 = I_2 R_2 = I_3 R_3$$

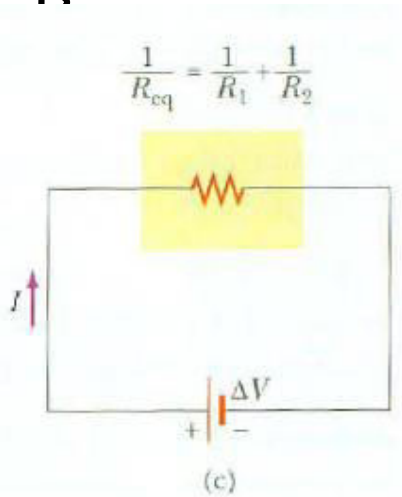




We want to replace these resistors by a single resistance R_{eq}:







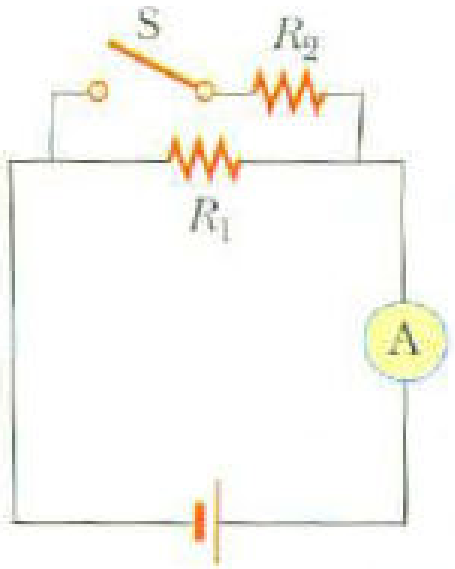
- Same voltage across each resistor
- Currents add: $I_{eq} = I_1 + I_2 + I_3 +$

$$\Rightarrow \frac{V}{R_{eq}} = I_{eq} = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \ldots$$

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots}$$

Example: find the equivalent resistance of resistors of 5 Ω and 10 Ω in series and parallel.

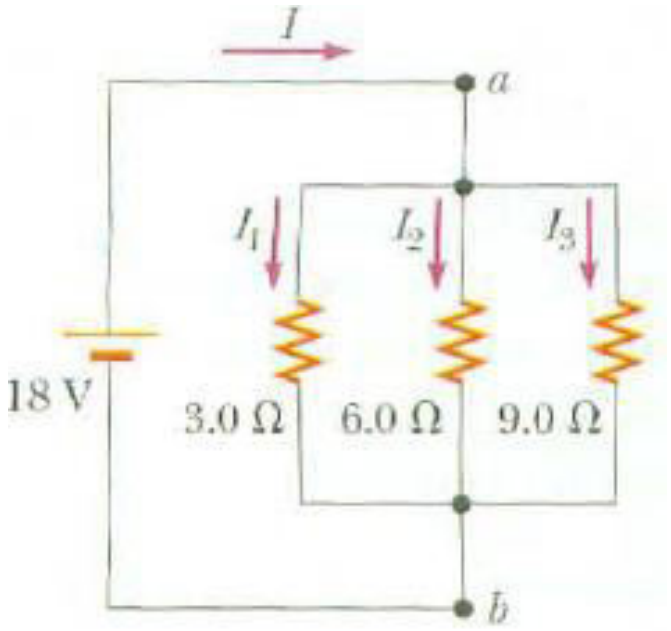
QUICK QUIZ 18.5 In Figure 18.7 the current is measured with the ammeter on the right side of the circuit diagram. When the switch is closed, does the reading on the ammeter (a) increase, (b) decrease, or (c) remain the same?



QUICK QUIZ 18.6 When the switch is open in Figure 18.7, power $\mathcal{P}_0$ is delivered to the resistor R_1. When the switch is closed, which of the following is true about the power $\mathcal{P}_c$ delivered to R_1? (Neglect the internal resistance of the battery.) (a) $\mathcal{P}_c < \mathcal{P}_0$ (b) $\mathcal{P}_c = \mathcal{P}_0$ (c) $\mathcal{P}_c > \mathcal{P}_0$

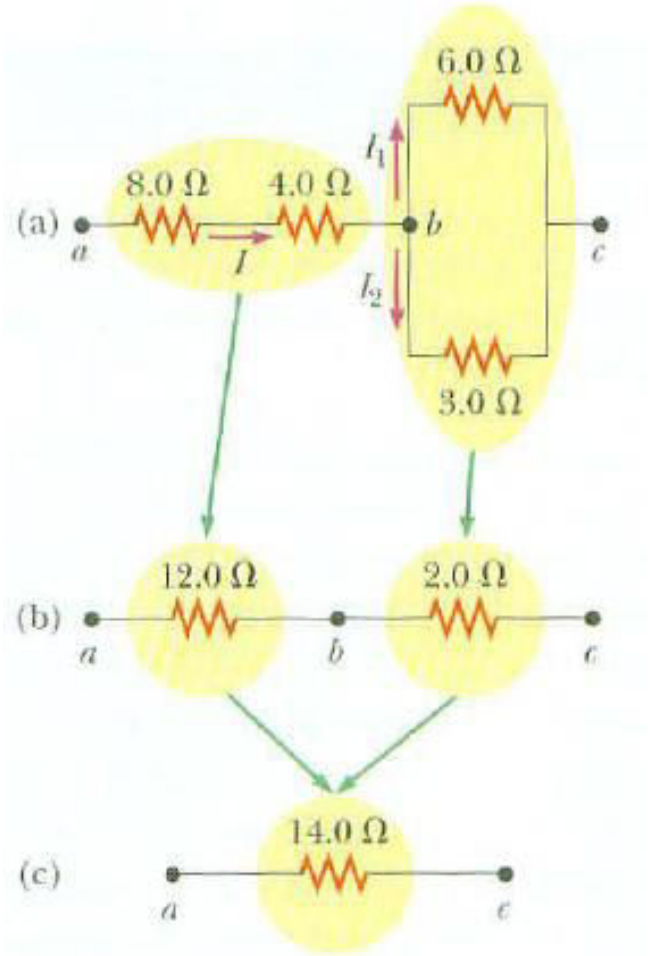
Example 18.2

Three resistors are connected in parallel as in the Figure A potential difference of 18 V is maintained between points a *and b*. (a) Find the current in each resistor. (b) Calculate the power delivered to each resistor and the total power. (c) Find the equivalent resistance of the circuit. (d) find the total power delivered tothe equivalent resistance.



Example 18.3

Four resistors are connected as shown in the Figure (a) Find the equivalent resistance between points *a* and c. (b) what is the current in each resistor if a 42-V battery is connected between *a* and c?



Problems

Q1. A piece of copper wire of resistance R is cut into ten equal parts. These parts are connected in parallel. The equivalent resistance of the parallel combination will be:

- سلك من النحاس له مقاومة R قطع الى عشره اجزاء متساوية حيث وصلت هذه الاجزاء على التوازي. فإن المقاومة المكافئة لدائرة التوصيل على التوازي هي:

- 0.01 R
- 0.1 R
- R
- 10 R

Q2. Three resistors; A, B and C are connected in series with a battery. If $R_A < R_B < R_C$, then the resistor with the greatest voltage is:

- ثلاثة مقاومات A, B and C وصلت B , C على التوالي ببطارية، اذا كانت $R_A < R_B < R_C$ ، فرق الجهد يكون اكبر على المقاومة:

- A
- B
- C
- All the same.

Q3. If the current given by a source is the same as that going back to the source, why do we pay money for the electricity company?

- اذا كان مقدار التيار الصادر من مصدر هو نفس مقدار التيار العائد اليه، لماذا يتم دفع النقود لشركة الكهرباء:

- This is true only for series circuits and what we have at home are parallel circuits.
- All appliances are rated in watts; we pay for power (kilowatts).
- What we pay for is energy.
- The statement itself is not true.

QUICK QUIZ 18.7 Suppose you have three identical lightbulbs, some wire, and a battery. You connect one lightbulb to the battery and take note of its brightness. You add a second lightbulb, connecting it in parallel with the previous lightbulbs, and again take note of the brightness. Repeat the process with the third lightbulb, connecting it in parallel with the other two. As the lightbulbs are added, what happens to (a) the brightness of the lightbulbs? (b) The individual currents in the lightbulbs? (c) The power delivered by the battery? (d) The lifetime of the battery? (Neglect the battery's internal resistance.)

QUICK QUIZ 18.8 If the lightbulbs in Quick Quiz 18.7 are connected one by one in series instead of in parallel, what happens to (a) the brightness of the lightbulbs? (b) The individual currents in the lightbulbs? (c) The power delivered by the battery? (d) The lifetime of the battery? (Again, neglect the battery's internal resistance.)

1. The terminals of a battery are connected across two different resistors in series. Which of the following statements are correct? (There may be more than one correct statement.) (a) The smaller resistor carries more current. (b) The larger resistor carries less current. (c) The current in each resistor is the same. (d) The voltage difference across each resistor is the same. (e) The voltage difference is greatest across the resistor closest to the positive terminal.

2. The terminals of a battery are connected across two different resistors in parallel. Which of the following statements are correct? (There may be more than one correct statement.) (a) The larger resistor carries more current than the smaller resistor. (b) The larger resistor carries less current than the smaller resistor. (c) The voltage difference across each resistor is the same. (d) The voltage difference across the larger resistor is greater than the voltage difference across the smaller resistor. (e) The voltage difference is greater across the resistor closer to the battery.

4. Two lightbulbs are in series, one operating at 120 W and the other operating at 60.0 W. If the voltage drop across the series combination is 120 V, what is the current in the circuit? (a) 1.0 A (b) 1.5 A (c) 2.0 A (d) 2.5 A (e) 3.0 A

11. Several resistors are connected in parallel. Which of the following statements are true of the corresponding equivalent resistance? (There may be more than one correct statement.) (a) It is greater than the resistance of any of the individual resistors. (b) It is less than the resistance of any of the individual resistors. (c) It is dependent on the voltage applied across the series. (d) It is equal to the sum of the resistances of all the resistors in the series. (e) It is equal to the reciprocal of the sum of the inverses of the resistances of all the resistors.

1. Is the direction of current in a battery always from the negative terminal to the positive one? Explain.

8. Two sets of Christmas lights are available. For set A, when one bulb is removed, the remaining bulbs remain illuminated. For set B, when one bulb is removed, the remaining bulbs do not operate. Explain the difference in wiring for the two sets.

10. (a) Two resistors are connected in series across a battery. Is the power delivered to each resistor (i) the same or (ii) not necessarily the same? (b) Two resistors are connected in parallel across a battery. Is the power delivered to each resistor (i) the same or (ii) not necessarily the same?

11. Why is it possible for a bird to sit on a high-voltage wire without being electrocuted? (See Fig. CQ18.11.)

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