Chapitre 25 – Courant, résistance et la fém [27 mai au 1 juin]

DEVOIR : 25.4, 25.58, 25.64, 25.68, 25.79

25.1. Courant

- Direction du courant: lire paragraphe 2 de p. 848. Attention: à l'école secondaire, on définit parfois la direction du courant dans le sens des charges négatives. Ici, nous prendrons le sens des charges positives.
- Eq. (25.1) : définition du courant *I*. Unité : ampère (A)
- Eq. (25.4) : densité de courant **J** (en A/m^2). $I = J\,A$.
- Lire l'exemple 25.1
- Autres exemples :

25.2. **IDENTIFY:** $I = Q/t$. Use $I = n|q|v_\mathrm{d}A$ to calculate the drift velocity v_d.

SET UP: $n = 5.8\times10^{28}\ \mathrm{m}^{-3}$. $|q| = 1.60\times10^{-19}\ \mathrm{C}$.

EXECUTE: **(a)** $I = \dfrac{Q}{t} = \dfrac{420\ \mathrm{C}}{80(60\ \mathrm{s})} = 8.75\times10^{-2}\ \mathrm{A}$.

(b) $I = n|q|v_\mathrm{d}A$. This gives $v_\mathrm{d} = \dfrac{I}{nqA} = \dfrac{8.75\times10^{-2}\ \mathrm{A}}{(5.8\times10^{28})(1.60\times10^{-19}\ \mathrm{C})(\pi(1.3\times10^{-3}\ \mathrm{m})^2)} = 1.78\times10^{-6}\ \mathrm{m/s}$.

EVALUATE: v_d is smaller than in Example 25.1, because *I* is smaller in this problem.

25.5. **IDENTIFY** and **SET UP:** Use Eq. (25.3) to calculate the drift speed and then use that to find the time to travel the length of the wire.

EXECUTE: **(a)** Calculate the drift speed v_d:

$$J = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{4.85\ \mathrm{A}}{\pi\left(1.025\times10^{-3}\ \mathrm{m}\right)^2} = 1.469\times10^6\ \mathrm{A/m^2}$$

$$v_\mathrm{d} = \frac{J}{n|q|} = \frac{1.469\times10^6\ \mathrm{A/m^2}}{\left(8.5\times10^{28}/\mathrm{m}^3\right)\left(1.602\times10^{-19}\ \mathrm{C}\right)} = 1.079\times10^{-4}\ \mathrm{m/s}$$

$$t = \frac{L}{v_\mathrm{d}} = \frac{0.710\ \mathrm{m}}{1.079\times10^{-4}\ \mathrm{m/s}} = 6.58\times10^3\ \mathrm{s} = 110\ \mathrm{min.}$$

(b) $v_\mathrm{d} = \dfrac{I}{\pi r^2 n|q|}$

$$t = \frac{L}{v_\mathrm{d}} = \frac{\pi r^2 n|q|L}{I}$$

t is proportional to r^2 and hence to d^2 where $d = 2r$ is the wire diameter.

$$t = \left(6.58\times10^3\ \mathrm{s}\right)\left(\frac{4.12\ \mathrm{mm}}{2.05\ \mathrm{mm}}\right)^2 = 2.66\times10^4\ \mathrm{s} = 440\ \mathrm{min.}$$

(c) EVALUATE: The drift speed is proportional to the current density and therefore it is inversely proportional to the square of the diameter of the wire. Increasing the diameter by some factor decreases the drift speed by the square of that factor.

25.2 et 25.3 Résistivité et résistance

- La résistivité est la version microscopique de la résistance, qui est macroscopique.
- Eq. (25.5) : définition de résistivité. Des valeurs sont dans le Tableau 25.1. Remarque: Eq. (25.5) peut être vue comme la version miscroscopique de la loi d'Ohm.
- Conductivité = (résistivité)$^{-1}$
- Eq. (25.6) : résistivité en fonction de la température.
- Autres exemples :

25.10. **(a) IDENTIFY:** Start with the definition of resisitivity and solve for E.
SET UP: $E = \rho J = \rho I/\pi r^2$
EXECUTE: $E = (1.72 \times 10^{-8}\ \Omega\cdot\text{m})(2.75\text{ A})/[\pi(0.001025\text{ m})^2] = 1.43 \times 10^{-2}$ V/m
EVALUATE: The field is quite weak, since the potential would drop only a volt in 70 m of wire.
(b) IDENTIFY: Take the ratio of the field in silver to the field in copper.
SET UP: Take the ratio and solve for the field in silver: $E_S = E_C(\rho_S/\rho_C)$
EXECUTE: $E_S = (0.0143\text{ V/m})[(1.47)/(1.72)] = 1.22 \times 10^{-2}$ V/m
EVALUATE: Since silver is a better conductor than copper, the field in silver is smaller than the field in copper.

25.12. **IDENTIFY:** $E = \rho J$, where $J = I / A$. The drift velocity is given by $I = n|q|v_d A$.
SET UP: For copper, $\rho = 1.72\times10^{-8}\ \Omega\cdot\text{m}$. $n = 8.5\times10^{28}\ /\ \text{m}^3$.
EXECUTE: **(a)** $J = \dfrac{I}{A} = \dfrac{3.6\text{ A}}{(2.3\times10^{-3}\text{ m})^2} = 6.81\times10^5\ \text{A/m}^2$.
(b) $E = \rho J = (1.72\times10^{-8}\ \Omega\cdot\text{m})(6.81\times10^5\ \text{A/m}^2) = 0.012\ \text{V/m}$.
(c) The time to travel the wire's length l is

$$t = \frac{l}{v_d} = \frac{ln|q|A}{I} = \frac{(4.0\text{ m})(8.5\times10^{28}/\text{m}^3)(1.6\times10^{-19}\text{ C})(2.3\times10^{-3}\text{ m})^2}{3.6\text{ A}} = 8.0\times10^4\text{ s.}$$

$t = 1333$ min $\approx$ 22 hrs!
EVALUATE: The currents propagate very quickly along the wire but the individual electrons travel very slowly.

- Lire la page 853. La loi d'Ohm, Eq. (25.11), est bien connue; ce qui est nouveau est la relation entre les quantité microscopiques et les valeurs macroscopiques.
- Lire les exemples 25.2 à 25.4

25.15. **(a) IDENTIFY:** Start with the definition of resistivity and use its dependence on temperature to find the electric field.
SET UP: $E = \rho J = \rho_{20}[1+\alpha(T-T_0)]\dfrac{I}{\pi r^2}$
EXECUTE: $E = (5.25 \times 10^{-8}\ \Omega\cdot\text{m})[1 + (0.0045/\text{C}\infty)(120°\text{C} - 20°\text{C})](12.5\text{ A})/[\pi(0.000500\text{ m})^2]$ = 1.21 V/m.
(Note that the resistivity at 120°C turns out to be $7.61 \times 10^{-8}\ \Omega\cdot\text{m}$.)
EVALUATE: This result is fairly large because tungsten has a larger resisitivity than copper.
(b) IDENTIFY: Relate resistance and resistivity.
SET UP: $R = \rho L/A = \rho L/\pi r^2$
EXECUTE: $R = (7.61 \times 10^{-8}\ \Omega\cdot\text{m})(0.150\text{ m})/[\pi(0.000500\text{ m})^2] = 0.0145\ \Omega$

EVALUATE: Most metals have very low resistance.
(c) IDENTIFY: The potential difference is proportional to the length of wire.
SET UP: $V = EL$
EXECUTE: $V = (1.21\ \text{V/m})(0.150\ \text{m}) = 0.182\ \text{V}$
EVALUATE: We could also calculate $V = IR = (12.5\ \text{A})(0.0145\ \Omega) = 0.181\ \text{V}$, in agreement with part (c).

25.18. **IDENTIFY:** $R = \dfrac{\rho L}{A} = \dfrac{\rho L}{\pi d^2/4}$.

SET UP: For aluminum, $\rho_{\text{al}} = 2.63\times10^{-8}\ \Omega\cdot\text{m}$. For copper, $\rho_{\text{c}} = 1.72\times10^{-8}\ \Omega\cdot\text{m}$.

EXECUTE: $\dfrac{\rho}{d^2} = \dfrac{R\pi}{4L} =$ constant, so $\dfrac{\rho_{\text{al}}}{d_{\text{al}}^2} = \dfrac{\rho_{\text{c}}}{d_{\text{c}}^2}$.

$$d_{\text{c}} = d_{\text{al}}\sqrt{\frac{\rho_{\text{c}}}{\rho_{\text{al}}}} = (3.26\ \text{mm})\sqrt{\frac{1.72\times10^{-8}\ \Omega\cdot\text{m}}{2.63\times10^{-8}\ \Omega\cdot\text{m}}} = 2.64\ \text{mm}.$$

EVALUATE: Copper has a smaller resistivity, so the copper wire has a smaller diameter in order to have the same resistance as the aluminum wire.

25.22. **IDENTIFY:** Apply $R_T = R_0(1+\alpha(T-T_0))$.

SET UP: Since $V = IR$ and V is the same, $\dfrac{R_T}{R_{20}} = \dfrac{I_{20}}{I_T}$. For tungsten, $\alpha = 4.5\times10^{-3}\ (\text{C°})^{-1}$.

EXECUTE: The ratio of the current at $20°\text{C}$ to that at the higher temperature is

$(0.860\ \text{A})/(0.220\ \text{A}) = 3.909$. $\dfrac{R_T}{R_{20}} = 1+\alpha(T-T_0) = 3.909$, where $T_0 = 20°\text{C}$.

$$T = T_0 + \frac{R_T/R_{20}-1}{\alpha} = 20°\text{C} + \frac{3.909-1}{4.5\times10^{-3}\ (\text{C°})^{-1}} = 666°\text{C}.$$

EVALUATE: As the temperature increases, the resistance increases and for constant applied voltage the current decreases. The resistance increases by nearly a factor of four.

25.26. **IDENTIFY** and **SET UP:** Use $V = EL$ to calculate E and then $\rho = E/J$ to calculate ρ.

EXECUTE: **(a)** $E = \dfrac{V}{L} = \dfrac{0.938\ \text{V}}{0.750\ \text{m}} = 1.25\ \text{V/m}$

(b) $E = \rho J$ so $\rho = \dfrac{E}{J} = \dfrac{1.25\ \text{V/m}}{4.40\times10^{7}\ \text{A/m}^2} = 2.84\times10^{-8}\ \Omega\cdot\text{m}$

EVALUATE: This value of ρ is similar to that for the good metallic conductors in Table 25.1.

25.4. Fém et circuits électriques

- PP. 857 et 858, la partie *Electromotive Force*
- Eq. (25.15) : résistance interne *r*
- Tableau 25.4 : symboles pour les circuits électriques
- Lire les exemple 25.5 à 25.8
- Fig. 25.21 illustre le comportement du potentiel dans un circuit.
- Autres exemples :

25.36. **IDENTIFY:** The sum of the potential changes around the circuit loop is zero. Potential decreases by IR when going through a resistor in the direction of the current and increases by $\mathcal{E}$ when passing through an emf in the direction from the $-$ to $+$ terminal.

SET UP: The current is counterclockwise, because the 16 V battery determines the direction of current flow.

EXECUTE: $+16.0\text{ V} - 8.0\text{ V} - I(1.6\ \Omega + 5.0\ \Omega + 1.4\ \Omega + 9.0\ \Omega) = 0$

$$I = \frac{16.0\text{ V} - 8.0\text{ V}}{1.6\ \Omega + 5.0\ \Omega + 1.4\ \Omega + 9.0\ \Omega} = 0.47\text{ A}$$

(b) $V_b + 16.0\text{ V} - I(1.6\ \Omega) = V_a$, so $V_a - V_b = V_{ab} = 16.0\text{ V} - (1.6\ \Omega)(0.47\text{ A}) = 15.2\text{ V}.$

(c) $V_c + 8.0\text{ V} + I(1.4\ \Omega + 5.0\ \Omega) = V_a$ so $V_{ac} = (5.0\ \Omega)(0.47\text{ A}) + (1.4\ \Omega)(0.47\text{ A}) + 8.0\text{ V} = 11.0\text{ V}.$

(d) The graph is sketched in Figure 25.36.

EVALUATE: $V_{cb} = (0.47\text{ A})(9.0\ \Omega) = 4.2\text{ V}$. The potential at point *b* is 15.2 V below the potential at point *a* and the potential at point *c* is 11.0 V below the potential at point *a*, so the potential of point *c* is $15.2\text{ V} - 11.0\text{ V} = 4.2\text{ V}$ above the potential of point *b*.

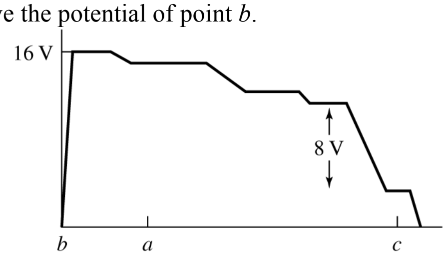

Figure 25.36

25.38. **IDENTIFY:** The sum of the potential changes around the loop is zero.

SET UP: The voltmeter reads the *IR* voltage across the $9.0\ \Omega$ resistor. The current in the circuit is counterclockwise because the 16 V battery determines the direction of the current flow.

EXECUTE: **(a)** $V_{bc} = 1.9\text{ V}$ gives $I = V_{bc}/R_{bc} = 1.9\text{ V}/9.0\ \Omega = 0.21\text{ A}.$

(b) $16.0\text{ V} - 8.0\text{ V} = (1.6\ \Omega + 9.0\ \Omega + 1.4\ \Omega + R)(0.21\text{ A})$ and $R = \dfrac{5.48\text{ V}}{0.21\text{ A}} = 26.1\ \Omega.$

(c) The graph is sketched in Figure 25.38.

EVALUATE: In Exercise 25.36 the current is 0.47 A. When the $5.0\ \Omega$ resistor is replaced by the $26.1\ \Omega$ resistor the current decreases to 0.21 A.

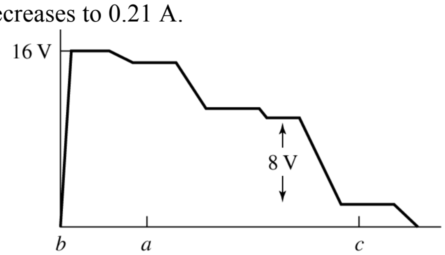

Figure 25.38

25.39. **(a) IDENTIFY** and **SET UP:** Assume that the current is clockwise. The circuit is sketched in Figure 25.39a.

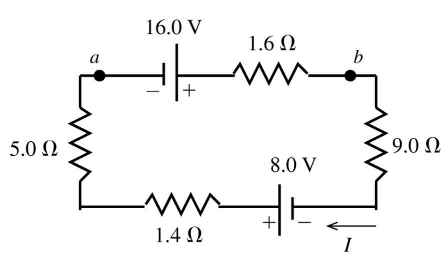

Figure 25.39a

Add up the potential rises and drops as travel clockwise around the circuit.

EXECUTE: $16.0\text{ V} - I(1.6\ \Omega) - I(9.0\ \Omega) + 8.0\text{ V} - I(1.4\ \Omega) - I(5.0\ \Omega) = 0$

$$I=\frac{16.0\text{ V}+8.0\text{ V}}{9.0\ \Omega+1.4\ \Omega+5.0\ \Omega+1.6\ \Omega}=\frac{24.0\text{ V}}{17.0\ \Omega}=1.41\text{ A, clockwise}$$

EVALUATE: The 16.0 V battery drives the current clockwise more strongly than the 8.0 V battery does in the opposite direction.

(b) IDENTIFY and SET UP: Start at point *a* and travel through the battery to point *b*, keeping track of the potential changes. At point *b* the potential is V_b.

EXECUTE: $V_a+16.0\text{ V}-I(1.6\ \Omega)=V_b$

$V_a-V_b=-16.0\text{ V}+(1.41\text{ A})(1.6\ \Omega)$

$V_{ab}=-16.0\text{ V}+2.3\text{ V}=-13.7\text{ V}$ (point *a* is at lower potential; it is the negative terminal)

EVALUATE: Could also go counterclockwise from *a* to *b:*

$V_a+(1.41\text{ A})(5.0\ \Omega)+(1.41\text{ A})(1.4\ \Omega)-8.0\text{ V}+(1.41\text{ A})(9.0\ \Omega)=V_b$

$V_{ab}=-13.7\text{ V}$, which checks.

(c) IDENTIFY and SET UP: State at point *a* and travel through the battery to point *c*, keeping track of the potential changes.

EXECUTE: $V_a+16.0\text{ V}-I(1.6\ \Omega)-I(9.0\ \Omega)=V_c$

$V_a-V_c=-16.0\text{ V}+(1.41\text{ A})(1.6\ \Omega+9.0\ \Omega)$

$V_{ac}=-16.0\text{ V}+15.0\text{ V}=-1.0\text{ V}$ (point *a* is at lower potential than point *c*)

EVALUATE: Could also go counterclockwise from *a* to *c*:

$V_a+(1.41\text{ A})(5.0\ \Omega)+(1.41\text{ A})(1.4\ \Omega)-8.0\text{ V}=V_c$

$V_{ac}=-1.0\text{ V}$, which checks.

(d) Call the potential zero at point *a*. Travel clockwise around the circuit. The graph is sketched in Figure 25.39b.

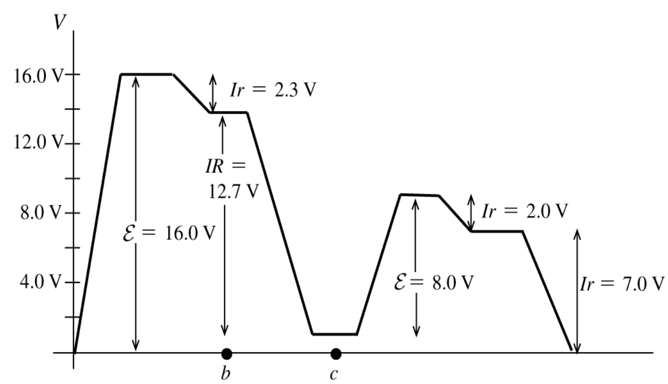

Figure 25.39b

25.5. Énergie et puissance dans les circuits électriques

- Eq. (25.17) est l'expression la plus générale de la puissance. Valide pour une pile, une résistance, etc.
- Eq. (25.18) n'est valide que pour une résistance.
- Lire pp. 864 et 865
- Lire les exemples 25.9 à 25.11
- Autres exemples:

25.43. **IDENTIFY:** The bulbs are each connected across a 120-V potential difference.
SET UP: Use $P=V^2/R$ to solve for R and Ohm's law ($I=V/R$) to find the current.

EXECUTE: **(a)** $R = V^2/P = (120\text{ V})^2/(100\text{ W}) = 144\ \Omega$.
(b) $R = V^2/P = (120\text{ V})^2/(60\text{ W}) = 240\ \Omega$
(c) For the 100-W bulb: $I = V/R = (120\text{ V})/(144\ \Omega) = 0.833\text{ A}$
For the 60-W bulb: $I = (120\text{ V})/(240\ \Omega) = 0.500\text{ A}$
EVALUATE: The 60-W bulb has *more* resistance than the 100-W bulb, so it draws less current.

25.47. **IDENTIFY** and **SET UP:** By definition $p = \dfrac{P}{LA}$. Use $P = VI$, $E = VL$ and $I = JA$ to rewrite this expression in terms of the specified variables.

EXECUTE: **(a)** E is related to V and J is related to I, so use $P = VI$. This gives $p = \dfrac{VI}{LA}$

$\dfrac{V}{L} = E$ and $\dfrac{I}{A} = J$ so $p = EJ$

(b) J is related to I and ρ is related to R, so use $P = IR^2$. This gives $p = \dfrac{I^2 R}{LA}$.

$I = JA$ and $R = \dfrac{\rho L}{A}$ so $p = \dfrac{J^2 A^2 \rho L}{LA^2} \rho J^2$

(c) E is related to V and ρ is related to R, so use $P = V^2/R$. This gives $p = \dfrac{V^2}{RLA}$.

$V = EL$ and $R = \dfrac{\rho L}{A}$ so $p = \dfrac{E^2 L^2}{LA}\left(\dfrac{A}{\rho L}\right) = \dfrac{E^2}{\rho}$.

EVALUATE: For a given material (ρ constant), p is proportional to J^2 or to E^2.

25.49. **(a) IDENTIFY** and **SET UP:** $P = VI$ and energy = (power) $\times$ (time).
EXECUTE: $P = VI = (12\text{ V})(60\text{ A}) = 720\text{ W}$
The battery can provide this for 1.0 h, so the energy the battery has stored is
$U = Pt = (720\text{ W})(3600\text{ s}) = 2.6 \times 10^6\text{ J}$

(b) IDENTIFY and **SET UP:** For gasoline the heat of combustion is $L_c = 46 \times 10^6$ J/kg. Solve for the mass m required to supply the energy calculated in part (a) and use density $\rho = m/V$ to calculate V.

EXECUTE: The mass of gasoline that supplies 2.6×10^6 J is $m = \dfrac{2.6 \times 10^6\text{ J}}{46 \times 10^6\text{ J/kg}} = 0.0565$ kg.

The volume of this mass of gasoline is
$$V = \frac{m}{\rho} = \frac{0.0565\text{ kg}}{900\text{ kg/m}^3} = 6.3 \times 10^{-5}\text{ m}^3\left(\frac{1000\text{ L}}{1\text{ m}^3}\right) = 0.063\text{ L}$$
(c) IDENTIFY and **SET UP:** Energy = (power) $\times$ (time); the energy is that calculated in part (a).
EXECUTE: $U = Pt,\ t = \dfrac{U}{P} = \dfrac{2.6 \times 10^6\text{ J}}{450\text{ W}} = 5800\text{ s} = 97\text{ min} = 1.6\text{ h}$.
EVALUATE: The battery discharges at a rate of 720 W (for 60 A) and is charged at a rate of 450 W, so it takes longer to charge than to discharge.

25.53. **IDENTIFY:** Solve for the current I in the circuit. Apply Eq. (25.17) to the specified circuit elements to find the rates of energy conversion.
SET UP: The circuit is sketched in Figure 25.53.

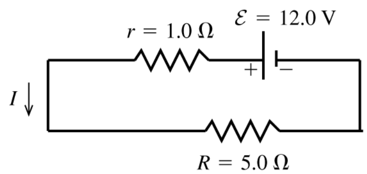

Figure 25.53

EXECUTE: Compute I:

$\mathcal{E} - Ir - IR = 0$

$$I = \frac{\mathcal{E}}{r+R} = \frac{12.0\ \text{V}}{1.0\ \Omega + 5.0\ \Omega} = 2.00\ \text{A}$$

(a) The rate of conversion of chemical energy to electrical energy in the emf of the battery is $P = \mathcal{E}I = (12.0\ \text{V})(2.00\ \text{A}) = 24.0\ \text{W}$.

(b) The rate of dissipation of electrical energy in the internal resistance of the battery is $P = I^2 r = (2.00\ \text{A})^2 (1.0\ \Omega) = 4.0\ \text{W}$.

(c) The rate of dissipation of electrical energy in the external resistor R is $P = I^2 R = (2.00\ \text{A})^2 (5.0\ \Omega) = 20.0\ \text{W}$.

EVALUATE: The rate of production of electrical energy in the circuit is 24.0 W. The total rate of consumption of electrical energy in the circuit is 4.00 W + 20.0 W = 24.0 W. Equal rate of production and consumption of electrical energy are required by energy conservation.

25.54. **IDENTIFY:** The power delivered to the bulb is $I^2 R$. Energy = Pt.

SET UP: The circuit is sketched in Figure 25.54. r_{total} is the combined internal resistance of both batteries.

EXECUTE: **(a)** $r_{\text{total}} = 0$. The sum of the potential changes around the circuit is zero, so $1.5\ \text{V} + 1.5\ \text{V} - I(17\ \Omega) = 0$. $I = 0.1765\ \text{A}$. $P = I^2 R = (0.1765\ \text{A})^2 (17\ \Omega) = 0.530\ \text{W}$. This is also $(3.0\ \text{V})(0.1765\ \text{A})$.

(b) Energy = (0.530 W)(5.0 h)(3600 s/h) = 9540 J

(c) $P = \dfrac{0.530\ \text{W}}{2} = 0.265\ \text{W}$. $P = I^2 R$ so $I = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{0.265\ \text{W}}{17\ \Omega}} = 0.125\ \text{A}$.

The sum of the potential changes around the circuit is zero, so $1.5\ \text{V} + 1.5\ \text{V} - IR - Ir_{\text{total}} = 0$.

$$r_{\text{total}} = \frac{3.0\ \text{V} - (0.125\ \text{A})(17\ \Omega)}{0.125\ \text{A}} = 7.0\ \Omega.$$

EVALUATE: When the power to the bulb has decreased to half its initial value, the total internal resistance of the two batteries is nearly half the resistance of the bulb. Compared to a single battery, using two identical batteries in series doubles the emf but also doubles the total internal resistance.

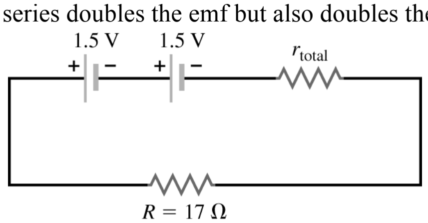

Figure 25.54