SOLUTION (*a*) The circuit with only the weak battery and no jumper cables is simple: an emf of 10.1 V connected to two resistances in series, $0.10\,\Omega + 0.15\,\Omega = 0.25\,\Omega$. Hence the current is $I = V/R = (10.1\text{ V})/(0.25\,\Omega) = 40\text{ A}$.
(*b*) We need to find the resistance of the jumper cables that connect the good battery. From Eq. 18–3, each has resistance $R_J = \rho L/A = (1.68 \times 10^{-8}\,\Omega\cdot\text{m})(3.0\text{ m})/(\pi)(0.25 \times 10^{-2}\text{ m})^2 = 0.0026\,\Omega$. Kirchhoff's loop rule for the full outside loop gives

$$12.5\text{ V} - I_1(2R_J + r_1) - I_3 R_S = 0$$
$$12.5\text{ V} - I_1(0.025\,\Omega) - I_3(0.15\,\Omega) = 0 \qquad (a)$$

since $(2R_J + r) = (0.0052\,\Omega + 0.020\,\Omega) = 0.025\,\Omega$.
The loop rule for the lower loop, including the weak battery and the starter, gives

$$10.1\text{ V} - I_3(0.15\,\Omega) - I_2(0.10\,\Omega) = 0. \qquad (b)$$

The junction rule at point B gives

$$I_1 + I_2 = I_3. \qquad (c)$$

We have three equations in three unknowns. From Eq. (*c*), $I_1 = I_3 - I_2$ and we substitute this into Eq. (*a*):

$$12.5\text{ V} - (I_3 - I_2)(0.025\,\Omega) - I_3(0.15\,\Omega) = 0,$$
$$12.5\text{ V} - I_3(0.175\,\Omega) + I_2(0.025\,\Omega) = 0.$$

Combining this last equation with (*b*) gives $I_3 = 71\text{ A}$, quite a bit better than in (*a*). The other currents are $I_2 = -5\text{ A}$ and $I_1 = 76\text{ A}$. Note that $I_2 = -5\text{ A}$ is in the opposite direction from that assumed in Fig. 19–15. The terminal voltage of the weak 10.1-V battery is thus $V_{BA} = 10.1\text{ V} - (-5\text{ A})(0.10\,\Omega) = 10.6\text{ V}$.

NOTE The circuit shown in Fig. 19–15, without the starter motor, is how a battery can be charged. The stronger battery pushes charge back into the weaker battery.

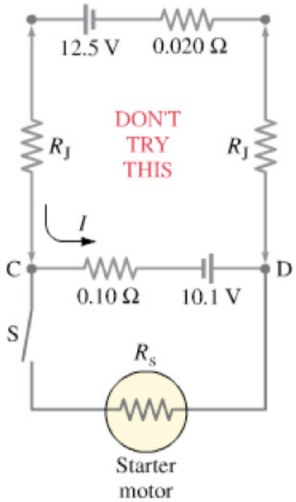
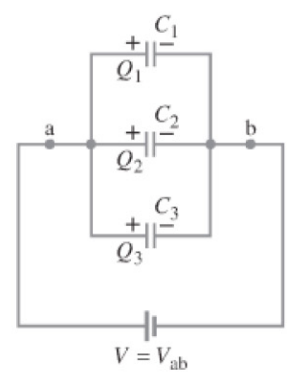


FIGURE 19–16 Exercise D.

EXERCISE D If the jumper cables of Example 19–9 were mistakenly connected in reverse, the positive terminal of each battery would be connected to the negative terminal of the other battery (Fig. 19–16). What would be the current I even before the starter motor is engaged (the switch S in Fig. 19–16 is open)? Why could this cause the batteries to explode?

19–5 Circuits Containing Capacitors in Series and in Parallel

FIGURE 19–17 Capacitors in parallel: $C_{eq} = C_1 + C_2 + C_3$.



Just as resistors can be placed in series or in parallel in a circuit, so can capacitors (Chapter 17). We first consider a **parallel** connection as shown in Fig. 19–17. If a battery supplies a potential difference V to points a and b, this same potential difference $V = V_{ab}$ exists across each of the capacitors. That is, since the left-hand plates of all the capacitors are connected by conductors, they all reach the same potential V_a when connected to the battery; and the right-hand plates each reach potential V_b. Each capacitor plate acquires a charge given by $Q_1 = C_1 V$, $Q_2 = C_2 V$, and $Q_3 = C_3 V$. The total charge Q that must leave the battery is then

$$Q = Q_1 + Q_2 + Q_3 = C_1 V + C_2 V + C_3 V.$$

Let us try to find a single equivalent capacitor that will hold the same charge Q at the same voltage $V = V_{ab}$. It will have a capacitance C_{eq} given by

$$Q = C_{eq} V.$$

Combining the two previous equations, we have

$$C_{eq} V = C_1 V + C_2 V + C_3 V = (C_1 + C_2 + C_3)V$$

or

$$C_{eq} = C_1 + C_2 + C_3. \qquad \text{[parallel]} \quad \textbf{(19–5)}$$

Capacitors in parallel

The net effect of connecting capacitors in parallel is thus to *increase* the capacitance. This makes sense because we are essentially increasing the area of the plates where charge can accumulate (see, for example, Eq. 17–8).