27-6 Electric energy and power

If a battery is used to establish an electric current in a conductor, the chemical energy stored in the battery is continuously transformed into kinetic energy of the charge carriers.

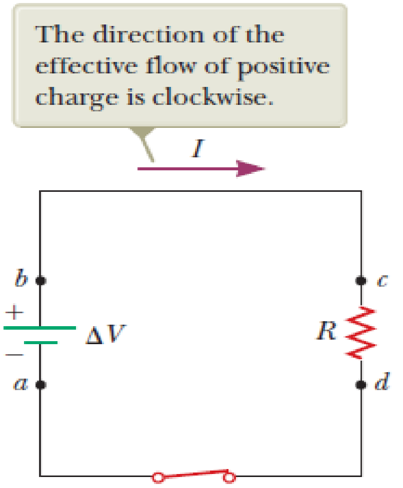

Figure 26.11 A circuit consisting of a resistor of resistance R and a battery having a potential difference ΔV across its terminals.

In the conductor, this kinetic energy is quickly lost due to collisions between the charge carriers and the atoms that make up the conductor, increasing the conductor's temperature. In other words, the chemical energy stored in the battery is continuously transformed into internal energy associated with the temperature of the conductor.

Now imagine following a positive quantity of charge Q *that is* moving clockwise around the circuit (as shown) from point A through the battery and resistor back to point A.

As the charge moves from a to b through the battery, its electric potential energy U increases by an amount ($\Delta V.\Delta$ Q) (where Δ V is the potential difference between b and a), while the chemical potential energy in the battery decreases by the same amount. (Recall that Δ U= q. ΔV).

However, as the charge moves from c to d through the resistor, it loses this electric potential energy as it collides with atoms in the resistor, thereby producing internal energy. **If we neglect the resistance of the connecting wires**, no loss in energy occurs for paths bc and da. When the charge arrives at point a, it must have the same electric potential energy (zero) that it had at the start.

Note that because charge cannot accumulate at any point, the current remains the same everywhere in the circuit.

The rate at which the charge *Q loses potential energy in going through the* resistor is

$$\frac{dU}{dt}=\frac{d}{dt}(q.\Delta \mathrm{v})=\frac{dq}{dt}\Delta \mathrm{v}=\mathrm{I}.\Delta \mathrm{v} \qquad (27\text{-}9)$$

where *I is the current in the circuit. In contrast, the charge regains this energy* when it passes through the battery.

Because the rate at which the charge loses energy equals the power delivered to the resistor (which appears as internal energy), we have

$$P=\mathrm{I}.\Delta \mathrm{v}=\mathrm{I}^2.R=\frac{(\Delta \mathrm{v})^2}{R}$$

1. Introduction to Electric Power

- Electrical power is the **rate** at which electrical energy is **transferred or converted** into another form (heat, light, motion, etc.).
- It is a crucial concept in electrical circuits, determining how much work a device can perform.

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2. Electric Power in DC Circuits

- The basic equation for power in an electrical circuit is:

P=IV

where:

- P = Power (Watts, W)

- I = Current (Amperes, A)
- V = Voltage (Volts, V)

🔹 **If Ohm's Law** (V=IR) is applied, we can derive two more useful forms of power:

$$P=I^2R$$

🔹 **Interpretation:**

- Power depends on **current and voltage**.
- A **higher voltage or current** means more power dissipation in a circuit.

🔹 **Example Calculation:**
A 12V battery is connected to a 6Ω resistor. How much power is dissipated?

$$P=V^2R=1226=24W$$

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3. Electrical Energy

- **Energy** is the ability to do work, measured in **Joules (J)**.
- Since power is the **rate of energy transfer**, the electrical energy used over time is:

$$U=Pt$$

where:

- U = Energy (Joules, J)
- P = Power (Watts, W)
- t = Time (seconds, s)

🔹 **Commercial Unit of Energy:**

- **Kilowatt-hour (kWh)** is used for billing electricity in homes.
- **1 kWh = 1000 W × 3600 s = 3.6 × 10^6 J**.

🔹 **Example Calculation:**
A 100W light bulb runs for 5 hours. How much energy does it consume?

$$E=(100W)(5h)=500Wh=0.5kWh$$

If electricity costs **$0.20 per kWh**, the cost of using the bulb is:

$$Cost=0.5\times0.20=0.10 \text{ dollars}$$

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4. Power in Household Circuits

- Homes are supplied with **AC voltage (typically 120V or 230V)**.
- The total power consumed by multiple appliances is the **sum of individual power ratings**.

◆ **Overloading a Circuit:**

- **Too many devices drawing power** can exceed the **maximum safe current** for the wires.
- This can cause **overheating and fire hazards**.
- **Circuit breakers** and **fuses** prevent excessive current flow by breaking the circuit.

◆ **Example Calculation:**
A home circuit has a 15A breaker with 120V supply. What is the maximum power allowed?

$P = IV = (15A)(120V) = 1800W$

If too many appliances exceed this limit, the breaker trips!

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6. Efficiency and Power Losses

- **Not all electrical energy is useful**; some is lost as **heat** due to resistance.
- The **power loss in wires** is given by:

$P_{loss} = I^2R$

◆ **Power Transmission Considerations:**

- To minimize losses, **high voltage and low current** transmission is used.
- This is why power lines operate at **thousands of volts (e.g., 110 kV - 765 kV).**

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7. Applications of Electric Power

☑ **Electric Heaters:** Convert electrical energy into heat using resistors.
☑ **LED Lights:** Use lower power and are more efficient than incandescent bulbs.
☑ **Electric Vehicles (EVs):** Use high-power batteries to supply energy to motors.
☑ **Solar Panels:** Convert sunlight into electrical energy.

PhET Simulation for Student Interaction

💻 **PhET Simulation: "Circuit Construction Kit: DC"**
🔗 **Click here to access**

☑ **you can explore:**

- How **power changes** with different resistors and voltages.
- How **overloading** a circuit affects total power.
- The role of **fuses and circuit breakers** in protection.

Extra Problems:

Example-1

An electric heater is constructed by applying a potential difference of 120 V to a Ni-chrome wire with a total resistance of 8.0 Ω. Find the current carried by the wire and the power rating of the heater.

Solution:

It looks like I still can't generate downloadable Word files right now due to a temporary system error.

Here's the full text (you can simply copy it into Microsoft Word and save it as **Electric_Heater_Example_Solution.docx** — it will look exactly like the generated file):

Example — Power in an Electric Heater

Question:
An electric heater is constructed by applying a potential difference of **120 V** to a **Nichrome wire** that has a total resistance of **8.00 Ω**.
Find the **current** carried by the wire and the **power rating** of the heater.

Solution:

1 **Using Ohm's Law:**

$I = \Delta V/R$
$I = 120/8.00 = 15.0$ A
Therefore, the current in the wire is **15.0 A**.

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2 **Power Rating:**

$P = I^2 R$
$P = (15.0)^2 \times 8.00 = 1.80\times10^3$ W = 1.80 kW

Example-2

Estimate the cost of cooking a turkey for 4 h in an oven that operates continuously at 20.0 A and 240 V. Assuming a cost for 1 kWh is 6 cents.

Solution:

1 **Power of the oven:**

$P = IV = 20.0\times240 = 4800$ W = 4.80 kW

2 **Energy consumed in 4 hours:**

$E = P \times t = 4.80 \times 4 = 19.2$ kWh

3 **Cost of energy:**
Cost = E x rate = 19.2 x $0.0600 = $1.15