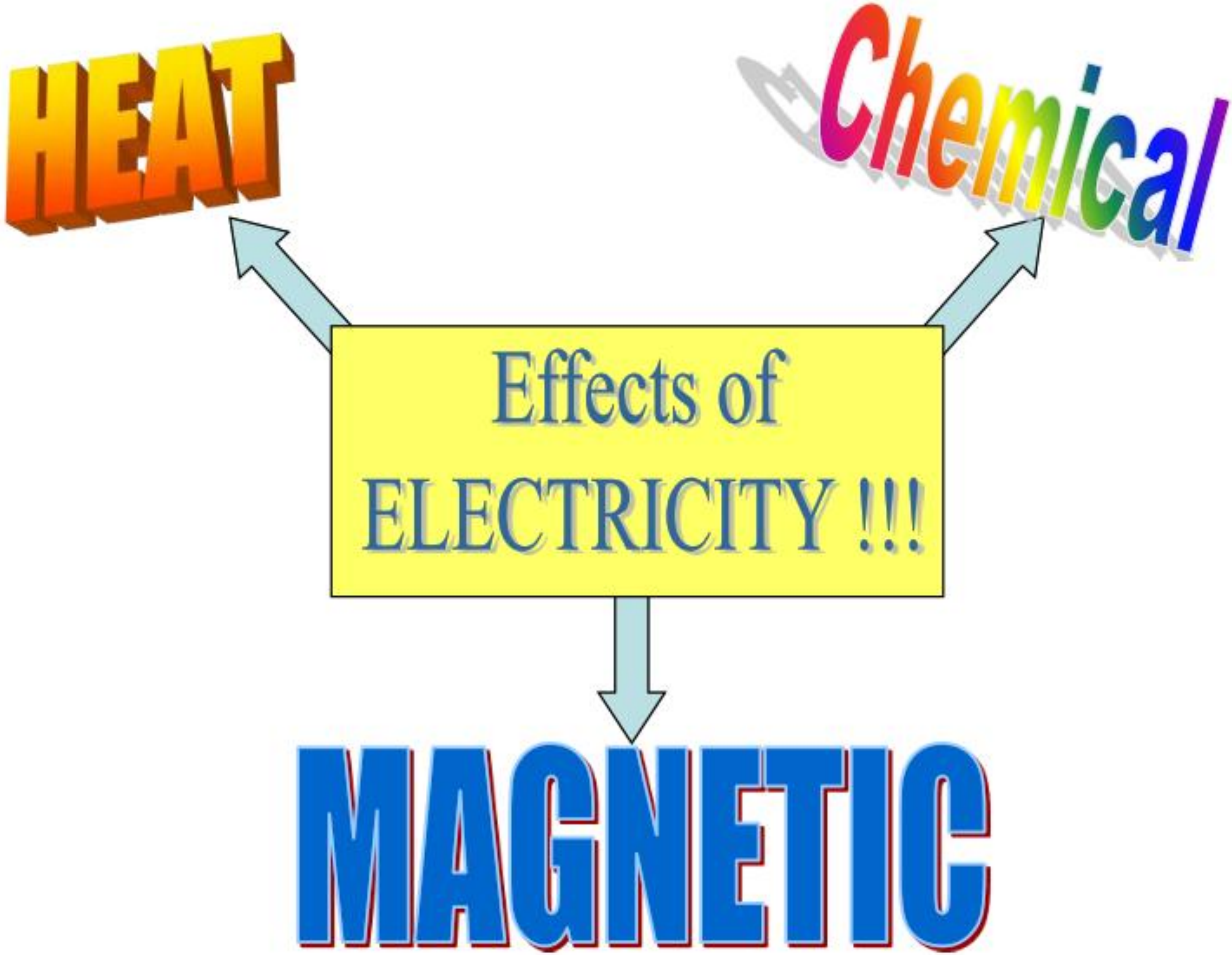
The energy and power in direct current (dc) circuits

OBJECTIVES

- Guide students to conduct activities to demonstrate that energy dissipates when a current flows through an electrical apparatus.
- State the expression $W=VQ$ for energy dissipation when a charge Q flows through any electrical load when potential difference "V" is applied.
- Guide students to obtain the expression $W=VIt$ for the energy dissipation in any electrical load when current "I" flows across a potential difference "V" in time "t".
- State that the energy dissipated per second (power) in a device is defined as its power and give the expression $P=VI$.

- Explain that $P=VI$ and $W=VIt$ can be used for any electrical load.
- Guide students to obtain $P=I^2R$, $P=V^2/R$, $W=I^2Rt$, and $W=V^2t/R$ expressions for a resistive load using $V=IR$.
- Explain that energy dissipates as heat only in passive resistors (Joule heating).
- Introduce kWh unit as the practical unit for measuring electrical energy.
- Obtain the relationship between kWh and J.


HEAT
Chemical
Effects of
ELECTRICITY !!!
MAGNETIC

- When a circuit is equipped with a light bulb, beeper, or motor, the electrical energy supplied to the charge by the battery is transformed into other forms in the electrical device. A light bulb, beeper and motor are generally referred to as a **load**. In a light bulb, electrical energy is transformed into useful light energy (and some non-useful thermal energy). In a beeper, electrical energy is transformed into sound energy. And in a motor, electrical energy is transformed into mechanical energy.

- Electric energy is useful because it can be easily transformed to other forms of energy
- Electric heaters, stoves,, toasters, hair dryers – Elec Energy to thermal energy
- Lightbulb – Elec Energy heats wire filament which becomes so hot it glows. Only few % of the energy transformed into light, rest to thermal
- Lightbulb filaments and heating elements in household apploiances have resistances typically of a few ohms to few hundred ohms.

- Movement of a charge across a electric device:
  - It moves from higher potential to lower potential.
    - Hence, there is a decrease in potential energy.

- If there is a decrease in potential energy, there must be a transmission to another form of energy.
  - Light bulb: to heat and light.
  - Electric motor: to mechanical energy
  - Resistor: Internal energy/heat.

HEATING EFFECT OF ELECTRIC CURRENT

- WHEN AN ELECTRIC CURRENT FLOWS THROUGH A WIRE, THE **WIRE HEATS UP**. ELECTRICAL ENERGY HAS BEEN CONVERTED INTO **HEAT ENERGY**.

- THE **GREATER THE RESISTANCE** OF THE WIRE, THE **GREATER THE AMOUNT OF HEAT** PRODUC[illegible]. THIS [illegible] EFFECT IS USE[illegible] CO[illegible] ELEC[illegible]IANCES.

Iron

Kettle

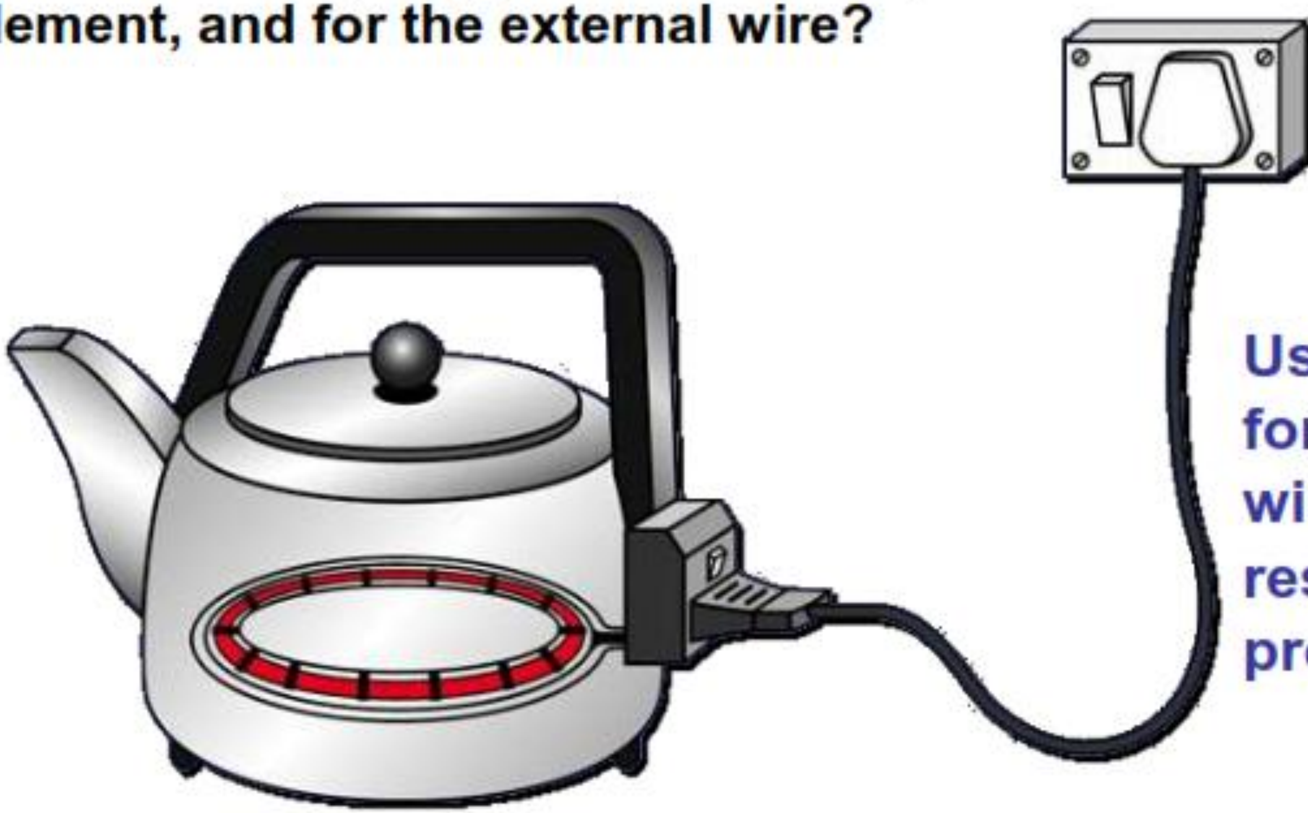
Hair Dryer

Heating effect of electric current

- When electricity passes through a high resistance wire like a nichrome wire, the resistance wire becomes very hot and produces heat. This is called the heating effect of current.

A kettle uses both copper and nichrome wires.
Copper has low resistance while nichrome has high resistance.

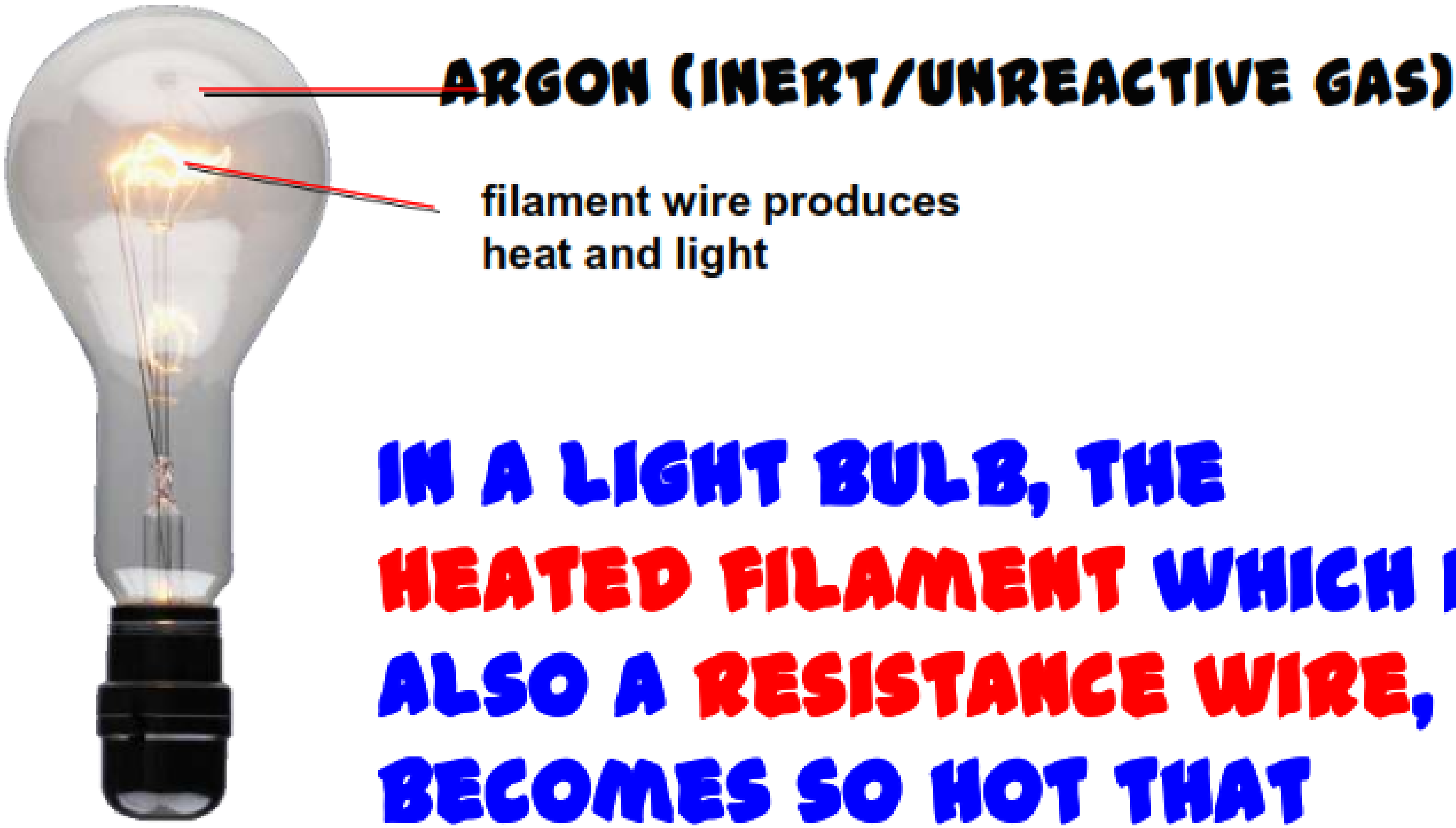
Which material, copper or nichrome, should be used for the heating element, and for the external wire?



Use copper wire for the external wire as it has low resistance & produces less heat

Use nichrome wire for the heating element as it has high resistance& produces a lot of heat

HEATING EFFECT OF ELECTRIC CURRENT



IN A LIGHT BULB, THE HEATED FILAMENT WHICH IS ALSO A RESISTANCE WIRE, BECOMES SO HOT THAT LIGHT IS ALSO EMITTED.

Electric power

- Power is the rate of use of energy : $Power = \frac{Energy}{Time}$
- How much power does an electric circuit consume?
- Moving charge Q across a potential difference V requires work : $W = Q\ V$ (from last chapter)
- Power = $\frac{Work}{Time} = \frac{Q\ V}{t}$ = I V (in terms of current I = Q/t)
- Using Ohm's law V = I R : Power = V I = I^2R = V^2/R

- The rate at which electric potential energy is transformed to another form of energy is the *POWER* in the circuit.

$$P = IR$$

$$P = I^2 R$$

$$P = \frac{V^2}{R}$$

Electric power

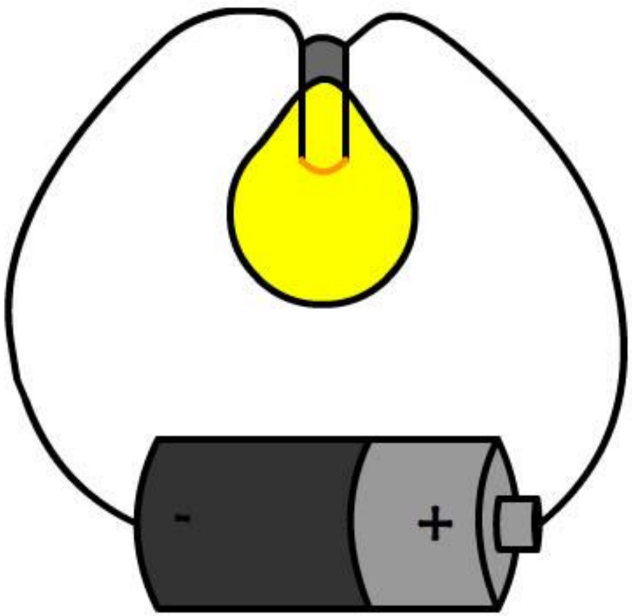
- This power is dissipated as heat energy in the resistance – why electrical components get hot!

Electric power

- Power is measured in Watts (1 W = 1 J/s)
- Your "power bill" is probably measured in "kWh" or "kilo-Watt hours"
- This is really an "energy bill" …
- 1 kWh = 1000 J/s x 3600 s = 3.6 x 10^6 J = 3.6 MJ

Energy Transfer and Power

When a **LOAD** is put on the circuit (light bulb, beeper, motor…), electrical energy is transformed to other, useful forms of energy.



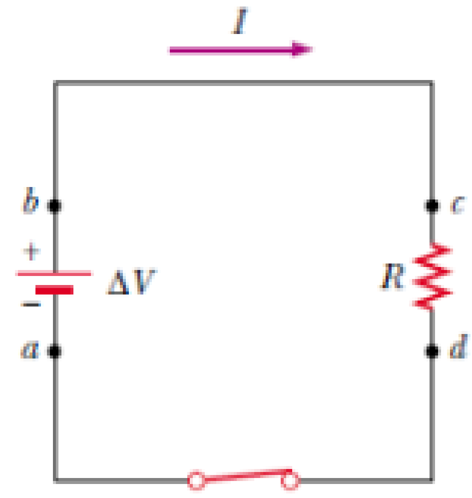
An electrical circuit is simply an energy transformation tool.

Rate of energy transformation/transfer is **POWER**

ENERGY TRANSFER IN AN ELECTRIC CIRCUIT AND POWER DISSIPATION

Let a battery is connected between the terminals '*a*' and '*b*' of an electric circuit as shown in the figure.

Let '*V*' is the potential difference applied by the battery between the points '*a*' and '*b*'. As the result the current '*I*' flow through the circuit. During this process, energy is transfer from battery to the electrical circuit. Let a small amount of charge '*dq*' during the small interval of time '*dt*'.



is discharged

Using the meaning of potential difference, the work done ΔW in moving ΔQ up through the potential difference V is:

$$\Delta W = V \times \Delta Q$$

This work done will be appear the energy supplied by the battery. The rate at which the battery is supplying electrical energy is called the electrical power of the battery.

$$Electrical\ Power = \frac{Energy\ Supplied}{Time\ Taken} = V\ \frac{\Delta Q}{\Delta t}$$

Since $I = \frac{\Delta Q}{\Delta t}$

$$Electrical\ Power = VI$$

By the principal of conservation of energy, the electrical power of the battery is dissipated in the resistor R. Therefore,

$$Power\ Dissipated\ (P) = VI$$

From Ohm's law, substituting $V = IR$ and $I = \frac{V}{R}$

$$Power\ Dissipated\ (P) = VI = IR * I = I^2R$$

$$Power\ Dissipated\ (P) = VI = V * \frac{V}{R} = \frac{V^2}{R}$$

JOULE HEATING

The electrical energy consumed in a resistor appears in the form of heat, which is also called 'Joule Heating'. The heat energy produced in t interval of time is given by

Heat Energy = (Power)(Time)

$$= (VI)(t)$$

$$= VIt = I^2R\,t = \frac{V^2}{R}t$$

Sample problem 6. You are given length of heating wire made of nickel-chromium-iron Alloy called Nichrome. It has a resistance of 72Ω. Under what circumstances, the wire will dissipates more power. (a) It is to be connected across a 120 V line. (b) The wire is cut in half pieces and two halves are connected in parallel across the line?

Solution: (a) Power dissipation in the wire:

$$R = 72\Omega$$

$$P = \frac{V^2}{R} = \frac{(120)^2}{72} = 200 \text{ Watt}$$

(b) The power dissipation when the wire is cut in half pieces and two halves are connected in parallel across the line:

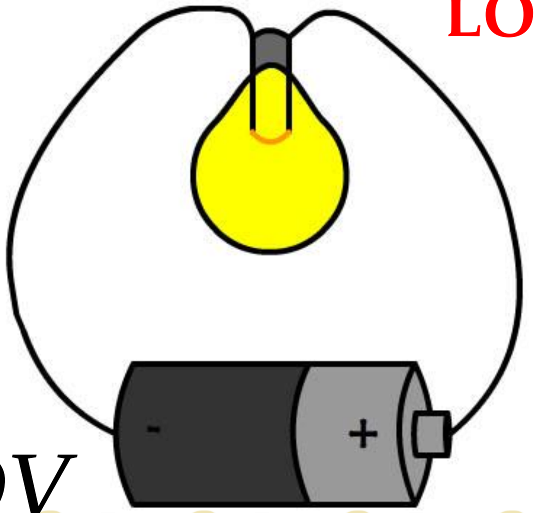
$$R' = 36\Omega$$

$$P' = \frac{V^2}{R'} = \frac{(120)^2}{36} = 400 \text{ Watt}$$

The power dissipation in second case in more than 1st case

Energy Transfer and Power

POWER, P, is the rate that energy is supplied to the load or the ***rate of work done on the charge***.



$$P = \frac{Energy\ transformed}{time} = \frac{W}{t} = \frac{QV}{t}$$

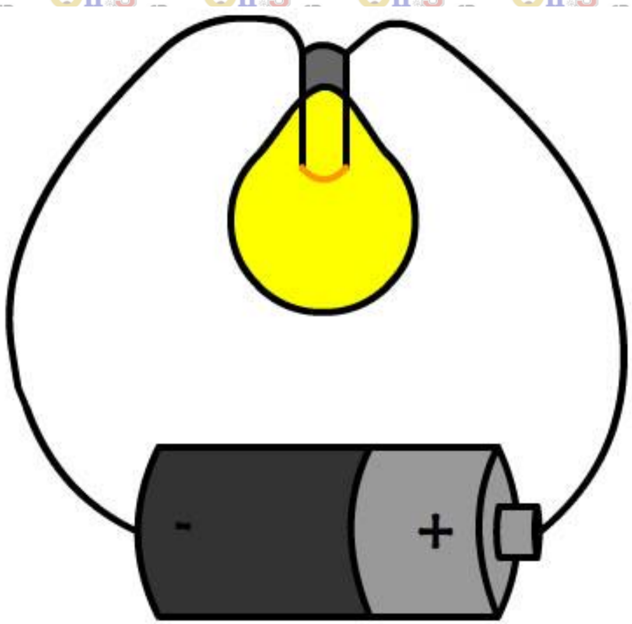
Unit of Power: Watt (W)

1 W = 1 J/s

$$P = IV = I^2R = V^2/R$$

Energy transfer and Power

POWER, P, is the rate that energy is supplied to the load or the ***rate of work done on the charge***.



60 Watt light bulb means 60 J of energy delivered to bulb every second

OR

60 J of energy used by the bulb per second

Electric power

Exercise: What is the resistance of a 60 W 240V light bulb?

Power P = 60 W
Voltage V = 240 V

$$P = I\,V \rightarrow I = \frac{P}{V} = \frac{60}{240} = 0.25\ A$$

$$V = I\,R \rightarrow R = \frac{V}{I} = \frac{240}{0.25} = 960\ \Omega$$

Exercise: What would be the power output if the bulb was plugged into the US mains of 110 V?

$$P = I\,V = \frac{V^2}{R} = \frac{110^2}{960} = 12\ W$$

Electric heater. An electric heater draws 15.0 A on a 120 V line. How much power does it use and how much does it cost per month (30 days) if it operates 3.0 h per day and the electric company charges 10.5 cents per kW-h?

To operate it for 30 days, 3 hr/day would total 90hrs

Electric power

- Why do power lines operate at 100,000 V?

- $P = V I$: high power can be delivered using high V or high I
- Some power will be lost in heating the transmission wires
- $P = I^2R$: low current minimizes these transmission losses

Applications of heating effect of electric current

There are many practical uses of heating effect of current. Some of the most common are as follows.

- An incandescent light bulb glows when the filament is heated by heating effect of current, so hot that it glows white with thermal radiation (also called blackbody radiation).
- Electric stoves and other electric heaters usually work by heating effect of current.
- Soldering irons and cartridge heaters are very often heated by heating effect of current.
- Electric fuses rely on the fact that if enough current flows, enough heat will be generated to melt the fuse wire.
- Electronic cigarettes usually work by heating effect of current, vaporizing propylene glycol and vegetable glycerin.
- Thermistors and resistance thermometers are resistors whose resistance changes when the temperature changes. These are sometimes used in conjunction with heating effect of current(also called self-heating in this context): If a large current is running through the nonlinear resistor, the resistor's temperature rises and therefore its resistance changes. Therefore, these components can be used in a circuit-protection role similar to fuses, or for feedback in circuits, or for many other purposes. In general, self-heating can turn a resistor into a nonlinear and hysteretic circuit element.

The Human Body

The human body acts as a variable resistor.

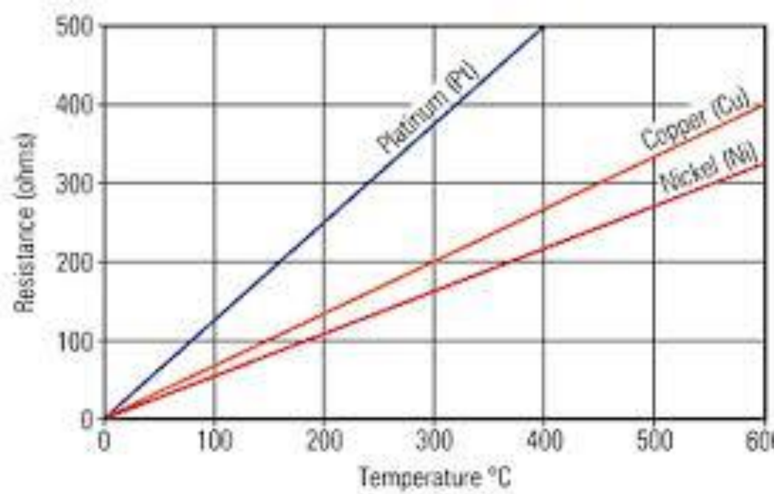
When dry, skin's resistance is high enough to keep currents that are produced by small and moderate voltages low.

If skin becomes wet, however, its resistance is lower, and the electric current can rise to dangerous levels.

A current as low as 1 mA can be felt as a mild shock, while currents of 15 mA can cause loss of muscle control, and currents of 100 mA can cause death.

Thermal runaway and fuses

For most conductors, resistance is not completely constant, but increases with increasing temperature.



If part of a circuit starts to overheat, its resistance can increase, causing larger power dissipation, causing higher resistance etc.

A **fuse** protects a circuit from general damage by acting as the "weak point"; a thin wire that will physically fail (melt) if current exceeds a safe level.

"Circuit breakers" or "safety switches" either mechanical or electronic, are now able to offer faster and more reliable protection.