IV. Uses of EM properties

Prepared by Belgian BioElectroMagnetics Group (BBEMG)

Note:
All the information on this page is available as Flash animation at the following address: http://www.bbemg.be/en/main-emf/electricity-fields/uses-of-em-properties.html

Introduction

In this module, we will endeavour to understand how common domestic electrical appliances work: specifically, heating appliances, different types of light bulbs, motors, computers, laser printers, and wireless power transmission to recharge an electric toothbrush.

Based on the various examples, we should gain an overall understanding of the operating principle behind those machines that convert electrical energy into thermal or mechanical energy or otherwise make use of electrostatic and electromagnetic properties.

Heating appliances

Let's recall that the incandescent lightbulb operating principle is in part based on the joule effect. In that case, the thermal energy released is a by-product of the primary function, which is to shed light!

In heating elements that can be found in electric stoves and ovens, toasters, hair dryers, and electric blankets, the primary objective this time is the conversion of electrical energy into thermal energy.

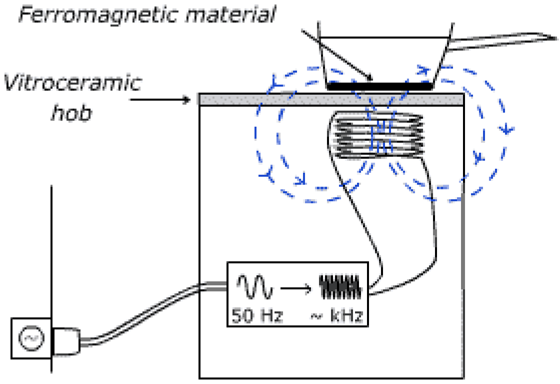
To reach that objective, the heating element (the resistor) is often made of nichrome: an alloy of chrome and nickel. It has a high resistivity (nearly 60 times that of copper), while withstanding high temperatures without oxidising and losing its properties.

The electrical power required by a toaster is in the 500 W range; that of stove top plate is around 2000 W. These appliances connect to the 230 V electric power network, they therefore draw currents of 2.2 and 8.7 A respectively.

The operating principle of the stove top plates above shouldn't be confused with that of induction stove tops which are heated by induced currents in the pots and pans themselves.

Induction stove top operation

Stove top induction plates are characterised by the fact that they heat only ferromagnetic materials (cast iron or steel) usually found at the bottom of purpose made pots and pans.



The principle of operation involves two methods:

- **Induction by itself:** a coil connected to a high frequency alternating current source is placed under the plate. The current variation in the coil generates in its vicinity a variable magnetic field, which in turns induces a current in the ferromagnetic material.
- **Joule effect:** as we saw earlier, when a current travels through a resistor, it will heat the resistor. It resists the current. The current generated in the ferromagnetic material will lead to heating of the material by Joule effect. Induction stove top plates heat the bottom of the pan directly. Unlike the standard stove heating plates, the induction plate itself remains relatively cold.
  For more information on the subject, you may refer to the FAQ on BBEMG website.

Light bulbs

Incandescent light bulbs work by using the joule effect, so do halogen lamps. It is quite different for fluorescent tubes, compact fluorescent lamps (also known as high efficiency light bulbs) and LEDs. Let's take them one at a time.

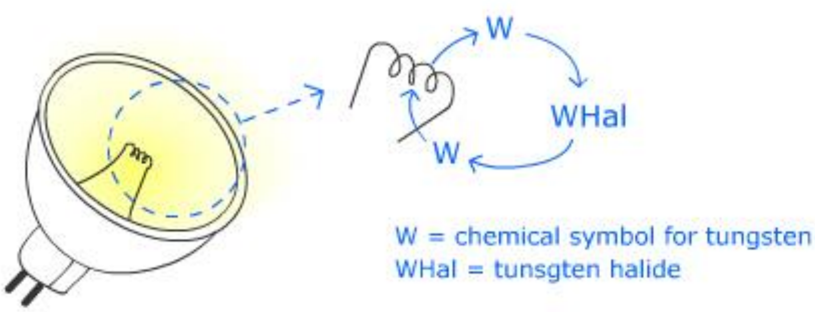
1. Halogen lamp operation

Halogen lamps are incandescent light bulbs: the light is produced by a heated tungsten filament. What makes them different than ordinary light bulbs is that they are filled with halogen gas rather than a noble (inert) gas or a vacuum. The halogen gas allows the filament to work at higher temperature and in addition, to last longer.

In a standard incandescent light bulb, the filament deteriorates at high temperature: it loses atoms of tungsten.

In a halogen bulb, tungsten atoms combine with the halogen gas (iodine or bromine) in the bulb to form tungsten halides. These compounds prevent deposits of tungsten on the glass (which is what happens in standard bulbs).

Furthermore, the tungsten halide circulates by convection within the bulb: when in proximity of the hot filament, the tungsten separates from the halide and returns atoms to filament, thus delaying its deterioration.



Thanks to this clever process, the filament can function at higher temperature (really higher, watch for burns!) while its useful life is increased.

At higher temperature, the emitted light approximates the feel of sun light, thus giving a more natural glow than standard light bulbs.

Halogen lamps are available in different models:

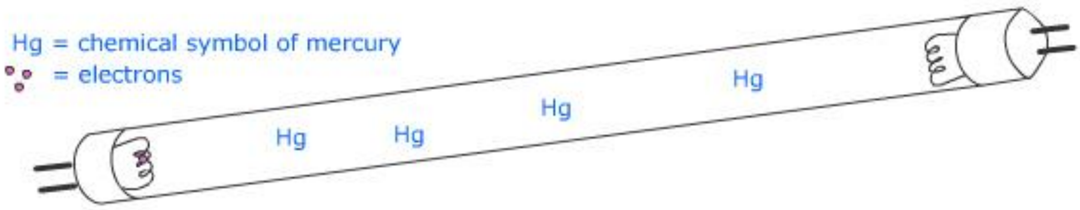
- 230 V operation or lower voltages (such as 12 V, after going through a step-up transformer);
- Different shapes available such as the spotlight above, or so-called linear double ended lamp.

2. Fluorescent tube operation

In a fluorescent tube, light is produced in two steps: 1) the electric current excites the atoms of the gas contained in the tube, and the excited gas generates a mostly ultraviolet radiation, and 2) this UV radiation is absorbed by the fluorescent coating on the inside of the tube and is transformed into visible light.
The picture to the left is a “compact fluorescent lamp”: it’s simply a fluorescent tube folded on itself.

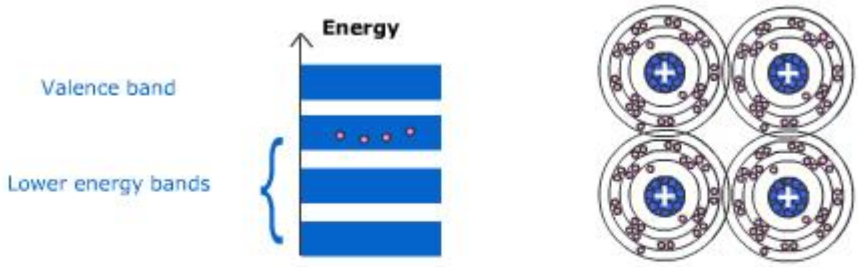
Two steps:

a. Excitation of the gas atoms in the tube and generation of UV radiation

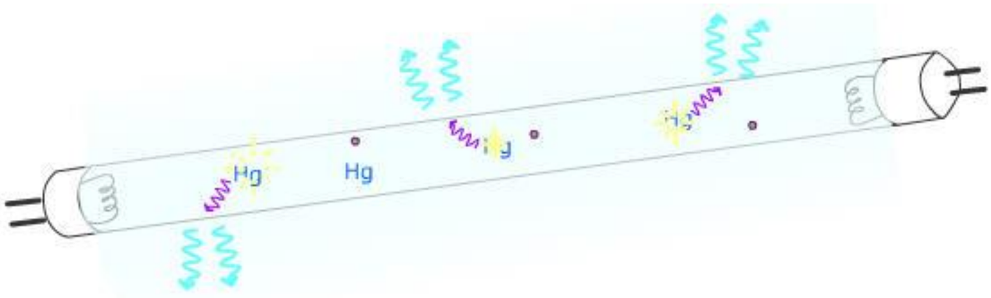


Fluorescent tubes contain a mixture of argon and mercury vapour.

When the switch is flipped on, the potential difference between both ends of the tube creates the force that propels the electrons from one end to the other. On their way, the electrons run into mercury atoms. The collision supplies energy to the mercury atoms which in turn retransmit that energy in the form of mostly ultraviolet (invisible) radiation.



b. Absorption of the UV radiation by the fluorescent coating on the inside wall of the tube and emission of visible light.



The UV radiation emitted by the mercury atoms electrons falling back in lower energy bands are absorbed by the fluorescent coating on the inside wall of the tube. The fluorescent material's electrons are in turn also excited: they jump from their unexcited state to a higher energy level (see Electrical concepts). When they return to their normal state, the released energy takes the form of visible light... we are enlightened!

The colour of the light is determined by the fluorescent material. Here, the light is white with a tinge of blue.

Note: Fluorescent tubes are often erroneously called “neon tubes”. Actually, neon tubes contain neon gas and produce a red colour.

3. LED operating principle

A LED (Light Emitting Diode), as the name implies, is a particular type of diode which emits light when traversed by an electric current. The spotlights at left comprise several LEDs. There is no filament in these lamps: LEDs make use of semiconductor material properties (see Electrical concepts). It is a fast developing lighting technology which might, relatively soon, displace all other lighting methods.

LED lamps are made of semiconductor material doped with impurities to create a p-n junction. When a current flows through the material, electrons (n) meet with holes (p), fall into a lower energy level and emit light.

The semiconductor material converts electrical energy into a monochromatic radiation. A monochromatic blue or UV radiation can then be absorbed by a phosphorescent material on the LED surface (very much like a fluorescent tube), and re-emitted as a broader spectrum radiation approximating white light.

Like all solid state devices, LEDs are particularly robust and last seemingly forever. At this stage of development, their main disadvantage is that the white light is “colder” than that of standard light bulbs or halogen lamps.

Note:

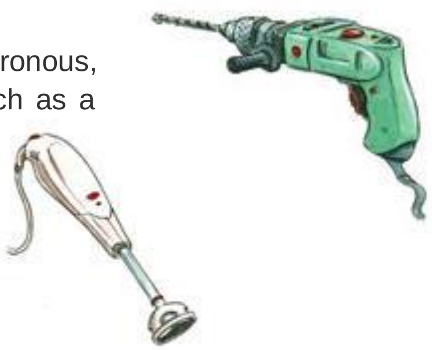
The electrical power rating (in watts, W) of various lamps is not directly related to the light output: their luminous efficacy (in lumen/watt, lm/W) needs to be taken into account.

You will find more information in appendix.

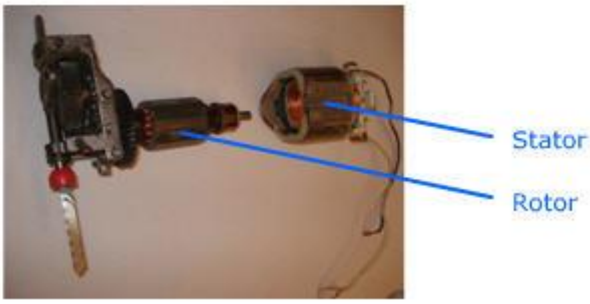
Motor driven appliances

In motor driven appliances, the electrical energy is mostly converted into mechanical energy. How does electricity actually makes the motor turn?

There are different types of motors: universal, synchronous, asynchronous, brushless... In small portable power tools and domestic appliances such as a drill, a jig saw, or a blender, the motor is almost always a universal motor. This is the type that we will talk about here.



Let’s look at a jig saw motor:



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The power rating (in W) of a motor driven device gives a first indication of its actual capabilities. The jig saw shown above has a power rating of 500 W (see appendix for further information).

In the case of a drill, for example, another value must be considered: its torque, or the force that rotates the drill bit. Some devices feature an adjustable torque which allows the power to match the work to accomplish.

Computer

We are surrounded by all sorts of equipment connected to the alternating 230 V 50 Hz (in Europe) power mains but which actually work with direct current (often less than 12 V). This includes computers, television sets, and generally anything that contains electronic circuitry. They all have one thing in common: a “power supply” at their power input which transforms alternating current into direct current.

There are different techniques to convert AC to DC: without getting into too much detail, two of the most common are the diode bridge rectifier (not used in IT hardware because of its low efficiency) and switching power supplies (used in computers because of their high efficiency).

The electric energy consumption of a computer is the sum of its components consumption (CPU, graphics card, hard disk and other drives, Ethernet card, audio card, etc.) and that of peripheral equipment (monitor, modem, printer, speakers, webcam, etc.).

The consumption of the various components depends on the computer usage and the time spent on “light use” (word processing, listening to music, web surfing, etc.), “heavy use” (3D games or multimedia applications) and on “standby”.

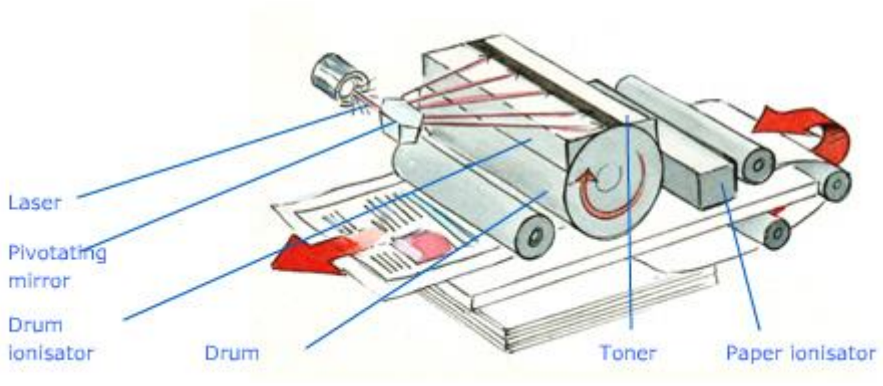
For a computer, not including peripherals, the consumption is around 200 – 250 W. When in standby, even extended standby, the computer is still using a few watts!

As to the screens, LCDs (flat screens) are far less hungry than CRTs (cathode ray tubes). Consumption, size, resolution, brightness are characteristics that vary greatly from one type of monitor to another; interested readers should consult the screens datasheets before selecting one over the other.

Laser printer

A laser printer reproduces the image transmitted by the computer in the form of dots. These dots are smaller than those of an inkjet printer; hence a higher definition and an improved printed object or text.

The high precision of the process is made possible by the use of static electricity properties. The printing process takes place in 6 steps:



(See more in http://www.bbemg.be/en/main-emf/electricity-fields/uses-of-em-properties.html)

Step 1: A corona wire or a primary charge roller charges the drum positively. The drum is a metallic cylinder coated with a semiconductor layer. At this point, the semiconductor is insulating, the positive charges stay put.

Step 2: A laser beam transcribes the data to be printed, in the form of dots, on the drum. The areas of the semiconductor coating that receive the beam of light start conducting at this point and they become negatively charged. The beam is directed to the points forming the printed image dots by a rotating scanning mirror.

Step 3: The toner (a mixture of plastic particles and powdered ink), which is positively charged is attracted to the areas of negative charge on the drum, the dots earlier lit by the laser.

Step 4: A charging roller gives the paper a negative charge. The paper then passes under the drum, and the positively charged toner is transferred to the paper.

Step 5: A heating wire fuses (melts) the toner onto the paper.

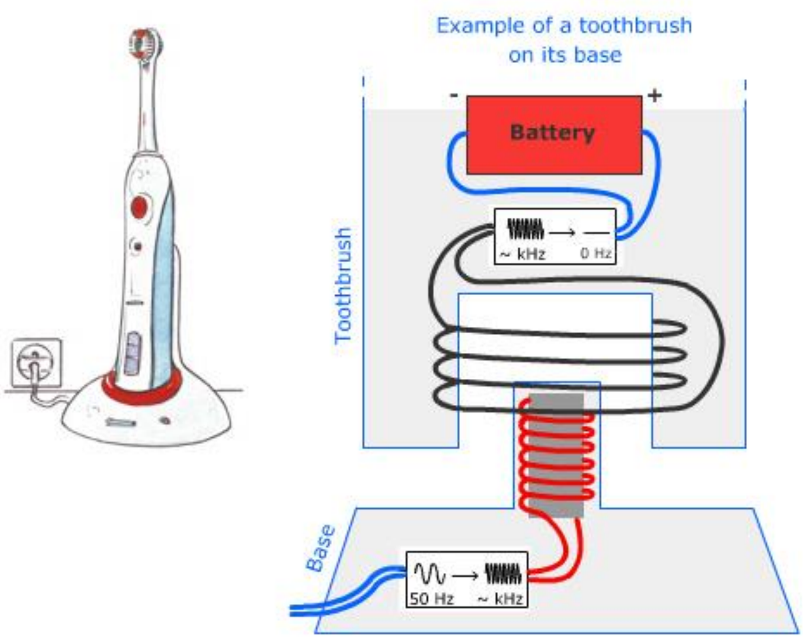
Step 6: The drum is discharged, toner residues are cleaned up, and the printer is ready for the next round... I mean the next cycle!

The energy consumption of printers vary greatly from model to model: it is in a range going from 250 W to 1500 W! In standby mode, the consumption remains around 50 W.

Wireless power transmission

We'll end our tour of electrical appliances with wireless power transmission, in order to recharge a battery in this case:

Let's use the electric toothbrush as an example: you set it on its base and it recharges its battery while there is no electrical connection at all, which means no contact between conductors. Magic? Not quite. It can be understood as an induced current by a magnetic field. Look at the figure below:



(See the Flash animation in http://www.bbemg.be/en/main-emf/electricity-fields/uses-of-em-properties.html)

About 2 W of power is thus supplied to recharge the Ni-MH type battery.

Note:

This technology may be convenient but it is terribly inefficient. This is why it has not found applications beyond very low power gadgets.

Quiz

To access the Quiz, click on the link: http://www.bbemg.be/en/main-emf/electricity-fields/uses-of-em-properties.html)

Appendices

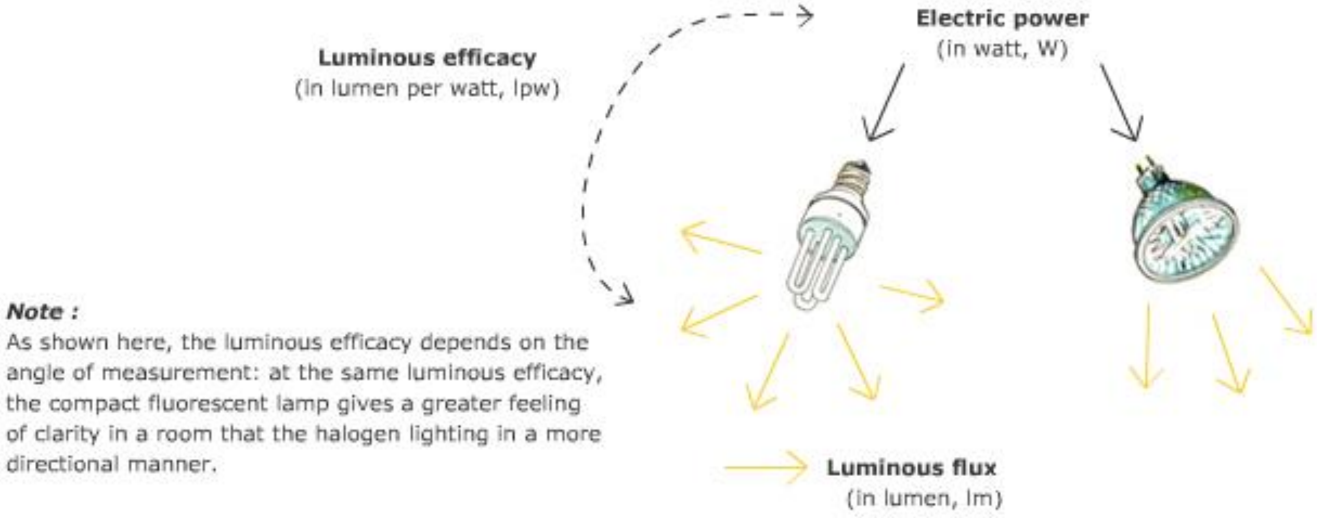
1. Meaning of luminous efficacy

If you've already bought compact fluorescent lamps (so-called high efficiency light bulbs) or LED lamps, you have already faced the inconsistencies in ratings and units listed on the package.

For incandescent light bulbs, we were accustomed to their wattage; we know the difference between 25, 60 and 100 W. This base of reference is useless when it comes to compact fluorescent or LED lamps. Manufacturers typically list 25 or 15 W maximum respectively, which is an indication of energy consumption but says nothing about the amount of light to expect.

The power varies widely with the type of light bulb. This is why a better measure of light output should be considered; the most useful would be the "luminous efficacy" which is expressed in lumen/watt (lm/w).

Let's attempt to clarify what various units characterising lighting are:



There are many other units used to quantify lighting (*). Another difference between types of light bulbs is what is referred to as the "colour" of the light, which is expressed in Kelvin, K because the colour depends of the temperature of the source:

- Hot white (yellow-orange) : < 3500 K
- Cool white (intermediate colour) : > 3500 and < 5000 K
- Cold white (bluish) : > 5000 K

(*) The **candela** (cd) is the unit of luminous intensity:
1 cd = luminous intensity in a given direction, of monochromatic radiation source at a 540 10^{12} Hz frequency (or a wavelength of 555 nm) which means a green light whose power is 1/683 watt per steradian (conical shape).

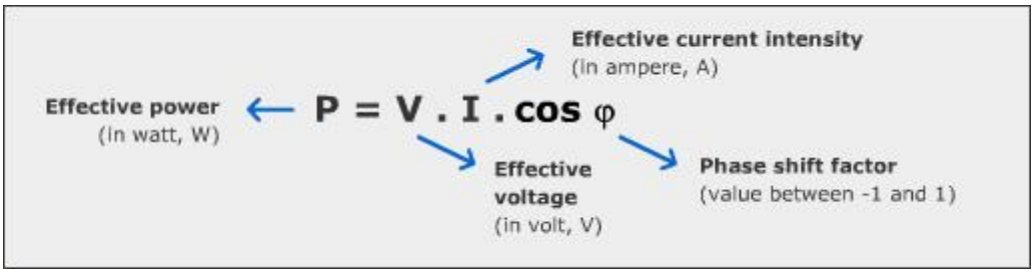
The **candela per square metre** (cd/m²) is the unit of luminance:
1 cd/m² = luminance of a source 1 m² in area which has a luminous intensity of 1 cd.

The **lumen** (lm) is the unit of luminous flux:
1 lm = flux emitted by a source which has a luminous intensity of 1 cd, within a solid angle of 1 steradian.
The luminous flux is a quantity which is adjusted to take into account the sensitivity of the eyes to different colours; for an identical luminous intensity, our eyes perceive green light better than other colours.

The **lux** (lx) is the unit of illuminance (do not confuse with luminance):
1 lx = 1 lumen/m².
It is the amount of light received by a surface 1 m² in area. It is measured with a lux meter.

2. Power of an electric motor

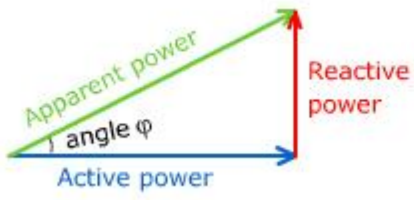
In Electrical concepts, we saw that the phase angle between current and voltage entered into the calculation of the power of an alternating current motor. The equation is:



The phase shift factor, more commonly called the "power factor" is related to magnetic phenomena in motor windings.

The real power of a motor (in W) is actually its "active" power, or the power which it uses to do its mechanical work. However, when you measure both effective voltage and effective current and multiply one by the other, you obtain a higher value: it's the "apparent" power (expressed in V.A). The difference between apparent and active power is called "reactive" power.

Here is a graphical representation of the relationship between the 3 powers:



Utility companies as well as users always strive to minimise reactive power in order to reduce the required current for the same amount of work.