ENERGY

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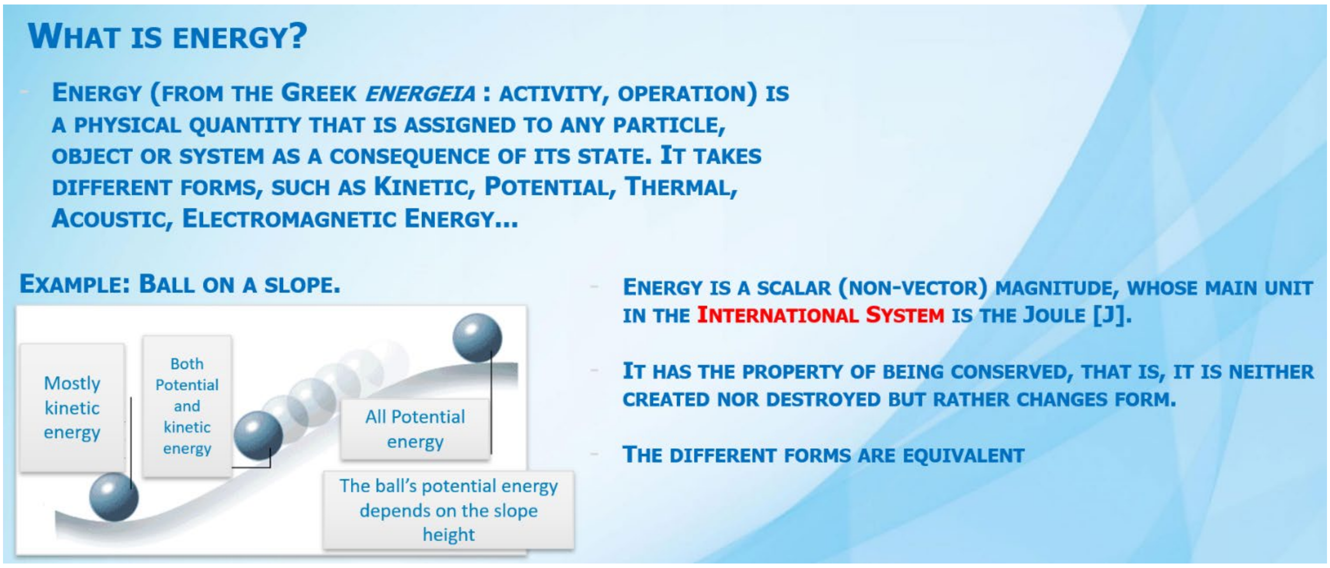
1. BASIC CONCEPTS OF ENERGY, POWER AND EFFICIENCY

1.1 BASIC DEFINITIONS: It is necessary to know some **energy concepts, from a physical or engineering point of view.** Its formal definitions allow us to introduce the topic. The infographic in Figure 1 gives the definition of energy, its units and characteristics, and an example that shows two of its forms (potential and kinetic energy).



WHAT IS ENERGY?

- ENERGY (FROM THE GREEK *ENERGEIA* : ACTIVITY, OPERATION) IS A PHYSICAL QUANTITY THAT IS ASSIGNED TO ANY PARTICLE, OBJECT OR SYSTEM AS A CONSEQUENCE OF ITS STATE. IT TAKES DIFFERENT FORMS, SUCH AS KINETIC, POTENTIAL, THERMAL, ACOUSTIC, ELECTROMAGNETIC ENERGY...

EXAMPLE: BALL ON A SLOPE.

- ENERGY IS A SCALAR (NON-VECTOR) MAGNITUDE, WHOSE MAIN UNIT IN THE INTERNATIONAL SYSTEM IS THE JOULE [J].
- IT HAS THE PROPERTY OF BEING CONSERVED, THAT IS, IT IS NEITHER CREATED NOR DESTROYED BUT RATHER CHANGES FORM.
- THE DIFFERENT FORMS ARE EQUIVALENT

Figure 1 Basic definitions of energy

Energy is conserved and its forms are equivalent (Figure 2), although the conversion between these forms is not always feasible. In general, the conversion always entails that a portion is dissipated into the environment as thermal energy ("losses") and its recovery into useful energy, due to the reduced temperature difference, is technically complex and expensive.

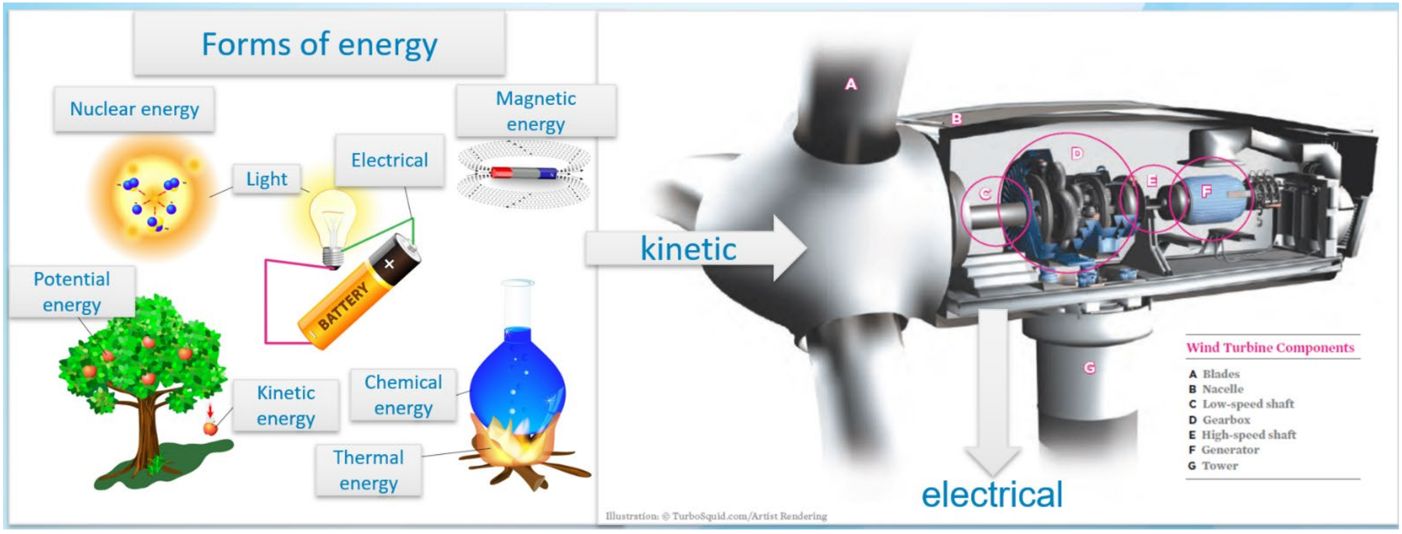


Figure 2 Forms of energy

1.2 WORK AND ENERGY: **Lifting a box** requires a specific amount of **energy *E*,** which is comparable to the work required. **This energy is measured in Joules [J], a unit derived from the International System of Units or SI** [SI-Wiki, 2024] [SI-Wiki-d, 2024]**.** To perform the task (Figure 3), the same amount of energy will be required whether the box is lifted quickly or slowly.

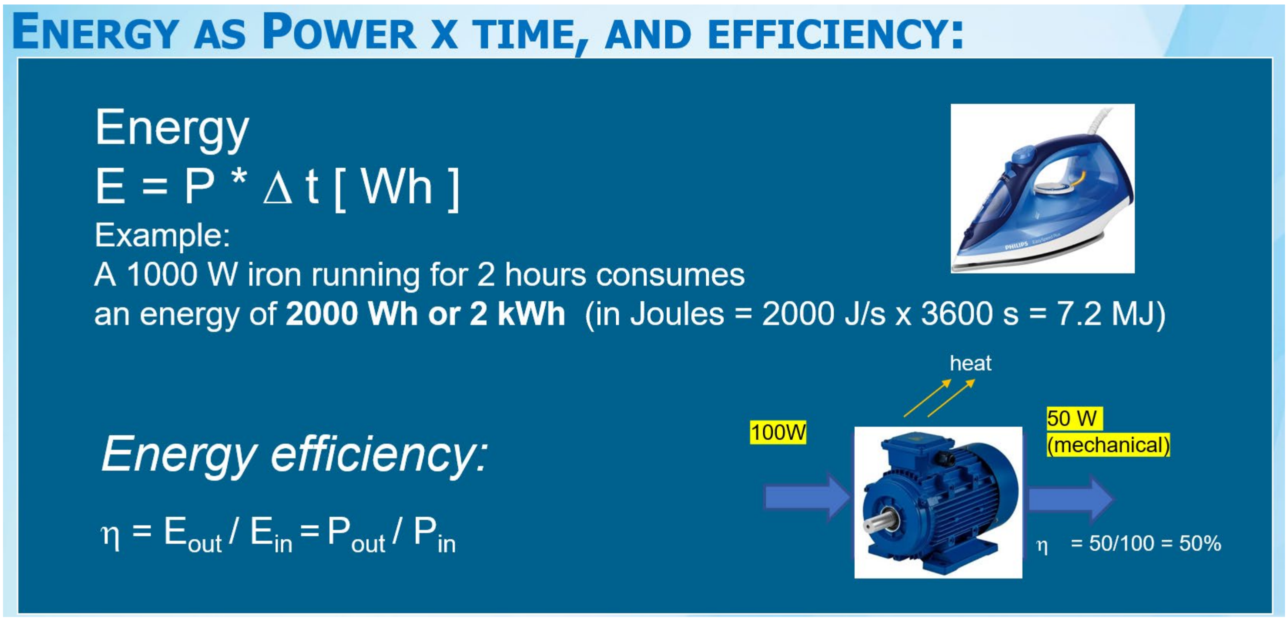
Figure 3 The work required to lift a box is expressed as energy E and is measured in Joules [J] – [UC-Energy Education, 2017]

To lift the box faster, we need to increase the **power *P***, that is, the change in energy over time. This is precisely expressed mathematically as:

$$P = \frac{\Delta E}{\Delta t} \quad [W] \tag{ Eq. 1}$$

and its unit, the Watt [W] (or watt), is equivalent to one [J/s].

In an expression of mechanical physics, work is equivalent to the product of a force ***F*** (expressed in newton[N]) by a distance ***d***, expressed in meters [m] therefore the unit of ***E*** is [Nm]=[J]. (Note that it has the same units as torque [Nm], although it is a different physical phenomenon.) A very important relationship, which arises from Eq. 1 and which links energy, power and elapsed time, can be seen with an example in Figure 4 . Mainly when it comes to electrical energy, the product of the power ***P*** times the elapsed time ***Δt*** is what is usually called the energy consumed (or delivered) in that period ***Δt***, and the most common unit is [Ws] or watt-second, which is the same as Joule. For electrical energy in particular, the use of Wh or watt-hour is preferred. In large quantities, it is common to use the prefixes k (x 1,000) or M (x 1,000,000).



ENERGY AS POWER X TIME, AND EFFICIENCY:

Energy

$E = P * \Delta t\ [\,Wh\,]$

Example:

A 1000 W iron running for 2 hours consumes
an energy of **2000 Wh or 2 kWh** (in Joules = 2000 J/s x 3600 s = 7.2 MJ)

Energy efficiency:

$\eta = E_{out} / E_{in} = P_{out} / P_{in}$

$\eta = 50/100 = 50\%$

Figure 4 Relationship between power ***P***, time ***t*** and energy ***E***, and efficiency relationship

The relationship that arises from the example in Figure 4 , and which refers to an energy (in this case consumed by an electric iron) in a certain period ***Δt*** operating at a power ***P*** can then be written in this way:

$$E_{\Delta t} = P \cdot \Delta t \quad [Ws \equiv J] \tag{Eq.2}$$

Note that this is a PRODUCT and is NOT W/h or kW/h, units that would express a variation or change in power over time.

The other important relationship is efficiency (often expressed with the Greek letter "eta" or η) which is the relationship between the "useful" output power P_{out} and the input power ("demanded or consumed") P_{in} on a device or machine. Over the same period, this is equivalent to the ratio of output energy to input energy. It should be noted that it is a dimensionless magnitude, with a value between 0 and 1 or in percentage notation, between 0 and 100%.

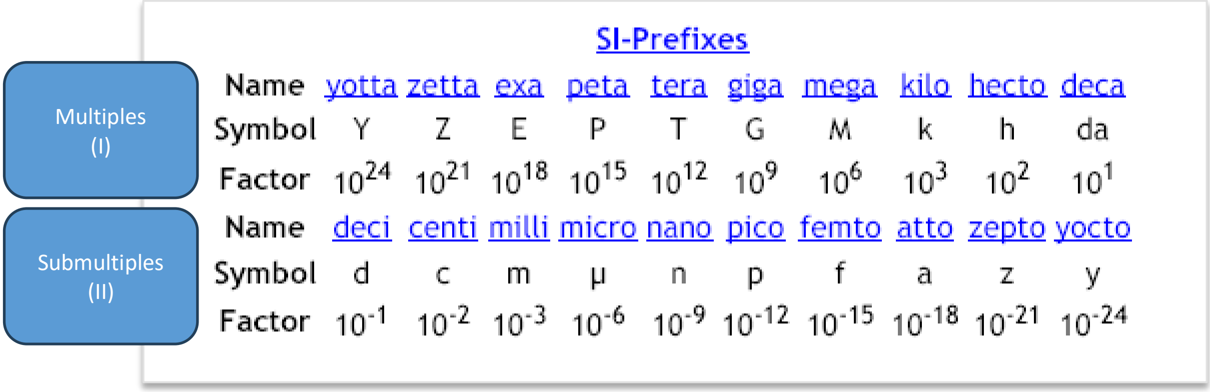
$$\eta = \frac{P_{out}}{P_{in}} = \frac{E_{\Delta t-out}}{E_{\Delta t-in}} \quad [\,] \qquad \text{(Eq.3)}$$

An efficiency of 100% is unattainable within the theoretical limits of current physics, although many devices reach very close values. On the right in Figure 4 , an extreme case is observed of a fictitious electric motor whose useful mechanical shaft power is 50 W, and the electrical power it demands is 100 W, which results in a ratio of 0.5 or an efficiency of 50%. (Typically, the efficiency of an industrial three-phase asynchronous motor exceeds 90%).

2. PREFIXES AND UNITS

When studying the topic of energy, as mentioned, physical concepts appear that we must know. Their precise representation is an important topic, which is why we dedicate this section to units and their prefixes.

2.1 PREFIXES: Prefixes indicate multipliers that make numbers more "manageable" in the representation of physical units. For example, it is more practical and understandable to say that a power plant has a power of 100 MW (one hundred megawatts) than to say that it has 100,000,000 W (one hundred million watts) even if the value is identical. The **SI** is an international agreement in constant updating [ISO-80000-1,2022] on the standard units to be used, their definitions and the names of these prefixes, which are shown in Figure 5 . The scheme of using multiples and submultiples of 10 to represent various quantities was adopted. It should be noted that the prefixes apply to all units, not only related to energy. For example, the speed of light is 30 cm/ns (30 centimeters per nanosecond).



SI-Prefixes

Multiples (I)	Name	yotta	zetta	exa	peta	tera	giga	mega	kilo	hecto	deca
	Symbol	Y	Z	E	P	T	G	M	k	h	da
	Factor	10^{24}	10^{21}	10^{18}	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	10^{2}	10^{1}
Submultiples (II)	Name	deci	centi	milli	micro	nano	pico	femto	atto	zepto	yocto
	Symbol	d	c	m	μ	n	p	f	a	z	y
	Factor	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

Figure 5 Prefixes of the SI or International System of Units [ISO-80000-1,2022]

The upper part (I) corresponds to the multiples and continuing with the example for the derived unit "power", Table 1 shows a typical application.

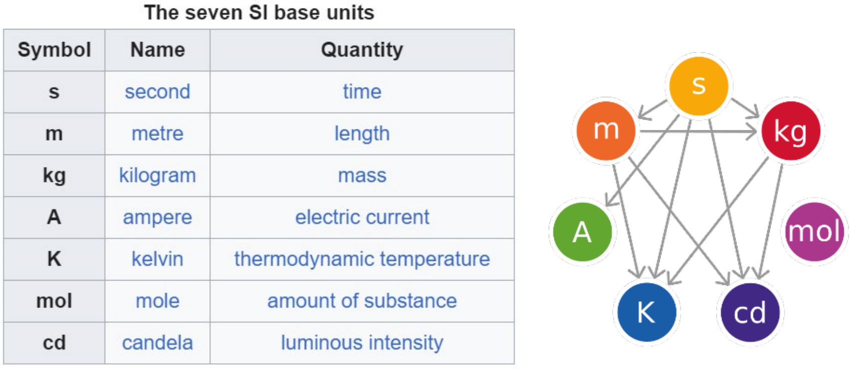
Table 1 Example of use of power multiples

Multiple	Example with power unit [W]
kilo = x 1.000	kW or kilowatt (1000 W = 1 kW, power of a typical household iron)
Mega = x 1.000.000	MW or Megawatt = 1000 kW
Giga = x 1.000.000.00	GW or Gigawatt = 1000 MW

Note that the prefixes in capital letters are multiples greater than one thousand. It is important to note that "kilo" (mil) is denoted by the lowercase k, to differentiate it from the base unit K (Kelvin) of temperature (see 2.2). Therefore, it is incorrect to write kilowatt-hour as KWh. The correct form is kWh.

To represent small quantities, submultiples are used (II in Figure 5). These less than one fractions are seen in the lower part of Figure 5 . They involve multiplying by 10 with negative powers, for example for the base unit meter (m) the hundredth part is known as the **cm** or centimeter (multiplier by $10^{-2} = 1/(10*10) = 1/100 = 0,01$ m, two zeros to the left of the decimal symbol). Similarly, the millimeter or **mm** involves dividing cm by 10 (for the meter it is a multiplier times $10^{-3} = 1/(10*10*10) = 1/1000 = 0.001$ m, three zeros to the left of the decimal symbol).

2.2 UNITS: The SI base units can be seen in Figure 6 and some of the derived units (which were mentioned in Part 1) in Table 2 . A very useful free infographic on base units and derived units is freely available at [NIST SI Base Units Relationships Poster, 2020]. Although the origin of the base units, the associated constants and the way to replicate the measurements are detailed in the ISO/IEC 80000 Standard, with versions for different branches of physics and technology, free guides with formatting recommendations, and its historical evolution such as [NIST- The International System of Units (SI), 2019] are available. Practical user guides such as [NIST Guide for the Use of the International System of Units (SI), 2008] are of great help. In these guides it is possible to find units not included in the SI but accepted in their use (hour, minute for example) and conversions to historical units (psi, foot, calorie, BTU) that are still widely used in the industry.



The seven SI base units

Symbol	Name	Quantity
s	second	time
m	metre	length
kg	kilogram	mass
A	ampere	electric current
K	kelvin	thermodynamic temperature
mol	mole	amount of substance
cd	candela	luminous intensity

Figure 6 Base units of the SI or International System

Table 2 Some derived units from the SI or International System, which are obtained from the base units (Formal names in Spanish/English).

Physical Magnitude	Formal unit (Sp/En)	Unit name	Unit Symbol	Expressed in derived units	Expressed in base units
Force	Newton	Newton	N		$kg \cdot m \cdot s^{-2}$
Pressure	Pascal	Pascal	Pa	$N \cdot m^{-2}$	$m^{-1} \cdot kg \cdot s^{-2}$
Work	Julio, joule	Joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
Power	Vatio, watt	Watt	W	$J \cdot s^{-1}$	$m^2 \cdot kg \cdot s^{-3}$
Electric charge	Culombio, coulomb	Coulomb	C		$A \cdot s$
Electrical potential, electromotive force	Voltio, volt	Volt	V	$J \cdot C^{-1}$	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Electrical resistance	Ohmio, ohm	Ohm	Ω	$V \cdot A^{-1}$	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$

Knowledge of energy issues, and the associated calculations, requires the management of many of these physical units and their correct expression. The advantage is universality and uniformity across languages and countries globally, which is important given the economic and strategic value of energy exchanges.

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