Lesson 1

Thermomechanical Measurements for Energy Systems (MENR)

Measurements for Mechanical Systems and Production (MMER)

A.A. 2015-16

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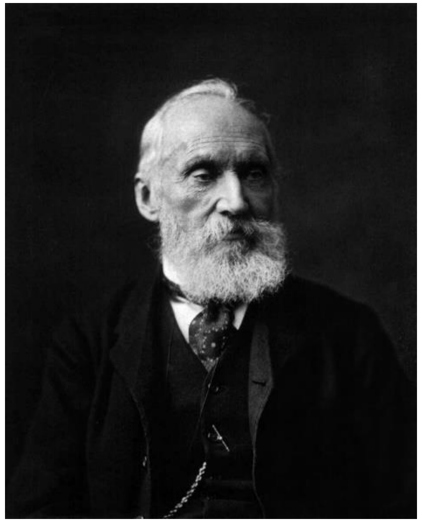
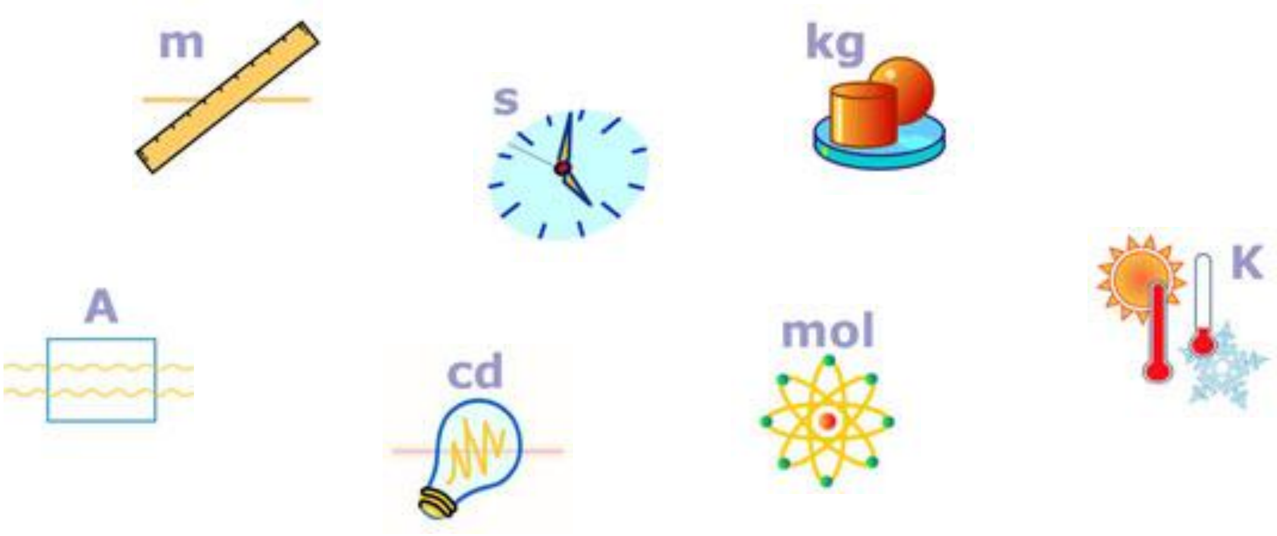
"I often say, when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the state of Science, whatever the matter may be."

Lord Kelvin, 1883

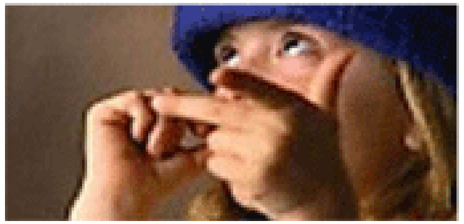


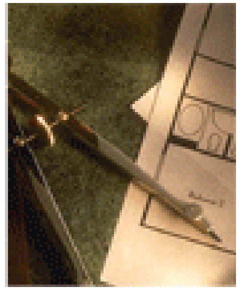
THE LANGUAGE OF MEASUREMENTS

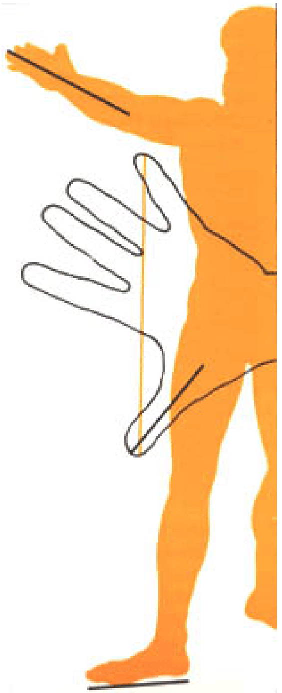


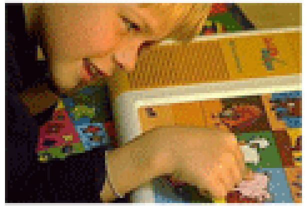
http://www.inrim.it/ldm/cd_ldm/index.html

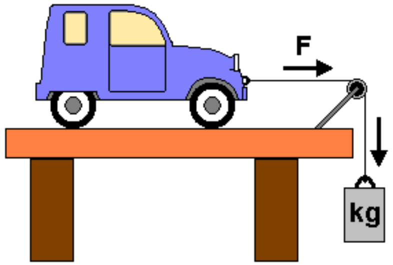
When man felt the need of «measuring» things around him ???



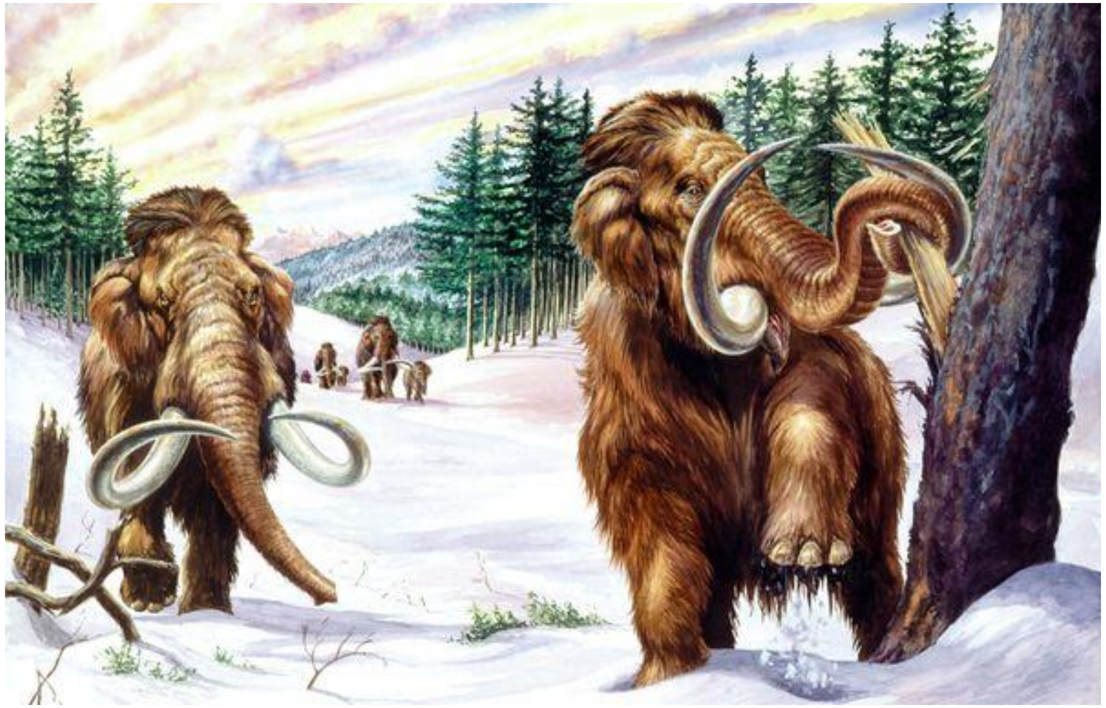








Some examples in antiquity :

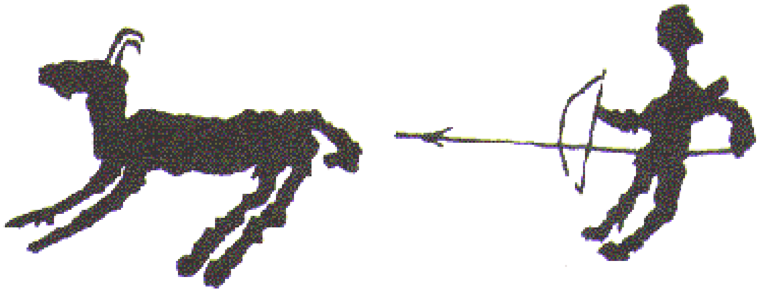


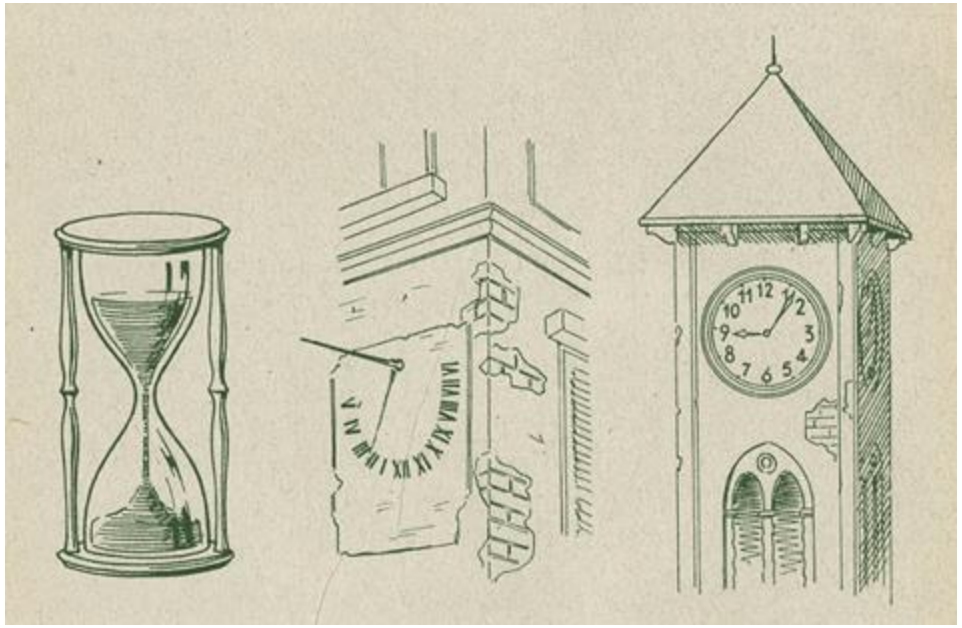
- «How big» is the mammuth we have to hunt ?
- «How far» is the danger from the village ?
- «How many» walking days from the village is the food ?

TO MEASURE something = relating to the world we live in and being able to communicate knowledge to our fellow !

Since ever, man has always "measured" ...
the distance between himself and the things (length),
the size of things (weight) and the time it takes to do things ...

These are still the fundamental measurements in the modern world !!!



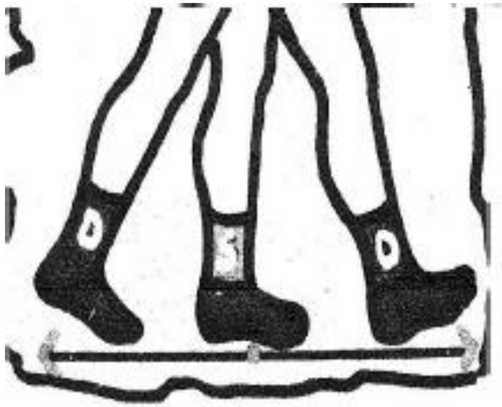


Egyptian length units :

With these units egyptian build their pyramids !!!

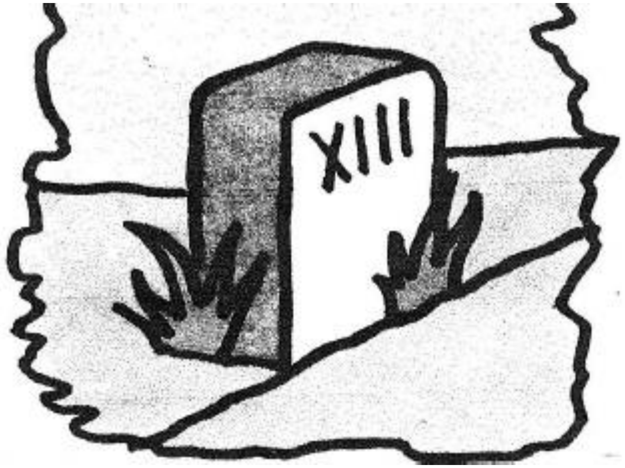
Roman and British length units :

Foot

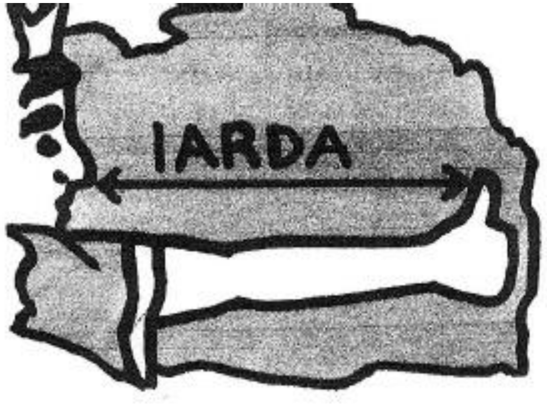


Doppio PASSO
(Double step)

Milestone (pietra miliare)



Miglio (Mile)



For romans : 1000 double steps = 1 mile

The «yard» was imposed by king Henry the 1st of England in year 1100 …

Approximate and accurate measurements !

To make “rough measurements” everyone can use their feet and their hands !

Those measurements will be "**made with the feet**" ...

*Saranno misure «**fatte con i piedi**» …*

To make “accurate measurements” it is necessary to define a sample and a measurement unit valid for everyone !

These will be measurements “taken with calibrated instruments”

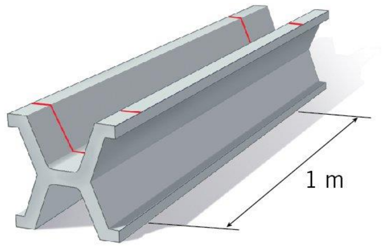
*Saranno misure «**fatte con strumenti tarati**»*

The metric system:

The «metric system» was introduced in France in 1790 with the French Revolution.

The new units of length, weight and time required about 10 years of work and the overcoming of many contrasts to be drawn.

They were attended by many famous scientists including **Borda, Lagrange, Laplace, Monge, Condorcet, Mechain, Delambre and Coulomb**.



In 1799, the first platinum iridium samples of **meter** and **kilogram** were deposited in the archives of France !

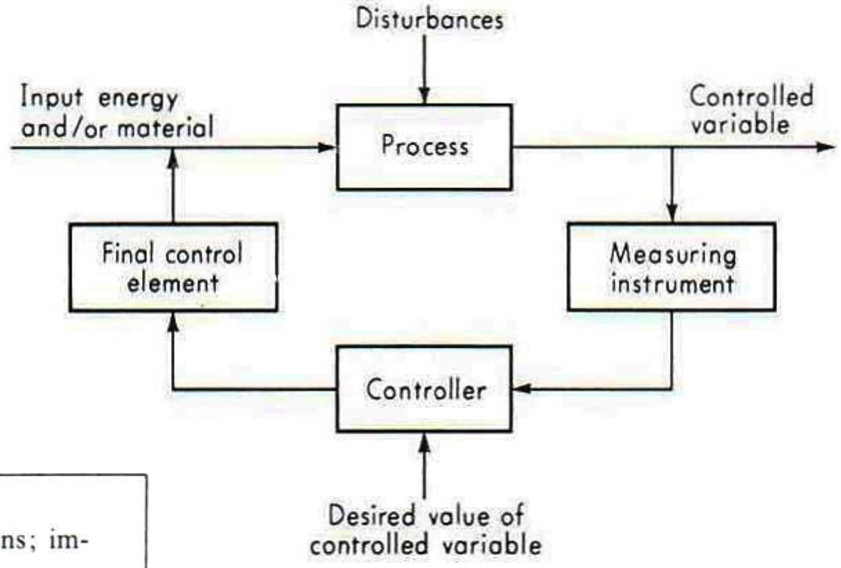
In 1875, 17 nations, including Italy, signed the "International Metre Convention".

In 1889 took place the first **General Conference on Weights and Measures** (1° GFCM), which definitively established the new units …

Types and applications of Measuremet instrumentation:

Why do we do *measurements* today ?

1. To **monitor** technical processes and operations
2. To **control** technical processes and operations
3. To perform **experimental engineering analysis**



1. Testing the validity of theoretical predictions based on simplifying assumptions; improvement of theory, based on measured behavior.
Example: frequency-response testing of mechanical linkage for resonant frequencies.

2. Formulation of generalized empirical relationships in situations where no adequate theory exists.
Example: determination of friction factor for turbulent pipe flow.

3. Determination of material, component, and system parameters, variables, and performance indices.
Examples: determination of yield point of a certain alloy steel, speed-torque curves for an electric motor, thermal efficiency of a steam turbine.

4. Study of phenomena with hopes of developing a theory.
Example: electron microscopy of metal fatigue cracks.

5. Solution of mathematical equations by means of analogies.
Example: solution of shaft torsion problems by measurements on soap bubbles.

Theorethical vs experimental analysis methods :

Features of **theorethical** methods:

1. Often give results that are of general use rather than for restricted application.
2. Invariably require the application of simplifying assumptions. Thus not the actual physical system but rather a simplified "mathematical model" of the system is studied. This means the theoretically predicted behavior is *always* different from the real behavior.
3. In some cases, may lead to complicated mathematical problems. This has blocked theoretical treatment of many problems in the past. Today, increasing availability of high-speed computing machines allows theoretical treatment of many problems that could not be so treated in the past.
4. Require only pencil, paper, computing machines, etc. Extensive laboratory facilites are not required. (Some computers are very complex and expensive, but they can be used for solving all kinds of problems. Much laboratory equipment, on the other hand, is special-purpose and suited only to a limited variety of tasks.)
5. No time delay engendered in building models, assembling and checking instrumentation, and gathering data.

Features of **experimental** methods:

1. Often give results that apply only to the specific system being tested. However, techniques such as dimensional analysis may allow some generalization.
2. No simplifying assumptions necessary if tests are run on an actual system. The true behavior of the system is revealed.
3. *Accurate* measurements necessary to give a true picture. This may require expensive and complicated equipment. *The characteristics of all the measuring and recording equipment must be thoroughly understood.*
4. Actual system or a scale model required. If a scale model is used, similarity of all significant features must be preserved.
5. Considerable time required for design, construction, and debugging of apparatus.

We will employ the «physical approach» to measurements:

What is a ***measurement*** ?

1. **<u>Classification</u>**:
    a) to identify the characteristics or the properties of an object or a physical phenomenon;
    b) to group the objects or phenomena into “classes” where the identified properties are homogeneous.

It’s a *qualitative* cognitive method !

2. **<u>Ordering</u>**:
    a) to consider only the properties that can be sorted according to a scale.

It‘s a first form of *quantification* of the properties, based on the intensity of the selected property.

3. **<u>Measurement</u>**:
    a) to associate to the property considered a number that represent it each time such property manifests itself equal to itself. This position establishes a ***measurement scale***.

This means establishing a correspondence between the “physical properties” of objects or phenomena and “real numbers”.

$$\frac{A}{B} = \alpha$$ ***measurement of A with respect to B***

α always exists and it is a ***real number*** !

When we choose a ***reference property*** or ***unit*** **B ≡ U** then we associate uniquely a number to the physical quantity and we can introduce the ***measurement of the quantity A*** **!**

$$\boxed{\frac{A}{U} = a}$$ ***measurement of A !***

To express «physical properties» with numbers we have to find and associate them with a suitable measurement unit !

Examples :

Length : $\frac{A}{m} = a$ *meters …*

Temperature: $\frac{B}{°C} = b$ *Celsius degree …*

What if I choose a new unit U’ for the same physical property A ???

$$\frac{A}{U'} = a' \neq a$$

The property stays the same but the *number* ***a*** changes in ***a’*** (of course) !

There is a simple rule to pass from ***a*** to ***a’*** :

$$\frac{A}{U'} = \frac{A}{U} \times \frac{U}{U'} = \frac{A}{U} \times \tau$$

or

$$a' = a \times \tau$$

The ratio of the two *units U* and *U’* is of course dimensionless :

$$\tau = \frac{U}{U'}$$

This rule accounts for the ***«change of the measurement units»*** in science and technology !

Example:

$$\tau = \frac{U}{U'} = \frac{1mm}{1km}$$

$$\frac{1mm}{10^6 mm} = 10^{-6}$$

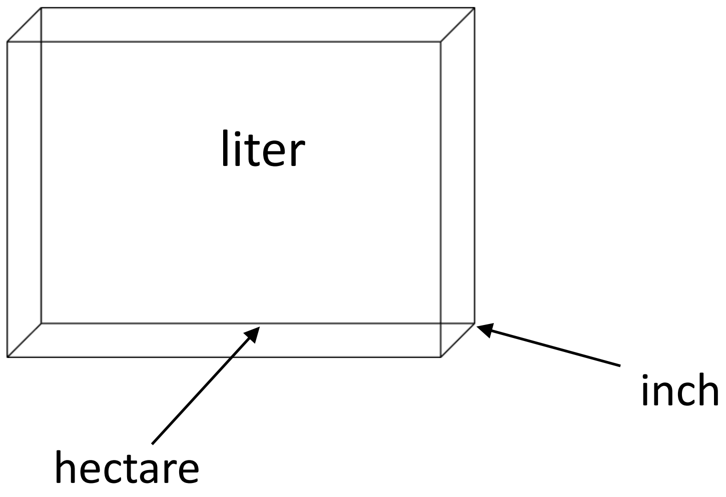
$$\frac{10^{-6} km}{1km} = 10^{-6}$$

Are we going to choose for every physical quantity or property an *arbitrary measurement unit* ?

NO !

Then we have to establish ***relationships*** between every quantity or property that allows it ….

Example:



Geometric Units

Lenght [L] ⟶ ***fundamental** unit* $U_L = m$ «meter»
(in the ***International Unit System***)

Area [A] ⟶ ***derived unit*** $U_A = m^2$
$[A] = [L \times L] = [L^2]$

Volume [V] ⟶ ***derived unit*** $U_V = m^3$
$[V] = [L \times L \times L] = [L^3]$

Dimensions

Kinematic Units

Time [t] ⟶ ***fundamental* unit** U_t **= s** «seconds»
(in the ***International Unit System***)

Velocity [v] ⟶ ***derived unit*** U_v **= m/s**
$[v] = [L \times t^{-1}]$

Acceleration [a] ⟶ ***derived unit*** U_a **= m/s²**
$[a] = [L \times t^{-1} \times t^{-1}] = [L \times t^{-2}]$

Kinematic relationships !

Dynamic Units

Mass [M] ⟶ ***fundamental* unit** U_F **= kg** «kilogram»
(in the ***International Unit System***)

Force [F] ⟶ ***derived unit*** $U_F = kg \cdot m/s^2$ «newton»
$[F] = [M \times L \times t^{-2}]$

Work [J] ⟶ ***derived unit*** $U_J = kg \cdot m^2/s^2$ «joule»
$[J] = [M \times L^2 \times t^{-2}]$

Power [W] ⟶ ***derived unit*** $U_a = kg \cdot m^2/s^3$ «watt»
$[W] = [M \times L^2 \times t^{-3}]$

Physical relationships !

A ***dimensional equation*** is an equation that expresses with the «Maxwell notation» every *derived quantity* or ***unit U*** as a function of the *fundamental quantity* or ***units*** $\boldsymbol{U_1}$, $\boldsymbol{U_2}$, $\boldsymbol{U_3}$, with the ***dimensions*** $\boldsymbol{\alpha_1}$, $\boldsymbol{\alpha_2}$, $\boldsymbol{\alpha_3}$.

$$[U]=[U_1^{\alpha_1}]\cdot[U_2^{\alpha_2}]\cdot[U_3^{\alpha_3}]$$

If we concentrate only on Mechanics, we define **10 physical quantities or units** and **7 relationships** between them: only **10 – 7 = 3** quantities or units are **fundamental**, the others are **derived** from the 3 fundamental !!!

$[L]=[L]$	→	m	(fundamental)
$[A]=[L^2]$	→	m^2	(derived)
$[V]=[L^3]$	→	m^3	(derived)
$[t]=[t]$	→	t	(fundamental)
$[v]=[L][t^{-1}]$	→	m/s	(derived)
$[a]=[L][t^{-2}]$	→	m/s^2	(derived)
$[M]=[M]$	→	kg	(fundamental)
$[F]=[M][L][t^{-2}]$	→	$kg\cdot m/s^2$ = N	(derived)
$[J]=[M][L^2][t^{-2}]$	→	$kg\cdot m^2/s^2$ = J	(derived)
$[W]=[M][L^2][t^{-3}]$	→	$kg\cdot m^2/s^3$ = W	(derived)

Since 1978 in Italy is in force the ***International System of Units*** (SI acronym), edited in 1976 by the "11th General Conference on Weights and Measures".

Physical quantity	Unit IS	
	Name	Symbol
[L] Length	meter	m
[M] Mass	kilogram	kg
[t] Time	second	s
[I] Electrical current intensity	ampère	A
[T] Thermodynamic Temperature	kelvin	K
[m] Substabce amount	mole	mol
[Lc] Light intensity	candle	cd

The primary units are held by the "International Metrology Laboratory" (B.I.P.M.) in Sevres, France, while in Italy the secondary units are held and disseminated by the **National Institute of Metrological Research** (I.N.RI.M) in Turin. The National Alternative Energies Authority (E.N.E.A.) holds the nuclear units.

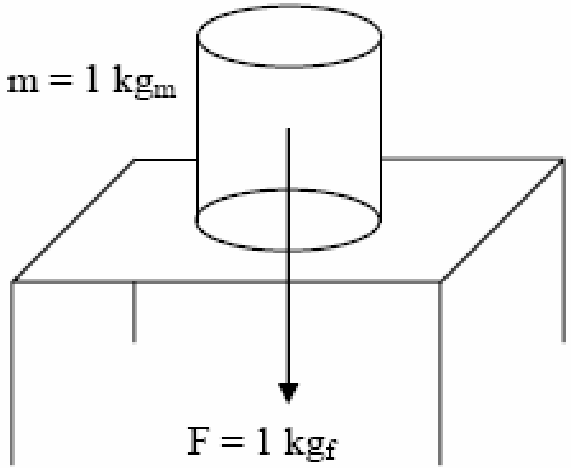
A very peculiar problem with *fundamental units* :

I.S.	T. S.
[L] → m	[L] → m
[t] → s	[t] → s
[M] → kg	[F] → kg

in the two systems of units, different physical quantities (a mass in the IS and a force in the TS) have the same name !

In hystory, engineers were always more interested in «forces» than in «mass», because their first goal was to make constructions that had not to collapse !

$$U_{F(ST)} = 1kg_f \equiv 1kg_m \times 9.81 m/s^2 = 9.81 N$$



1 kg_f is 10 times bigger than the N !

$$U_{M(ST)} = 1m_p = \frac{1kg_f}{1ms^{-2}}$$ but $$1kg_f \equiv 1kg_m \times 9.81 ms^{-2}$$ therefore: $$1m_p \equiv \frac{1kg_m \times 9.81 ms^{-2}}{1ms^{-2}} = 9.81 kg_m$$

1 m_p is also 10 times bigger than the kg_m !

Exercise:
calculate the density (*specific mass*) and the *specific weight* of air in the two measurement unit systems

We start with the specific weight:

	S.I.	S.T.
$\rho = \frac{M}{V}$	$1.19 \frac{kg_m}{m^3}$	$0.121 \frac{kg_f s^2}{m^4}$
$\gamma = \frac{F_p}{V}$	$11.67 \frac{N}{m^3}$	$1.19 \frac{kg_f}{m^3}$

$$[\gamma] = \left[\frac{F_P}{V}\right] \Rightarrow \frac{kg_f}{m^3}$$

pV = nRT → Ideal gas law

$$[p] \Rightarrow \frac{kg_f}{m^2} \qquad p = 1Atm = 10333 \frac{kg_f}{m^2} \cong 1 \frac{kg_f}{cm^2}$$

$$[T] \Rightarrow K \qquad T = 25°C = 298K$$

$$[V] \Rightarrow m^3 \qquad R = 29.27 \frac{kg_f m}{K}$$

We now consider an amount of air that weights 1kg$_f$ …

$$\gamma = \frac{1kg_f}{V} = 1kg_f \cdot \frac{p}{RT} = \frac{1kg_f \times 10333\, kg_f m^{-2}}{29.27 kg_f mK^{-1} \times 298K} = 1.19 \frac{kg_f}{m^3}$$