Chapter 6
Dimensions and Units

Length

The standard unit of length in the metric system is the meter. Other units of length and their equivalents in meters are as follows:

1 millimeter = 0.001 meter

1 centimeter = 0.01 meter

1 decimeter = 0.1 meter

1 kilometer = 1000 meters

We abbreviate these lengths as follows:

1 millimeter = 1 mm

1 centimeter = 1 cm

1 meter = 1 m

1 decimeter = 1 dm

1 kilometer = 1 km

Volume

The standard unit of volume in the metric system is the liter. One liter is equal to 1000 cubic centimeters in volume. Other units of volume and their equivalents in liters are as follows:

1 milliliter = 0.001 liter

1 centiliter = 0.01 liter

1 deciliter = 0.1 liter

1 kiloliter = 1000 liters

Decimals in measurement

We use decimals to specify units of measurement when we need more precision about length, volume, mass, or time. For example, when specifying the height of a person 1.63 meters tall, to say that person is 1 or 2 meters tall doesn't give us a very good idea of how tall that person really is.

The prefixes for the different units of length, volume, and mass in the metric system obey the following rules:

Prefix	**Multiply by**
milli-	0.001
centi-	0.01
deci-	0.1
deka-	10
hecto-	100

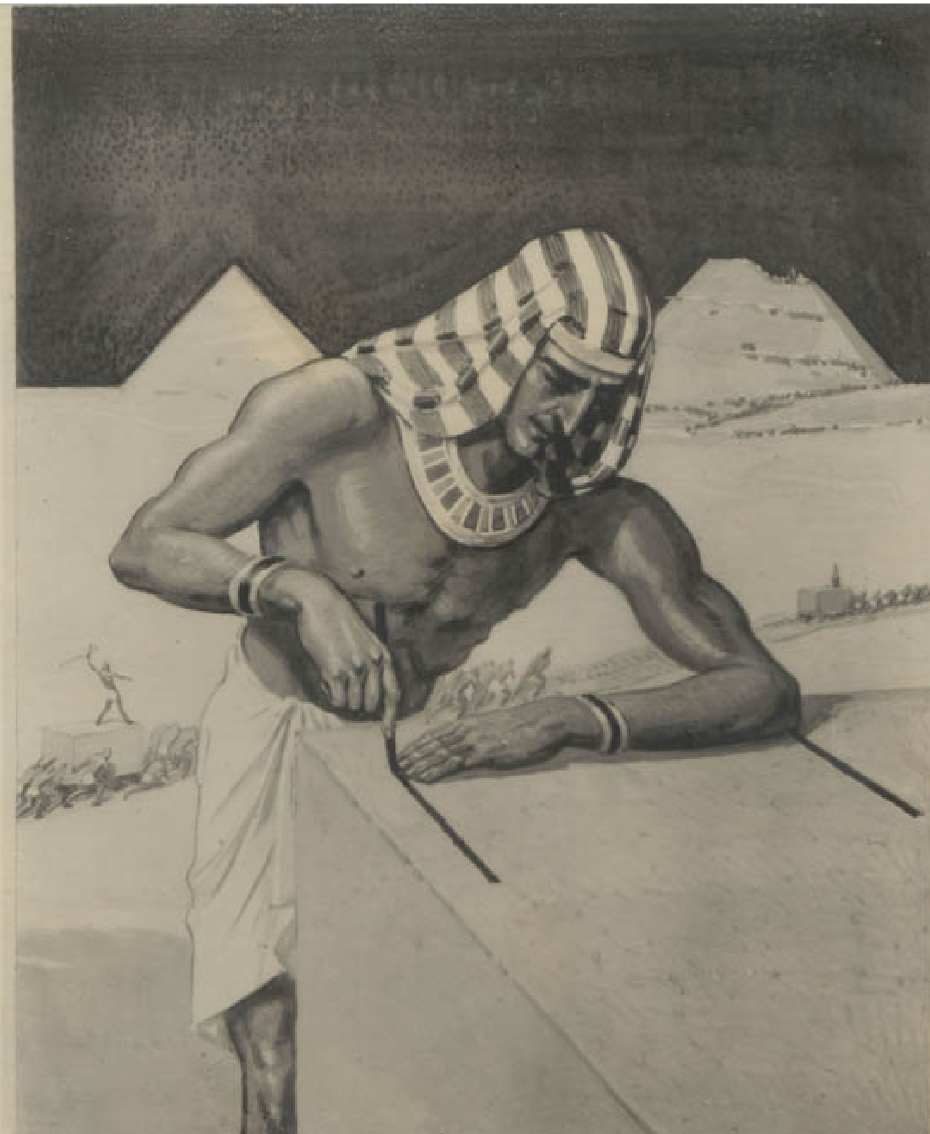
So for example:

1 *hecto*meter = 100 meters

1 *centi*gram = 0.01 gram

3 *milli*liters = 3 × (0.001 liters) = 0.003 liters

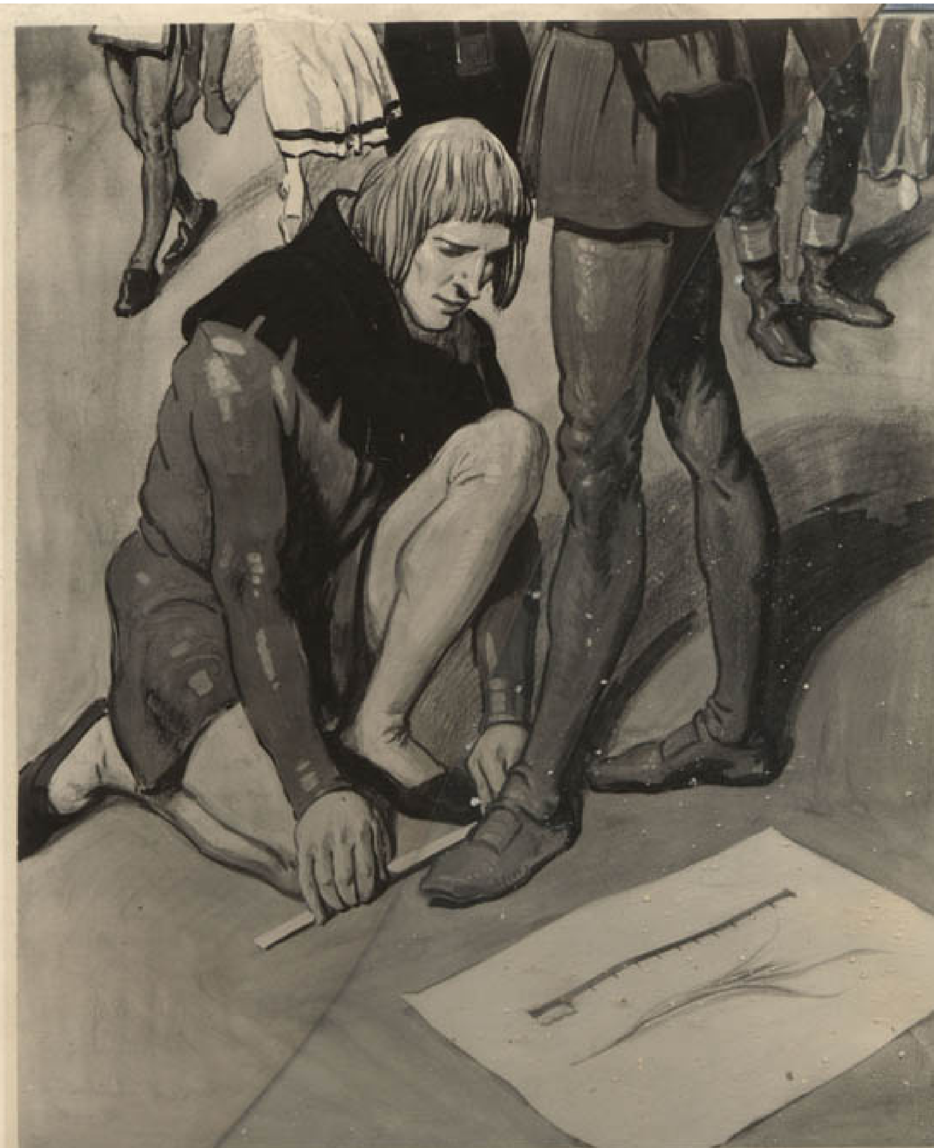
0.9 *kilo*meters = 0.9 × (1000 meters) = 900 meters



— Cubit —

First known measurement.
About 20 inches.
Length of forearm from point of elbow to end of the middle finger.

It was not until the reign of Richard the Lionheart that the standardisation of units of measurement was first documented. In the Assize of Measures in 1196 it was stated that "Throughout the realm there shall be the same yard of the same size and it should be of iron". The Magna Carta (1215) also attempted to standardise measurements throughout the kingdom, although it concentrated on measures of wine and beer!



– Inch and Foot –

Three barley corns taken from center of ear placed end to end equals one inch.
(Edward II 1324)
A foot ranged from 9¾ inch to 19 inches.

The metric system of measurement.

The metric system of measurement is used generally throughout the world, particularly in Europe. It is not in general use in the United States. Because the metric system is a decimal system, it is less subject to arithmetical error than the English system of measurement.

Fundamental and standard units

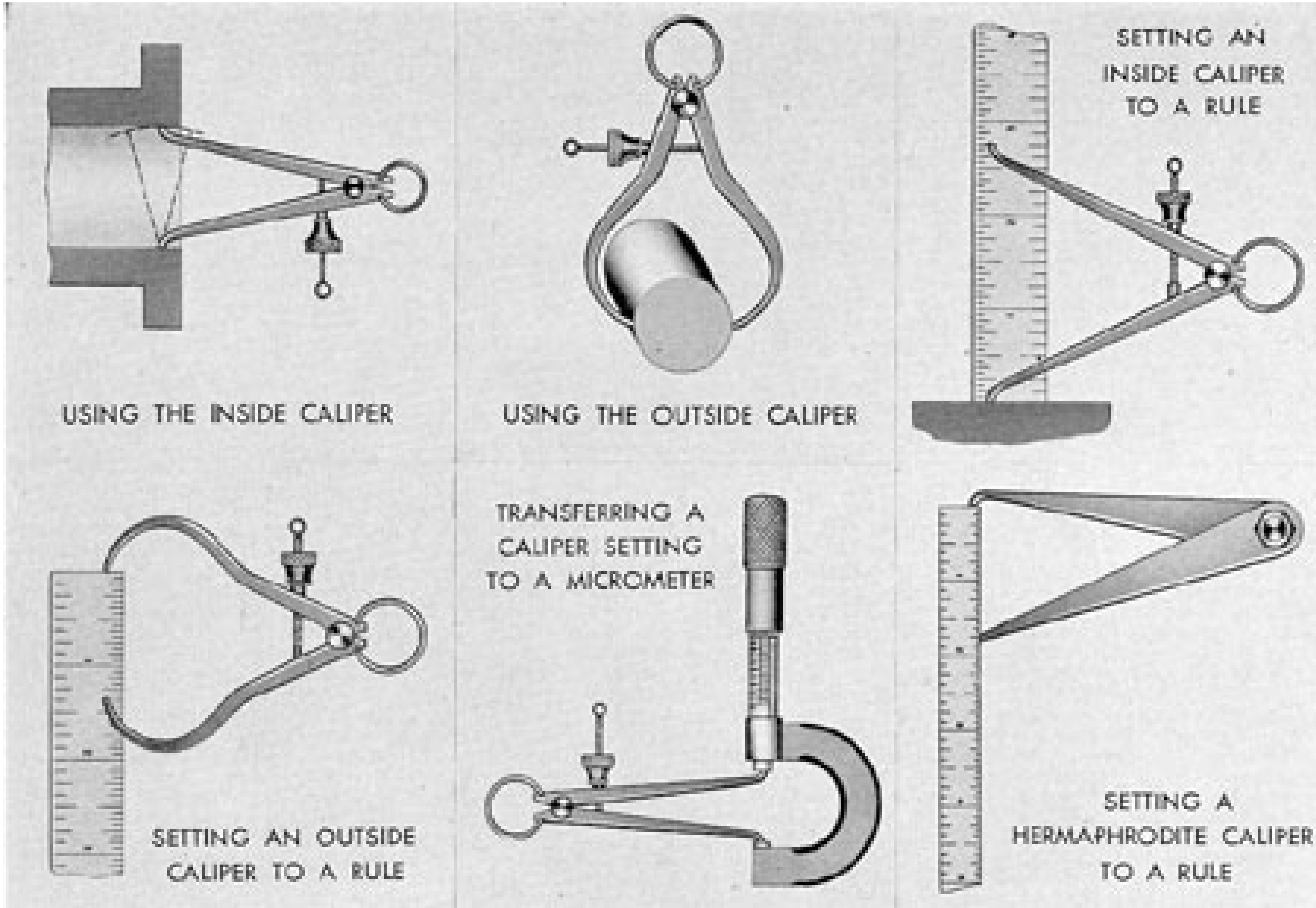
The *fundamental units* are units of mass, length, time, and other units.

Table 6.2 Base Units

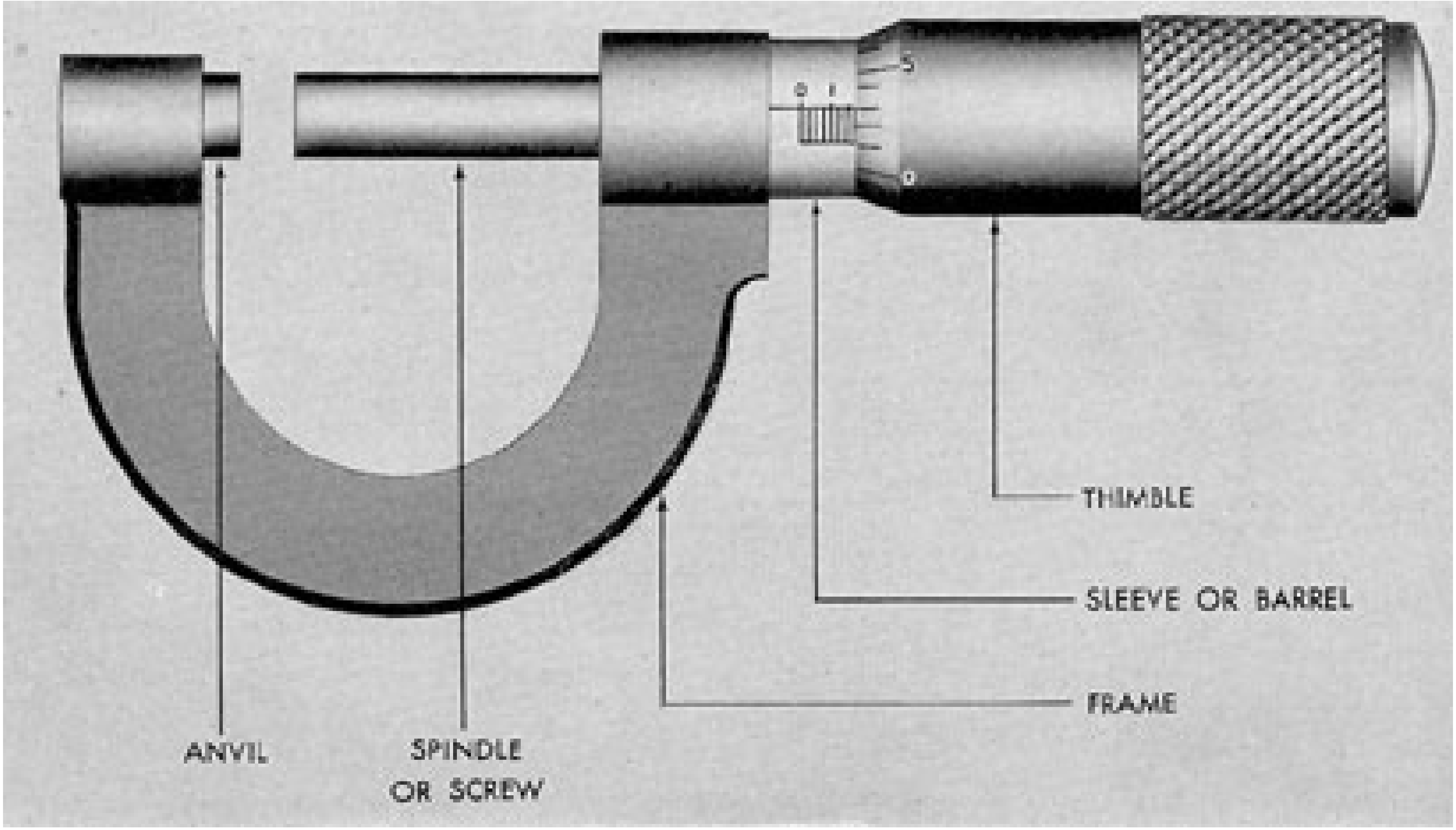
Quantity	Name	Symbol
Length	meter	m
Mass	Kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temp.	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Definition: METER

In 1791, soon after the French Revolution, the French Academy of Sciences defined the meter as **10^{-7}** or one ten-millionth of the length of the meridian through Paris from pole to the equator. However, the first prototype was short by 0.2 millimeters because researchers miscalculated the flattening of the earth due to its rotation.

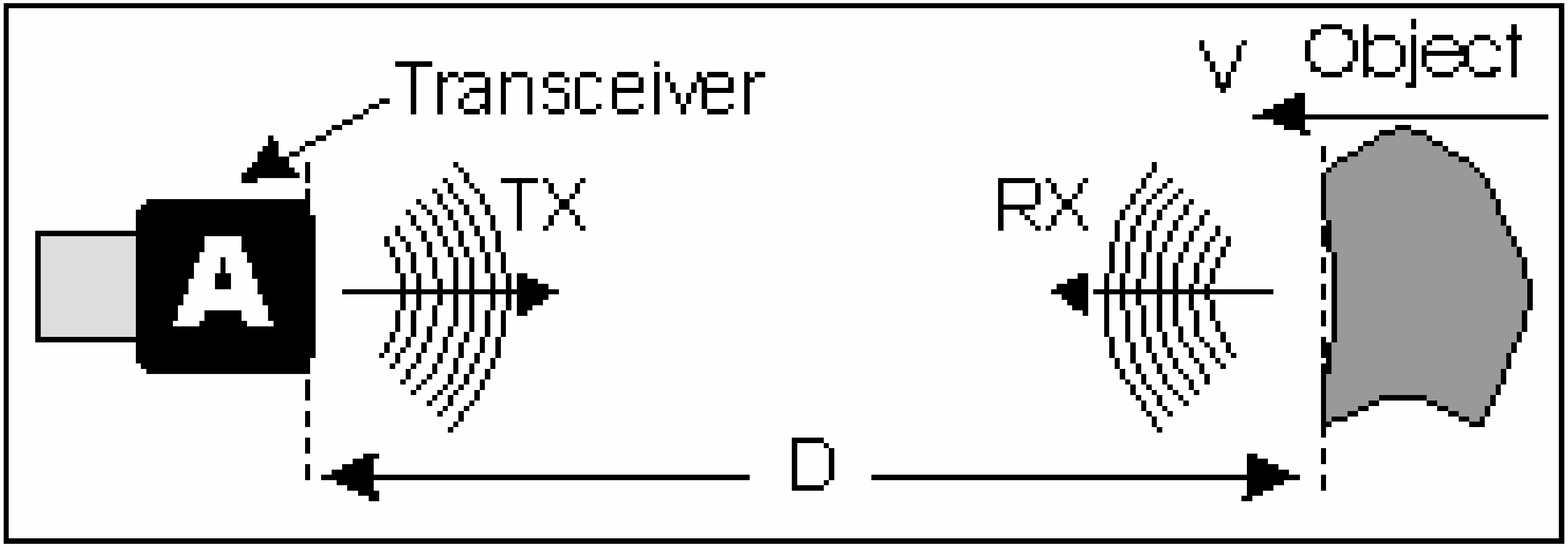

USING THE INSIDE CALIPER
USING THE OUTSIDE CALIPER
SETTING AN INSIDE CALIPER TO A RULE
SETTING AN OUTSIDE CALIPER TO A RULE
TRANSFERRING A CALIPER SETTING TO A MICROMETER
SETTING A HERMAPHRODITE CALIPER TO A RULE

In 1889, a new international prototype was made of an alloy of platinum with 10 percent iridium, that was to be measured at the melting point of ice. In 1927, the meter was more precisely defined as the distance, at 0°, between the axes of the two central lines marked on the bar of platinum-iridium



Micrometer

Laser distance measurement



Ultrasound distance measurement

New Units of distance measurement

The 1983 definition:

The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

Question: what is the advantage of this definition?

Unit of mass (kilogram)

At the end of the 18th century, a kilogram was the mass of a cubic decimeter of water. In 1889, the 1st CGPM sanctioned the international prototype of the kilogram, made of platinum-iridium, and declared: *This prototype shall henceforth be considered to be the unit of mass*.

The 3d CGPM (1901), in a declaration intended to end the ambiguity in popular usage concerning the word "weight," confirmed that:

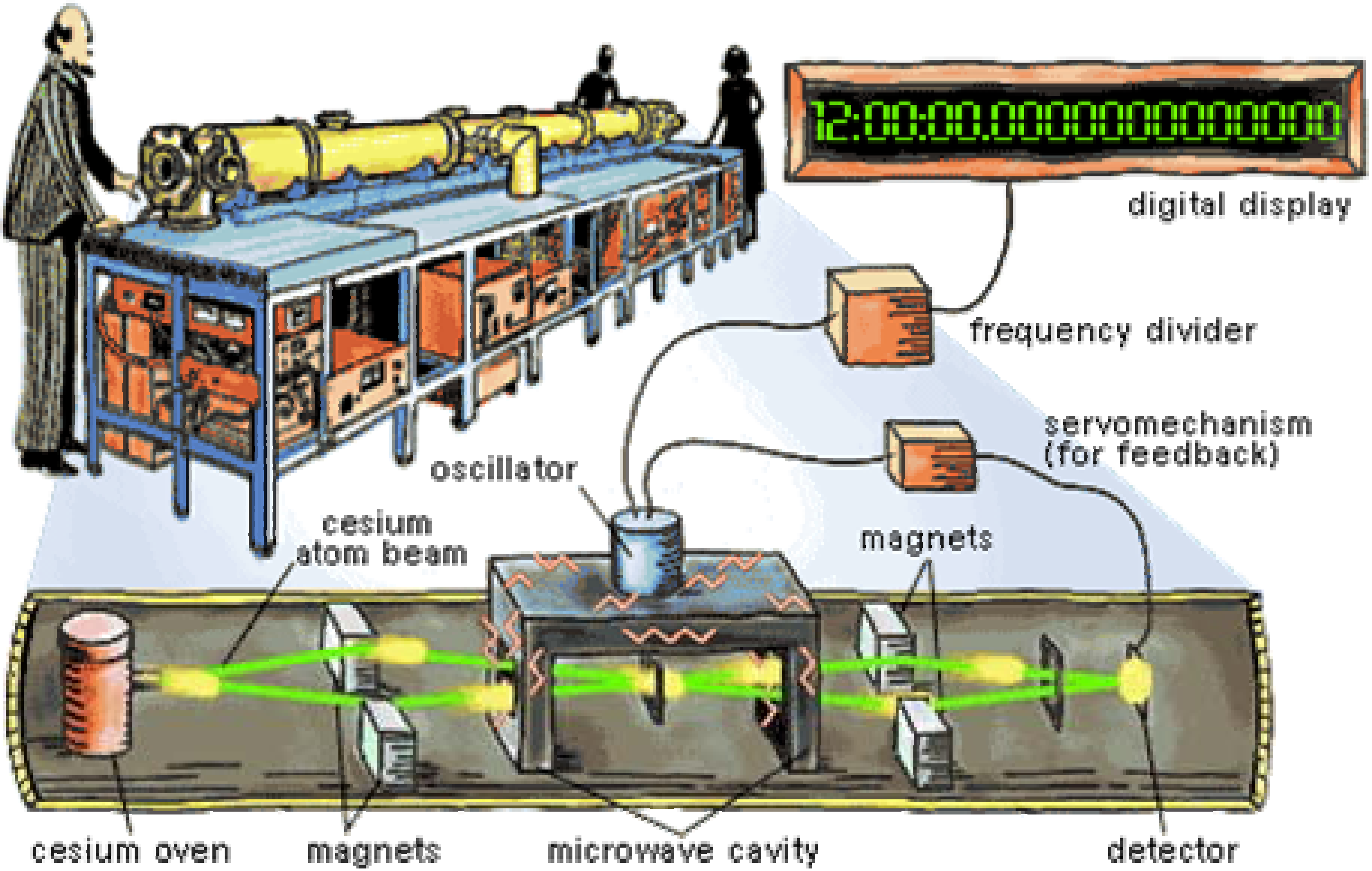
The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

The kilogram

The platinum-iridium international prototype, as kept at the International Bureau of Weights and Measures

Unit of time (second)

The unit of time, the second, was defined originally as the fraction 1/86 400 of the mean solar day. The exact definition of "mean solar day" was left to astronomical theories.



Cesium Clock

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

Unit of electric current (ampere)

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

Unit of thermodynamic temperature (kelvin)

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

Conversion:

$t/°C = T/K - 273.15.$

Measurement Standards

Quantity (SI Unit)	Length (m)	Mass (kg)	Time (s)	Therodynamic Temperature (k)	Electric Current (A)	Luminous Intensity (cd)	Amount of Substance (mol)	Volme, Force Power, etc. (Derived Units)
Definition Prototype	I_2-Stabilized H_2 N_2 Laser	Kilogram prototype	Transition frequency of ^{133}Cs atom	Triple point of water	Josephson effect and Quantum Hall effect	Special luminous efficacy at 540 THz	Atomic weight of ^{12}C atom	Definitions of Derived Units
Standards Realization	Interferometer System	Precision Mass Comporator	Cs atomac clock	International temperature scale -90	Standard electric current unit	FCR & Self calibrated Si photodiode		Standard for Derived Units
Reference Standards	Master guage block standard scale	Reference standard weights	Quartz frequency standards	Reference Standard thermometers	Standard cells and standard registor sets	Reference Standard lamp		Reference Standard
Transfer Standards	Gauge block, Standard scale	Standard weight sets	Standard HF broadcast	Standard thermometers	Standard cells and resistors	Standard lamp		Working standards

SI derived units

Other quantities, called ***derived quantities***, are defined in terms of the seven base quantities via a system of quantity equations. The ***SI derived units*** for these derived quantities are obtained from these equations and the seven SI base units. Examples of such SI derived units are given below.

Examples of SI derived units

area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg

Examples of SI derived units

Force	newton	$1N = 1m \cdot kg \cdot s^{-2}$
Frequency	hertz	$1\ Hz = 1\ s^{-1}$
Pressure, stress	pascal	$1\ Pa = 1N/m^2 = 1m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	$1\ J = 1\ N \cdot m = 1\ m^2 \cdot kg \cdot s^{-2}$

Examples of SI derived units

Power	watt	**1W** = 1J·s^{-1} = **1 V*1A** = **1 Nm ·s^{-1}**
energy, work	joule	1 J = 1 N·m = 1 m^2·kg·s^{-2}

Note: The power company measures consumption of electricity in kilowatt-hours (kWh).

What are we buying?

Examples of SI derived units

Power (symbol: *P*) is the amount of work done per unit of time. This can be modeled as an energy flow, equivalent to the rate of change of the energy in a system. The **average power** is the average amount of work done or energy transferred per unit time. The **instantaneous power** is then the limiting value of the average power as the time interval Δt approaches zero.

$$P = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t} = \lim_{\Delta t \to 0} P_{\mathrm{avg}}$$

When the rate of energy transfer or work is constant, all of this can be simplified to

$$P = \frac{W}{t} = \frac{E}{t} ,$$

where *W* and *E* are, respectively, the work done or energy transferred in time *t*.

Examples of SI derived units

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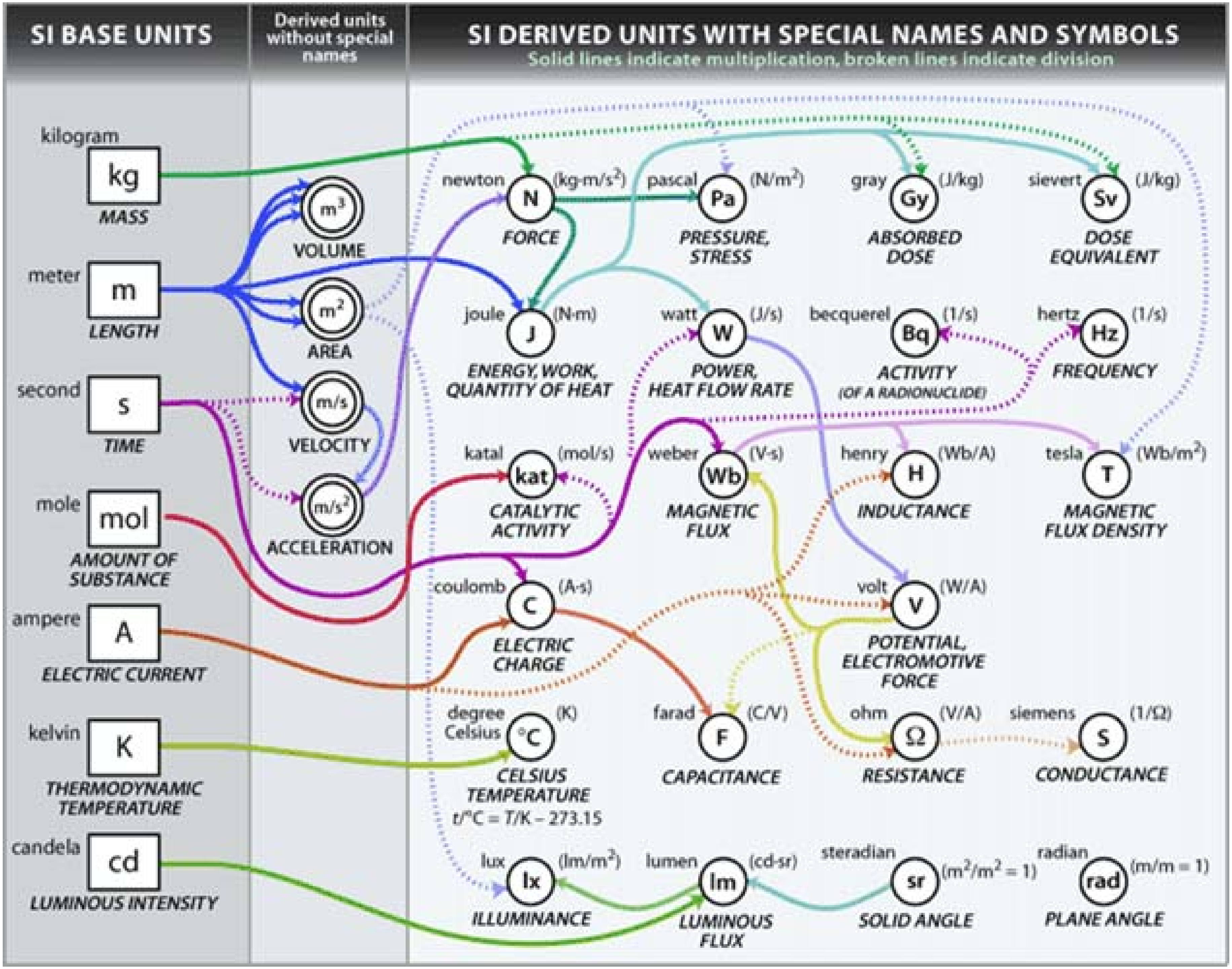
What are we buying?


SI BASE UNITS
Derived units without special names
SI DERIVED UNITS WITH SPECIAL NAMES AND SYMBOLS
Solid lines indicate multiplication, broken lines indicate division
kilogram
kg
MASS
meter
m
LENGTH
second
s
TIME
mole
mol
AMOUNT OF SUBSTANCE
ampere
A
ELECTRIC CURRENT
kelvin
K
THERMODYNAMIC TEMPERATURE
candela
cd
LUMINOUS INTENSITY
m^3
VOLUME
m^2
AREA
m/s
VELOCITY
m/s^2
ACCELERATION
newton N (kg·m/s²) FORCE
pascal Pa (N/m²) PRESSURE, STRESS
gray Gy (J/kg) ABSORBED DOSE
sievert Sv (J/kg) DOSE EQUIVALENT
joule J (N·m) ENERGY, WORK, QUANTITY OF HEAT
watt W (J/s) POWER, HEAT FLOW RATE
becquerel Bq (1/s) ACTIVITY (OF A RADIONUCLIDE)
hertz Hz (1/s) FREQUENCY
katal kat (mol/s) CATALYTIC ACTIVITY
weber Wb (V·s) MAGNETIC FLUX
henry H (Wb/A) INDUCTANCE
tesla T (Wb/m²) MAGNETIC FLUX DENSITY
coulomb C (A·s) ELECTRIC CHARGE
volt V (W/A) POTENTIAL, ELECTROMOTIVE FORCE
degree Celsius °C (K) CELSIUS TEMPERATURE
t/°C = T/K – 273.15
farad F (C/V) CAPACITANCE
ohm Ω (V/A) RESISTANCE
siemens S (1/Ω) CONDUCTANCE
lux lx (lm/m²) ILLUMINANCE
lumen lm (cd·sr) LUMINOUS FLUX
steradian sr (m²/m² = 1) SOLID ANGLE
radian rad (m/m = 1) PLANE ANGLE

End