Physics: Basics

Some useful definitions

A quantity in the general sense is a property ascribed to phenomena, bodies, or substances that can be quantified for, or assigned to, a particular phenomenon, body, or substance. Examples are mass and electric charge.

A quantity in the particular sense is a quantifiable or assignable property ascribed to a particular phenomenon, body, or substance. Examples are the mass of the moon and the electric charge of the proton.

A physical quantity is a quantity that can be used in the mathematical equations of science and technology.

A unit is a particular physical quantity, defined and adopted by convention, with which other particular quantities of the same kind are compared to express their value.

The value of a physical quantity is the quantitative expression of a particular physical quantity as the product of a number and a unit, the number being its numerical value.

Thus, the numerical value of a particular physical quantity depends on the unit in which it is expressed.

For example, the value of the height hW of the Washington Monument is hW = 169 m = 555 ft. Here hW is the physical quantity, its value expressed in the unit "meter," unit symbol m, is 169 m, and its numerical value when expressed in meters is 169. However, the value of hW expressed in the unit "foot," symbol ft, is 555 ft, and its numerical value when expressed in feet is 555.
SI base units

The SI is founded on seven SI base units for seven base quantities assumed to be mutually independent

	SI base unit	
Base quantity	Name	Symbol
Length	meter	m
Mass	kilogram	kg

Time	second	s
Electric current	ampere	A
Thermodynamic Temperature	kelvin	K
Amount of Substance	mole	mol
Luminous Intensity	candela	cd

The following definitions of the SI base units are taken from NIST Special Publication 330 (SP 330), The International System of Units (SI).

Definitions of the SI base units

Unit of length	meter	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.
Unit of mass	kilogram	The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
Unit of time	second	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 x 10^{-7} newton per meter of length.
Unit ofthermodynamictemperature	kelvin	The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Unit of amount of substance	mole	1. The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; its symbol is "mol." 2. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions,electrons, other particles, or specified groups of such particles.
Unit ofluminousintensity	candela	The candela is the luminous intensity, in a given

direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

SI Unit System

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, where it should be noted that the symbol 1 for quantities of dimension 1 such as mass fraction is generally omitted.

Examples of SI derived units

	SI derived unit	
Derived quantity	**Name**	**Symbol**
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
wave number	reciprocal meter	m^{-1}
mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
amount-of-substance concentration	mole per cubic meter	mol/m^3
luminance	candela per square meter	cd/m^2
mass fraction	kilogram per kilogram, which may be represented by the number 1	kg/kg = 1

SI Derived Units

For ease of understanding and convenience, 22 SI derived units have been given special names and symbols

SI derived units with special names and symbols

	SI derived unit			
Derived quantity	**Name**	**Symbol**	**Expression in terms of other SI units**	**Expression in terms of SI base units**
plane angle	radian [a]	rad	-	$m \cdot m^{-1} = 1$ [b]
solid angle	steradian [a]	sr [c]	-	$m^2 \cdot m^{-2} = 1$ [b]
frequency	hertz	Hz	-	s^{-1}
force	newton	N	-	$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	N·m	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C	-	s·A
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$

For ease of understanding and convenience, 22 SI derived units have been given special names and symbols

Derived quantity	**Name**	**Symbol**	**Expression in terms of other SI units**	**Expression in terms of SI base units**
magnetic flux	weber	Wb	V·s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius	°C	-	K
luminous flux	lumen	lm	cd·sr [c]	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
activity (of a radionuclide)	becquerel	Bq	-	s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent [(d)]	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
catalytic activity	katal	kat		$s^{-1} \cdot mol$

[(a)] The radian and steradian may be used advantageously in expressions for derived units to distinguish between quantities of a different nature but of the same dimension; some examples are given in Table 4.
[(b)] In practice, the symbols rad and sr are used where appropriate, but the derived unit "1" is generally omitted.
[(c)] In photometry, the unit name steradian and the unit symbol sr are usually retained in expressions for derived units.
[(d)] Other quantities expressed in sieverts are ambient dose equivalent, directional dose equivalent, personal dose equivalent, and organ equivalent dose.

Note on Degree Celsius

The derived unit in above table with the special name degree Celsius and special symbol °C deserves comment. Because of the way temperature scales used to be defined, it remains common practice to express a thermodynamic temperature, symbol T, in terms of its difference from the reference temperature T0 = 273.15 K, the ice point. This temperature difference is called a Celsius temperature, symbol t, and is defined by the quantity equation t= T- T0.

The unit of Celsius temperature is the degree Celsius, symbol °C. The numerical value of a Celsius temperature t expressed in degrees Celsius is given by

t/°C = T/K - 273.15.

It follows from the definition of t that the degree Celsius is equal in magnitude to the kelvin, which in turn implies that the numerical value of a given temperature difference or temperature interval whose value is expressed in the unit degree Celsius (°C) is equal to the numerical value of the same difference or interval when its value is expressed in the unit kelvin (K).

Thus, temperature differences or temperature intervals may be expressed in either the degree Celsius or the kelvin using the same numerical value. For example, the Celsius temperature difference Δt and the thermodynamic temperature difference ΔT between the melting point of gallium and the triple point of water may be written as
Δt = 29.7546 °C = ΔT = 29.7546 K.

Matter

One of the main quests of science throughout the ages has been to discover what matter is made of - and what holds it together. All matter is made out of many tiny particles called atoms. The study of how these atoms interact is called chemistry. Modern physics has discovered how atoms are made up of smaller particles and how these particles interact to build atoms into molecules and larger objects of matter.

The philosopher Democritus came very close to our modern understanding when he proposed that everything is made up of very small particles, which he called atoms, from the Greek atomus, for 'indivisible'.

In the 1600s, Sir Isaac Newton and other scientists experimented with materials, light, and heat, and developed many basic laws of physics. By the early 1800s, the theory of the atom became popular. By the 1900s, scientists had discovered that atoms are themselves made of even smaller particles. This century research in particle physics has taken us deep into the heart of the atom, far beyond the limits of the most powerful conventional microscopes.

The Building Blocks of Matter

What is matter made of? If you could see the smallest piece of matter, what would it look like? If you cut a piece of material into halves, and cut one of the halves into halves, and then continued cutting halves into halves - assuming you had a very fine blade and a very powerful microscope - could you continue cutting forever?

Until very recently, there was no microscope powerful enough to see the 'building blocks' of matter. But scientists were able to deduce that there were fundamental particles, which they called atoms (for indivisible), by performing experiments such as firing electrons into targets and seeing how the pieces came out.

Atoms are extremely small particles, out of which all matter is made. They are the smallest particles of a chemical element that still have the properties of that element.

A typical atom is about one millionth of a millimetre across - a million of them laid in a line would measure one millimetre across. The lightest atom is that of hydrogen, while one of the heaviest is that of uranium - about 200 times heavier than hydrogen.

Splitting large atoms into smaller ones or 'fusing' small ones to create larger ones, releases energy - this is what happens inside nuclear reactors and atom bombs (fission) and inside hydrogen bombs and the sun (fusion).
SI base units

Matter consists of atoms held together by electromagnetic forces. How tight these bonds are determines which of the four states: solid, liquid, gas or plasma, matter exists as. Plasmas are only found naturally in the coronae and cores of stars. They can also be created experimentally in laboratories such as JET.

As the atoms move faster, the distances between them increases. Heating increases the motion of atoms and causes the matter to go from solid (ice) to liquid (water) to gas (vapor).

Heat and temperature is explained in atomic theory as the motion of the atoms (faster = hotter).
Pressure is explained as the momentum transfer of those moving atoms on the walls of the container (faster atoms = higher temperature = more momentum/hits = higher pressure).

In the physical sciences, a phase is a set of states of a macroscopic physical system that have relatively uniform chemical composition and physical properties (i.e. density, crystal structure, index of refraction, and so forth).

The most familiar examples of phases are solids, liquids, and gases. Less familiar phases include: plasmas and quark-gluon plasmas; Bose-Einstein condensates and fermionic condensates; strange matter; liquid crystals; superfluids and supersolids; and the paramagnetic and ferromagnetic phases of magnetic materials.

Phases are sometimes called states of matter, but this term can lead to confusion with thermodynamic states. For example, two gases maintained at different pressures are in different thermodynamic states, but the same "state of matter".

Fluids and Gases

A subset of the phases of matter, fluids include liquids, gases, plasmas and, to some extent, plastic solids. Fluids are divided into liquids and gases.

• Liquids form a free surface (that is, a surface not created by their container) while gases do not.

• A gas is one of the four main phases of matter (after solid and liquid, and followed by plasma), that subsequently appear as a solid material is subjected to increasingly higher temperatures. Thus, as energy in the form of heat is added, a solid (e.g. ice) will first melt to become a liquid (e.g. water), which will then boil or evaporate to become a gas (e.g. water vapor). In some circumstances, a solid (e.g. "dry ice") can directly turn into a gas: this is called sublimation. If the gas is further heated, its atoms or molecules can become (wholly or partially) ionized, turning the gas into a plasma.

Surface Tension

Certain substances can break down surface tension in a liquid. In this experiment, the surface tension of the milk initially holds the drops of food colouring in place. However, what will happen lo the drops of food colouring when you add washing-up liquid to the dish? You will need: shallow dish; milk; two eye-droppers; food colouring; washing-up liquid.

• Pour milk into a shallow dish and leave it to warm up to room temperature. Using an eye-dropper, carefully squeeze a few drops of different food colourings onto the surface. Notice that the drops of food colouring form separate circles on the surface. The food colouring does not break the surface tension of the milk.

• Using a different dropper, squeeze some washing-up liquid onto the milk. Watch the colours spread as the flexible skin on the milk starts to break down where the drops of washing-up liquid fall. The stronger surface tension around the edge of the dish then pulls the milk and food colouring outwards.

Air Streams

Another aspect of fluid flow is that the pressure in a fluid drops as it moves faster. This is known as the Bernoulli effect, named after the Swiss mathematician Daniel Bernoulli (1700-82). We can use this theory to explain how we are able to make a ping- pong ball hover in the air. You will need: a hairdryer set to "cool"; a ping-pong ball.

• Hold a hairdryer so that it points upwards. Place the ping-pong ball in the middle of the airstream.

• You'll find that the ball will stay put. In the middle, the air flows faster (less pressure) than it does at the edges (higher pressure). The higher pressure always pushes the ball back.

Reflection of Light

If we draw a line perpendicular to a surface, this line is the normal of the surface. When a ray of light hits the surface of an object, part of the light is reflected. If the ray of light is in angle with the surface, then the angle between the incident ray and the normal will be the same angle between the normal and the reflected ray.

They are not completely flat surfaces. When millions of rays of light hit the rough surface of an object, they are reflected in all directions. This is how we can see illuminated objects.
Refraction of light

When a ray of light passes from one medium to another, it bends. Depending of the new medium the light will travel faster or slower. If the light travels faster in the second medium, then this medium is called the rarer medium. On the other hand, the medium in which the light travels slower, in this case the first one, is called the denser medium.

When a ray of light enters a denser medium, it is bent towards the normal.

When a ray of light enters a rarer medium, it is bent away from the normal.

There is an index of refraction (n) between the two mediums. To get a value, we have to divide the sine of the angle in vacuum or air by the sine of the angle in the denser medium.

In the example above, the index of refraction would be

$n = \sin a / \sin b$

Some of the light is always reflected. However, when a ray of light goes from a denser medium to a rarer medium, all the light will be reflected if the angle of incidence is greater than the critical angle. The critical angle is the angle of incidence for which the refracted ray is at 90 degrees with the normal.

Absorption

Light falling on an object may be absorbed, transmitted, or reflected. What happens to it depends on the color of the object: a red object reflects red light and absorbs much of the rest of the other colors that we see. The color of an object is that color which is reflected rather than absorbed. Absorption, in optics, is the process by which the energy of a photon is taken up by another entity, for example, by an atom whose valence electrons make a transition between two electronic energy levels. The photon is destroyed in the process. The absorbed energy can be lost by heat and radiation.

The absorbance of an object quantifies how much light is absorbed by it. This may be related to other properties of the object through the Beer-Lambert law. For most substances, the amount of absorption varies with the wavelength of the light, leading to the appearance of colour in pigments that absorb some wavelengths but not others. For example, an object that absorbs blue, green and yellow light will appear red when viewed under white light. More precise measurements at many wavelengths allow the indentification of a substance via absorption spectroscopy.

Interference

Interference is the superposition of two or more waves resulting in a new wave pattern. As most commonly used, the term usually refers to the interference of waves which are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. Two non-monochromatic waves are only fully coherent with each other if they both have exactly the same range of wavelengths and the same phase differences at each of the constituent wavelengths.

The principle of superposition of waves states that the resultant displacement at a point is equal to the sum of the displacements of different waves at that point. If a crest of a wave meets a crest of another wave at the same point then the crests interfere constructively and the resultant wave amplitude is greater. If a crest of a wave meets a trough then they interfere destructively, and the overall amplitude is decreased. Interference is the net effect of the combination of two or more wave trains moving on intersecting or coincident paths. The effect is that of the addition of the amplitudes of the individual waves at each point affected by more than one wave.

If two of the components are of the same frequency and phase (i.e., they vibrate at the same rate and are maximum at the same time), the wave amplitudes are reinforced, producing constructive interference; but, if the two waves are out of phase by 1/2 period (i.e., one is minimum when the other is maximum), the result is destructive interference, producing complete annulment if they are of equal amplitude.

One of the best examples of interference is demonstrated by the light reflected from a film of oil floating on water or a soap bubble, which reflects a variety of beautiful colors when illuminated by natural or artificial light sources.