

MEASUREMENT

The International System of Units

The 7 base units, the 2019 constant-based definitions, prefixes and derived units, and a 10-question practice set with full solutions.

SUBJECT	LEVEL	INCLUDES
Physics	High school and early college	Practice set, answer key, revision sheet

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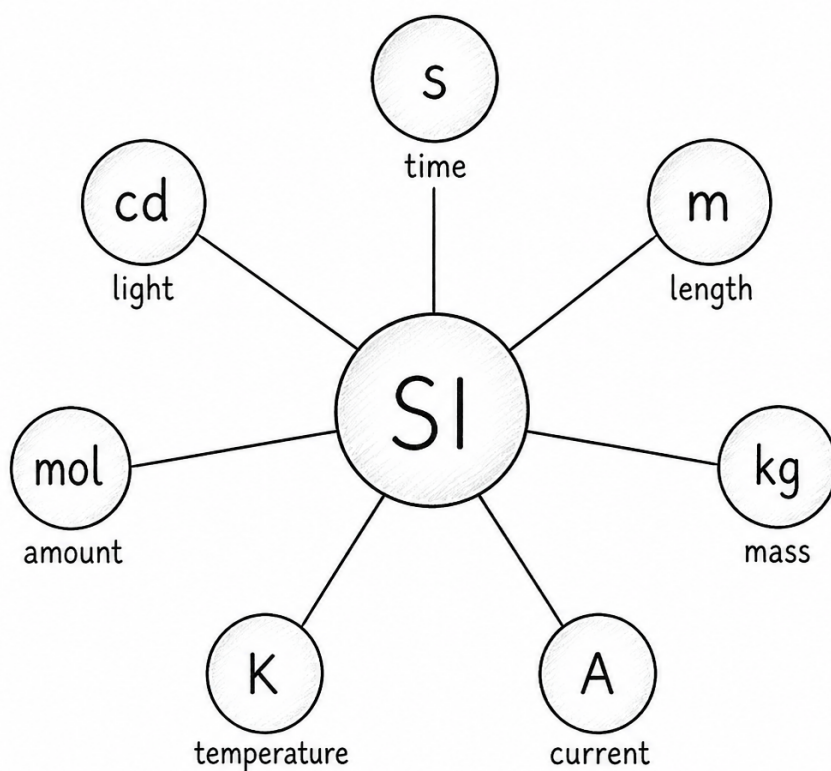
When you measure something in physics, you need a standard everyone agrees on. Without that, measurements are meaningless. The International System of Units provides exactly this universal framework. Over the centuries, different countries developed their own systems, and three of them became widely used:

- The **CGS system** (centimeter, gram, and second)
- The **MKS system** (meter, kilogram, and second)
- The **FPS system** (foot, pound, and second)

The internationally accepted system today is the **Systeme Internationale d' Unites**, abbreviated as SI. You'll see it called the International System of Units in most textbooks. SI is built on the metric system, which means conversions are based on powers of 10. That makes your calculations far simpler than working with feet and inches. If you're studying physics at any level, understanding [units and measurements](#) starts with knowing the International System of Units inside and out.

History of the International System of Units

The roots of the International System of Units trace back to the French Revolution. In the 1790s, French scientists proposed a decimal-based measurement system that would replace the chaotic patchwork of local units used across Europe. They defined the meter as one ten-millionth of the distance from the North Pole to the equator along a meridian through Paris. The kilogram was defined as the mass of one liter of water at its densest temperature (about 4°C).



The 7 base units: every other unit in science is assembled from these.

France officially adopted the metric system in 1795, making it the first country to do so. Other nations followed slowly. By 1875, the need for international coordination led to the **Metre Convention**, a treaty signed by 17 nations that established the **Bureau International des Poids et Mesures (BIPM)** near Paris. The BIPM's job was to maintain international prototype standards and coordinate measurement science worldwide.

The metric system evolved through several stages. The CGS system (centimeter-gram-second) dominated 19th-century physics, while engineers preferred the MKS system (meter-kilogram-second). In 1960, the 11th General Conference on Weights and Measures (CGPM) formally established the International System of Units as the modern form of the metric system. It included six base units initially. The mole was added as the seventh base unit in 1971.

KEY FACT

As of [year], the BIPM has 64 member states and 36 associate states. The International System of Units is now the official measurement system in every country except the United States, Myanmar, and Liberia, though even these countries use SI in scientific contexts.

Units: Fundamental and Derived

Physical quantities fall into two categories based on how their units are defined. The units for base or fundamental quantities are called **fundamental units**. You can't break these down into simpler units. The units of all other physical quantities, which you can express as combinations of fundamental units, are called **derived units**. This distinction is central to how the International System of Units organizes all of measurement science.

A complete set of fundamental and derived units together is called a **system of units**.

For any unit to be useful in science, it must satisfy four basic properties:

- 1 It should be readily available and reproducible.
- 2 It must be well-defined, leaving no room for ambiguity.
- 3 It should be invariable, meaning it doesn't change with time, location, or conditions.
- 4 It should be universally acceptable across all countries and scientific disciplines.

The Seven SI Base Units

The SI system rests on **seven fundamental or base units**. These are completely independent of each other, and you can express every other physical quantity in terms of these seven. Think of them as the building blocks of all measurement in physics.

BASE QUANTITY	SI UNIT	SYMBOL	WHAT IT MEASURES
Length	Meter	m	Distance between two points
Mass	Kilogram	kg	Amount of matter in an object
Time	Second	s	Duration of an event
Electric Current	Ampere	A	Flow of electric charge
Temperature	Kelvin	K	Thermodynamic temperature
Amount of Substance	Mole	mol	Number of elementary entities (atoms, molecules, etc.)
Luminous Intensity	Candela	cd	Power of light emitted in a given direction

Let's look at each one so you understand exactly what it represents and how it's defined.

Meter (m)

The meter is the SI unit of length. It's defined as the distance light travels in a vacuum in exactly $1/299,792,458$ of a second. This ties the meter directly to the speed of light, making it one of the most precisely defined units you'll encounter.

Kilogram (kg)

The kilogram is the SI unit of mass. Until 2019, it was defined by a physical platinum-iridium cylinder kept in a vault in France. Now it's defined using the Planck constant ($h = 6.62607015 \times 10^{-34} \text{ J s}$). This means the kilogram is no longer tied to any physical object, which makes it far more stable and reproducible.

Second (s)

The second is the SI unit of time. It's defined as the duration of 9,192,631,770 periods of the radiation corresponding to a specific transition of the cesium-133 atom. Atomic clocks based on this definition are so accurate that they would lose less than one second over millions of years.

Ampere (A)

The ampere is the SI unit of electric current. It's now defined by fixing the elementary charge (e) to exactly $1.602176634 \times 10^{-19}$ coulombs. In simpler terms, one ampere corresponds to the flow of about 6.24×10^{18} electrons per second past a given point.

Kelvin (K)

The kelvin is the SI unit of thermodynamic temperature. It's defined by fixing the [Boltzmann constant](#) (k) to exactly 1.380649×10^{-23} J/K. Zero kelvin (0 K) represents absolute zero, the lowest temperature theoretically possible, where all molecular motion would cease.

Mole (mol)

The mole is the SI unit for the amount of substance. One mole contains exactly $6.02214076 \times 10^{23}$ elementary entities. This number is called the Avogadro constant. When you use the mole, you must always specify what entities you're counting, whether atoms, molecules, ions, or electrons.

Candela (cd)

The candela is the SI unit of luminous intensity. It measures the power of light emitted by a source in a particular direction, weighted by the sensitivity of the human eye. It's defined by fixing the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz to be 683 lumens per watt.

The 2019 SI Redefinition

On 20 May 2019, the SI system underwent its most significant overhaul in decades. Four of the seven base units (kilogram, ampere, kelvin, and mole) were redefined in terms of fixed numerical values of fundamental physical constants. The kilogram was the last unit still defined by a physical artifact, and that changed with this revision.

What this means for you as a student is that every SI base unit is now anchored to an unchanging constant of nature, not to any physical object that could degrade or vary over time. The definitions became more elegant and, more importantly, more precise and universally reproducible.

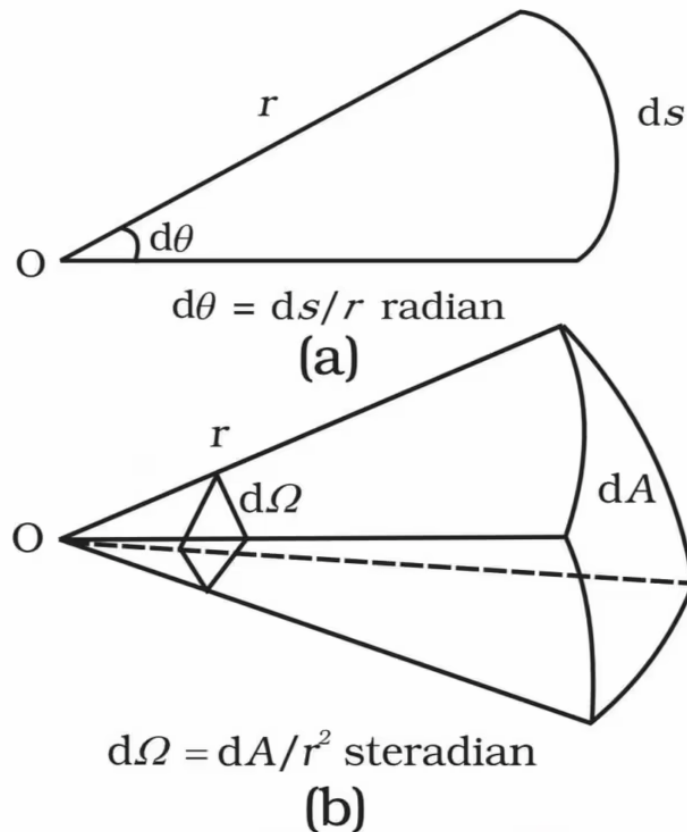
Here are the four constants that now define these units:

CONSTANT	SYMBOL	EXACT VALUE	DEFINES
Planck constant	h	$6.62607015 \times 10^{-34} \text{ J s}$	Kilogram
Elementary charge	e	$1.602176634 \times 10^{-19} \text{ C}$	Ampere
Boltzmann constant	k	$1.380649 \times 10^{-23} \text{ J/K}$	Kelvin
Avogadro constant	N_A	$6.02214076 \times 10^{23} \text{ mol}^{-1}$	Mole

Supplementary Units

Apart from the seven base units, the SI system also recognizes two supplementary quantities for measuring angles:

- 1 **Plane angle** ($d\theta$) is defined as the ratio of the length of arc (ds) to the radius (r). Its unit is the **radian** (rad).
- 2 **Solid angle** ($d\Omega$) is defined as the ratio of the intercepted area (dA) of a spherical surface, described about the apex O as the center, to the square of its radius (r^2). Its unit is the **steradian** (sr).



Plane angle and solid angle

Both the radian and steradian are dimensionless quantities. They were originally classified as "supplementary units" by the SI, but since 1995 they're treated as derived units with a special status.

Derived Units in the International System of Units

Every physical quantity that isn't one of the seven base quantities is a derived quantity. Its unit is a derived unit, formed by combining base units through multiplication or division. For example, speed is measured in meters per second (m/s), which combines the base units for length and time.

Some derived units are used so frequently that they get their own names and symbols. The table below lists the most important named derived units you'll encounter in physics. Each can be traced back to combinations of the seven base units.

DERIVED QUANTITY	SI UNIT	SYMBOL	IN BASE UNITS
Force	Newton	N	kg m s^{-2}
Pressure	Pascal	Pa	$\text{kg m}^{-1} \text{s}^{-2}$
Energy / Work	Joule	J	$\text{kg m}^2 \text{s}^{-2}$
Power	Watt	W	$\text{kg m}^2 \text{s}^{-3}$
Electric Charge	Coulomb	C	A s
Voltage	Volt	V	$\text{kg m}^2 \text{s}^{-3} \text{A}^{-1}$
Resistance	Ohm	Ω	$\text{kg m}^2 \text{s}^{-3} \text{A}^{-2}$
Frequency	Hertz	Hz	s^{-1}
Capacitance	Farad	F	$\text{kg}^{-1} \text{m}^{-2} \text{s}^4 \text{A}^2$
Magnetic Flux	Weber	Wb	$\text{kg m}^2 \text{s}^{-2} \text{A}^{-1}$

Whenever you express a derived unit, make sure you can trace it back to the base units. For instance, $1 \text{ N} = 1 \text{ kg m s}^{-2}$. This skill of dimensional analysis will help you verify equations and catch errors in your calculations. You'll use this constantly when solving problems involving [kinematic equations](#).

SI Prefixes

The International System of Units uses a set of prefixes to express very large or very small quantities without writing out long strings of zeros. These prefixes represent powers of 10 and attach directly to the unit name. For example, 1 kilometer = 1,000 meters, and 1 milligram = 0.001 grams. Mastering prefixes is essential for working with [significant figures](#) and unit conversions.

PREFIX	SYMBOL	FACTOR	EXAMPLE
yotta	Y	10^{24}	Mass of Earth (~6 Yg)
zetta	Z	10^{21}	Global data storage
exa	E	10^{18}	Age of universe (~0.4 Es)
peta	P	10^{15}	Distance to nearest stars
tera	T	10^{12}	1 THz infrared radiation
giga	G	10^9	Computer memory (GB)
mega	M	10^6	Radio frequencies (MHz)
kilo	k	10^3	1 km = 1,000 m
hecto	h	10^2	Atmospheric pressure (hPa)
deca	da	10^1	1 daL = 10 liters
deci	d	10^{-1}	1 dL = 0.1 liter
centi	c	10^{-2}	1 cm = 0.01 m
milli	m	10^{-3}	1 mg = 0.001 g
micro	μ	10^{-6}	Bacteria size (~1 μ m)
nano	n	10^{-9}	Semiconductor features (nm)
pico	p	10^{-12}	Atomic bond lengths
femto	f	10^{-15}	Nuclear radius (~1 fm)
atto	a	10^{-18}	Electron orbital period
zepto	z	10^{-21}	Single molecule mass
yocto	y	10^{-24}	Proton mass (~1.67 yg)

In 2022, four new prefixes were added: **ronna** (R, 10^{27}), **quetta** (Q, 10^{30}), **ronto** (r, 10^{-27}), and **quecto** (q, 10^{-30}). These were the first new prefixes added since 1991 and were driven by the growing need to express extremely large quantities in data science and cosmology.

Real-World Applications of SI Units

SI units aren't just abstract definitions in a textbook. They're the backbone of nearly every measurement you'll encounter in science, engineering, medicine, and daily life. Here's how different fields depend on the International System of Units.

Science and Research

Every published physics experiment reports results in SI units. CERN measures particle energies in electronvolts (a non-SI unit accepted for use with SI), but all fundamental measurements, from collision energies to detector dimensions, use SI base and derived units. NASA's Mars Climate Orbiter was famously lost in 1999 because one engineering team used imperial units while another used SI, resulting in a trajectory error that destroyed a \$125 million spacecraft.

Engineering and Manufacturing

Modern manufacturing depends on SI units for precision. Semiconductor fabs measure transistor features in nanometers (nm). A single Intel processor has transistors as small as 3 nm. Structural engineers calculate forces in newtons, pressures in pascals, and energy in joules. Without a unified system, global supply chains would be impossible to coordinate.

Medicine and Pharmacology

Drug dosages are prescribed in milligrams (mg) or micrograms (μg). Blood pressure is measured in millimeters of mercury (mmHg, another non-SI unit accepted for medical use), while body temperature uses degrees Celsius (derived from kelvin). Lab results report concentrations in moles per liter (mol/L). A dosage error of even a few milligrams can be the difference between treatment and toxicity, which is why precision in SI units is literally life-or-death in medicine.

Everyday Life

You interact with SI units constantly, even if you don't think about it. Your phone's screen brightness is measured in candelas per square meter (cd/m^2). The energy content on food labels is in kilojoules (kJ). Your electricity bill is calculated in kilowatt-hours (kWh). Road signs in most countries show distances in kilometers and speed limits in km/h.

TIP

When solving physics problems, always convert all quantities to SI base units before plugging them into equations. This prevents unit mismatch errors and ensures your final answer comes out in the correct unit automatically. For example, convert centimeters to meters and grams to kilograms before you start calculating.

Practice Questions

Work each question before reading its solution. The set runs from direct recall and substitution to the applied questions that exams actually use to separate grades.

Q1. List the 7 SI base units with their symbols and quantities.

SOLUTION

Second (s, time), meter (m, length), kilogram (kg, mass), ampere (A, current), kelvin (K, temperature), mole (mol, amount of substance), candela (cd, luminous intensity). Everything else, newtons to sieverts, derives from these.

Q2. How has the meter been defined since 1983, and what does that make of the speed of light?

SOLUTION

The meter is the distance light travels in vacuum in $\frac{1}{299,792,458}$ of a second. This makes c exactly 299,792,458 m/s by definition, no longer a measured quantity with error bars. Measuring "the speed of light" today is really calibrating your meter.

Q3. What replaced the platinum-iridium kilogram in 2019, and why was the change necessary?

SOLUTION

The kilogram is now fixed through an exact value of Planck's constant, $h = 6.62607015 \times 10^{-34}$ J·s, realized by the Kibble balance. The Paris cylinder drifted by tens of micrograms relative to its own copies, and a unit that changes when its prototype is cleaned is not a foundation. Constants of nature cannot be scratched.

Q4. Express these with SI prefixes: 3×10^{-9} s, 5×10^6 W, 2×10^{-6} m.

SOLUTION

3 ns (nano), 5 MW (mega), $2 \mu\text{m}$ (micro). Prefixes step in factors of 1000 through the working range: kilo, mega, giga, tera up; milli, micro, nano, pico down. One symbol replaces a power of ten and kills a class of exponent errors.

Q5. Why is the kilogram, not the gram, the SI base unit of mass, and what trap does this set in formulas?

SOLUTION

History: the base was chosen to match practical 18th-century standards, and the name kept its prefix. The trap: formulas like $KE = \frac{1}{2}mv^2$ want kilograms, so a 500 g mass enters as 0.5, not 500. Feeding grams into an SI formula inflates every answer a thousandfold.

Q6. Derive the SI units of the pascal and the watt from their definitions.

SOLUTION

Pressure is force per area: $\text{Pa} = \text{N}/\text{m}^2 = \text{kg}/(\text{m}\cdot\text{s}^2)$. Power is energy per time: $\text{W} = \text{J}/\text{s} = \text{kg}\cdot\text{m}^2/\text{s}^3$. Chaining definitions down to base units is mechanical, and the result is the dimensional fingerprint any valid formula must match.

Q7. Is the kelvin scale just Celsius shifted? Convert 25°C and explain what makes kelvin absolute.

SOLUTION

$T = 25 + 273.15 = 298.15 \text{ K}$. The size of 1 kelvin equals the size of 1°C , so differences match, but kelvin starts at absolute zero, the point of minimal thermal motion, so it never goes negative. Physics formulas (gas laws, Boltzmann factors) demand the absolute scale; Celsius in $pV = nRT$ is a wrong answer every time.

Q8. The mole was redefined in 2019 too. What is a mole now?

SOLUTION

Exactly $6.02214076 \times 10^{23}$ elementary entities, with Avogadro's number fixed by decree rather than tied to 12 g of carbon-12. A mole of anything, atoms, molecules, electrons, is now literally a fixed count, making the unit conceptually the same kind of thing as "a dozen."

Q9. Which everyday "metric" units are accepted for use with the SI without being SI units? Name 3 and their SI equivalents.

SOLUTION

The liter ($1 \text{ L} = 10^{-3} \text{ m}^3$), the tonne ($1 \text{ t} = 10^3 \text{ kg}$), and the hour ($1 \text{ h} = 3600 \text{ s}$); also the degree Celsius and the electronvolt. They are tolerated companions, defined exactly in SI terms, but formal derived-unit algebra runs on cubic meters, kilograms, and seconds.

Q10. A US customer orders parts milled to "0.5 inches" from a metric shop. Convert exactly, and state why the inch has an exact metric value.

SOLUTION

Since 1959 the international inch is defined as exactly 25.4 mm, so $0.5 \text{ in} = 12.7 \text{ mm}$ precisely, no rounding. Imperial units survive only as fixed multiples of SI: the inch, pound, and gallon are all defined through metric constants. There is only one measurement system underneath.

Answer Key

QUICK ANSWERS

Q1 s, m, kg, A, K, mol, cd **Q2** defined via light; c is exact **Q3** a fixed h via the Kibble balance **Q4** 3 ns, 5 MW, $2\ \mu\text{m}$ **Q5** historical; always convert g $\rightarrow$ kg first
Q6 $\text{Pa} = \text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-2}$; $\text{W} = \text{kg}\cdot\text{m}^2\cdot\text{s}^{-3}$ **Q7** 298.15 K; zero means absolute zero **Q8** a fixed count: $6.02214076 \times 10^{23}$ **Q9** L, t, h (and $^{\circ}\text{C}$, eV) **Q10** 12.7 mm exactly

Revision Sheet

7 base units

second, meter, kilogram, ampere, kelvin, mole, candela.

Prefix ladder

T G M k, m μ n p: steps of 1000. Convert before computing.

2019 rule

All units fixed by exact constants: c , h , e , k , N_A , $\Delta\nu_{Cs}$, K_{cd} .

Formula discipline

SI formulas eat kg, m, s, K. Grams, cm, hours, and $^{\circ}\text{C}$ must be converted first.

Key derived units

$\text{N} = \text{kg}\cdot\text{m}/\text{s}^2$; $\text{J} = \text{N}\cdot\text{m}$; $\text{W} = \text{J}/\text{s}$; $\text{Pa} = \text{N}/\text{m}^2$; $\text{Hz} = \text{s}^{-1}$; $\text{C} = \text{A}\cdot\text{s}$; $\text{V} = \text{W}/\text{A}$.

Accepted guests

L, t, h, $^{\circ}\text{C}$, eV: exact SI multiples, fine for stating, converted for algebra.

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