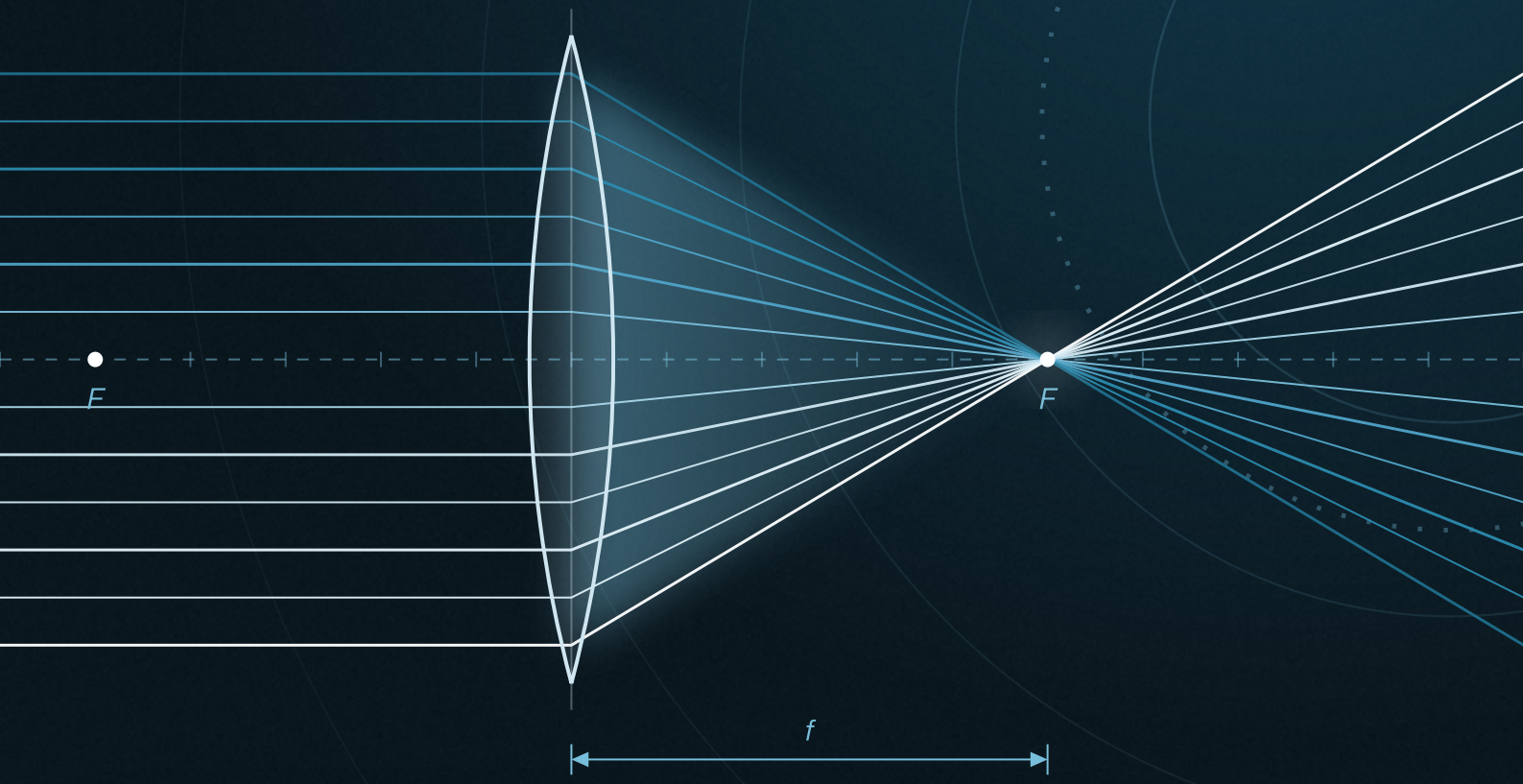
XamAgent

PRELIMS 2027

ED. 2027 · 15 CH · PYQ-PROOF · 189 FIG · 400 ★★★ · 183 MCQ



PRELIMS NOTES

Physics

The night before Prelims, you'll want just one book.

PYQ-PROOF

Every UPSC & BPSC question since 2011 is answerable from these notes.

16 · YEARS

UPSC CSE · BPSC · UPPCS · SSC CGL

Also in हिन्दी

A note to the reader

Most short notes are short for a reason. Forty or fifty pages, small type, every page full to the edge. One page takes twenty minutes to read and is forgotten by the next. After the exam, they count the questions that “came from” them.

This book does not work that way.

- **Readable type.** Set to be read, not squeezed.
- **Two to three minutes a page.** Measured, not estimated.
- **Built for recall.** Every idea has a diagram, a memory hook, an everyday example and the trap examiners set around it.

It is longer than short notes because memory needs room. The extra pages hold no extra facts to cram.

You will like this book if you value:

- understanding an idea before memorising it;
- knowing which facts to revise first, and which can wait;
- pages that are easy to read and quick to revise;
- notes tested against real papers before the exam, not credited with them after it.

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How to read: ★★★ asked again and again, ★★ asked sometimes, ★ good to know. Read the whole chapter once, then revise only the revision card and ★★★ points. Green boxes are memory tricks, red boxes are the traps examiners set, orange boxes show the idea in daily life.

Revision reminders: scan once

Add the page to your home screen. After each chapter, one tap adds reminders to revise it on day 1, 3, 7 and 21. No sign-in, nothing collected.

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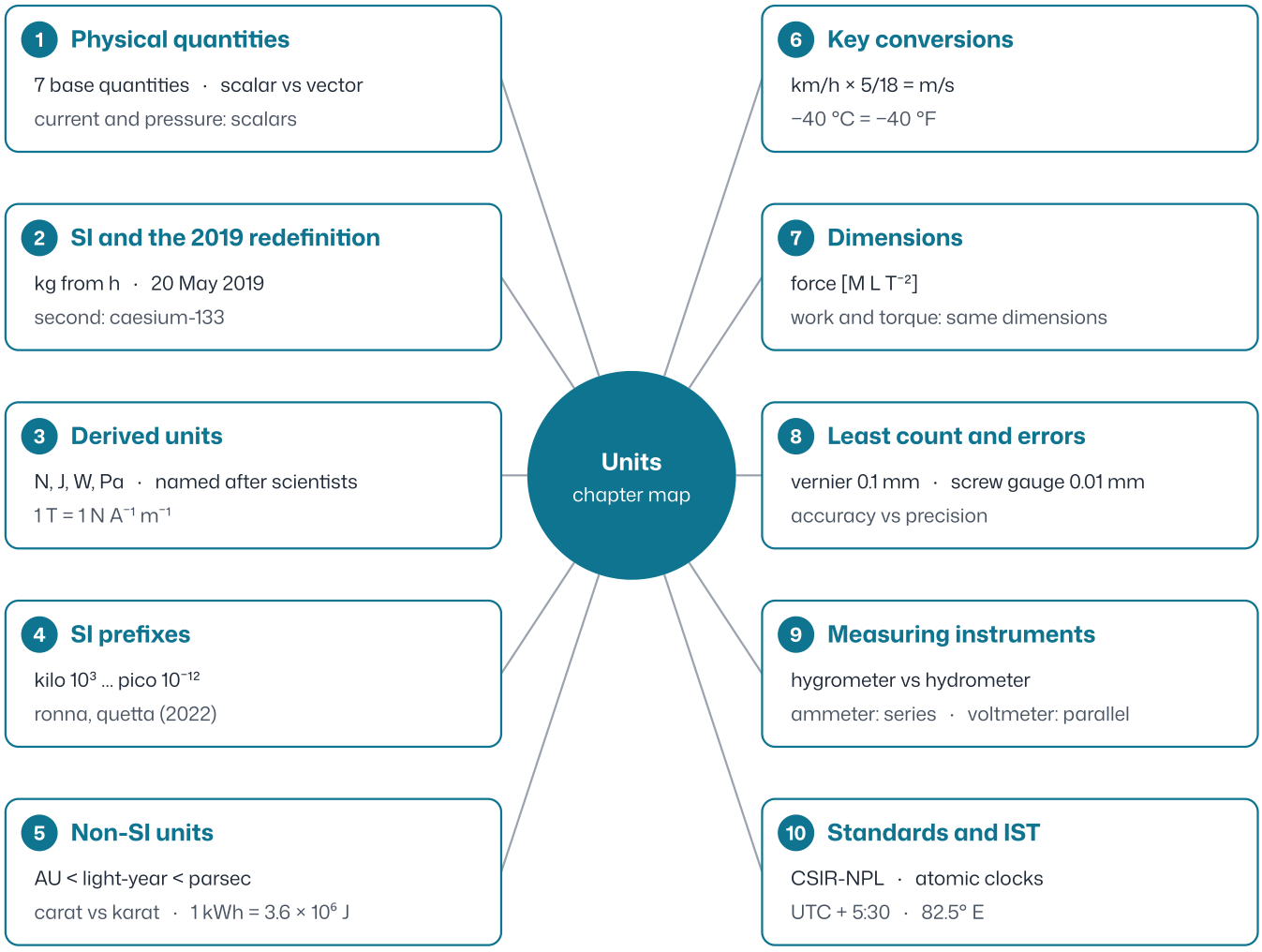
CHAPTER 1

Units, Measurement and Measuring Instruments

BPSC asks two to four questions from here almost every year: which unit measures what, scalar or vector, light-year, kWh to joule, and which '-meter' measures what. SSC and UPPCS repeat the same unit and instrument lists.

Asked 16 times in past papers: UPSC 1 · BPSC 15

≈ 58 min to read ≈ 7 min to revise ★★★ Revise on: Day 1 | Day 3 | Day 7 | Day 21



Revision card

1. Seven SI base units: metre, kilogram, second, ampere, kelvin, mole, candela. Hook: King Mohan Sells Apples, Keeps Mangoes, Candies (kg, m, s, A, K, mol, cd).
2. Since 20 May 2019 all SI units rest on fixed constants: kilogram on Planck constant h, ampere on charge e, kelvin on Boltzmann k, mole on Avogadro N_A.
3. Light-year is a distance (≈ 9.46×10^{12} km). Parsec ≈ 3.26 light-years. AU ≈ 1.5×10^8 km (Earth–Sun).
4. 1 unit of electricity = 1 kWh = 3.6×10^6 J. So 250 units = 9×10^8 J.
5. 1 hp ≈ 746 W; 1 cal ≈ 4.186 J; 1 eV = 1.6×10^{-19} J; 1 atm = 1.013×10^5 Pa = 760 mm Hg.
6. Ångström = 10^{-10} m (wavelength, atom size); fermi = 10^{-15} m (nucleus); micron = 10^{-6} m.
7. Tesla = magnetic field = Wb/m² = N A^{-1} m^{-1} = 10^4 gauss. Hertz = frequency. Watt = power. Pascal = pressure.
8. Scalars: speed, pressure, current, work, energy. Vectors: displacement, velocity, force, torque, current density.
9. No unit at all: strain, refractive index, relative density, Mach number, coefficient of friction.
10. Hygrometer = humidity; hydrometer = liquid density; lactometer = milk; odometer = distance; speedometer = speed; tachometer = rpm.
11. Dynamo makes electricity; dynamometer measures force or engine power. Thermostat keeps temperature steady, it does not measure it.
12. Carat = 0.2 g for gems; karat = gold purity (24K pure, 22K ≈ 91.6%). Knot = a speed (1.852 km/h).
13. Newest prefixes (2022): ronna 10^{27}, quetta 10^{30}, ronto 10^{-27}, quecto 10^{-30}.
14. CSIR-NPL, New Delhi keeps India's national standards and IST (UTC + 5:30, 82.5° E); 2026 rules make IST the single legal time.

Physical quantities: base, derived, scalar, vector

7 base quantities

scalar vs vector

current: scalar

pressure: scalar

speed vs velocity

Anything we can measure is a **physical quantity**: a number plus a unit (5 kg, 20 m/s). A handful of quantities are chosen as **base (fundamental)** quantities; every other quantity is **derived** from them by multiplying or dividing. Speed is length ÷ time, so it needs no unit of its own.

★★★ **Base quantities (7)**: length, mass, time, electric current, temperature, amount of substance, luminous intensity. Force, velocity, work and pressure are derived.

★★ **Derived quantity** = built from base ones, e.g. force = mass × acceleration (kg m s^{-2}), density = mass ÷ volume (kg m^{-3}).

★★★ **Scalar**: has only size (magnitude). Mass, length, time, speed, distance, temperature, work, energy, power, pressure, density, volume, charge, potential, frequency.

★★★ **Vector**: has size and direction and adds by the triangle (parallelogram) rule. Displacement, velocity, acceleration, force, weight, momentum, impulse, torque, angular momentum, electric field, magnetic field.

★★★ **Electric current is a scalar** even though it 'flows' in a direction: two currents meeting at a junction simply add, they do not follow vector addition.

★★★ **Current density** (current per unit area) **is a vector**; it points along the flow at each point.

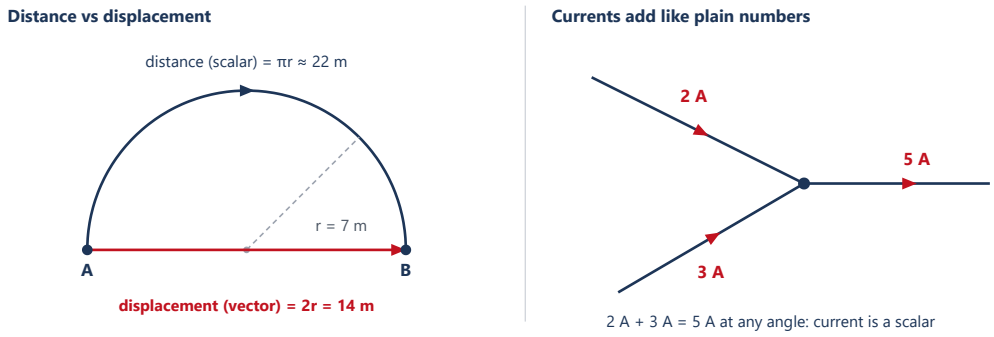
★★★ **Pressure is a scalar**: at a point in a fluid it acts equally in all directions. The force it produces on a surface is a vector.

★★ **Speed vs velocity**: speed = distance ÷ time (scalar); velocity = displacement ÷ time (vector). A runner finishing one full lap has zero displacement and zero average velocity but non-zero average speed.

★ **Tensors**: stress and moment of inertia are neither simple scalars nor vectors; prelims usually lists stress with pressure because both are force per area.

Scalar or vector: the ones examiners pick ★★★

Scalar	Vector
Distance	Displacement
Speed	Velocity
Mass	Weight (a force)
Work, energy, power	Force, torque
Pressure	Thrust (force on a surface)
Electric current	Current density
Electric potential, charge	Electric field
Magnetic flux	Magnetic field (flux density) B
Temperature, heat	Momentum, impulse
Time, volume, density	Acceleration, angular velocity



Left: going from A to B round a semicircle of radius 7 m covers a distance of πr ≈ 22 m, but the displacement is only the straight line AB = 14 m (drawn to scale). Right: 2 A and 3 A meeting at a junction always give 5 A, whatever the angle between the wires, so current is a scalar.

Remember it: Ask: 'Does it point somewhere?' A push (force), a twist (torque) and a shift in place (displacement) all point. A price tag (mass, energy, temperature) does not. Current is the odd one: it flows but obeys plain addition, like water from two taps filling one bucket.

⚠ Exam trap: 'Which is NOT a vector?' with options displacement, speed, velocity, torque: the answer is speed. 'Current is a vector' is false; 'current density is a vector' is true. 'Pressure is a vector' is false.

Quick check

1. How many base quantities does SI have? Is force one of them?
2. Current flows in a direction. Why is it still a scalar?
3. After one full lap of a track, which is zero: average speed or average velocity?

Answer: 1. seven; no, force is derived · 2. currents at a junction add as plain numbers, not by vector rules · 3. average velocity (displacement is zero)

The SI system and the 2019 redefinition

7 base units

kg from h

20 May 2019

caesium-133

metre from c

Kibble balance

Different regions once used feet, seers and tolas, so trade and science needed one common language of measurement. The **Metre Convention (20 May 1875)** set up the **BIPM** near Paris, and the **11th CGPM (1960)** named the modern metric system the **SI (Système International d'Unités)**. In 2019 every base unit was tied to a fixed constant of nature, so a unit can be made anywhere and never drifts.

The seven SI base units ★★★

Base quantity	SI unit	Symbol	Named after
Length	metre	m	Greek 'metron', measure
Mass	kilogram	kg	Greek 'gramma'
Time	second	s	second division of the hour
Electric current	ampere	A	André-Marie Ampère
Thermodynamic temperature	kelvin	K	Lord Kelvin (William Thomson)
Amount of substance	mole	mol	German 'Molekül'
Luminous intensity	candela	cd	Latin 'candle'

Remember it: King Mohan Sells Apples, Keeps Mangoes, Candies → kg, m, s, A, K, mol, cd. Only two base units carry a person's name: Ampère and Kelvin (A and K are the capital letters).

The 7 SI base units and the constant that fixes each (since 20 May 2019)

Quantity	Unit (symbol)	Fixed constant	Defined so since
Time	second (s)	Cs-133 frequency = 9 192 631 770 Hz	1967
Length	metre (m)	speed of light c = 299 792 458 m/s	1983
Mass	kilogram (kg)	Planck constant h	**2019 (new)**
Electric current	ampere (A)	elementary charge e	**2019 (new)**
Temperature	kelvin (K)	Boltzmann constant k	**2019 (new)**
Amount of substance	mole (mol)	Avogadro constant N_a	**2019 (new)**
Luminous intensity	candela (cd)	luminous efficacy K = 683 lm/W	1979

Red rows changed in 2019: the metal kilogram cylinder in France was retired.

Each base unit is now fixed by a constant. The four red rows (kg, A, K, mol) changed on 20 May 2019.

★★★ **2019 redefinition**: agreed by the 26th CGPM in November 2018, in force from **20 May 2019** (World Metrology Day). The values of h, e, k and N_A were fixed exactly.

★★★ **Kilogram** is now defined by the **Planck constant h = 6.626 070 15 × 10^{-34} J s**. The old platinum–iridium cylinder (International Prototype Kilogram, 1889) kept at Sèvres near Paris was retired.

★★ **Ampere** fixed by the **elementary charge e = 1.602 176 634 × 10^{-19} C**; **kelvin** by the **Boltzmann constant k = 1.380 649 × 10^{-23} J/K**; **mole** by the **Avogadro constant N_A = 6.022 140 76 × 10^{23} mol^{-1}**.

★★★ **Second** = time of **9 192 631 770** oscillations of the radiation from the **caesium-133** atom (atomic clock definition since 1967).

★★ **Metre** = distance light travels in vacuum in **1/299 792 458 of a second** (since 1983), so the speed of light is exactly 299 792 458 m/s.

★ **Candela** fixed by the luminous efficacy of 540 THz green light, 683 lm/W (since 1979).

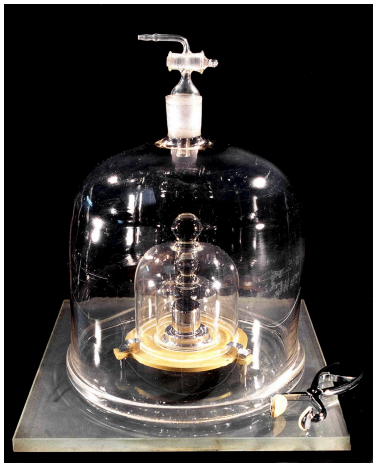
★ **Kibble balance**: the machine that balances the weight of a mass against an electromagnetic force, linking the kilogram to h.

★★ **28th CGPM (October 2026)**: the second is still defined by the **caesium-133** clock; a proposal for a new definition, expected to rest on **optical clocks**, is due at the **29th CGPM (2030)**.

★★ **Leap seconds end**: the 2026 CGPM made **UTC continuous from 20 May 2027**, so no more leap seconds will be added; UT1 and UTC may drift apart by up to one hour.

★ **Supplementary units** (old term): **radian** (plane angle) and **steradian** (solid angle); since 1995 they count as dimensionless derived units. 1 rad ≈ 57.3°.

★ **Older systems**: CGS (centimetre–gram–second), FPS (foot–pound–second, British), MKS (metre–kilogram–second, the parent of SI).



The International Prototype Kilogram ('Le Grand K'): a platinum–iridium cylinder kept under two glass bell jars near Paris. It defined the kilogram from 1889 until 20 May 2019; now the Planck constant does. Image: BIPM, Wikimedia Commons, CC BY-SA 3.0 IGO

⚠ **Exam trap:** 'The kilogram is still defined by a metal cylinder in France' is false since 2019. 'Mass, length and time are the only fundamental quantities' is false: SI has seven. Force and velocity are never base quantities.

☑ Quick check

1. Since 20 May 2019 the kilogram is fixed by which constant?
2. Radiation from which atom defines the second?
3. Which two SI base units are named after people?

Answer: 1. the Planck constant h · 2. caesium-133 (9 192 631 770 oscillations) · 3. ampere and kelvin

Derived units and units named after scientists

newton = kg m s^{-2}

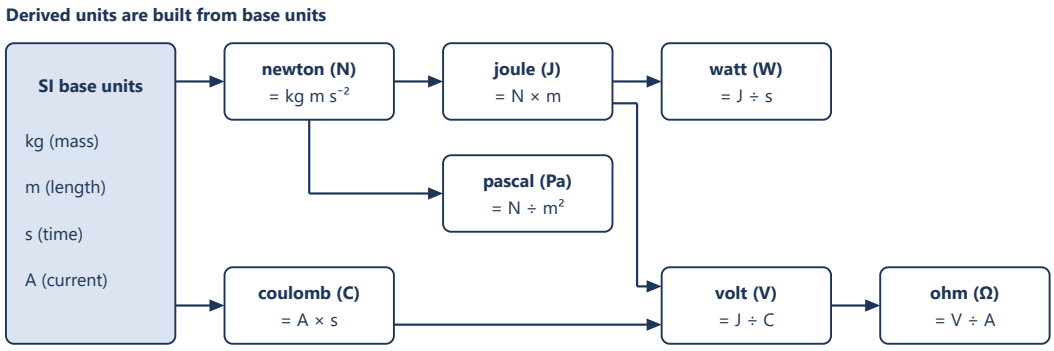
tesla = N A^{-1} m^{-1}

gray vs sievert

lumen vs lux

strain: no unit

A derived unit is a short name for a bundle of base units. The newton is just kg m s^{-2}; the watt is just a joule per second. Twenty-two derived units have special names, and most honour a scientist. Written in full the name is lower case (newton, watt); the symbol takes a capital letter when it comes from a person (N, W, Pa).



Derived units are short names for bundles of base units: the newton is kg m s^{-2}; the joule is a newton-metre and the watt a joule per second; the volt is a joule per coulomb and the ohm a volt per ampere.

SI derived units with special names ★★★

Quantity	Unit (symbol)	In other units	Named after
Force	newton (N)	kg m s^{-2}	Isaac Newton
Work, energy, heat	joule (J)	N m	James Prescott Joule
Power (incl. electric power)	watt (W)	J/s	James Watt
Pressure, stress	pascal (Pa)	N/m^2	Blaise Pascal
Frequency	hertz (Hz)	s^{-1} (cycles per second)	Heinrich Hertz
Electric charge	coulomb (C)	A s	Charles-Augustin de Coulomb
Potential difference, emf	volt (V)	J/C = W/A	Alessandro Volta
Resistance	ohm (Ω)	V/A	Georg Simon Ohm
Conductance	siemens (S)	$Ω^{-1}$ (old name mho)	Werner von Siemens
Capacitance	farad (F)	C/V	Michael Faraday
Magnetic flux	weber (Wb)	V s	Wilhelm Weber
Magnetic field (flux density)	tesla (T)	Wb/m^2 = N A^{-1} m^{-1}	Nikola Tesla
Inductance	henry (H)	Wb/A	Joseph Henry
Celsius temperature	degree Celsius (°C)	K − 273.15	Anders Celsius
Radioactivity (activity)	becquerel (Bq)	one decay per second	Henri Becquerel
Absorbed radiation dose	gray (Gy)	J/kg	Louis Harold Gray
Dose equivalent (biological effect)	sievert (Sv)	J/kg	Rolf Sievert
Luminous flux	lumen (lm)	cd sr	Latin 'light'
Illuminance	lux (lx)	lm/m^2	Latin 'light'
Catalytic activity	katal (kat)	mol/s	Greek 'dissolve'
Plane angle / solid angle	radian (rad) / steradian (sr)	dimensionless	-

★★★ **Tesla from F = BIL**: force on a wire = field × current × length, so B = F/(IL) and **1 T = 1 N A^{-1} m^{-1}** (newton per ampere-metre). Also 1 T = 1 Wb/m^2 = **10^4 gauss**.

★★★ **Watt** is the unit of all power, electric power included: P = VI, so 1 W = 1 V × 1 A.

★★★ **Hertz** = one cycle per second; it measures frequency of any wave or vibration (sound, AC mains at 50 Hz in India, radio).

★★ **Gray vs sievert**: both are J/kg. Gray is the raw energy absorbed; sievert weights it for harm to living tissue.

★★ **Lumen vs lux**: lumen = total light given out by a source; lux = light falling on each square metre (illuminance). LED bulbs are rated in lumens; a lux meter checks room lighting.

★★ **Coulomb** = charge passed by 1 ampere in 1 second; one coulomb ≈ 6.25×10^{18} electrons.

Common quantities whose units have no special name ★★

Quantity	SI unit
Velocity, speed	m/s
Acceleration	m/s^2
Momentum, impulse	kg m/s = N s
Torque (moment of force)	N m (never written J)
Surface tension	N/m
Viscosity (coefficient)	Pa s (CGS: poise; 1 Pa s = 10 poise)
Density	kg/m^3
Specific heat capacity	J kg^{-1} K^{-1}
Latent heat	J/kg
Thermal conductivity	W m^{-1} K^{-1}
Resistivity	Ω m (ohm-metre)
Electric field	N/C = V/m
Angular velocity	rad/s
Moment of inertia	kg m^2
Power of a lens	dioptre (D) = m^{-1}
Young's modulus	Pa (N/m^2)
Sound intensity	W/m^2 (level in decibels)

★★★ **Quantities with no unit (dimensionless)**: **strain** (change in length ÷ original length), refractive index, relative density (specific gravity), coefficient of friction, Poisson's ratio, relative permittivity (dielectric constant), Mach number, efficiency.

★★★ **Stress and pressure** are both force per area, so both are measured in **pascal**. Strain has no unit because it is a ratio of two lengths.

Remember it: Light units (candela, lumen, lux) are the 'no-name' family: none is named after a person. Electric units read like a roll call of 19th-century electricity pioneers: Volta (volt), Ohm (ohm), Faraday (farad), Henry (henry), and Weber and Tesla for the magnetic units.

⚠ **Exam trap:** Torque and work share N m, but torque is never written in joules. 'Ohm-metre is the unit of resistance' is wrong: ohm-metre is resistivity. 'Siemens measures resistance' is wrong: it measures conductance (the reverse of resistance).

Quick check

1. Write the tesla in newton, ampere and metre.
2. Is ohm-metre the unit of resistance or of resistivity?
3. Name a quantity that has no unit at all.

Answer: 1. 1 T = 1 N A^{-1} m^{-1} (from F = BIL) · 2. resistivity · 3. strain (also refractive index, relative density)

SI prefixes

kilo to tera

milli to pico

ronna, quetta (2022)

M vs m

Prefixes let one unit cover atoms and galaxies without long strings of zeros. Above kilo and below milli, each step is a factor of 1000. The 27th CGPM in **November 2022** added four new prefixes because data storage was heading past yotta.

SI prefixes: each step is ×1000

BIG: names end in -a		SMALL: names end in -o	
quetta (Q)	10^{30} (2022)	**quecto (q)**	10^{-30} (2022)
ronna (R)	10^{27} (2022)	**ronto (r)**	10^{-27} (2022)
yotta (Y)	10^{24}	yocto (y)	10^{-24}
zetta (Z)	10^{21}	zepto (z)	10^{-21}
exa (E)	10^{18}	atto (a)	10^{-18}
peta (P)	10^{15}	femto (f)	10^{-15}
tera (T)	10^{12}	pico (p)	10^{-12}
giga (G)	10^{9}	nano (n)	10^{-9}
mega (M)	10^{6}	micro (μ)	10^{-6}
kilo (k)	10^{3}	milli (m)	10^{-3}

In between: hecto (h) 10^{2} · deca (da) 10^{1} · deci (d) 10^{-1} · centi (c) 10^{-2}

Symbols are capital from mega upward; kilo is small k

Big prefixes end in -a, small ones end in -o. The four in red were added in 2022.

★★★ **Everyday prefixes**: kilo 10^{3}, mega 10^{6}, giga 10^{9}, tera 10^{12}; milli 10^{-3}, micro 10^{-6}, nano 10^{-9}, pico 10^{-12}.

★★ **Next ones**: peta 10^{15}, exa 10^{18}, zetta 10^{21}, yotta 10^{24}; femto 10^{-15}, atto 10^{-18}, zepto 10^{-21}, yocto 10^{-24}.

★★ **Added in 2022**: **ronna (R) 10^{27}, quetta (Q) 10^{30}, ronto (r) 10^{-27}, quecto (q) 10^{-30}**. Earth's mass is about 6 ronnagrams; an electron's mass is about 1 rontogram.

★ **hecto 10^{2}, deca 10^{1}, deci 10^{-1}, centi 10^{-2}**: the only prefixes that are not powers of 1000 (hectare, decibel, centimetre).

★ **Symbol case matters**: M (mega) vs m (milli); P (peta) vs p (pico). 1 mW is a thousandth of a watt; 1 MW is a million watts.

Remember it: Big ladder: Kind Men Give Tea, People Enjoy Zesty Yellow Rich Quality (kilo, mega, giga, tera, peta, exa, zetta, yotta, ronna, quetta). Small ladder: My Mother Never Prepares Food After Zero Yoga, Really Quickly (milli, micro, nano, pico, femto, atto, zepto, yocto, ronto, quecto).

⚠ **Exam trap:** Micro is 10^{-6} (one millionth), not 10^{-9}; nano is 10^{-9}. Femto (10^{-15}) is the 'fermi' size of a nucleus. A 'giga' byte is 10^{9}, a 'tera' 10^{12}.

Quick check

1. Micro or nano: which is 10^{-6}?
2. Which four prefixes were added in 2022?
3. 1 MW is how many times 1 mW?

Answer: 1. micro (nano is 10^{-9}) · 2. ronna, quetta, ronto, quecto · 3. 10^{9} times

Non-SI and traditional units exams love

light-year: distance

AU < ly < parsec

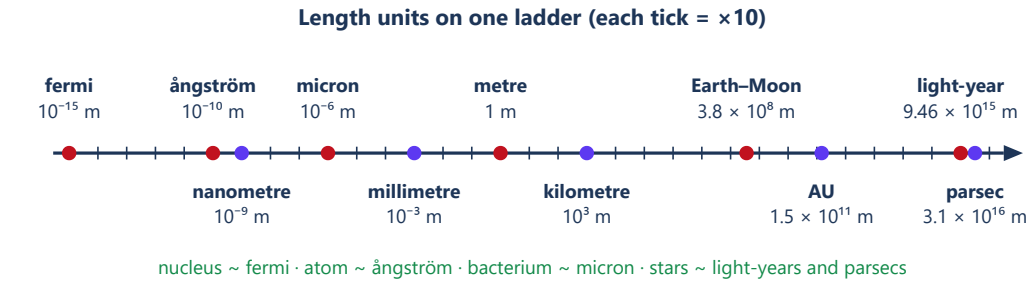
carat vs karat

kWh = 3.6 × 10^6 J

knot: speed

decibel

Many old or specialist units survive because they fit their job: astronomers need huge lengths, jewellers need tiny masses, sailors measure by the Earth's own curve. Exams test what each unit measures, so learn them by family.



From nucleus to stars: fermi < ångström < nanometre < micron < ... < AU < light-year < parsec.

Length and distance ★★★

Unit	Value	Used for
Light-year (ly)	distance light travels in one year ≈ 9.46 × 10^{15} m ≈ 9.46 × 10^{12} km	distances to stars
Astronomical unit (AU)	mean Earth–Sun distance ≈ 1.496 × 10^{11} m ≈ 150 million km	solar-system distances
Parsec (pc)	≈ 3.26 ly ≈ 3.09 × 10^{16} m ≈ 206 265 AU	distances to stars and galaxies
Ångström (Å)	10^{-10} m = 0.1 nm	wavelength of light, X-rays; size of atoms
Fermi (femtometre, fm)	10^{-15} m	size of nucleus
Micron (micrometre, µm)	10^{-6} m	cells, bacteria, dust (PM2.5 = particles ≤ 2.5 µm)
Nanometre (nm)	10^{-9} m = 10 Å	visible light 400–700 nm; chip technology
Nautical mile	1852 m exactly (1.852 km)	sea and air navigation; one minute of latitude
Mile (statute)	≈ 1.609 km	road distance (UK, USA)
Fathom	6 feet ≈ 1.83 m	depth of water
Foot / inch / yard	1 ft = 12 in = 30.48 cm; 1 in = 2.54 cm; 1 yd = 3 ft = 0.9144 m	everyday length

★★★ **Light-year measures distance, not time.** Light covers about 3 × 10^5 km every second; in a year that adds up to about 9.46 × 10^{12} km.

★★★ **Why astronomers use light-years**: the **speed of light in vacuum is the same everywhere and always**, so it makes a perfect, unchanging yardstick for huge distances.

★★★ **Order of size**: AU < light-year < parsec. 1 ly ≈ 63 000 AU; 1 pc ≈ 3.26 ly.

★★ **Parsec** = 'parallax of one arc-second': the distance at which 1 AU would look only 1 arc-second wide.

★★ **Nearest star** after the Sun, Proxima Centauri, is about 4.2 ly away; sunlight takes about 8 minutes 20 seconds to reach Earth (1 AU).

⚠ **Exam trap:** 'Light-year is a unit of time' and 'light-year is a unit of speed' are both wrong: it is distance. In UPSC 2021 the reason asked was the constancy of the speed of light, not that stars stay fixed: stellar distances do change, and light does bend near massive bodies.

Mass, volume, area ★★

Unit	Value	Note
Carat (ct)	200 mg = 0.2 g	mass of diamonds and gems
Karat (K)	parts of gold out of 24	purity of gold: 24K pure, 22K ≈ 91.6%, 18K = 75%
Quintal / tonne	100 kg / 1000 kg	crops (quintal), freight (tonne)
Atomic mass unit (u, dalton)	≈ 1.66×10^{-27} kg	1/12 of a carbon-12 atom
Tola	≈ 11.66 g	traditional Indian unit for gold and silver
Pound (lb)	≈ 0.4536 kg	British mass
Litre (L)	1 dm^3 = 1000 cm^3; 1 m^3 = 1000 L	1 mL = 1 cm^3 (cc)
Barrel (oil)	42 US gallons ≈ 159 litres	crude oil trade
Gallon	US ≈ 3.785 L; imperial ≈ 4.546 L	fuel in USA/UK
Hectare (ha)	10 000 m^2	land; 1 ha ≈ 2.47 acres
Acre	≈ 4047 m^2	land

Remember it: Carat with a C is for the Crystal (diamond, a mass). Karat with a K is for the Kangan (gold bangle, a purity out of 24). 22K hallmarked jewellery is marked 916: 22 ÷ 24 = 0.916.

Energy, power and pressure ★★★

Unit	Value in SI	Note
Kilowatt-hour (kWh) = 1 'unit' of electricity	3.6×10^6 J	1000 W for 3600 s; your electricity bill
Calorie (cal)	≈ 4.186 J (≈ 4.2 J)	heat; food 'Calorie' (kcal) = 1000 cal
Electron-volt (eV)	1.602×10^{-19} J	atomic and nuclear energy; MeV, GeV
Erg (CGS)	10^{-7} J	1 J = 10^7 erg
British thermal unit (BTU)	≈ 1055 J	heating, air conditioners
Horsepower (hp)	≈ 746 W	engines, motors, pumps
Ton of refrigeration	≈ 3.5 kW of cooling	AC capacity ('1.5-ton AC')
Dyne (CGS force)	10^{-5} N	1 N = 10^5 dyne
Kilogram-force (kgf)	≈ 9.8 N	pressure unit kgf/cm² ≈ 0.98 bar
Bar	10^5 Pa	weather: 1 millibar = 1 hPa = 100 Pa
Standard atmosphere (atm)	101 325 Pa ≈ 1.013 bar	= 760 mm of mercury
Torr	1/760 atm ≈ 133 Pa	≈ 1 mm Hg; vacuum work
mm of Hg	≈ 133 Pa	blood pressure (120/80 mm Hg)
psi (pound per square inch)	≈ 6.9 kPa	tyre pressure (30–35 psi)

★★★ **kWh to joule**: 1 kWh = 1000 W × 3600 s = **3.6×10^6 J**. Example: 250 units = 250 × 3.6 × 10^6 = **9×10^8 J**.

★★★ **kWh is energy, kW is power.** The meter counts energy used; the rating on a heater (2 kW) is its power.

★★★ **Pressure** = force ÷ area; SI unit **pascal (N/m²)**. 'kg/cm²' is strictly mass per area; the pressure unit is **kgf/cm²** (kilogram-force per square centimetre). So if the options are only kg/cm², kg/cm, kg/mm and kg/cm³, the answer is **none of these**: each is a mass unit over a length, area or volume.

★★ **Electron-volt** is energy, not charge or voltage: the energy one electron gains across 1 volt.

See it around you: A 1.5 kW geyser run for 2 hours uses 1.5 × 2 = 3 kWh = 3 units = 3 × 3.6 × 10^6 = 1.08 × 10^7 J.

Electricity, magnetism, radiation, sound, speed ★★

Unit	Measures	Value / note
Gauss (G)	magnetic field (CGS)	1 T = 10^4 G; Earth's field ≈ 0.25–0.65 G
Maxwell	magnetic flux (CGS)	1 Wb = 10^8 maxwell
Curie (Ci)	radioactivity	3.7 × 10^{10} Bq (activity of 1 g of radium)
Rad / rem	absorbed dose / dose equivalent	1 rad = 0.01 Gy; 1 rem = 0.01 Sv
Röntgen (R)	X-ray and gamma exposure (ionisation of air)	old unit
Decibel (dB)	loudness (sound level)	logarithmic; +10 dB = 10 × intensity
Mach number	speed ÷ speed of sound	no unit; Mach 1 ≈ 343 m/s ≈ 1235 km/h in air at 20 °C
Knot	speed of ships and aircraft	1 nautical mile per hour = 1.852 km/h
rpm	rotational speed	revolutions per minute (read on a tachometer)
Dobson unit (DU)	thickness of ozone column	1 DU = 0.01 mm of pure ozone at 0 °C and 1 atm
Cusec / cumec	river or canal flow	cubic foot per second (≈ 28.3 L/s) / cubic metre per second
Barn	nuclear cross-section (area)	10^{-28} m^2

★★★ **Decibel** (one-tenth of a **bel**, after Alexander Graham Bell): 0 dB = faintest audible sound; whisper ≈ 30 dB; talk ≈ 60 dB; long exposure above ≈ 85 dB damages hearing; pain around 120–130 dB.

★★ **Mach**: subsonic < Mach 1 < supersonic; above Mach 5 is hypersonic. Mach number has no unit.

★★ **Knot is a speed**, not a distance and not a length of rope: 20 knots ≈ 37 km/h.

⚠ **Exam trap:** Pairs that get swapped: carat (mass) vs karat (purity); knot (speed) vs nautical mile (distance); kWh (energy) vs kW (power); eV (energy) vs volt (potential); gauss vs tesla (same quantity, 1 T = 10 000 G); decibel measures loudness, hertz measures pitch (frequency).

☑ **Quick check**

1. A light-year is a unit of _____ .
2. Why does the light-year make a good yardstick for stars?
3. 1 kWh is how many joules?

Answer: 1. distance (≈ 9.46 × 10^{15} m) · 2. light's speed in vacuum is the same everywhere and always · 3. 3.6 × 10^6 J

Key conversions at a glance

km/h × 5/18

K = °C + 273

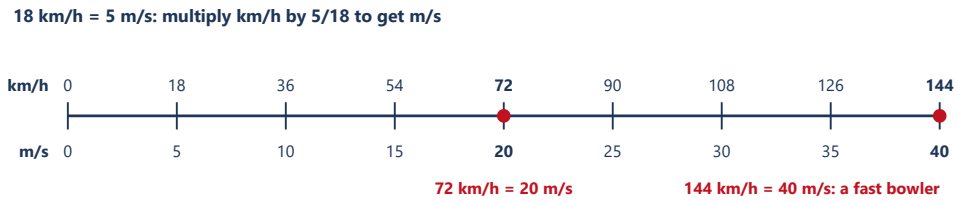
°F = 9/5 °C + 32

−40 °C = −40 °F

37 °C = 98.6 °F

Conversions worth memorising ★★★

From	To	Rule
km/h	m/s	multiply by 5/18 (72 km/h = 20 m/s)
Celsius	Kelvin	K = °C + 273.15 (often 273)
Celsius	Fahrenheit	°F = (9/5) °C + 32
Body temperature	-	37 °C = 98.6 °F ≈ 310 K
Water boils / freezes (1 atm)	-	100 °C = 212 °F = 373 K / 0 °C = 32 °F = 273 K
Same reading on °C and °F	-	−40 °C = −40 °F
1 N	dyne	10^5 dyne
1 J	erg	10^7 erg
1 kWh	J	3.6×10^6 J
1 hp	W	≈ 746 W
1 cal	J	≈ 4.186 J
1 atm	Pa / mm Hg	1.013×10^5 Pa / 760 mm Hg
1 T	gauss	10^4 G
1 inch / 1 foot	cm	2.54 cm / 30.48 cm
1 mile / 1 nautical mile	km	1.609 km / 1.852 km
1 rad	degree	≈ 57.3°



A speed line drawn to scale: each km/h mark sits exactly above its m/s value. Every 18 km/h is 5 m/s, so 72 km/h = 20 m/s and a 144 km/h delivery is 40 m/s.

Remember it: Speed trick: '18 km/h = 5 m/s'. Cricket bowlers at 144 km/h are bowling 40 m/s. And −40 is the one temperature where Celsius and Fahrenheit 'shake hands'.

Quick check

1. 72 km/h in m/s?
2. At which temperature do Celsius and Fahrenheit read the same?
3. Body temperature 37 °C is about how many kelvin?

Answer: 1. 20 m/s (× 5/18) · 2. −40 · 3. ≈ 310 K

Dimensions in brief

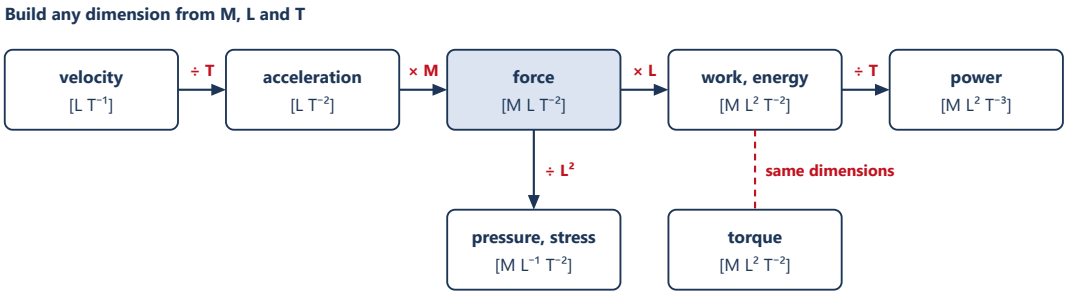
[M L T]

force [M L T⁻²]

work and torque alike

homogeneity

Writing a quantity in powers of mass [M], length [L] and time [T] shows what it is really made of. Two sides of a correct equation must have the same dimensions (principle of homogeneity), which lets us check formulas and convert units quickly.



Each step multiplies or divides by one base dimension. Work and torque end with the same dimensions [M L² T⁻²], though work is a scalar and torque a vector.

Dimensional formulas ★★

Quantity	Dimensions	SI unit
Velocity	[L T⁻¹]	m/s
Acceleration	[L T⁻²]	m/s²
Force	[M L T⁻²]	N
Momentum, impulse	[M L T⁻¹]	N s
Work, energy, torque	[M L² T⁻²]	J (torque: N m)
Power	[M L² T⁻³]	W
Pressure, stress, Young's modulus	[M L⁻¹ T⁻²]	Pa
Surface tension, spring constant	[M T⁻²]	N/m
Frequency, angular velocity	[T⁻¹]	Hz, rad/s
Planck constant, angular momentum	[M L² T⁻¹]	J s
Gravitational constant G	[M⁻¹ L³ T⁻²]	N m² kg⁻²
Strain, refractive index, angle	[M⁰ L⁰ T⁰]	none

★★ **Same dimensions, different quantities**: work and torque; pressure and stress (and energy per volume); impulse and momentum; Planck constant and angular momentum; light-year and wavelength (both length).

★ **Limits of dimensional analysis**: it cannot give pure-number constants (the ½ in ½mv²) and cannot handle formulas with sine, log or exponentials.

⚠ **Exam trap:** 'Quantities with the same dimensions must be the same physical quantity' is false: work (scalar) and torque (vector) share [M L² T⁻²].

Quick check

1. Dimensional formula of force?
2. Which two different quantities share the dimensions [M L² T⁻²]?
3. Why can dimensions not give the ½ in ½mv²?

Answer: 1. [M L T⁻²] · 2. work (energy) and torque · 3. pure numbers have no dimensions

Measuring: least count, vernier, screw gauge, errors

least count

vernier 0.1 mm

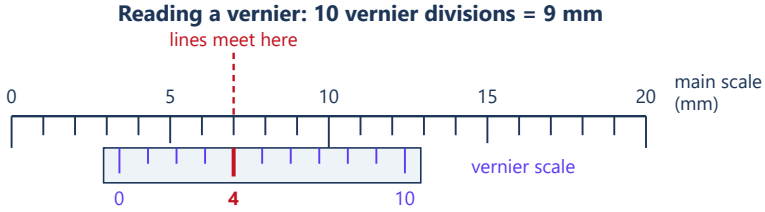
screw gauge 0.01 mm

accuracy vs precision

systematic vs random

No instrument reads finer than its smallest division. That smallest reading is its **least count**; the smaller the least count, the more precise the instrument. A vernier and a screw gauge both use a clever second scale to read a fraction of the main division.

Reading a vernier: 10 vernier divisions = 9 mm



Vernier zero is just past 3 mm on the main scale → main reading = 3 mm
4th vernier line meets a main line → add 4 × least count (0.1 mm) = 0.4 mm
Reading = 3 + 0.4 = 3.4 mm. Least count = 1 mm − 0.9 mm = 0.1 mm

Find the vernier line that meets a main-scale line; its number × 0.1 mm is added to the main reading.

Least count of common instruments ★★

Instrument	Least count	Typical use
Metre scale	1 mm	lengths in cm and m
Vernier callipers	0.1 mm (0.01 cm)	inner and outer diameter, depth of a tube
Screw gauge (micrometer)	0.01 mm (0.001 cm)	thickness of wire or sheet
Spherometer	0.01 mm	curvature (radius) of lens or spherical surface
Clinical thermometer	0.1 °C	body temperature, 35–42 °C
Digital stopwatch	0.01 s	short time intervals

★★ **Vernier callipers**: least count = 1 main-scale division − 1 vernier division = 1 mm − 0.9 mm = **0.1 mm**. Named after **Pierre Vernier** (1631).

★★ **Screw gauge**: least count = pitch ÷ number of circular-scale divisions, e.g. 0.5 mm ÷ 50 = **0.01 mm**; ten times finer than a vernier.

★★ **Accuracy** = how close a reading is to the true value; **precision** = how close repeated readings are to each other (and how fine the least count is).

★ **Systematic error** (same direction every time, e.g. zero error, faulty calibration) is removed by adjusting each reading for it; **random error** (unpredictable scatter) is reduced by averaging many readings.

★ **Parallax error**: reading a scale from an angle; avoid by keeping the eye straight above the mark.

★ **Significant figures**: the reliable digits plus the first doubtful one; 2.50 m claims more precision than 2.5 m.

Remember it: Dartboard picture: darts clustered tightly but far from the bull = precise, not accurate. Darts scattered evenly around the bull = accurate on average, not precise. Clustered on the bull = both.

Quick check

1. Least count of vernier callipers, and of a screw gauge?
2. Darts tightly grouped but far from the bull: accurate or precise?
3. Which error shrinks when you average many readings?

Answer: 1. 0.1 mm; 0.01 mm · 2. precise, not accurate · 3. random error

Measuring instruments: what each one measures

-meter, -scope, -graph

hygrometer vs hydrometer

lactometer: milk

odometer vs speedometer

ammeter: series

dynamo vs dynamometer

Most instrument names are Greek or Latin roots plus '-meter' (measure), '-scope' (see) or '-graph' (write/record). Learn about twenty roots and you can decode almost any option an examiner sets.

Decode the name from its root ★★

Root	Meaning	Instrument
hygro-	moisture	hygrometer: humidity
hydro-	water	hydrometer: density of liquids
lacto-	milk	lactometer: purity of milk
pyro-	fire	pyrometer: very high temperature
baro-	weight, pressure	barometer: air pressure
mano-	thin (gas)	manometer: gas pressure
anemo-	wind	anemometer: wind speed
alti-	height	altimeter: altitude
audio-	hearing	audiometer: hearing / sound level
chrono-	time	chronometer: exact time at sea
tacho-	speed	tachometer: rotation speed (rpm)
odo-	road, way	odometer: distance travelled
seismo-	shaking	seismograph: earthquake waves
sphygmo-	pulse	sphygmomanometer: blood pressure
cresco-	I grow (Latin)	crescograph: plant growth
sacchari-	sugar	saccharimeter: sugar in solution
onde (French)	wave	ondometer: frequency of radio waves
tele-	far	telemeter: measuring at a distance
dynamo-	power, force	dynamometer: force, torque, engine power

Weather, earth, sea and navigation ★★★

Instrument	Measures / does	Remember
Barometer	atmospheric pressure	Torricelli, 1643; sudden fall = storm coming, slow rise = fair weather
Barograph	continuous record of air pressure	a recording barometer
Altimeter	height (altitude) of aircraft	works like an aneroid barometer: pressure falls with height
Anemometer	wind speed	spinning cups; a wind vane gives direction
Hygrometer	humidity of air	wet-and-dry-bulb type is a psychrometer
Hygroscope	shows change in humidity	indicates only, does not measure
Rain gauge (udometer)	rainfall	mm of rain
Pyrheliometer	intensity of direct solar radiation	not a furnace thermometer
Seismograph	records earthquake waves	Richter scale = magnitude; Mercalli scale = intensity (damage)
Fathometer (echo sounder)	depth of the sea	times an echo of a sound pulse (SONAR idea)
Hypsometer	height above sea level	from the boiling point of water
Gravimeter	small changes in g	oil and mineral prospecting
Sextant	angle of the Sun or a star above the horizon	finds latitude at sea; heights of distant objects
Chronometer	very accurate time, especially on ships	John Harrison; accurate time gives longitude
Compass / gyrocompass	direction	magnetic needle / spinning gyroscope

Liquids, pressure and matter ★★★

Instrument	Measures / does	Remember
Hydrometer	density (relative density) of liquids	floats deeper in lighter liquids
Lactometer	purity of milk (its density)	a special hydrometer; water lowers milk's density
Manometer	pressure of gases (in a pipe or vessel)	U-tube of liquid
Saccharimeter	concentration of sugar in solution	uses rotation of polarised light
Salinometer	salinity (salt content) of water	seawater, boiler water
Viscometer	viscosity of liquids	engine oil, paints
Refractometer	refractive index	sugar in fruit juice, gems
Spherometer	curvature of spherical surfaces	lenses, mirrors
Venturimeter	rate of flow of liquid in a pipe	Bernoulli's principle
Pitot tube	speed of fluid flow; airspeed of aircraft	Bernoulli's principle

Heat, light and radiation ★★

Instrument	Measures / does	Remember
Thermometer	temperature	mercury, alcohol, digital
Pyrometer	very high temperature (furnaces, molten metal)	reads the heat radiation from a distance
Cryometer	very low temperature	cryo = cold
Bolometer	heat (infrared) radiation	tiny change in resistance
Calorimeter	quantity of heat	specific heat and latent heat experiments
Thermostat	keeps temperature constant	fridge, iron, geyser; regulates, does not measure
Photometer	luminous intensity of a light source	compares two lamps
Lux meter	illuminance (light falling on a surface)	reads in lux
Radiometer	intensity of radiant energy	Crookes radiometer spins in light
Spectroscope / spectrometer	spectrum: splits light into wavelengths	identifies elements in stars
Ondometer (wavemeter)	frequency of electromagnetic (radio) waves	onde = wave
Geiger counter (Geiger–Müller counter)	detects and counts ionising radiation (α, β, γ)	clicks on each particle
Dosimeter	radiation dose received by a person	worn by X-ray and nuclear workers

Electricity and magnetism ★★★

Instrument	Measures / does	Remember
Ammeter	electric current	low resistance; joined in series
Voltmeter	potential difference (voltage)	high resistance; joined in parallel
Galvanometer	detects and measures very small currents	becomes an ammeter with a shunt, a voltmeter with a series resistance
Potentiometer	emf and potential difference very accurately; compares emfs	draws no current at balance, so more accurate than a voltmeter
Ohmmeter / megger	resistance / very high (insulation) resistance	-
Multimeter (AVO meter)	current, voltage and resistance	A-V-O = amps, volts, ohms
Wattmeter	electric power	watts
Energy meter	electrical energy used	kWh ('units') on your bill
Electroscope	detects electric charge	gold-leaf electroscope
Electrometer	charge or potential difference	-
Oscilloscope (CRO)	displays the waveform of a signal	cathode-ray oscilloscope
Dynamo	converts mechanical energy into electrical energy	a generator, not a measuring device
Dynamometer	force, torque or power of an engine	a measuring device

Vehicles, machines and distance ★★★

Instrument	Measures / does	Remember
Odometer	total distance travelled by a vehicle	the 'km reading' on the dashboard
Speedometer	instantaneous speed of a vehicle	the needle
Tachometer	rotational speed of an engine or shaft (rpm)	the rev counter
Telemeter	records readings at a distant place and sends them; range-finder in surveying	satellites send telemetry
Stroboscope	makes fast-rotating or vibrating objects look still	measures their speed
Pedometer	steps walked	fitness bands
Gyroscope	keeps direction / measures rotation	aircraft, ships, phones

Medicine and biology ★★★

Instrument	Measures / does	Remember
Sphygmomanometer	blood pressure	normal about 120/80 mm Hg
Stethoscope	hears heart and lung sounds	René Laennec, 1816
Cardiograph (electrocardiograph, ECG)	records electrical activity of the heart	ECG = electrocardiogram (the graph)
Audiometer	sharpness of hearing; sound intensity	hearing test
Audiophone	hearing aid	helps hearing, does not measure
Crescograph	growth of plants	invented by J.C. Bose
Kymograph	graphic record of muscle movement, pulse, blood pressure	physiology labs
Endoscope	views inside the body	uses optical fibres (total internal reflection)
Pulse oximeter	oxygen saturation of blood	clips on a finger
Polygraph	pulse, breathing, blood pressure together	the 'lie detector'

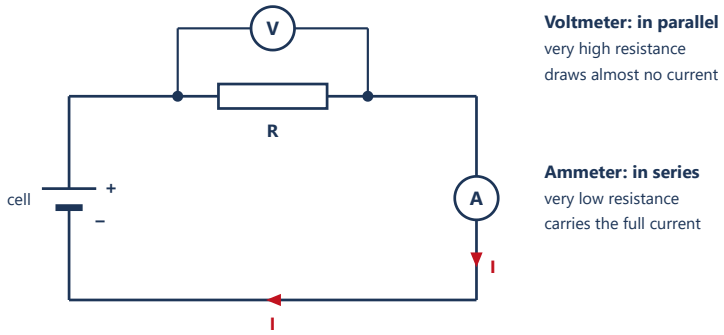
★★★ **Odometer vs speedometer**: odometer = distance covered (km); speedometer = speed right now (km/h). A **chronometer** keeps precise time; an **ammeter** measures current.

★★★ **Hygrometer vs hydrometer**: hygro = moisture in air (humidity); hydro = water, i.e. density of liquids. The **lactometer** is a hydrometer for milk.

★★ **Ammeter in series, voltmeter in parallel**: an ammeter must carry the full current, so it has very low resistance; a voltmeter must not draw current, so it has very high resistance.

★★ **Barometer vs manometer**: barometer = pressure of the atmosphere; manometer = pressure of a gas in a closed vessel or pipe.

★★ **Pyrometer vs pyrheliometer**: pyrometer = furnace temperature; pyrheliometer = sunlight intensity.



The ammeter sits in the loop itself (series), so the whole current passes through it; the voltmeter is connected across the resistor R (parallel) and draws almost no current. Current I flows out of the + terminal of the cell.

⚠ **Exam trap:** Look-alike pairs: hygrometer (humidity) / hydrometer (liquid density) / hygroscope (only shows humidity change); dynamo (makes electricity) / dynamometer (measures force or power); altimeter (height) / audiometer (hearing); odometer (distance) / speedometer (speed) / tachometer (rpm); thermostat (controls) / thermometer (measures); seismograph (instrument) / Richter scale (a scale, not an instrument).

See it around you: Your scooter's dashboard: the needle is the speedometer, the running km total is the odometer, and a bike with a 'rpm' dial has a tachometer. The milkman's lactometer floats higher in pure milk and sinks deeper when water is added.

Quick check

1. Hygrometer or hydrometer: which measures humidity?
2. Why is an ammeter joined in series and a voltmeter in parallel?
3. What does a crescograph measure, and who invented it?

Answer: 1. hygrometer (hydrometer: density of liquids) · 2. the ammeter must carry the full current (low R); the voltmeter must draw almost none (high R) · 3. plant growth; J.C. Bose

India's national standards and Indian Standard Time

CSIR-NPL

atomic clocks

UTC + 5:30

82.5° E, Mirzapur

IST Rules 2026

Every country needs one trusted keeper of its kilogram, metre and second so that a weighing scale in Patna and a meter in Chennai agree. In India that keeper is the **CSIR-National Physical Laboratory (NPL), New Delhi**, the country's **National Metrology Institute**, set up in 1947. Its standards are traceable to the BIPM, so Indian measurements are accepted worldwide.

★★★ **CSIR-NPL, New Delhi** realises and maintains India's national standards of the SI units (mass, length, time, temperature, current, light and others) and calibrates instruments against them.

★★★ **CSIR-NPL keeps Indian Standard Time (IST)** with a set of **atomic clocks (caesium standards)**, linked to world time (UTC) through the BIPM.

★★★ **IST = UTC + 5 hours 30 minutes**, based on the **82.5° E (82°30′ E) meridian**, which passes near **Mirzapur (Uttar Pradesh)**; India uses a single time zone.

★★★ The **82.5° E** meridian crosses **five states**: **Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Odisha and Andhra Pradesh** (north to south). Hook: 'U-M-C-O-A'.

★★ **Legal Metrology (Indian Standard Time) Rules, 2026**: notified in **August 2026** by the Department of Consumer Affairs under the Legal Metrology Act, 2009, they make **IST the single mandatory time reference** for legal, administrative, commercial and official use (telecom, banking and payments, power grids, transport); they apply 180 days after publication in the Gazette.

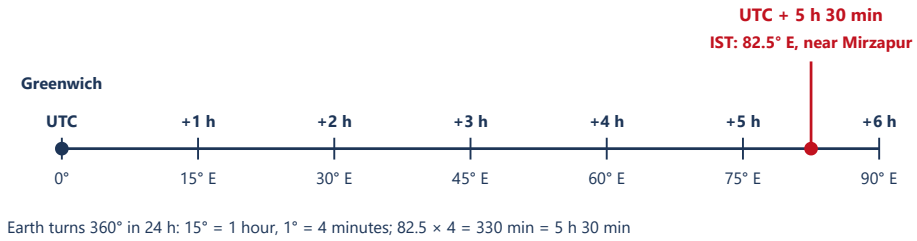
★★ **'One Nation, One Time'**: IST is sent out from CSIR-NPL through five **Regional Reference Standard Laboratories** (Ahmedabad, Bengaluru, Bhubaneswar, Faridabad, Guwahati), internet time servers and **NavIC** satellites, reducing dependence on foreign GPS time.

★ **National Prototype Kilogram No. 57** (a platinum–iridium copy) is held at CSIR-NPL; since 2019 the kilogram itself is defined through the Planck constant.

★ **Bharatiya Nirdeshak Dravya (BND)**: Indian certified reference materials issued by CSIR-NPL for testing labs (e.g. for metals, cement, pollution checks).

★ **Metric India**: India joined the Metre Convention in 1957; the Standards of Weights and Measures Act, 1956 brought metric units into use from 1958.

★ **Legal Metrology** (weights and measures used in trade, petrol pumps, shop scales) is administered by the Department of Consumer Affairs and state legal metrology departments; **BIS** sets product standards (ISI mark, hallmarking).



Earth turns 360° in 24 h: 15° = 1 hour, 1° = 4 minutes; 82.5 × 4 = 330 min = 5 h 30 min

Why IST is UTC + 5:30: the Earth turns 15° an hour, so the 82.5° E meridian near Mirzapur is 82.5 × 4 = 330 minutes, or 5 h 30 min, ahead of Greenwich. Spacing to scale.

Remember it: NPL = 'Nation's Precise Lab': it holds India's kilogram, its second and its clock. Think of IST as 'Mirzapur time' in 5½-hour lead over Greenwich.

⚠ **Exam trap:** IST is kept by CSIR-NPL, not by ISRO, IMD or BIS. ISRO's NavIC helps spread the time signal; IMD forecasts weather; BIS sets product standards. Also, IST is UTC + 5:30, not + 5:00.

Quick check

1. Which body keeps Indian Standard Time?
2. IST is UTC plus how much, and from which meridian?
3. Which Indian satellite system helps send IST across the country?

Answer: 1. CSIR-National Physical Laboratory, New Delhi · 2. 5 h 30 min; 82.5° E, near Mirzapur · 3. NavIC

Asked in past papers (16)

BPSC 64th Angstrom is a unit of
(a) wavelength (b) energy (c) frequency (d) velocity (e) None of the above/More than one of the above
Answer: (a) wavelength. One angstrom (Å) is 10^{-10} m, used for wavelengths and atomic sizes

BPSC 64th Frequency is measured in
(a) hertz (b) meter/second (c) radian (d) watt (e) None of the above/More than one of the above
Answer: (a) hertz. The SI unit of frequency is the hertz (one cycle per second)

BPSC 64th The unit of electric power is
(a) ampere (b) volt (c) coulomb (d) watt (e) None of the above/More than one of the above
Answer: (d) watt. The SI unit of power, electric power included, is the watt (joule per second)

BPSC 64th Which instrument is used to measure humidity?
(a) Hydrometer (b) Hygrometer (c) Pyrometer (d) Lactometer
(e) None of the above/More than one of the above
Answer: (b) Hygrometer. A hygrometer measures humidity; a hydrometer measures liquid density

BPSC 65th The unit of pressure is
(a) kg/cm^2 (b) kg/cm (c) kg/mm (d) kg/cm^3 (e) None of the above/More than one of the above
Answer: (e) None of the above/More than one of the above. Pressure is force per unit area; its SI unit is the pascal (N/m^2); kg/cm^2 is mass per area; the pressure unit is kgf/cm^2

BPSC 65th Which one of the following is a scalar quantity?
(a) Force (b) Pressure (c) Velocity (d) Acceleration (e) None of the above/More than one of the above
Answer: (b) Pressure. Pressure is a scalar; force, velocity and acceleration are vectors

BPSC 65th Which one of the following quantities does not have unit?
(a) Stress (b) Force (c) Strain (d) Pressure (e) None of the above/More than one of the above
Answer: (c) Strain. Strain is a ratio of change in size to original size, so it has no unit; Stress and pressure are both force per area, measured in pascals

BPSC 65th What is measured in hertz?
(a) Frequency (b) Energy (c) Heat (d) Quality (e) None of the above/More than one of the above
Answer: (a) Frequency. The hertz is the SI unit of frequency, one cycle per second

BPSC 66th 'Light-year' is a unit of
(a) time (b) speed (c) distance (d) intensity of light (e) None of the above/More than one of the above
Answer: (c) distance. A light-year is a unit of distance: how far light travels in one year

UPSC 2021 Which one of the following is a reason why astronomical distances are measured in light-years?
(a) Distances among stellar bodies do not change. (b) Gravity of stellar bodies does not change.
(c) Light always travels in straight line. (d) Speed of light is always same.
Answer: (d) Speed of light is always same.. A light-year is the distance light travels in vacuum in a year, about 9.46 × 10^{12} km; The speed of light in vacuum is a universal constant, about 3 × 10^8 m/s

BPSC 67th re-exam Which of the following is not a vector quantity?
(a) Displacement (b) Speed (c) Velocity (d) Torque (e) None of the above/More than one of the above
Answer: (b) Speed. Speed is a scalar; displacement, velocity and torque are vectors

BPSC 69th Current density is
(a) a scalar quantity (b) a vector quantity (c) dimensionless (d) None of the above
Answer: (b) a vector quantity. Current density is a vector, but electric current is a scalar

BPSC 70th The meter that is used to measure the distance moved by the vehicle is known as
(a) Speedometer (b) Ammeter (c) Odometer (d) Chronometer
Answer: (c) Odometer. An odometer records distance travelled; a speedometer shows instantaneous speed; A chronometer is a precise timekeeper; an ammeter measures electric current

BPSC 70th Which of the following is equivalent to tesla ?
(a) Newton per Coulomb (b) Ampere per Newton (c) Newton per ampere meter
(d) Newton per ampere-second
Answer: (c) Newton per ampere meter. From F = BIL, 1 tesla = 1 newton per ampere-metre (N A^{-1} m^{-1})

BPSC 70th re-exam What is the unit of measure of magnetic field ?
(a) Ohm (b) Tesla (c) Ampere (d) Cobalt
Answer: (b) Tesla. The SI unit of magnetic field (flux density) is the tesla; 1 T = 10^4 gauss

BPSC 71st Energy consumed in a home is 250 units then the total energy in Joule will be :
(a) 9×10^5 (b) 8×10^6 (c) 9×10^8 (d) 10^5
Answer: (c) 9×10^8. One unit of electricity is 1 kWh = 3.6 × 10^6 joules

Test yourself (13)

1. Which one of the following pairs is wrongly matched?
(a) Anemometer – wind speed (b) Hygrometer – density of liquids (c) Pyrometer – very high temperature
(d) Tachometer – rotational speed of an engine

2. Since 20 May 2019 the kilogram is defined by fixing the exact value of the
(a) Avogadro constant (b) Boltzmann constant (c) Planck constant (d) gravitational constant

3. A household meter records 50 units in a month. The energy used is about
(a) 1.8×10^8 J (b) 5×10^4 J (c) 3.6×10^6 J (d) 1.8×10^5 J

4. Which one of the following is NOT a unit of length or distance?
(a) Parsec (b) Fermi (c) Knot (d) Fathom

5. Which one of the following is a vector quantity?
(a) Electric current (b) Pressure (c) Momentum (d) Work

6. The SI prefix for 10^{-15} is
(a) atto (b) pico (c) nano (d) femto

7. Weber per square metre is the unit of
(a) magnetic flux (b) inductance (c) electric field (d) magnetic flux density

8. Jewellery hallmarked '22K' contains gold to the extent of about
(a) 75% (b) 91.6% (c) 99.9% (d) 22%

9. Which instrument is used to find the depth of the sea?
(a) Altimeter (b) Hypsometer (c) Fathometer (d) Manometer

10. Which pair of quantities have the same dimensions?
(a) Work and torque (b) Force and power (c) Momentum and energy (d) Pressure and force

11. Consider the following statements:
1. Since 20 May 2019 the kilogram is defined through the Planck constant.
2. The second is defined by the radiation of the caesium-133 atom.
3. The ampere is defined by fixing the value of the Boltzmann constant.
Which of the statements given above is/are correct?
(a) 1 only (b) 1 and 2 only (c) 2 and 3 only (d) 1, 2 and 3

12. Consider the following pairs:
Unit : Quantity
1. Tesla : magnetic flux density
2. Siemens : electrical resistance
3. Light-year : time
How many of the above pairs are correctly matched?
(a) Only one (b) Only two (c) All three (d) None

13. A jeweller sells a ring: an 18K gold band set with a 2-carat diamond. Which description of the ring is correct?
(a) The band is 18% gold; the diamond weighs 2 g (b) The band is 75% gold; the diamond weighs 2 g
(c) The band is 18% gold; the diamond weighs 0.4 g (d) The band is 75% gold; the diamond weighs 0.4 g

Answers: 1. (b) A hygrometer measures humidity; density of liquids is measured by a hydrometer. · 2. (c) The kilogram rests on h = 6.626 070 15 × 10^{-34} J s; the old metal prototype was retired. · 3. (a) 1 unit = 1 kWh = 3.6×10^6 J, so 50 units = 1.8×10^8 J. · 4. (c) A knot is a speed, one nautical mile per hour (1.852 km/h). · 5. (c) Momentum (mass × velocity) has direction; current, pressure and work are scalars. · 6. (d) Femto = 10^{-15} (fermi-sized nucleus); pico 10^{-12}, nano 10^{-9}, atto 10^{-18}. · 7. (d) 1 Wb/m² = 1 tesla, the unit of magnetic field (flux density); weber alone is flux. · 8. (b) Karat counts parts of gold in 24: 22/24 ≈ 91.6% (hence the hallmark 916). · 9. (c) A fathometer (echo sounder) times the echo of a sound pulse from the sea floor. · 10. (a) Both are [M L^2 T^{-2}]; work is a scalar in joules, torque a vector in N m. · 11. (b) h fixes the kilogram and caesium-133 the second; the ampere rests on the elementary charge e, while the Boltzmann constant fixes the kelvin. · 12. (a) Only the tesla pair is right; the siemens measures conductance (the reverse of resistance) and the light-year is a distance. · 13. (d) Karat is purity out of 24, so 18K = 18/24 = 75% gold; carat is mass, 0.2 g each, so 2 carats = 0.4 g.

CHAPTER 8

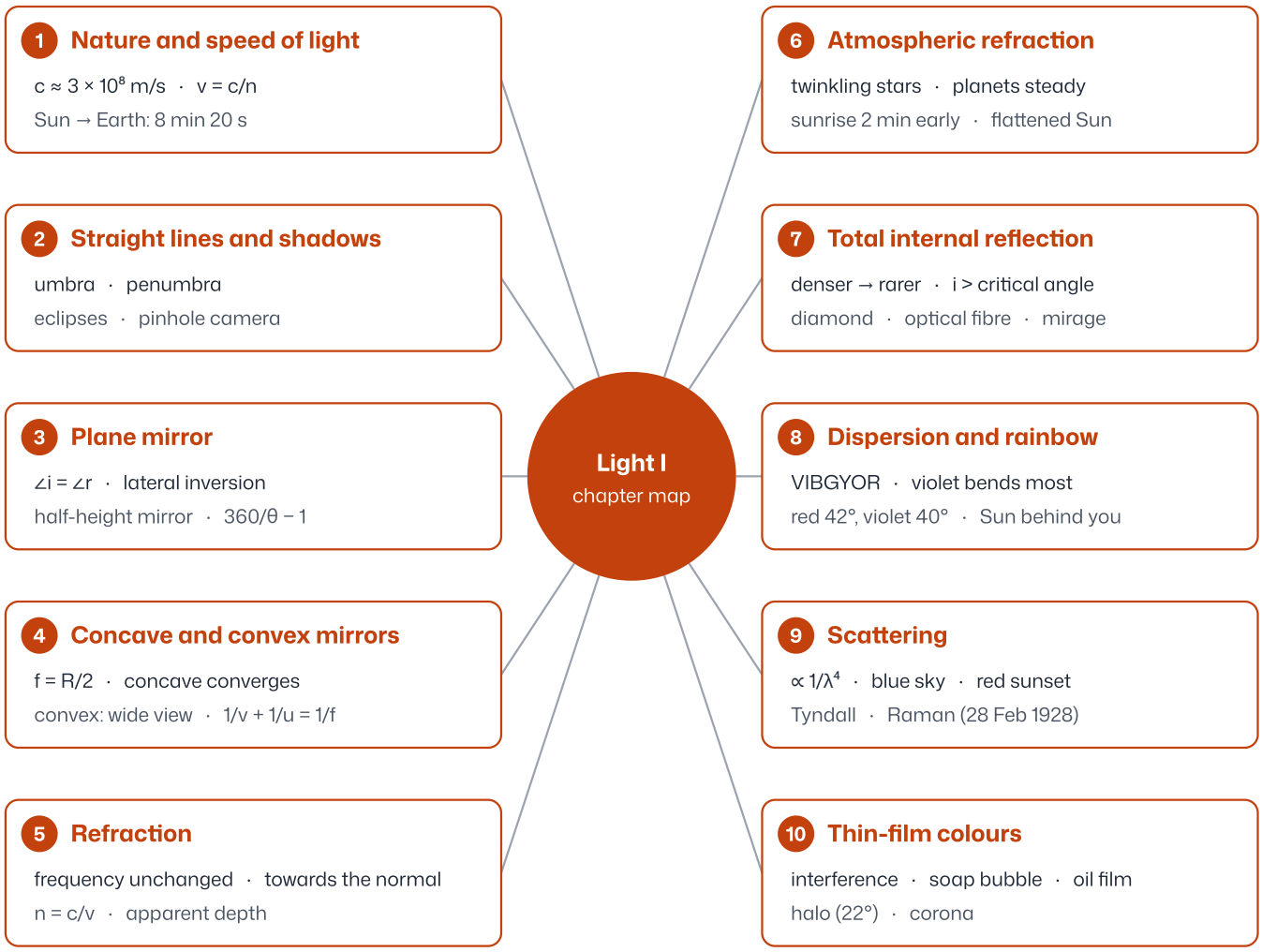
Light I: Reflection, Refraction and Optical Phenomena

Image by mirror type and object position, slowest light in the densest medium, twinkling of stars, total internal reflection, rainbow, scattering (blue sky, red sunset) and the Raman effect are asked almost every year.

Asked 10 times in past papers: UPSC 2 · BPSC 8

≈ 50 min to read ≈ 9 min to revise ★★★

Revise on: Day 1 | Day 3 | Day 7 | Day 21



Revision card

1. Light in vacuum: c ≈ 3 × 10^8 m/s; slower in water (≈ 2.25 × 10^8) and glass (≈ 2 × 10^8); slowest in diamond (n = 2.42). Sunlight reaches Earth in ≈ 8 min 20 s.
2. On refraction **frequency never changes**; speed and wavelength change. Light bends **towards the normal** entering a denser medium.
3. Shadows and the pinhole camera (real, inverted image) prove light travels in straight lines (rectilinear propagation).
4. Plane mirror: virtual, erect, same size, laterally inverted; focal length infinite; full-length mirror needs only half your height; images between two mirrors = 360/θ − 1.
5. Concave mirror: object at C → real, inverted, same-size image at C; object inside F → virtual, erect, enlarged (shaving mirror). Convex mirror: always virtual, erect, smaller, wide view (rear-view mirror).
6. Twinkling of stars, Sun seen ~2 min before sunrise and after sunset, flattened Sun at horizon, pencil bent in water, pond looking shallow: all refraction.
7. Total internal reflection needs denser → rarer and angle > critical angle (glass ≈ 42°, water ≈ 49°, diamond ≈ 24°): diamond sparkle, optical fibre, mirage, looming.
8. Prism dispersion: VIBGYOR; violet bends most, red least (Newton). Rainbow = refraction + dispersion + internal reflection; Sun behind you; red outside in the primary bow.
9. Rayleigh scattering ∝ $1/\lambda^4$: blue sky, red sunrise/sunset, red danger signals, black sky in space; white clouds scatter all colours equally.
10. Tyndall effect: beam made visible by colloidal particles (sunbeam in a dusty room, headlights in fog).
11. Raman effect: scattered light changes frequency; C.V. Raman, 28 Feb 1928; Nobel 1930; National Science Day 28 Feb.
12. Colours of soap bubbles and oil films come from interference, not dispersion.

What light is and how fast it goes

dual nature

c = 3 × 10^8 m/s

v = c/n

8 min 20 s

light year

Light is energy that travels as an **electromagnetic wave**: it needs no medium, so it crosses empty space from the Sun. Yet when it hits matter it also acts like a stream of tiny energy packets. Both pictures are true; which one shows up depends on the experiment.

★★ **Dual nature**: light behaves as a **wave** (reflection, refraction, interference, diffraction, polarisation) and as a **particle** (photoelectric effect).

★★ **Photon**: a packet (quantum) of light energy, E = hf. Einstein used light quanta in **1905** to explain the photoelectric effect (Nobel Prize **1921**).

★ **Theories in order**: Newton's corpuscles (particles) → Huygens' waves (1678) → Young's double-slit proof of waves (1801) → Maxwell: light is an electromagnetic wave (1860s) → Einstein's photons (1905).

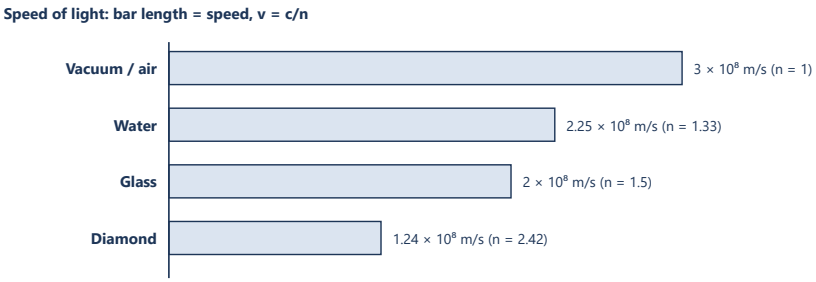
★★★ **Speed of light in vacuum** c = 299,792,458 m/s exactly (≈ **3 × 10^8 m/s**). Nothing travels faster. The metre itself is defined from this value.

★★★ **Slower in matter**: air ≈ c; water ≈ 2.25 × 10^8 m/s; glass ≈ 2 × 10^8 m/s; diamond ≈ 1.24 × 10^8 m/s. The higher the refractive index, the slower the light (v = c/n).

★★★ **Sun to Earth**: light takes ≈ **8 min 20 s** (≈ 499 s) over 1 AU (≈ 1.5 × 10^8 km). Moon to Earth ≈ **1.3 s**.

★ **First measurement** of light's speed: Ole Rømer (1676), from delays in eclipses of Jupiter's moon Io.

★★ **Light year** = distance light travels in one year ≈ 9.46×10^{15} m. It is a unit of **distance**, not time.



Speed of light drawn to scale: each bar is c/n. The higher the refractive index, the shorter the bar and the slower the light.

⚠ **Exam trap:** 'The speed of light will be minimum in: glass / water / vacuum / air' → **glass** (highest refractive index of the four). Vacuum is the fastest, not the slowest.

Remember it: Sunlight you see left the Sun **8 minutes 20 seconds ago**: think of it as 'Sun's 8:20 news'. Lightning is seen before thunder is heard because light is about a million times faster than sound.

Quick check

1. Sunlight takes about how long to reach Earth?
2. Air, water, glass, diamond: in which is light slowest, and why?
3. A light year is a unit of _____ , not of time.

Answer: 1. ≈ 8 min 20 s · 2. diamond: highest n (2.42), and v = c/n · 3. distance (≈ 9.46×10^{15} m)

Light travels in straight lines: shadows, eclipses, pinhole camera

rectilinear propagation

umbra / penumbra

solar eclipse

lunar eclipse

pinhole camera

In a uniform medium light goes in **straight lines** (rectilinear propagation). So an opaque object blocks the rays that would have passed through it, leaving a dark region behind: a **shadow**. Diffraction, interference and polarisation are wave effects and do not explain shadows.

★★★ **Shadow** forms because of **rectilinear propagation** of light: opaque objects stop light, transparent ones let it pass, translucent ones let some through.

★★ **Umbra**: the fully dark central part where no light from the source arrives. **Penumbra**: the partly lit fringe where only part of the source is hidden. A point source gives only an umbra; a big source (Sun) gives both.

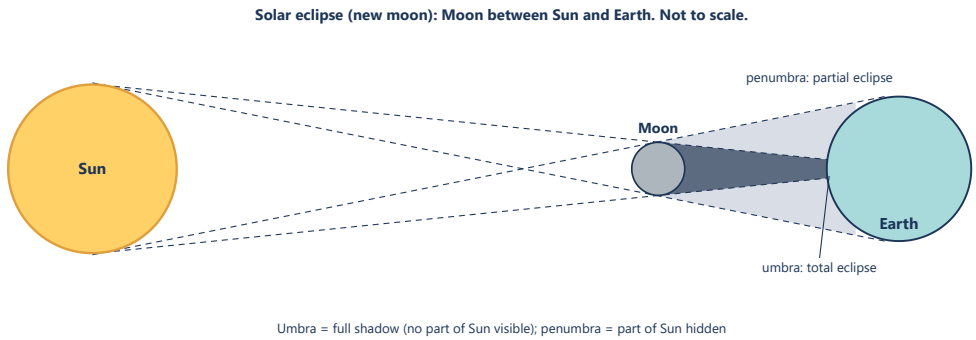
★★ **Solar eclipse**: Moon comes between Sun and Earth, only on a **new-moon day (amavasya)**. Inside the Moon's umbra: total eclipse; in the penumbra: partial eclipse. When the Moon is far (umbra does not reach Earth) the Sun's rim shows as a ring: **annular eclipse** ('ring of fire').

★★ **Lunar eclipse**: Earth comes between Sun and Moon, only on a **full-moon night (purnima)**. In a total lunar eclipse the Moon looks coppery red ('blood moon') because Earth's atmosphere bends and scatters red sunlight into the shadow.

★ **Not every month**: the Moon's orbit is tilted about 5° to Earth's orbit, so Sun, Moon and Earth line up exactly only a few times a year.

★★ **Pinhole camera**: a box with a tiny hole forms a **real, inverted** image on the opposite screen, because rays from the top of the object go straight through the hole to the bottom of the screen. A smaller hole gives a sharper but dimmer image.

★ **Never look at the Sun** during a solar eclipse without proper solar filters; a pinhole projection is the safe way.



Solar eclipse. The dark cone behind the Moon is the umbra (total eclipse where it touches Earth); the lighter region is the penumbra (partial eclipse). Not to scale.

See it around you: Under a tree on a sunny day the bright spots on the ground are **round**, whatever the shape of the gaps between leaves: each gap acts as a pinhole and makes an image of the round Sun. During a partial solar eclipse the spots turn into crescents.

Quick check

1. A shadow proves which property of light?
2. Inside the umbra or the penumbra: where is a solar eclipse total?
3. A solar eclipse can happen only on amavasya or on purnima?

Answer: 1. rectilinear propagation: it travels in straight lines · 2. umbra (penumbra gives a partial eclipse) · 3. amavasya (new moon); a lunar eclipse on purnima

Reflection and the plane mirror

laws of reflection

lateral inversion

half-height mirror

360/θ − 1

kaleidoscope

When light hits a surface and bounces back into the same medium, it is **reflected**. A smooth surface sends all parallel rays off in one direction (clear image); a rough surface scatters them in all directions. That scattered, **diffuse reflection** is how we see a page, a wall or a face.

★★★ **Laws of reflection**: (1) angle of incidence = angle of reflection, both measured from the **normal**; (2) incident ray, reflected ray and normal lie in **one plane**. They hold for plane and curved mirrors alike.

★ **Regular vs diffuse**: mirror, still water → regular (image); paper, wall, cloth → diffuse (no image, but the object becomes visible from every side).

★★★ **Plane-mirror image**: **virtual, erect, same size**, as far behind the mirror as the object is in front, and **laterally inverted** (left and right swapped).

★★★ **AMBULANCE** is painted in mirror writing on the front so that a driver ahead reads it correctly in the rear-view mirror.

★★★ **Focal length of a plane mirror = infinity** (its radius of curvature is infinite). Magnification = +1.

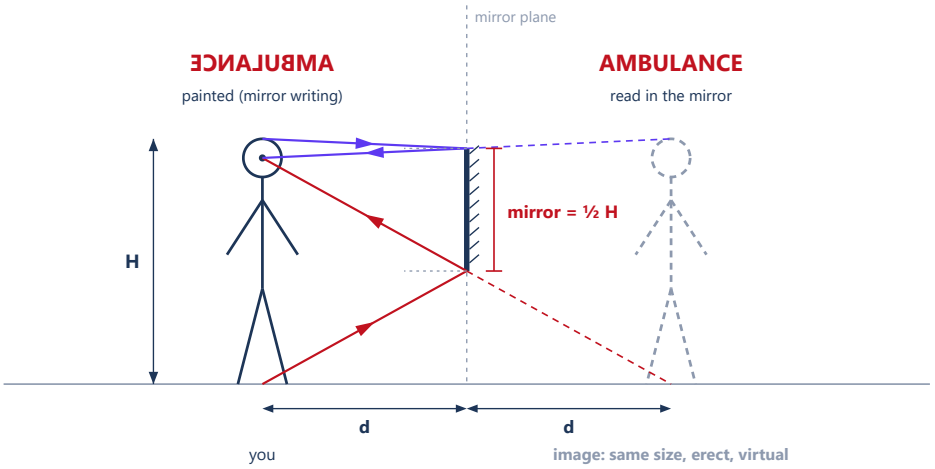
★★★ **Full-length image**: the mirror needs to be only **half your height**, whatever your distance from it (top edge level with the point midway between eyes and the top of the head).

★★ **Walking towards a mirror** at speed v, your image approaches **you** at 2v. Turning a mirror by angle θ turns the reflected ray by 2θ.

★★★ **Two mirrors at angle θ** give **360/θ − 1** images (exact when 360/θ is even): 90° → 3, 60° → 5, 45° → 7, 30° → 11. **Parallel mirrors** (θ = 0, as in a barbershop or lift) give **infinite** images.

★★ **Kaleidoscope**: three long plane mirrors at **60°** to each other form a triangular tube; repeated reflections of loose coloured bits make symmetric patterns. **Periscope**: two plane mirrors at 45°, facing each other, to see over obstacles.

Remember it: Half-height rule: light from your toes reaches your eyes after reflecting from a point **halfway down** between eyes and toes; from your hair, halfway up. So only half your height of glass is ever used.



Plane mirror, drawn to scale. Light from your toes and from the top of your head reflects at points halfway between them and your eyes, so the mirror needs only half your height (90 of 180 units here). The image is as far behind the mirror (d) as you are in front, and AMBULANCE painted in mirror writing reads correctly in the mirror.

⚠ **Exam trap:** Lateral inversion swaps **left–right**, not **up–down**. Your raised right hand appears as the image's left hand, but your head stays on top.

Quick check

1. Shortest plane mirror in which you see your full height?
2. Why is AMBULANCE painted in mirror writing?
3. How many images do two mirrors at 60° form?

Answer: 1. half your height, at any distance · 2. lateral inversion: it reads correctly in a rear-view mirror · 3. 5 (360/60 − 1)

Spherical mirrors: concave and convex

concave: converging

convex: diverging

f = R/2

object at C

rear-view mirror

A spherical mirror is a slice of a hollow shining ball. If the shining side is the **inside** (caved in), it is **concave** and pulls parallel rays together to a point: a **converging** mirror. If the shining side **bulges out**, it is **convex** and spreads rays apart: a **diverging** mirror.

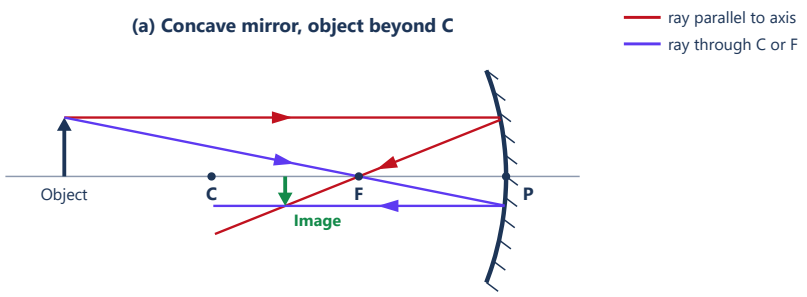
★★ **Key points**: pole P (centre of the mirror), centre of curvature C (centre of the sphere), principal focus F, radius R = PC, **focal length f = R/2**.

★★ **Concave mirror** focus is real (in front); **convex mirror** focus is virtual (behind the mirror).

★ **Three easy rays** for drawing: a ray parallel to the axis reflects through F (or appears to come from F for convex); a ray through (or towards) F reflects parallel; a ray through (or towards) C returns along itself.

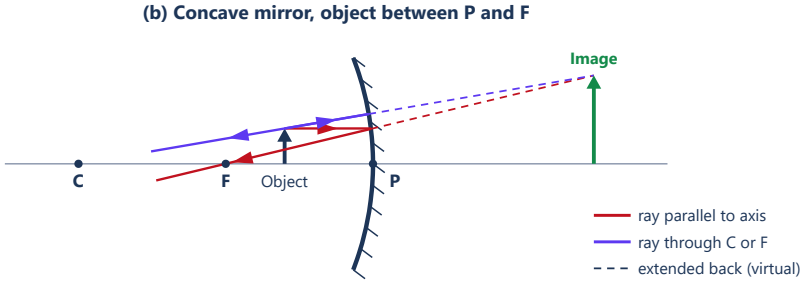
Concave mirror: where the image forms ★★★

Object at	Image at	Size	Nature	Use
Infinity	F	Point-sized	Real, inverted	Solar cooker, solar furnace
Beyond C	Between F and C	Diminished	Real, inverted	No common use
C	**C**	**Same size**	**Real, inverted**	No common use
Between C and F	Beyond C	Enlarged	Real, inverted	No common use
F	Infinity	Highly enlarged	Real, inverted	Torch, headlight (bulb at F gives a parallel beam)
Between F and P	Behind the mirror	**Enlarged**	**Virtual, erect**	Shaving / make-up mirror, dentist's mirror



Real, inverted, diminished, between F and C

(a) Concave mirror, object beyond C: real, inverted, smaller image between F and C. Drawn to scale (R = 200 units).

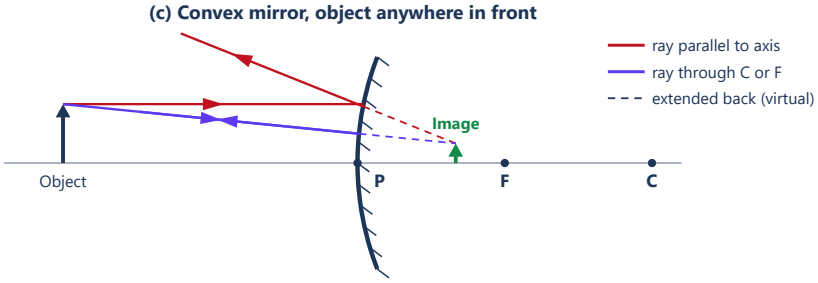


Virtual, erect, enlarged, behind the mirror

(b) Concave mirror, object between P and F: virtual, erect, enlarged image behind the mirror, as in a shaving mirror. Drawn to scale (R = 200 units).

Convex mirror ★★

Object at	Image at	Size	Nature
Infinity	F, behind the mirror	Point-sized	Virtual, erect
Anywhere in front	Between P and F, behind	Diminished	Virtual, erect



Virtual, erect, diminished, between P and F behind the mirror

(c) Convex mirror: wherever the object is, the image is virtual, erect and smaller, between P and F behind the mirror, as in a rear-view mirror. Drawn to scale (R = 200 units).

★★★ **Concave mirror uses**: shaving and make-up mirrors, dentist's and ENT doctor's mirrors (enlarged erect view), reflectors of torches, vehicle headlights and searchlights (bulb at focus), solar cookers and solar furnaces (sunlight focused to a hot spot), reflecting telescopes, dish antennas.

★★★ **Convex mirror uses**: rear-view and side mirrors of vehicles, blind-turn mirrors on hill roads, security mirrors in shops and ATMs: always an erect image and a much **wider field of view**.

★★ **Mirror formula**: 1/v + 1/u = 1/f; magnification m = h′/h = −v/u. Sign idea in one line: distances measured from the pole, positive along the incoming light and negative against it, so a concave mirror has negative f and a convex mirror positive f.

★★ **Quick identification by the image**: same-size erect → plane; larger erect → concave (object inside F); smaller erect at every distance → convex.

Remember it: Con**cave** = a **cave** you look into: it gathers light (converges). Con**vex** bulges out like a **vexed** puffed-up cheek: it spreads light and shows more of the road but smaller.

⚠ **Exam trap:** 'Objects in mirror are closer than they appear' is printed on **convex** side mirrors: the small image makes cars look farther than they are. A person who sees an **enlarged** image of himself is in front of a **concave** mirror, inside its focus.

Quick check

1. Object at C of a concave mirror: where is the image, and what is it like?
2. Which mirror is used for a vehicle's rear view, and why?
3. Focal length of a spherical mirror in terms of R?

Answer: 1. at C: real, inverted, same size · 2. convex: always erect, much wider field of view · 3. f = R/2

Refraction: why light bends

frequency unchanged

towards the normal

Snell's law

n = c/v

apparent depth

Light **changes speed** when it passes from one medium into another, and if it enters at a slant, one side of the beam slows down first, so the beam turns: this is **refraction**. Think of a car whose left wheels roll off the road into sand: those wheels slow and the car swerves. Going into a slower (optically denser) medium light bends **towards the normal**; coming out it bends **away**.

★★★ **Frequency stays the same** when light goes from one medium to another; **speed and wavelength change** (λ in medium = λ in vacuum / n). Colour depends on frequency, so a red light still looks red under water.

★★★ **Bending rule**: rarer → denser: towards the normal; denser → rarer: away from the normal. A ray along the normal (90° to the surface) goes straight without bending.

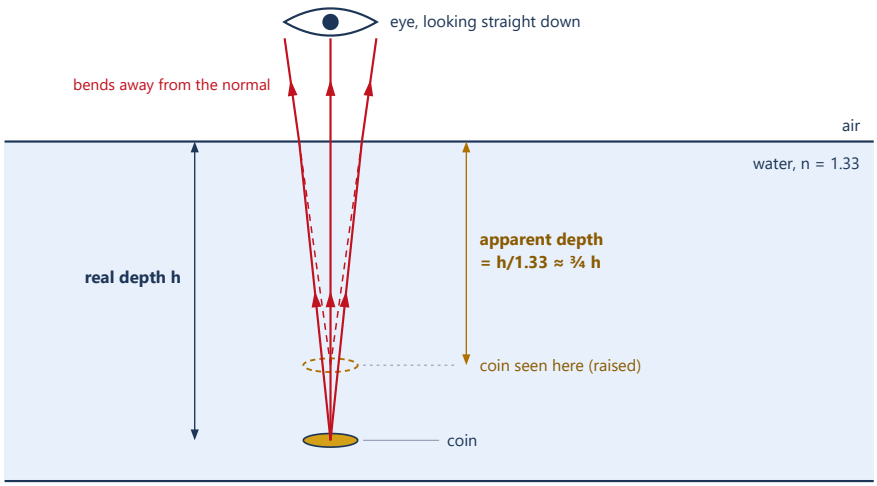
★★ **Snell's law**: sin i / sin r = constant = refractive index of the second medium relative to the first. Incident ray, refracted ray and normal lie in one plane.

★★★ **Refractive index** n = c / v (speed in vacuum ÷ speed in medium). Air 1.0003, ice 1.31, **water 1.33**, alcohol 1.36, kerosene 1.44, **glass ≈ 1.5**, rock salt 1.54, ruby 1.71, **diamond 2.42**.

★★ **n depends on colour**: in glass it is largest for violet, smallest for red; that is why a prism splits white light.

★★ **Apparent depth**: a pond, bucket or swimming pool looks **shallower** than it is (apparent depth = real depth / n ≈ ¾ of the real depth for water).

★★ **Everyday refraction**: a pencil in water looks bent at the surface; a coin at the bottom of a bowl seems raised, and comes into view when water is poured in; a fish looks higher than it really is, so a spear must be aimed below it; letters under a glass slab look raised.



Apparent depth, drawn with Snell's law for water (n = 1.33). Rays from the coin bend away from the normal as they leave the water; traced back, they meet about ¾ of the way down, so the coin looks raised. Seen from straight above, apparent depth = real depth ÷ 1.33.

⚠ **Exam trap:** Optical density is **not** mass density. Kerosene (n = 1.44) is lighter than water but optically denser; light travels slower in it than in water.

⚠ **Exam trap:** An **air bubble in water** acts as a **diverging** (concave) lens, though it is shaped like a convex lens, because the bubble is the rarer medium.

Remember it: Slow → bends towards the normal: like a student slowing down and turning to face the teacher (normal) when entering the classroom.

Quick check

1. When light enters water, which does not change: speed, wavelength or frequency?
2. Light going from air into glass bends towards or away from the normal?
3. Why does a pond look shallower than it is?

Answer: 1. frequency · 2. towards the normal (into a denser medium) · 3. refraction: apparent depth = real depth / n, about ¾ for water

Refraction by the atmosphere

twinkling

planets steady

advanced sunrise

flattened Sun

Air is not uniform: lower layers are denser than upper ones, and warm and cold pockets keep moving. So starlight and sunlight bend gradually as they come down through the atmosphere, and the bending keeps flickering.

★★★ **Twinkling of stars** is due to **atmospheric refraction**. A star is so far away that it is a **point source**; its light passes through moving air layers of changing refractive index, so its apparent position and brightness keep flickering.

★★★ **Planets do not twinkle**: they are near enough to look like small **discs**. A disc is many point sources together; their flickers average out.

★★ **No twinkling in space**: seen from the Moon or by an astronaut, stars shine steadily (no atmosphere). Stars near the horizon twinkle most (longest path through air).

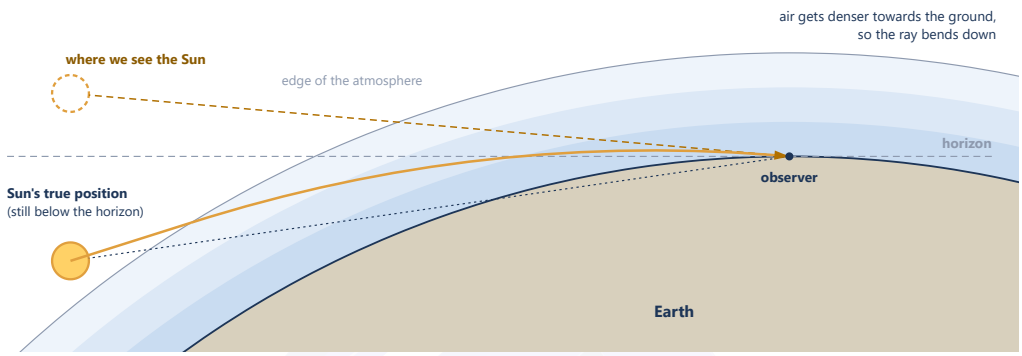
★★ **Stars appear slightly higher** than their true position, because their light bends towards the normal as it enters denser air.

★★★ **Advanced sunrise and delayed sunset**: refraction lets us see the Sun about **2 minutes before** it actually rises and **2 minutes after** it sets, lengthening the day by about 4 minutes.

★★ **Flattened (oval) Sun at the horizon**: light from the lower edge passes through denser air and is lifted more than light from the upper edge, so the disc looks squashed vertically.

★★ **Optical illusions of the sky**: twinkling of stars (refraction), the reddish Sun at dawn and dusk (scattering) and the **big-looking Sun or Moon near the horizon** (a trick of perception; refraction actually makes it slightly smaller vertically). A Moon visible at dawn or the Pole Star in the sky are real sights, not illusions.

★ **Shimmering** of objects seen through hot air above a fire, a road or a tandoor is the same effect on a small scale.



Advanced sunrise. Air gets denser towards the ground, so incoming sunlight bends down and reaches us from a little above the horizon while the Sun is still below it. Not to scale: the air layer and the bending are hugely exaggerated.

⚠ **Exam trap:** Twinkling is **refraction**, not reflection, polarisation or interference. And it is the **stars** that twinkle; planets shine steadily.

Remember it: Stars are tiny dots, planets are tiny plates: a dot flickers easily, a plate does not.

Quick check

1. Why do stars twinkle but planets do not?
2. Refraction lets us see the Sun how long before it actually rises?
3. Why does the Sun look flattened at the horizon?

Answer: 1. a star is a point source; a planet is a disc whose flickers average out · 2. about 2 minutes (the day is ≈ 4 minutes longer) · 3. its lower edge is lifted more by the denser air below

Total internal reflection

denser → rarer

critical angle

diamond sparkle

optical fibre

mirage / looming

When light goes from a denser medium into a rarer one, it bends away from the normal. Tilt the ray more and the refracted ray bends further until it skims along the surface: that angle of incidence is the **critical angle**. Tilt it any more and no light can get out at all: it is **totally reflected** back, losing almost nothing. Even the best mirror loses some light; TIR loses practically none.

★★★ **Two conditions for TIR**: light must go from **denser to rarer** medium, and the angle of incidence must be **greater than the critical angle**.

★★ **Critical angle** C: sin C = 1/n. Water ≈ **48.6°**, crown glass ≈ **42°**, diamond ≈ **24.4°** (smallest, because n is largest).

★★★ **Diamond sparkles** because its critical angle is tiny; light entering a well-cut diamond is totally reflected again and again inside before escaping through the top.

★★★ **Optical fibre**: a thin glass core of higher n inside a cladding of lower n. Light keeps hitting the boundary above the critical angle and is trapped, following the fibre even round bends. Used for internet and telephone links, endoscopy (seeing inside the body) and decorative lamps.

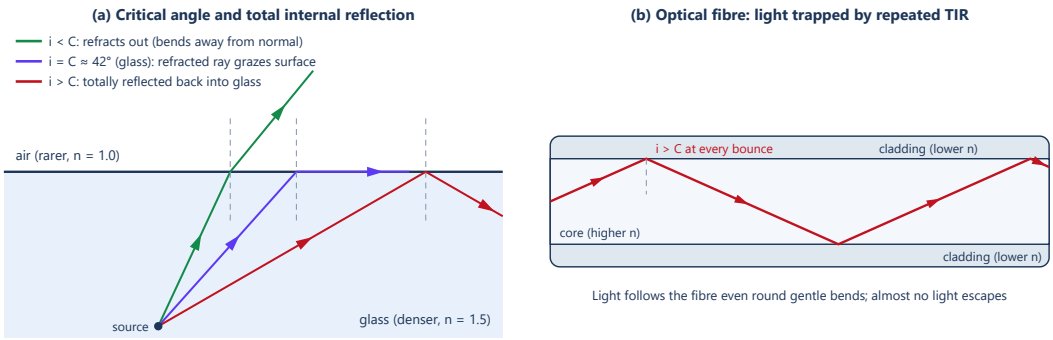
★ **Indian link**: Narinder Singh Kapany, born in Moga (Punjab), is called the father of fibre optics; Charles Kao won the 2009 Nobel Prize for showing fibres could carry signals over long distances.

★★★ **Mirage** (deserts and hot roads in summer): air near the hot ground is hotter and **rarer**. Light from the sky bends more and more upward through the layers and is finally totally reflected, so the eye sees an inverted image of the sky on the ground that looks like a pool of water.

★★ **Looming** (cold regions, polar seas): air near the cold sea is **denser** than above, so light from a distant ship bends downward and the ship appears **raised, floating in the sky**.

★★ **Silvery test tube**: an empty test tube dipped slantwise in water shines like a mirror when seen from above, because light is totally reflected at the glass–air surface inside. Pour water into the tube and the shine disappears. An **air bubble in water** shines for the same reason.

★ **Prisms in place of mirrors**: right-angled glass prisms use TIR to turn light by 90° or 180° in binoculars, periscopes and cameras; they give brighter images than silvered mirrors.



(a) Light from inside glass: below the critical angle it escapes, at the critical angle it grazes the surface, above it it is totally reflected. (b) In an optical fibre every bounce is above the critical angle, so light stays inside.



Mirage on a hot highway: the road ahead looks wet and the cars seem reflected in it. The "water" is an image of the sky, formed by refraction and total internal reflection in the hot air just above the road. Image: Michael from Calgary, AB, Canada, Wikimedia Commons, CC BY 2.0

⚠ **Exam trap:** A mirage is **not** a hallucination and not reflection from water; it is refraction through layers of hot air ending in total internal reflection, and it can be photographed.

Remember it: Mirage = hot below (desert, road), image below. Looming = cold below (sea ice), image above.

Quick check

1. The two conditions for total internal reflection?
2. Why does a diamond sparkle?
3. Mirage: is the air near the ground hotter or colder than above?

Answer: 1. denser → rarer, and angle of incidence > critical angle · 2. its critical angle is tiny (≈ 24.4°), so light is totally reflected again and again · 3. hotter and rarer (looming: colder and denser)

Dispersion and the rainbow

VIBGYOR

violet bends most

rainbow: 3 processes

red outside

Sun behind you

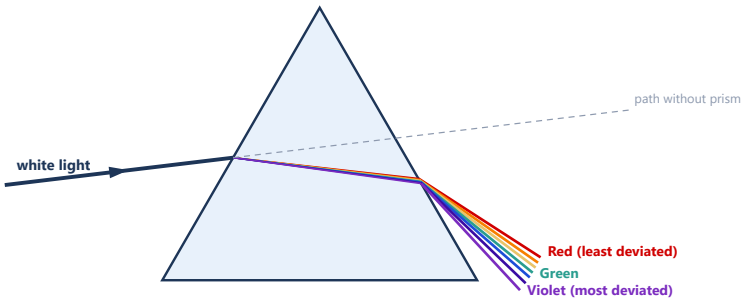
White light is a mixture of colours. Glass slows each colour by a different amount: violet most, red least. So in a prism each colour bends through a different angle and the colours fan out into a **spectrum**. This splitting is **dispersion**.

★★★ **Dispersion**: splitting of white light into seven colours, **VIBGYOR** (violet, indigo, blue, green, yellow, orange, red). **Isaac Newton** showed it with a glass prism (1666).

★★★ **Violet deviates most, red least**: glass has the highest refractive index for violet, so violet travels slowest in glass and bends most. In vacuum all colours travel at the same speed.

★★ **Recombination**: a second, inverted prism placed after the first joins the colours back into white light (Newton's proof that the colours were in sunlight, not made by the glass).

★★ **Order of wavelength**: red longest (~700 nm), violet shortest (~400 nm); frequency is the reverse.



Glass prism: each colour bends by a different amount (spread exaggerated)

Each colour leaves the prism in a different direction. All colours bend towards the base; violet bends most, red least. Spread exaggerated.

A **rainbow** is the same dispersion done by millions of raindrops. Each drop **refracts** sunlight as it enters, **reflects** it once off its back surface and **refracts** it again on the way out; both refractions spread the colours. Light comes back at about **42° for red and 40° for violet** from the line joining the Sun to your head.

★★★ **Rainbow = refraction + dispersion + internal reflection** inside water drops.

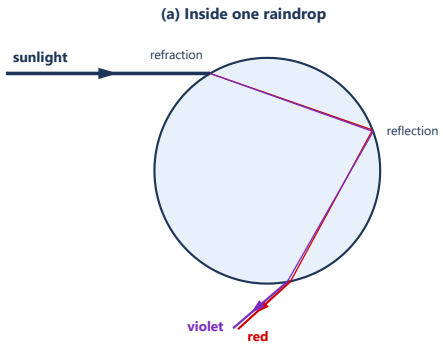
★★★ **Sun behind the observer**, rain in front: a rainbow is always seen in the part of the sky **opposite the Sun**: in the **west in the morning**, in the **east in the evening**.

★★★ **Primary rainbow**: one internal reflection, brighter, **red on the outside (top)**, violet inside.

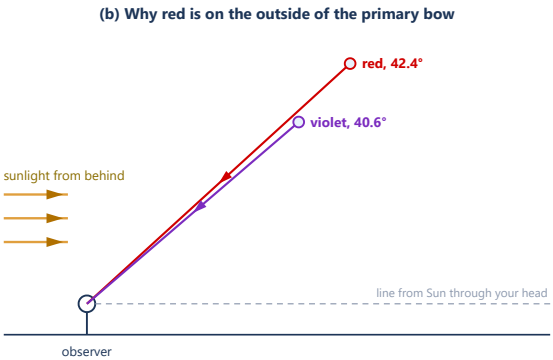
★★ **Secondary rainbow**: two internal reflections, fainter, higher (about 51°), **colours reversed** (red inside). The darker sky between the two bows is called Alexander's band.

★ **Why rainbows are low or absent at noon**: the bow lies 42° from the point opposite the Sun; when the Sun is higher than 42° the whole bow is below the horizon. From an aircraft a rainbow can be a full circle.

★ **Each person sees a personal rainbow**, made by a different set of drops.



1 refraction in → 1 internal reflection at the back → refraction out
colours separate at both refractions (drawn to scale)



Red reaches your eye from higher drops, violet from lower drops

(a) Path inside one drop: refraction in, one reflection at the back, refraction out; colours separate at both refractions. (b) Red reaches the eye from higher drops and violet from lower ones, so red is the outer band of a primary rainbow. Both panels are drawn to scale with the minimum-deviation angles from Snell's law: red (n = 1.331) 42.4°, violet (n = 1.343) 40.6°, usually rounded to 42° and 40°.



A double rainbow. The bright primary bow has red on the outside; in the fainter secondary bow above it the colours are reversed, and the sky between the two bows is darker (Alexander's band). Image: Eric Rolph, Wikimedia Commons, CC BY-SA 2.5

⚠ **Exam trap:** The reflection inside a raindrop is called internal reflection; it is a partial reflection, because the angle at the back of the drop is less than water's critical angle. If an option lists 'dispersion, refraction and internal reflection', all three are correct.

Remember it: Morning rainbow in the West, evening rainbow in the East: keep the Sun at your back. Primary bow: **R**ed **O**utside, like the **R**oof **O**n top.

Quick check

1. In a prism, which colour deviates most, and which least?
2. Name the three processes that make a rainbow.
3. In which part of the sky do you see an evening rainbow?

Answer: 1. violet most, red least · 2. refraction, dispersion, internal reflection · 3. east, opposite the Sun

Scattering: blue sky, red sunset, Tyndall and Raman

$1/\lambda^4$

blue sky

red sunset

red signals

Tyndall effect

Raman effect

When light hits particles much smaller than its wavelength (molecules of nitrogen and oxygen), they absorb and re-send it in all directions: **scattering**. Lord Rayleigh showed that the amount scattered goes as $\mathbf{1/\lambda^4}$, so short-wavelength blue light is scattered several times more than red. Large particles (water drops, dust) scatter all colours about equally.

★★★ **Blue sky**: air molecules scatter blue far more than red; this scattered blue reaches our eyes from every direction of the sky. (Violet scatters even more, but sunlight has less violet and our eyes are less sensitive to it.)

★★★ **Red/orange Sun at sunrise and sunset**: light from the low Sun crosses a much longer path of air; most blue is scattered out on the way, leaving red and orange. At noon the path is short and the Sun looks white.

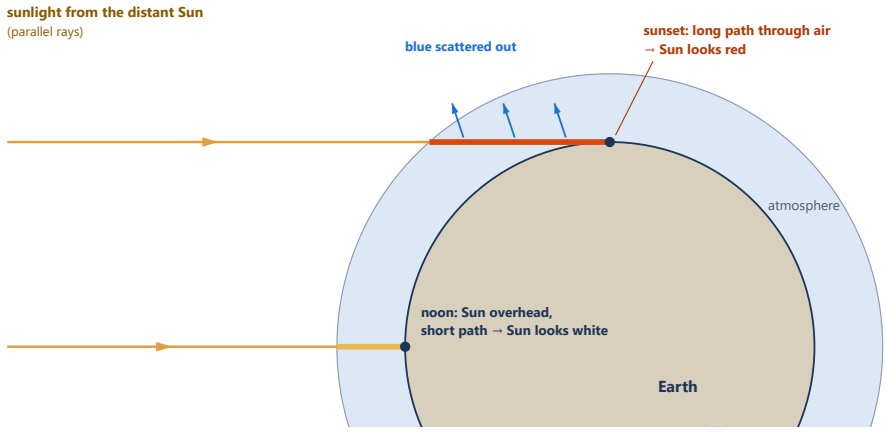
★★★ **Danger and stop signals are red**: red is scattered least, so it travels farthest through fog, smoke and dust and is seen from a distance.

★★★ **Black sky in space**: with no air to scatter sunlight, the sky looks black to astronauts and from the Moon, even in daytime.

★★ **White clouds**: cloud droplets are much larger than the wavelength of light and scatter all colours almost equally, which adds up to white. Dark rain clouds are thick enough to stop most light.

★★ **Bluish smoke** from a two-wheeler's exhaust or a cigarette: very fine particles scatter mostly blue.

★ **Blue sea**: partly reflection of the blue sky and partly because water absorbs red light and scatters blue (Raman studied this on a sea voyage in 1921).



Same sunlight, two observers. At noon the light crosses a short path of air and the Sun looks white; at sunset it skims through a much longer path, most blue is scattered out on the way, and the Sun looks red. Not to scale: the air layer is drawn far thicker than it is.

⚠ **Exam trap:** Blue sky is **scattering**, not reflection of the oceans, and not dispersion. Red danger signals are chosen because red is **least scattered**, not because it is 'most visible to the eye' (the eye is most sensitive to yellow-green).

Tyndall effect: a beam of light becomes visible from the side when it passes through a **colloid** (fine particles suspended in a medium), because the particles scatter the light. A true solution shows no such beam, so the effect separates colloids from true solutions. Named after John Tyndall.

★★ **Tyndall effect examples**: sunbeams in a dusty room or through a gap in a window, sunlight streaming through the canopy of a dense misty forest, car headlights in fog, the projector beam in a cinema hall, a torch beam through milky water.

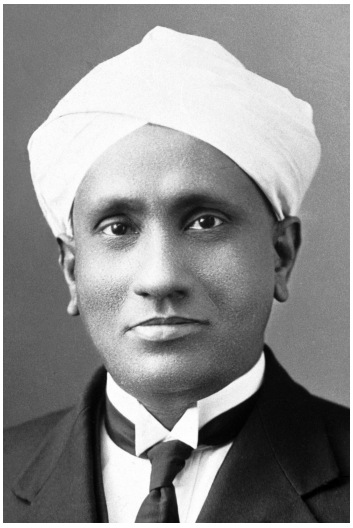
👁 **See it around you:** Switch on a torch in a dark room and nothing shows in the air; clap two dusty dusters near the beam and the path suddenly lights up. That is the Tyndall effect.

Raman effect: when light is scattered by molecules, a very small fraction of it comes out with a **slightly changed frequency (and wavelength)**, because the molecule has taken or given a little energy. The pattern of these shifts is a fingerprint of the molecule.

★★★ **C.V. Raman** discovered it with **K.S. Krishnan** in Kolkata; announced on **28 February 1928**. Raman won the **Nobel Prize in Physics, 1930**, the first Asian to win a Nobel Prize in science. He received the Bharat Ratna in 1954.

★★★ **National Science Day** is celebrated on **28 February** every year (since 1987) to mark the discovery.

★★ **Raman spectroscopy** identifies substances without destroying them: medicines, gemstones, forensic samples, art pigments; the Perseverance rover on Mars carries a Raman instrument.



C.V. Raman, who discovered the Raman effect with K.S. Krishnan (announced 28 February 1928) and won the Nobel Prize in Physics in 1930. Image: Nobel Foundation, Wikimedia Commons, public domain

Three kinds of scattering ★★★

Effect	Particles	What happens	Example
Rayleigh	Much smaller than λ (air molecules)	Short λ (blue) scattered far more ($\propto 1/\lambda^4$); frequency unchanged	Blue sky, red sunset
Tyndall	Colloidal particles (dust, smoke, fog droplets)	Path of the beam becomes visible	Sunbeam in a dusty room
Raman	Molecules	Tiny fraction of light comes out with changed frequency	Raman spectroscopy

Remember it: Raman: 28.2.28: Feb **28**, 19**28**. Science Day falls on the same date.

⚠ **Exam trap:** In Rayleigh and Tyndall scattering the colour (frequency) of scattered light is unchanged; only in the **Raman effect** does the frequency change.

Quick check

1. Rayleigh scattering is proportional to _____ .
2. Why are danger signals red?
3. Which scattering changes the frequency of light, and when was it announced?

Answer: 1. $1/\lambda^4$ (blue scattered far more than red) · 2. red is scattered least, so it is seen from farthest · 3. Raman effect, 28 February 1928

Other colour effects in daily life

interference

soap bubble, oil film

peacock feather

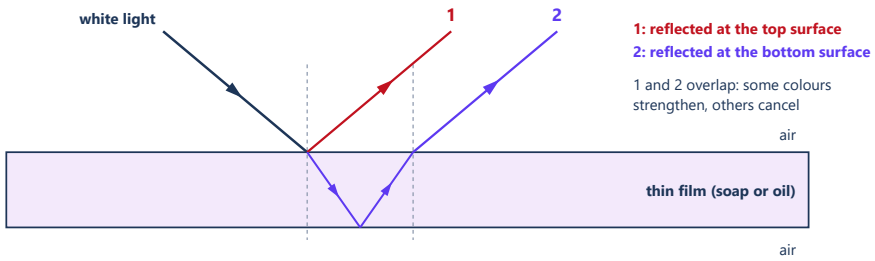
Not every display of colours is dispersion. When light reflects from the top and bottom surfaces of a very thin film, the two reflected waves overlap and reinforce some colours while cancelling others. This is **interference** (explained further in the chapter on wave optics).

halo / corona

★★★ **Soap bubbles and oil films** on a wet road show colours because of **interference** of light in thin films; the colours change as the film thickness changes.

★★ **Peacock feathers and butterfly wings** owe their shimmering colours to interference from tiny structures, not to pigment.

★ **Halo**: a ring around the Sun or Moon, made by refraction through ice crystals in high thin clouds (about 22° radius). **Corona**: small coloured rings close to the Moon, made by diffraction by water droplets.



Thin-film interference, angles from Snell's law (n = 1.33). Light reflected from the top surface (1) and from the bottom surface (2) leaves in the same direction; the two overlap, strengthening some colours and cancelling others. Film thickness hugely exaggerated.

⚠ **Exam trap:** Soap-film colours: **interference** (not diffraction, refraction or polarisation). Prism and rainbow colours: **dispersion**.

Quick check

1. The colours of a soap bubble are due to _____ .
2. Halo or corona: which is made by refraction through ice crystals?

Answer: 1. interference of light in a thin film · 2. halo (about 22°); a corona is diffraction

Asked in past papers (10)

UPSC 2013 Consider the following phenomena :
1. Size of the sun at dusk
2. Colour of the sun at dawn
3. Moon being visible at dawn
4. Twinkle of stars in the sky
5. Polestar being visible in the sky
Which of the above are optical illusions?
(a) 1, 2 and 3 (b) 3, 4 and 5 (c) 1, 2 and 4 (d) 2, 3 and 5
Answer: (c) 1, 2 and 4. Stars twinkle because their light is refracted by moving layers of air; The Sun looks larger and redder near the horizon due to the atmosphere and perception

UPSC 2013 Rainbow is produced when sunlight falls on drops of rain. Which of the following physical phenomena are responsible for this?
1. Dispersion
2. Refraction
3. Internal reflection
Select the correct answer using the codes given below.
(a) 1 and 2 only (b) 2 and 3 only (c) 1 and 3 only (d) 1, 2 and 3
Answer: (d) 1, 2 and 3. A rainbow forms by refraction, dispersion and internal reflection in raindrops

BPSC 66th Which of the following does not change when light travels from one medium to another?
(a) Velocity (b) Wavelength (c) Frequency (d) Refractive index
(e) None of the above/More than one of the above
Answer: (c) Frequency. Frequency of light stays constant on refraction; speed and wavelength change

BPSC 67th A person standing in front of a mirror finds his image larger than himself. This implies that the mirror is
(a) concave (b) plane (c) convex (d) cylindrical with bulging side outwards
(e) None of the above/More than one of the above
Answer: (a) concave. A concave mirror gives an enlarged, erect image when the object is within its focus; A plane mirror gives a same-size image and a convex mirror a smaller one

BPSC 67th Twinkling of stars in clear sky during nighttime can be explained with
(a) refraction of light (b) reflection of light (c) polarization of light (d) interference of light
(e) None of the above/More than one of the above
Answer: (a) refraction of light. Stars twinkle because of atmospheric refraction of their light

BPSC 67th When a soap film on the water is seen in the daytime, it shows beautiful colours. This phenomenon is due to
(a) diffraction of light (b) refraction of light (c) polarization of light (d) interference of light
(e) None of the above/More than one of the above
Answer: (d) interference of light. Colours of thin films such as soap bubbles and oil on water come from interference

BPSC 67th re-exam The speed of light will be minimum while passing through
(a) glass (b) water (c) vacuum (d) air (e) None of the above/More than one of the above
Answer: (a) glass. Light is slowest in the medium of highest refractive index ($v = c/n$)

BPSC 69th The image formed by concave mirror is real, inverted and of the same size as that of the object. The position of the object should be
(a) at the focus (b) at the centre of curvature (c) between the focus and centre of curvature
(d) beyond the centre of curvature
Answer: (b) at the centre of curvature. Concave mirror: an object at C gives a real, inverted, same-size image at C

BPSC 70th re-exam Which of the following is responsible for production of shadow ?
(a) Diffraction (b) Interference (c) Rectilinear propagation of light (d) Polarisation
Answer: (c) Rectilinear propagation of light. Light travels in straight lines, so an opaque object blocking it casts a shadow; Diffraction, interference and polarisation show the wave nature of light

BPSC 71st The focal distance of a plane mirror is
(a) +1 cm (b) −1 cm (c) 2 cm (d) Infinity
Answer: (d) Infinity. A plane mirror has infinite radius of curvature, so its focal length is infinite

Test yourself (12)

1. Two plane mirrors are kept at 60° to each other. How many images of an object placed between them are formed?
(a) 3 (b) 5 (c) 6 (d) Infinite

2. A ray of light passes from water into air. Which of the following is correct?
(a) It bends towards the normal and its frequency increases
(b) It bends away from the normal and its frequency is unchanged
(c) It bends away from the normal and its wavelength decreases (d) It goes straight whatever the angle

3. Which mirror is used as a rear-view mirror in vehicles, and why?
(a) Concave, because it gives an enlarged image (b) Plane, because it gives the same size image
(c) Convex, because it always gives an erect image and a wide field of view
(d) Concave, because it gives a real image

4. Consider the following: 1. Sparkling of a diamond 2. Mirage on a hot road 3. Working of an optical fibre 4. Blue colour of the sky. Which are due to total internal reflection?
(a) 1 and 2 only (b) 1, 2 and 3 only (c) 2, 3 and 4 only (d) 1, 2, 3 and 4

5. The Sun is visible a little before actual sunrise because of
(a) scattering of light (b) dispersion of light (c) atmospheric refraction (d) total internal reflection

6. In a primary rainbow, which colour is on the outer edge and where is the Sun?
(a) Violet; in front of the observer (b) Red; behind the observer (c) Red; in front of the observer
(d) Violet; behind the observer

7. Why are danger signals red?
(a) Red light is scattered the least by fog and smoke (b) Red light has the highest frequency
(c) The human eye is most sensitive to red (d) Red light travels fastest in air

8. National Science Day (28 February) commemorates the discovery of
(a) the photoelectric effect (b) Bose–Einstein statistics (c) the Raman effect (d) the Chandrasekhar limit

9. An object is placed between the focus and the pole of a concave mirror. The image is
(a) real, inverted and enlarged (b) virtual, erect and enlarged (c) virtual, erect and diminished
(d) real, inverted and same size

10. Consider the following statements:
1. Lateral inversion in a plane mirror swaps the top and bottom of the image.
2. The critical angle of diamond is smaller than that of glass.
3. Kerosene is lighter than water but optically denser than water.
Which of the statements given above is/are correct?
(a) 1 only (b) 1 and 2 only (c) 1 and 3 only (d) 2 and 3 only

11. Consider the following:
1. Twinkling of stars
2. The Sun being visible about 2 minutes before it actually rises
3. The flattened shape of the Sun near the horizon
How many of the above are caused by atmospheric refraction?
(a) Only one (b) Only two (c) All three (d) None

12. During a partial solar eclipse, the patches of sunlight on the ground under a leafy tree look like small crescents. Why?
(a) The leaves diffract sunlight into crescent shapes (b) Atmospheric refraction distorts the Sun's disc
(c) The Moon's shadow falls on the ground in patches (d) Each gap between leaves acts as a pinhole camera

Answers: 1. (b) Number of images = 360/θ − 1 = 360/60 − 1 = 5. · 2. (b) Denser to rarer: bends away from the normal; speed and wavelength increase, frequency stays the same. · 3. (c) A convex mirror forms a virtual, erect, diminished image and covers a wide area behind. · 4. (b) Blue sky is due to scattering; the other three involve total internal reflection. · 5. (c) Atmospheric refraction bends sunlight over the horizon, so the Sun is seen about 2 minutes early. · 6. (b) The primary bow has red outside and is seen opposite the Sun, which is behind the observer. · 7. (a) Red has the longest wavelength and is least scattered, so it is seen from far away. · 8. (c) C.V. Raman announced the Raman effect on 28 February 1928. · 9. (b) Inside F a concave mirror acts as a magnifier: virtual, erect, enlarged image behind the mirror. · 10.

(d) Lateral inversion swaps left and right, not top and bottom; diamond's critical angle (about 24.4°) is below glass's (about 42°), and kerosene (n = 1.44) is optically denser than water (n = 1.33). · 11. (c) All three come from light bending as it passes through layers of air of different density; the red colour of the rising Sun, by contrast, is due to scattering. · 12. (d) Each small gap works as a pinhole and forms an image of the Sun, round on a normal day and a crescent when the Moon hides part of it; this follows from light travelling in straight lines.

CHAPTER 11

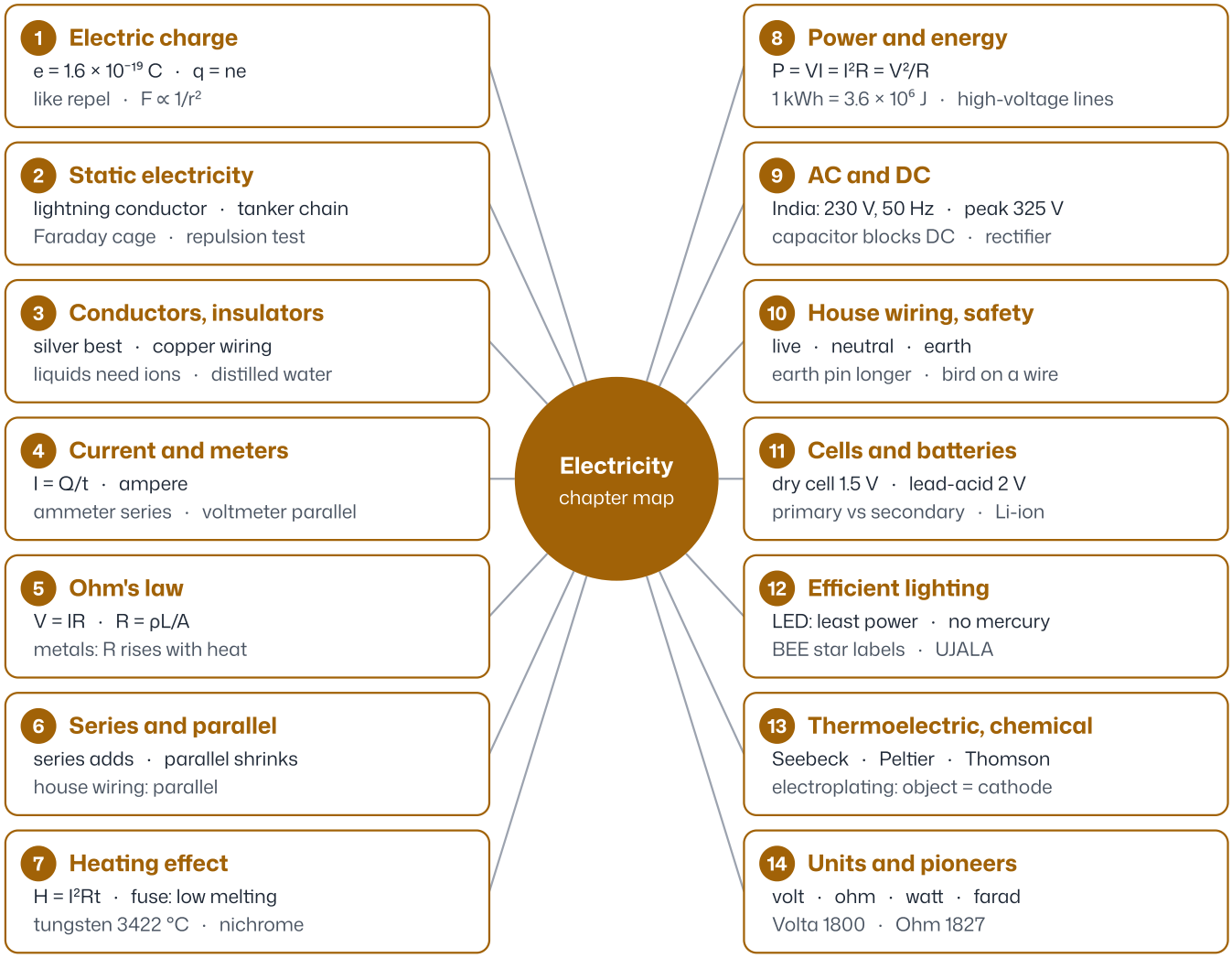
Electricity: Charge, Current and Circuits

Measuring instruments, Ohm's law, power formulas, series-parallel resistance, fuse and household safety come up almost every year, especially in BPSC.

Asked 12 times in past papers: BPSC 12

≈ 59 min to read ≈ 8 min to revise ★★★

Revise on: Day 1 | Day 3 | Day 7 | Day 21



Revision card

1. Charge is quantised (q = ne) and conserved; e = 1.6 × 10^{-19} C; 1 C ≈ 6.25 × 10^{18} electrons.
2. Ammeter measures current: in series, very low resistance. Voltmeter measures potential difference: in parallel, very high resistance.
3. Galvanometer detects small currents; potentiometer measures emf; ohmmeter measures resistance; voltameter is an electrolysis cell, not a voltmeter.
4. Ohm's law V = IR, so R = V/I; R = ρL/A. Metals' resistance rises with temperature; semiconductors' falls.
5. Series: R = R_1 + R_2 (bigger). Parallel: 1/R = 1/R_1 + 1/R_2 (smaller than the smallest). House wiring is parallel.
6. Power P = VI = I^2R = V^2/R, in watts. IR^2 is NOT a power formula.
7. 1 unit = 1 kWh = 3.6 × 10^6 J. Heat H = I^2Rt (Joule's law).
8. Fuse: tin-lead alloy, low melting point, in series on the live wire. Filament: tungsten (melts at 3422 °C), bulb filled with argon/nitrogen. Heater coil: nichrome.
9. Short circuit: resistance ≈ 0, so current becomes very large; the fuse melts or the MCB trips.
10. India: 230 V (often quoted as 220 V), 50 Hz AC (USA 120 V, 60 Hz). Current reverses 100 times a second.
11. Wire colours: live brown (old red), neutral blue (old black), earth green-and-yellow (old green). Earth pin is longest and thickest.
12. Capacitive reactance Xc = 1/(2πfC) falls with frequency; inductive reactance XL = 2πfL rises with it.
13. Thomson effect: emf along ONE conductor with a temperature gradient. Seebeck: two metals, heat → emf. Peltier: current → heating/cooling at a junction.
14. Volta made the first battery (1800). Lead-acid in cars (2 V per cell, 12 V); Li-ion in phones and EVs (Chemistry Nobel 2019).

Electric charge

like vs unlike

e = 1.6 × 10^{-19} C

q = ne

conservation

Coulomb's law

volt = J/C

Every atom holds positive protons in the nucleus and negative electrons around it. Normally they balance, so matter is neutral. Rubbing, touching or heating can move **electrons** from one body to another: the body that gains electrons turns **negative**, the one that loses them turns **positive**. Protons never move in such charging.

★★★ **Two kinds** of charge: positive and negative. **Like charges repel, unlike charges attract.**

★★★ **SI unit**: coulomb (C). Charge of one electron **e = 1.6 × 10^{-19} C** (negative); a proton carries the same amount, positive.

★★ Since the 2019 SI redefinition, e is fixed **exactly** at 1.602 176 634 × 10^{-19} C, and the ampere is defined from it.

★★★ **Quantisation**: any charge is a whole-number multiple of e (q = ne). You can never have 1.5 e on a body.

★★★ **Conservation**: charge is neither created nor destroyed; in rubbing it only moves. Glass and silk end up with equal and opposite charges.

★★ **1 coulomb** ≈ charge of **6.25 × 10^{18} electrons**.

★★ **Millikan's oil-drop experiment** (1909) measured e and showed charge comes in fixed lumps.

★ A body that becomes negative gains electrons, so its mass increases very slightly; a positive body loses a tiny mass.

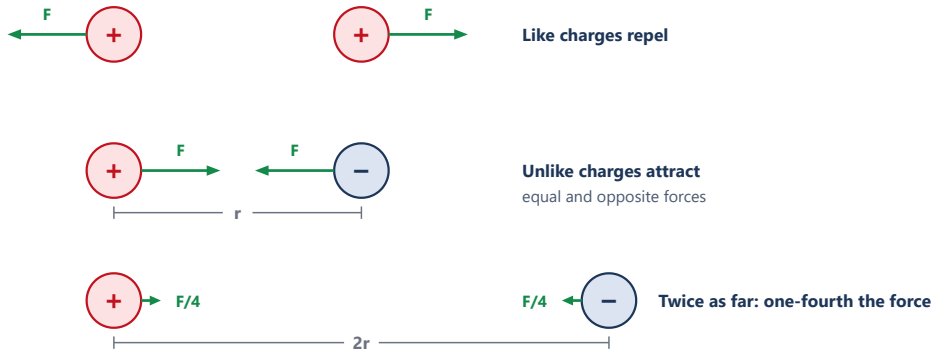
★★ **Coulomb's law** (1785): $F = k\, q_1 q_2 / r^2$, with $k \approx 9 \times 10^9$ N m^2 C^{-2}. Force doubles if one charge doubles; it falls to one-fourth if distance doubles (inverse square).

★ **In a medium** the force weakens: in water it is about 1/80 of that in air (dielectric constant of water ≈ 80). This is why water pulls salts apart so easily.

★ **Electric force vs gravity**: between two protons the electric force is about 10^{36} times the gravitational pull.

★★ **Electric field** E = force per unit charge; unit **N/C** (= V/m). Field lines start on + charges, end on − charges, and never cross.

★★ **Electric potential** = work done per unit charge to bring it from far away; unit **volt** (1 V = 1 J/C). Positive charge flows from high to low potential, like water flowing downhill.



Forces between charges, arrows to scale. Like charges repel and unlike charges attract, always with equal and opposite forces. Move the charges twice as far apart and each force falls to one-fourth ($F \propto 1/r^2$).

Remember it: GSP: Glass rubbed with Silk turns Positive. The plastic comb in dry hair, the balloon on a sweater and ebonite on wool all grab electrons and turn negative.

Quick check

1. Glass is rubbed with silk. Which way do electrons move, and what charge does the glass get?
2. Can a body carry a charge of 1.5 e? Why?
3. Double the distance between two charges: the force becomes _____ .

Answer: 1. electrons leave the glass; it turns positive · 2. no: charge is quantised, q = ne · 3. one-fourth ($F \propto 1/r^2$)

Static electricity in daily life

charging methods

repulsion test

Charge that stays put on a body is **static electricity**. It builds up when two surfaces rub, and escapes suddenly as a **spark** when it finds a path. Dry air lets it build; humid air lets it leak away slowly, which is why sparks are a winter problem, not a monsoon one.

lightning conductor

tanker chain

Faraday cage

Three ways to charge a body ★★

Method	What happens	Sign of charge gained
Friction (rubbing)	Electrons move from one surface to the other	Opposite on the two bodies
Conduction (touching)	A charged body shares its charge on contact	Same as the charging body
Induction (no contact)	A charged body nearby pushes the free electrons to one side; earthing the far side and then removing it leaves a charge	Opposite to the inducing body

★★ **Why a charged comb lifts paper bits**: it induces opposite charge on the near side of the paper, and attraction wins. Attraction alone does not prove a body is charged.

★★★ **Repulsion is the sure test** of charge: only two charged bodies can repel.

★★ **Gold-leaf electroscope** detects charge: two thin leaves receive the same charge and spread apart. The wider they open, the more charge.

★★★ **Lightning**: friction among ice and water particles separates charge inside a cumulonimbus cloud; when the field gets strong enough, air breaks down and a giant spark jumps to another cloud or to the ground. **Benjamin Franklin** showed lightning is electricity with his kite experiment (1752).

★★★ **Lightning conductor**: a pointed metal (copper) rod above the highest point of a building, joined by a thick strip to a plate buried in moist earth. Charge crowds at sharp points, so the rod leads the strike safely to the ground.

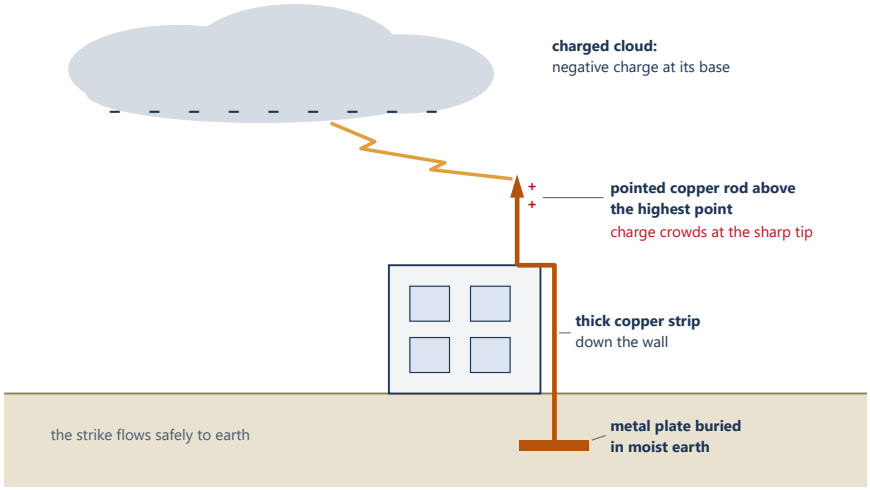
★★ **Thunder** is heard after the flash because light travels far faster than sound.

★★ **Fuel tankers** build up charge as fuel sloshes and tyres roll. A **metal chain or conducting strip** touching the road drains it to earth, so no spark ignites the fuel vapour.

★★ **Woollen and synthetic clothes** crackle and give small sparks in dry winter: rubbing charges them, and dry air cannot leak the charge away.

★★ **Charge sits on the outer surface** of a conductor and the field inside a closed metal shell is zero (**Faraday cage**). So a closed car, bus or aircraft is a safe place in a lightning storm.

★ **Uses of static**: photocopiers and laser printers (charged drum picks up toner), electrostatic precipitators that remove fly ash from thermal power plant chimneys, spray painting.



Lightning conductor. The cloud's negative base induces positive charge that crowds at the rod's sharp tip; a strike is led down the thick copper strip to the plate buried in moist earth, bypassing the building. Not to scale.

See it around you: Taking off a sweater in Delhi's December dark: you hear crackles and see tiny blue sparks. Touching a metal door handle after walking on a carpet gives a small jolt. Both are static charge escaping.

Exam trap: In a thunderstorm, standing under a lone tall tree or in an open field is dangerous; sitting inside a closed car is safe. The car protects because of its metal shell, not because of its rubber tyres.



Lightning striking the Eiffel Tower, 1902. The flash goes for the tallest metal point, and the iron structure carries the charge safely to earth: the same job a lightning conductor does for a building. Image: Gabriel Loppé, Wikimedia Commons, public domain

Quick check

1. Which is the sure test that a body is charged: attraction or repulsion?
2. Why does a fuel tanker carry a metal chain touching the road?
3. In a thunderstorm, why is a closed car safe?

Answer: 1. repulsion · 2. it drains static charge to earth, so no spark ignites the fuel vapour · 3. its metal shell (Faraday cage), not its rubber tyres

Conductors, insulators and semiconductors

free electrons

silver best

copper wiring

aluminium lines

ions in liquids

distilled water

A material conducts if it has charges free to move. Metals have a sea of free electrons. In liquids the carriers are **ions**, so a liquid conducts only if something is dissolved in it that splits into ions.

Who conducts and who does not ★★★

Type	Why	Examples
Conductor	Many free electrons; low resistance	Silver (best), copper, gold, aluminium, iron, graphite, the human body, the earth
Insulator	Almost no free charges; very high resistance	Rubber, plastic, glass, dry wood, porcelain, mica, dry air
Semiconductor	In between; conduction rises with heat or added impurities	Silicon, germanium (more in the chapter on electronics)
Conducting liquids (electrolytes)	Dissolved ions carry charge	Salt water, lemon juice, orange juice, vinegar, acids, tap water, molten salts
Poorly conducting liquids	No ions	Distilled water, kerosene, petrol, vegetable oil

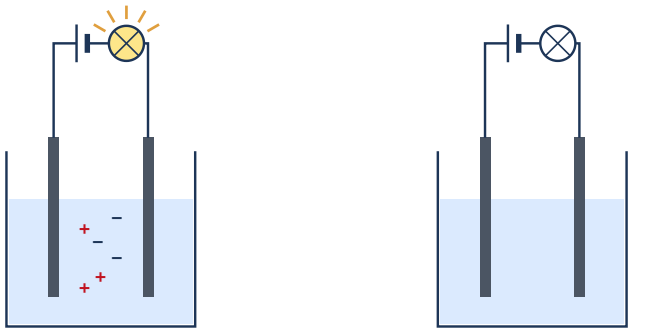
★★★ **Silver** is the best conductor; **copper** is used in household wiring (nearly as good, much cheaper); **aluminium** in overhead transmission lines (light and cheap).

★★ **Graphite** is a non-metal that conducts; it is used for electrodes and in dry-cell carbon rods.

★★ **Mercury** is a liquid metal and conducts well; it does not need ions.

★★ **Pure (distilled) water** barely conducts; the tap water that gives shocks conducts because of dissolved salts.

★ **Porcelain discs** on electric poles insulate the live wires from the pole.



The same circuit dipped in two liquids. Salt water holds ions that carry charge, so the bulb glows; distilled water has almost none, so the bulb stays dark. Lemon juice or vinegar would light the bulb too.

⚠ **Exam trap:** "Which liquid is a bad conductor: salt water, orange juice or lemon juice?" None of them. All three contain ions and conduct. Choose distilled water, oil or kerosene as the bad conductor if offered.

Quick check

1. Best conductor of electricity among metals?
2. Why is aluminium, not copper, used in overhead transmission lines?
3. Salt water, lemon juice, kerosene: which one is a poor conductor?

Answer: 1. silver · 2. it is light and cheap · 3. kerosene (no ions)

Current, potential difference and the meters that measure them

I = Q/t

electron drift

ammeter: series

voltmeter: parallel

galvanometer

voltameter ≠ voltmeter

Think of a water tank: the **height difference** (potential difference) pushes water, the **flow rate** is the current, and a **narrow pipe** is the resistance. A battery is the pump that keeps the height difference alive.

★★★ **Electric current** I = charge flowing per second, I = Q/t. Unit **ampere** (A), one of the seven SI base units; 1 A = 1 C/s.

★★★ **Conventional current** flows from + to − outside the cell; **electrons** actually drift the other way, from − to +.

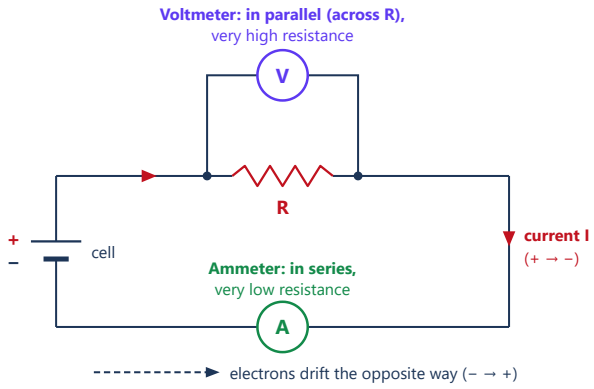
★★ **Drift speed** of electrons in a wire is tiny (well under a millimetre per second), yet a bulb lights at once because the electric field travels along the wire at nearly the speed of light.

★★★ **Potential difference** (voltage) = work done per unit charge between two points; unit **volt** (V), named after Alessandro Volta.

★★ **EMF** (electromotive force) = energy a cell gives each coulomb; measured in volts. It is not a force. Terminal voltage is a little less than emf when current flows, because the cell has internal resistance.

Instruments: what each one measures ★★★

Instrument	Measures / does	How it is connected
Ammeter	Electric current	In series; very low resistance
Voltmeter	Potential difference	In parallel; very high resistance
Galvanometer	Detects small currents and their direction	In series; becomes an ammeter with a low resistance (shunt) in parallel, a voltmeter with a high resistance in series
Potentiometer	EMF of a cell, accurately (draws no current at balance); compares emfs	Long uniform wire with a galvanometer (null method)
Ohmmeter	Resistance	Across the component, with the circuit switched off
Multimeter	Current, voltage and resistance	In series for current, in parallel for voltage
Wheatstone bridge / metre bridge	Unknown resistance	Four resistances with a galvanometer (null method)
Rheostat	Varies resistance to control current	In series
Voltameter	An electrolytic cell; shows electrolysis and measures charge passed	In series: the whole current passes through it
Energy meter	Electrical energy in kWh (units)	At the house entry
Electroscope	Detects static charge	Not in a circuit: the charged body touches its cap



Ammeter A in series, so the whole current passes through it; voltmeter V in parallel, across the resistor whose voltage it measures. Conventional current leaves the + terminal; electrons drift the other way.

Remember it: Ammeter stands in the queue (series); Voltmeter stands beside it to compare heights (parallel). An ammeter must not slow the queue, so its resistance is tiny; a voltmeter must not steal current, so its resistance is huge.

⚠ Exam trap: Voltameter ≠ voltmeter. And a galvanometer detects current; it does not measure resistance. "Galvanometer: electric resistance" is the wrongly matched pair.

Quick check

1. How is an ammeter connected, and what is its resistance?
2. Outside the cell, electrons in a wire drift from _____ to _____; conventional current flows the other way.
3. Which instrument measures the emf of a cell accurately, drawing no current at balance?

Answer: 1. in series; very low · 2. − to + · 3. potentiometer

Ohm's law and resistance

V = IR

R = ρL/A

resistivity (Ω m)

stretched wire: 4R

temperature effect

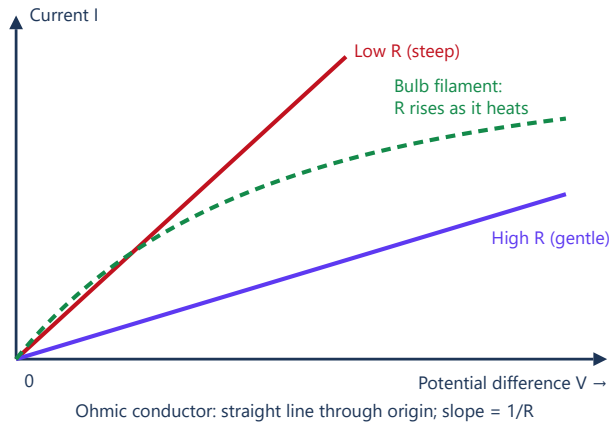
Push harder and more current flows. **Georg Simon Ohm** (1827) found that for a metal wire at steady temperature, current is exactly proportional to the voltage. The ratio V/I is fixed for that wire and is called its **resistance**.

★★★ **Ohm's law**: V = IR, so **R = V/I** and I = V/R. Holds when temperature and physical conditions stay the same.

★★★ **Unit of resistance**: ohm (Ω); 1 Ω = 1 V/A. **Conductance** G = 1/R, unit siemens (S), old name mho (℧).

★★ **V–I graph** of an ohmic conductor is a straight line through the origin. The steeper the I-vs-V line, the smaller the resistance.

★★ **Non-ohmic** devices: filament bulb (resistance rises as it heats), diode, transistor, electrolytes.



Straight line = Ohm's law obeyed. Steeper line = lower resistance. A bulb filament bends away because it gets hotter and its resistance rises.

★★★ **R = ρL/A**: resistance grows with **length** (L) and falls with **cross-sectional area** (A). ρ (rho) is the **resistivity**.

★★★ **Resistivity** depends only on the material and its temperature, not on shape or size. Unit **ohm-metre (Ω m)**.

★★ **Values at 20 °C**: silver ≈ 1.6×10^{-8} Ω m, copper ≈ 1.7×10^{-8} Ω m, nichrome ≈ 1.1×10^{-6} Ω m (about 65 times copper).

★★ **Thick wire, low resistance**: doubling the diameter makes area 4 times, so resistance falls to one-fourth.

★★ **Stretching** a wire to twice its length (volume unchanged) halves its area, so resistance becomes **4 times**.

★★★ **Temperature**: in metals resistance **rises** with heat (vibrating atoms block electrons); in **semiconductors it falls** (heat frees more charge carriers).

★ **Alloys** such as manganin and constantan barely change resistance with temperature, so standard resistors are made of them.

★★ **Superconductors** lose all resistance below a critical temperature: Heike Kamerlingh Onnes saw it in mercury at 4.2 K (1911). Used in MRI magnets and maglev trains (detail in the chapter on electronics and materials).

Remember it: VIR triangle: put V on top, I and R below. Cover what you want: V = I × R, I = V/R, R = V/I. "Very Intelligent Rahul" never forgets Ohm.

Exam trap: Resistance R changes with length and thickness; resistivity ρ does not. A long thin copper wire and a short thick one have different resistance but the same resistivity.

Quick check

1. A wire is stretched to twice its length. Its resistance becomes?
2. Heating raises a metal wire's resistance. What does heating do to a semiconductor's resistance?
3. Does resistivity change if you cut a wire in half?

Answer: 1. 4 times · 2. lowers it · 3. no: it depends only on the material and temperature

Series and parallel circuits

series: R adds

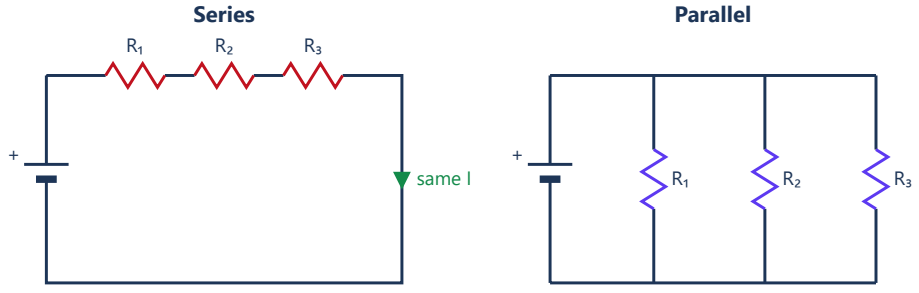
parallel: 1/R adds

house wiring parallel

60 W vs 100 W

ratio n^2

In **series** there is one path, so the same current must squeeze through every resistor one after another: resistances add. In **parallel** each resistor offers a fresh path, like opening more toll booths: the total resistance drops below even the smallest one.



$R = R_1 + R_2 + R_3$ (grows)
Same current; voltage is shared
One break: everything stops

$1/R = 1/R_1 + 1/R_2 + 1/R_3$ (shrinks)
Same voltage; current is shared
One break: the others keep working

Series: one path, same current, resistances add. Parallel: many paths, same voltage, total resistance falls.

Series vs parallel ★★★

Feature	Series	Parallel
Equivalent resistance	$R = R_1 + R_2 + R_3$ (more than the largest)	$1/R = 1/R_1 + 1/R_2 + 1/R_3$ (less than the smallest)
Current	Same through each	Divides; more through the smaller resistance
Voltage	Divides among them	Same across each
If one component fails	Whole circuit stops	Others keep working
n equal resistors R	nR	R/n
Everyday use	Fuse with the circuit; cheap decorative light strings	House wiring; car headlights

★★★ **House wiring is parallel**: every appliance gets the full 230 V, each has its own switch, one fused bulb does not black out the house, and total resistance stays low.

★★ **Two resistors in parallel**: $R = R_1R_2/(R_1 + R_2)$ ("product over sum").

★★ **Worked example**: two resistors in parallel give 1.403 kΩ; one is 2.0 kΩ. Then $1/R_2 = 1/1.403 - 1/2.0 = 0.7128 - 0.5 = 0.2128$, so $\mathbf{R_2 \approx 4.70\ k\Omega}$. Check: the total (1.403) is below both 2.0 and 4.70.

★★ **Same n resistors**: series total ÷ parallel total = $\mathbf{n^2}$. Two equal resistors: series 2R, parallel R/2, ratio 4.

★★ **Cheap decorative light strings** are often wired in series: when one bulb fails the whole string goes dark.

★ **Cells in series** add their voltages (four 1.5 V cells give 6 V); cells in parallel give the same voltage but last longer.

⚠ **Exam trap:** A 60 W and a 100 W bulb in **series**: the **60 W bulb glows brighter** (it has higher resistance, and the same current gives it more I^2R). In **parallel** (as at home) the 100 W bulb glows brighter. Examiners love to reverse this.

Quick check

1. Why is house wiring done in parallel? Give one reason.
2. A 60 W and a 100 W bulb are joined in series. Which glows brighter?
3. Two equal resistors R in parallel give?

Answer: 1. each appliance gets the full 230 V (and one failure does not stop the rest) · 2. the 60 W bulb (higher resistance) · 3. R/2

Heating effect: fuse, filament and heater

$H = I^2Rt$

nichrome element

tungsten 3422 °C

Electrons moving through a wire keep bumping into atoms and hand over energy as heat. **James Prescott Joule** measured it: the heat rises with the square of the current, so doubling the current gives four times the heat. Some devices want this heat (iron, heater), some must survive it (bulb filament), and one is designed to die from it (fuse).

fuse: tin-lead

MCB, RCCB

★★★ **Joule's law of heating**: H = I²Rt (heat in joules, current in A, resistance in Ω, time in s).

★★ **Uses of heating effect**: electric iron, room heater, geyser, toaster, kettle, hot plates, filament bulb, fuse.

★★★ **Heating element**: **nichrome** (nickel-chromium alloy): high resistivity, high melting point (about 1400 °C), does not oxidise easily when red-hot.

★★★ **Bulb filament**: **tungsten**, the metal with the highest melting point (**3422 °C**). It glows white-hot at around 2500 °C.

★★★ **Bulb gas**: filled with inert **argon and/or nitrogen** so the hot tungsten does not oxidise and evaporates more slowly. The filament is coiled to pack more length in.

★★★ **Fuse**: a short wire of **tin-lead alloy** with a **low melting point** (and higher resistivity than copper), connected **in series on the live wire**. When current exceeds its rating it melts and breaks the circuit, protecting wiring and appliances.

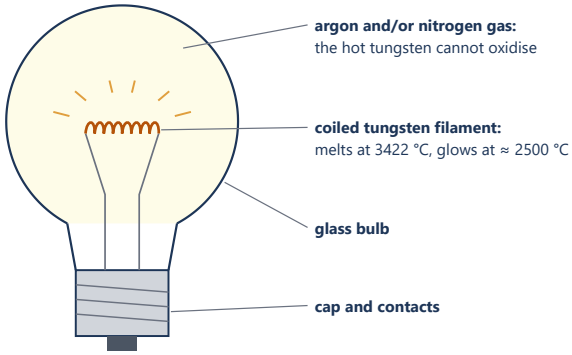
★★ **Fuse rating** is in amperes (e.g. 5 A for lights, 15 A for heavy appliances). Replacing a fuse with a thick copper wire defeats it and invites fire.

★★★ **Short circuit**: live and neutral touch directly (damaged insulation). Resistance falls to almost zero, so **current becomes very large**, wires heat up and can start a fire.

★★ **Overloading**: too many appliances on one socket draw more current than the wire is rated for.

★★★ **MCB** (miniature circuit breaker): an automatic switch that trips on overload or short circuit and can simply be switched back on; it is replacing fuses.

★★★ **ELCB / RCCB** (earth-leakage / residual-current circuit breaker): compares current in live and neutral. If some current leaks away, for example through a person to earth, it trips within a fraction of a second (typical setting 30 mA). It protects **people** from shock.



Filament bulb. The coiled tungsten filament glows white-hot at about 2500 °C without melting (melting point 3422 °C); argon and/or nitrogen inside keep it from oxidising.

Which wire for which job ★★

Device	Material	Property needed
Fuse wire	Tin-lead alloy	Low melting point
Bulb filament	Tungsten	Very high melting point
Heater, iron, toaster coil	Nichrome	High resistivity, high melting point, no oxidation
House wiring	Copper	Very low resistivity
Overhead power lines	Aluminium (often steel-reinforced)	Low resistivity, light, cheap

Remember it: Fuse is the Fragile hero: it dies so the house lives. The filament is the opposite: the toughest survivor of heat (tungsten, 3422 °C).

⚠ **Exam trap:** Fuse and MCB guard **wiring and appliances** against too much current; the ELCB/RCCB guards **people**. But if a question asks which device protects equipment from electric shock and offers only fuse, generator, motor and current controller, the answer is the **fuse**.

Quick check

1. The current through the same wire doubles for the same time. The heat produced becomes?
2. Fuse wire needs a _____ melting point; a bulb filament needs a _____ one.
3. Which device protects people from shock by tripping on leakage current?

Answer: 1. 4 times ($H = I^2Rt$) · 2. low; very high (tungsten) · 3. ELCB / RCCB

Electric power, energy and your bill

$P = VI = I^2R = V^2/R$

$1\ kWh = 3.6 \times 10^6\ J$

1 hp = 746 W

high-voltage transmission

765 kV

Power is how fast energy is used. A 1000 W iron uses energy ten times as fast as a 100 W fan. The electricity board does not bill you for power, but for **energy**: power × time.

★★★ **Electric power** $P = VI = I^2R = V^2/R$. Unit **watt** (W) = 1 J/s. 1 kW = 1000 W; 1 horsepower = 746 W.

★★★ **Energy** = power × time. Commercial unit: **kilowatt-hour (kWh) = 1 unit = 3.6×10^6 J** (1000 W × 3600 s).

★★ **Rating** "100 W, 230 V" means the bulb draws 100 W at 230 V: current = 100/230 ≈ 0.43 A, hot resistance = $V^2/P = 230^2/100 \approx 529\ \Omega$.

★★ **Same voltage, more watts = less resistance**: a 1000 W heater has far lower resistance than a 100 W bulb ($R = V^2/P$).

★★ **Sample bill**: two 60 W fans for 10 h a day = 1.2 kWh; one 1000 W geyser for 1 h = 1 kWh. Daily total 2.2 units; for 30 days 66 units; at ₹6 per unit, **₹396**.

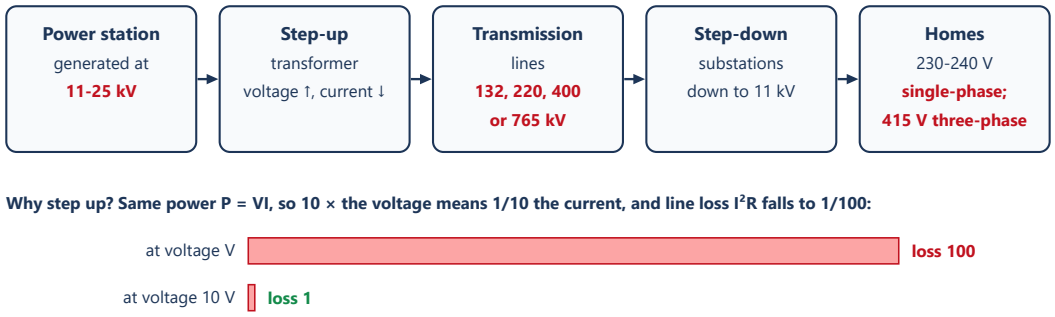
Remember it: Power is VIP: P = V·I. Then swap V = IR to get I^2R, or I = V/R to get V^2/R. Any formula with R squared (like IR^2) is a fake.

Why transmit at high voltage? For a fixed power P = VI, raising V lowers I. The heat wasted in the lines is I^2R, so it falls with the square of the current.

★★★ **Step up 10 times** in voltage → current falls to 1/10 → line loss falls to **1/100**.

★★ **In India** power is generated at roughly 11-25 kV, stepped up to 132, 220, 400 or 765 kV for transmission, then stepped down in stages to 11 kV and finally **415 V (three-phase) / 230–240 V (single-phase)** for consumers. 765 kV is the highest AC transmission voltage in commercial use in India.

★ **HVDC** lines (India runs links up to ±800 kV) carry bulk power over very long distances with lower losses.



From power station to home: voltage is stepped up for the long journey and stepped down near you. Bottom bars, drawn to scale: for the same power, 10 times the voltage cuts the line loss to 1/100.

☑ Quick check

1. 1 kilowatt-hour equals how many joules?
2. Voltage is stepped up 10 times for the same power. The line loss becomes?
3. Same 230 V supply: which has the lower resistance, a 1000 W heater or a 100 W bulb?

Answer: 1. 3.6×10^6 J · 2. 1/100 · 3. the 1000 W heater ($R = V^2/P$)

AC and DC; capacitors and inductors

230 V, 50 Hz

100 reversals a second

peak 325 V

rectifier vs inverter

Xc = 1/(2πfC)

choke coil

Direct current (DC) flows one way, as from a battery or solar cell. **Alternating current (AC)** reverses direction many times a second, as from a power-station generator. AC won the "war of currents" (Tesla and Westinghouse against Edison's DC) because transformers can step AC voltage up and down cheaply.

AC vs DC ★★★

Feature	AC	DC
Direction	Reverses periodically	One direction
Frequency	50 Hz in India; 60 Hz in USA	Zero
Source	AC generator (alternator)	Cell, battery, solar cell, DC dynamo
Voltage change	Easy, with a transformer	Needs electronic converters
Used for	Mains supply, grid, motors at home	Phones, laptops, LEDs, EV batteries, electroplating

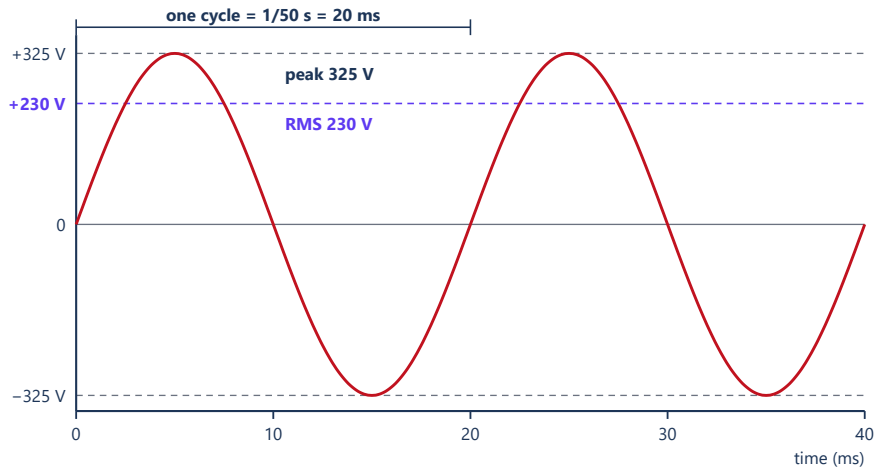
★★★ **India**: 230 V, 50 Hz single-phase supply (three-phase 415 V); the Indian Standard system voltage is 240/415 V, and **220 V** is the older figure many questions still use. **USA**: 120 V, 60 Hz. Japan uses 50 Hz in the east and 60 Hz in the west.

★★ **50 Hz** means 50 full cycles per second, so the current **reverses direction 100 times a second**.

★★ **230 V is the RMS value**; the peak voltage is √2 times it, about **325 V**.

★★ **Rectifier** (diodes) converts AC → DC (phone chargers, adapters). **Inverter** converts DC → AC (home inverter, solar systems).

★★ **AC is more dangerous** at the same voltage: its 50 Hz pulses make muscles clamp, so a victim often cannot let go.



Indian mains drawn to scale: 50 Hz, so one cycle lasts 20 ms and the current reverses 100 times a second. The voltage swings between +325 V and −325 V; 230 V is its RMS value (325 ÷ √2). DC would be a flat line.

★★ **Capacitor**: two conducting plates separated by an insulator (dielectric); it stores charge and energy in an electric field. Capacitance C = Q/V; unit **farad** (F). Practical values are in μF and pF.

★★★ **Capacitive reactance** $X_C = 1/(2\pi fC)$: **inversely proportional to frequency**. A capacitor blocks DC (f = 0) and passes high-frequency AC easily.

★★ **Inductor** (coil): opposes any change in current; unit **henry** (H). **Inductive reactance** $X_L = 2\pi fL$ rises in proportion to frequency: an inductor passes DC freely and chokes high-frequency AC.

★★ **Uses of capacitors**: starting a ceiling fan's motor, camera flash (dumps stored charge in a flash), tuning radios with an inductor, improving the power factor of motors, smoothing DC.

★ **Choke coil**: an inductor used to limit AC current (old tube lights, old fan regulators) while wasting very little power as heat, unlike a resistor.

Remember it: "Capacitor Can't stand Calm DC; inductor Loves Lazy DC." Xc falls as frequency rises; XL rises with frequency.

Quick check

1. Frequency of the mains supply in India, and in the USA?
2. How many times a second does 50 Hz AC reverse its direction?
3. Which device converts AC to DC, and which converts DC to AC?

Answer: 1. 50 Hz; 60 Hz · 2. 100 · 3. rectifier; inverter

Household wiring, earthing and electric shock

live, neutral, earth

wire colours

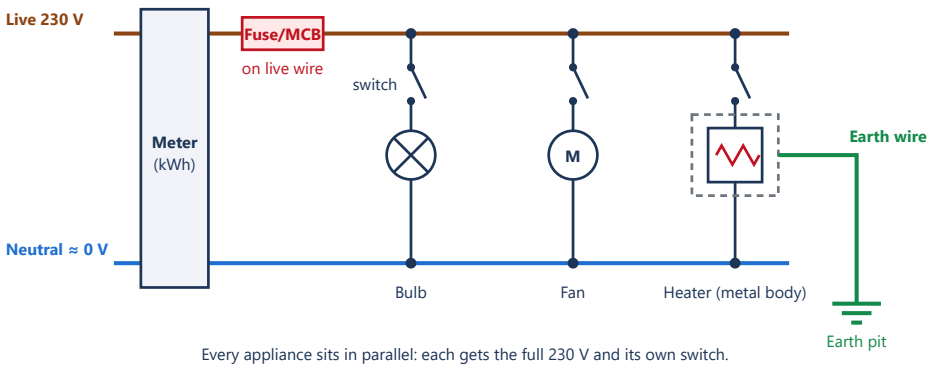
earthing

earth pin longer

bird on a wire

100 mA

Two wires come from the pole: the **live** (phase) wire at 230 V and the **neutral** wire near 0 V. A third, the **earth** wire, comes from a metal plate or pipe buried deep in moist soil next to the house. It carries no current normally; it is a safety escape route.



Every appliance sits in parallel: each gets the full 230 V and its own switch.

Fuse/MCB and every switch sit on the live wire. Appliances are in parallel. The heater's metal body is earthed, so a fault current runs to the earth pit instead of through you.

Wire colours in Indian homes ★★★

Wire	Current standard	Older installations	Potential
Live (phase)	Brown	Red	230 V
Neutral	Blue	Black	≈ 0 V
Earth	Green-and-yellow stripes	Green	0 V (ground)

Remember it: Brown = Bijli (the live one), **Blue = Back** (neutral, the return path), **Green-yellow = Ground** (like green earth).

★★★ **Earthing**: the metal body of an iron, fridge, washing machine, geyser or cooler is joined to the earth wire. If the live wire touches the body, a large current rushes to earth, the fuse blows or MCB/RCCB trips, and the body never stays at 230 V.

★★★ **Three-pin plug**: the **earth pin is longer and thicker**. Longer, so it connects first and disconnects last; thicker, so it cannot be pushed into a live or neutral hole.

★★★ **Switches and fuses go on the live wire**, so that switching off cuts the appliance away from 230 V.

★★★ **Bird on a wire is safe**: both feet touch the same wire at the same potential, so there is no potential difference across its body and no current flows. A bird or monkey that touches two wires, or a wire and the pole, is electrocuted.

★★ **Electric shock**: current through the body does the damage. About 1 mA is felt; 10-20 mA makes muscles lock; around **100 mA** across the chest can stop the heart's rhythm and kill.

★★ **Wet skin** cuts the body's resistance from roughly 100 kΩ (dry) to about 1 kΩ, so the same voltage drives a far larger current. Never touch switches with wet hands.

★★ **Rescue**: switch off the mains first, or push the person away with a dry wooden stick; never grab a person who is still in contact.

⚠ **Exam trap:** It is not the voltage alone but the **current through the body** that kills. A bird on an 11 kV line is safe; a person touching a 230 V wire while standing barefoot on wet ground is not.

Quick check

1. Live, neutral, earth: what colour is each in the current Indian standard?
2. Why is the earth pin of a three-pin plug made longer?
3. Why is a bird sitting on a single live wire safe?

Answer: 1. brown, blue, green-and-yellow · 2. so it connects first and disconnects last · 3. both feet are at the same potential, so no current flows through it

Cells and batteries

chemical → electrical

voltaic pile 1800

dry cell 1.5 V

lead-acid 2 V

primary vs secondary

lithium-ion

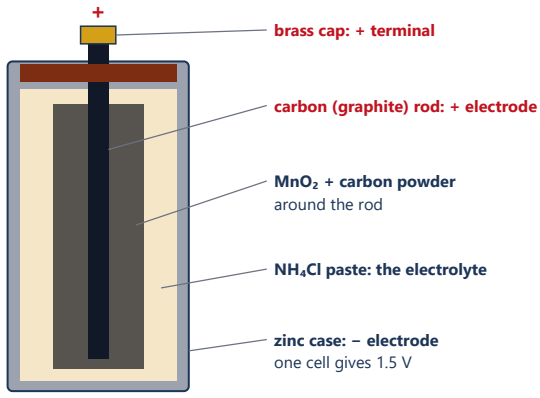
A cell turns **chemical energy into electrical energy** by letting two different electrodes react through an electrolyte. **Luigi Galvani** saw frog legs twitch ("animal electricity", 1780s); **Alessandro Volta** showed the metals were the real source and built the **voltaic pile** (1800), the first battery: zinc and copper discs separated by brine-soaked cloth.



An early voltaic pile on display at the Tempio Voltiano, Volta's museum in Como, Italy: a stack of metal discs separated by brine-soaked cloth. Volta's pile (1800) was the first battery. Image: GuidoB, Wikimedia Commons, CC BY-SA 3.0

Cells you meet every day ★★★

Cell	Type	Voltage per cell	Key facts / uses
Dry cell (Leclanché type)	Primary (use and throw)	1.5 V	Zinc case (−), carbon rod (+), MnO_2 and NH_4Cl paste; torches, remotes, clocks
Alkaline cell	Primary	1.5 V	Longer life than ordinary dry cell
Button cells (silver oxide, mercury)	Primary	≈ 1.35-1.55 V	Watches, hearing aids, calculators
Lead-acid	Secondary (rechargeable)	2 V (6 cells = 12 V)	Lead and lead dioxide plates in dilute sulphuric acid; car batteries, inverters; Gaston Planté, 1859
Nickel-cadmium, nickel-metal hydride	Secondary	1.2 V	Rechargeable AA cells, cordless tools
Lithium-ion	Secondary	≈ 3.6-3.7 V	Highest energy per kg; phones, laptops, electric vehicles
Fuel cell (hydrogen-oxygen)	Runs as long as fuel is fed	≈ 0.7-1 V in use	Only by-product is water; spacecraft, fuel-cell vehicles
Solar (photovoltaic) cell	Light → electricity	≈ 0.5-0.6 V (silicon)	Gives DC; rooftop solar, satellites



Dry (Leclanché-type) cell, cut open. The zinc case is the negative electrode and the carbon rod with its brass cap the positive one; the MnO_2 mixture and the NH_4Cl paste lie between them. One cell gives 1.5 V.

★★★ **Primary cells** cannot be recharged (the reaction is one-way); **secondary cells** can be recharged by passing current backwards.

★★ **Nobel Prize in Chemistry 2019**: John Goodenough, M. Stanley Whittingham and Akira Yoshino, for developing the **lithium-ion battery**.

★ **Sodium-ion batteries** swap lithium for cheap, abundant sodium: safer and cheaper but heavier for the same energy; suited to grid storage and low-cost vehicles.

★★ **Battery capacity** is quoted in mAh or Ah (charge); energy stored = voltage × capacity, in Wh.

★ **Lead-acid** batteries are the most recycled; their sulphuric acid and lead make careless disposal toxic.

Remember it: Volta → volt; Galvani → galvanometer. The frog twitched for Galvani, but the battery belongs to Volta.

Quick check

1. Voltage of one dry cell, and of one lead-acid cell?
2. In a dry cell, which part is the negative electrode?
3. Primary or secondary: which kind of cell can be recharged?

Answer: 1. 1.5 V; 2 V · 2. the zinc case (the carbon rod is +) · 3. secondary (lead-acid, Li-ion)

Efficient lighting and star labels

lumens per watt

LED most efficient

CFL: mercury

blue LED Nobel 2014

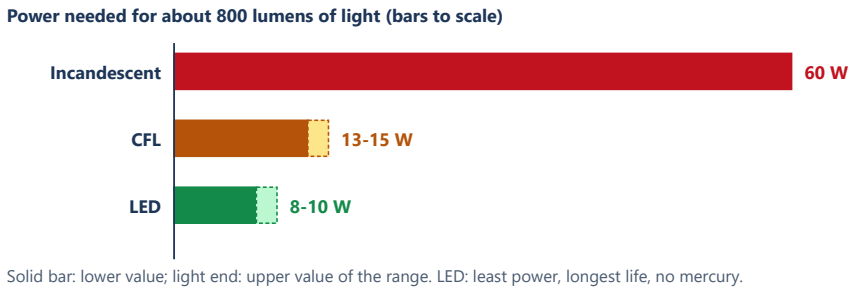
BEE stars

UJALA 2015

A filament bulb makes light by getting white-hot, so most of its energy leaves as heat. An LED makes light directly from electrons crossing a semiconductor junction, so very little is wasted. Efficiency is measured in **lumens per watt** (light out per watt in).

Bulb vs CFL vs LED (for about the same light) ★★★

Feature	Incandescent	CFL	LED
Power for ~800 lumens	60 W	13-15 W	8-10 W
Efficiency	≈ 10-17 lm/W; about 90% lost as heat	≈ 50-70 lm/W	≈ 80-150 lm/W (most efficient)
Life	≈ 1000 hours	≈ 8000-10,000 hours	15,000-50,000 hours
Hazard	Gets very hot	Contains mercury	No mercury



Power each lamp needs for about the same light (≈ 800 lumens), bars to scale. An LED does the job of a 60 W bulb with 8-10 W.

★★ **Blue LED** made white LED lighting possible: **Nobel Prize in Physics 2014** to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura.

★★ **UJALA** scheme (2015) distributed LED bulbs at low prices across India, cutting household lighting bills.

★★ **BEE star labels**: the Bureau of Energy Efficiency (set up under the Energy Conservation Act 2001, Ministry of Power) rates appliances from 1 to 5 stars; **more stars = less electricity** for the same work.

★ **Thomas Edison** made the first long-lasting practical incandescent bulb (1879).

Quick check

1. The efficiency of a lamp is measured in _____ .
2. Which lamp contains mercury: incandescent, CFL or LED?
3. More BEE stars on an appliance mean?

Answer: 1. lumens per watt · 2. CFL · 3. less electricity for the same work

Thermoelectric and chemical effects of current

Seebeck: heat → emf

Peltier: cooling

Thomson: one wire

electrolysis

object = cathode

Heat and electricity can trade places at the junction of two different metals, or along one metal that is hot at one end. These three effects carry the names of their discoverers, and examiners mix them up on purpose.

Thermoelectric effects ★★★

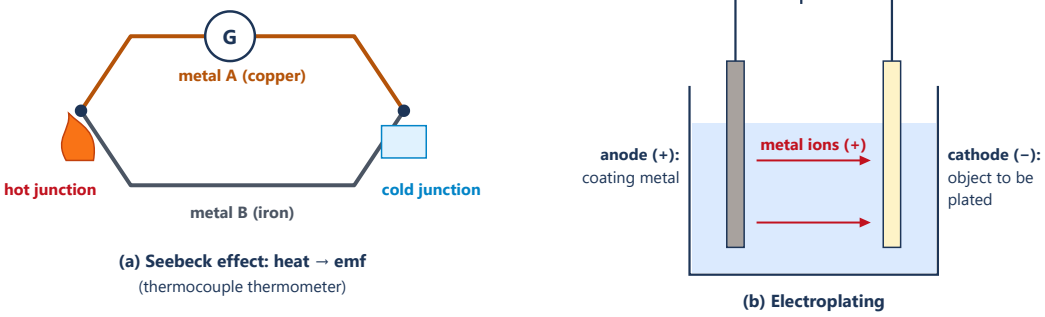
Effect	What happens	Use
Seebeck effect (1821)	Two different metals joined in a loop; junctions at different temperatures produce an emf (heat → electricity)	Thermocouple thermometers for very high temperatures; radioisotope generators on deep-space probes
Peltier effect (1834)	Current through a junction of two metals heats one junction and cools the other	Thermoelectric coolers: mini-fridges, CPU and camera-sensor cooling
Thomson effect	In a single conductor whose ends are at different temperatures, the temperature gradient sets up a potential difference; current along it absorbs or gives out heat	Theory and design of thermoelectric devices
Joule effect	Current through any resistance produces heat I^2Rt; irreversible	Heaters, irons, fuses

Remember it: Seebeck: "See" a voltage from heat (two metals). Peltier: "Pass" a current, heat moves. Thomson: one lonely wire ("Tom" is alone).

★★ **Chemical effect**: current through an electrolyte breaks it up (**electrolysis**). Faraday's laws: mass deposited ∝ charge passed.

★★ **Electroplating**: the object to be coated is the cathode (−); the coating metal is the anode. Chromium on taps and cycle parts, silver and gold on jewellery, tin on food cans.

★ **Electrolytic refining** of copper: impure copper as anode, pure copper collects on the cathode.



(a) Two different metals joined in a loop: keep one junction hot and the other cold and the galvanometer shows a current (Seebeck effect). (b) Electroplating: the coating metal is the anode (+), the object is the cathode (−), and metal ions travel through the electrolyte to coat it.

☑ Quick check

1. Thermocouple thermometers work on which effect?
2. Which effect lets a current cool one junction, as in a mini-fridge?
3. In electroplating, is the object to be coated the anode or the cathode?

Answer: 1. Seebeck effect · 2. Peltier effect · 3. cathode (−)

Units and pioneers at a glance

coulomb, ampere, volt

ohm, siemens

watt, kWh

farad, henry

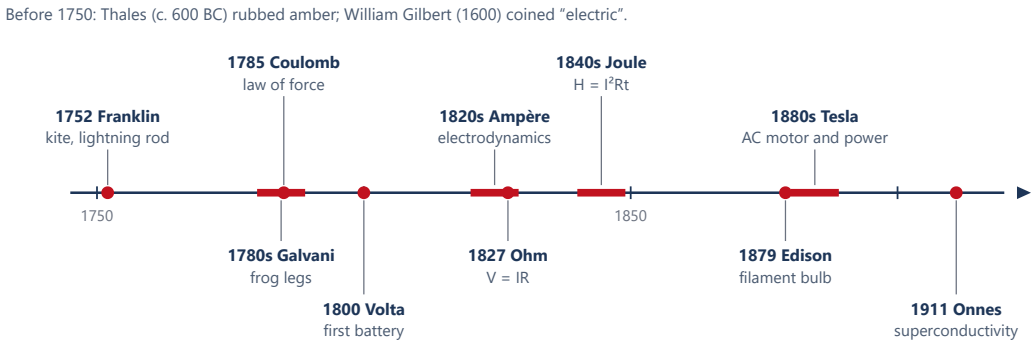
Volta, Ohm, Joule

Quantities and SI units ★★★

Quantity	Formula	SI unit
Charge	q = ne	coulomb (C)
Current	I = Q/t	ampere (A), SI base unit
Potential difference, emf	V = W/Q	volt (V)
Resistance	R = V/I	ohm (Ω)
Resistivity	ρ = RA/L	ohm-metre (Ω m)
Conductance	G = 1/R	siemens (S) or mho
Power	P = VI = I^2R = V^2/R	watt (W)
Energy	E = Pt	joule (J); commercial: kWh
Capacitance	C = Q/V	farad (F)
Inductance	L = Φ/I	henry (H)
Electric field	E = F/q	N/C or V/m

Who did what ★★

Scientist	Contribution
Thales of Miletus (c. 600 BC)	Rubbed amber attracts light objects
William Gilbert (1600)	Coined "electric"; studied magnetism
Benjamin Franklin (1752)	Kite experiment; lightning conductor; named + and − charges
Charles-Augustin de Coulomb (1785)	Law of force between charges
Luigi Galvani (1780s)	Animal electricity (frog legs)
Alessandro Volta (1800)	Voltaic pile, the first battery
André-Marie Ampère (1820s)	Electrodynamics; unit of current
Georg Simon Ohm (1827)	Ohm's law
James Prescott Joule (1840s)	Heating effect $H = I^2Rt$
Thomas Edison (1879)	Practical filament bulb; DC power stations
Nikola Tesla (1880s)	AC motor and AC power system
Heike Kamerlingh Onnes (1911)	Superconductivity



Who did what, on a time line drawn to scale: dots mark single years, bars mark decades.

In India, **CSIR-National Physical Laboratory** (New Delhi) keeps the national standards of measurement, including electrical units, and the **Bureau of Indian Standards** sets the standard supply voltages and the 50 Hz frequency (IS 12360).

Quick check

1. SI unit of conductance?
2. Who built the first battery, and in which year?
3. Who discovered superconductivity (1911)?

Answer: 1. siemens (S); old name mho · 2. Alessandro Volta, 1800 · 3. Heike Kamerlingh Onnes

Asked in past papers (12)

BPSC 64th The device to measure electric current is
(a) voltmeter (b) ammeter (c) voltameter (d) potentiometer
(e) None of the above/More than one of the above
Answer: (b) ammeter. An ammeter measures electric current; a voltmeter measures potential difference

BPSC 65th The device to measure electric current is
(a) voltmeter (b) ammeter (c) voltameter (d) potentiometer
(e) None of the above/More than one of the above
Answer: (b) ammeter. An ammeter measures electric current; a voltmeter measures potential difference

BPSC 65th The unit of electric power is
(a) ampere (b) volt (c) coulomb (d) watt (e) None of the above/More than one of the above
Answer: (d) watt. Electric power is measured in watts; $P = V \times I$

BPSC 66th The total resistance of a circuit having two parallel resistors is 1.403 kilo-ohm. If one of the resistors is 2.0 kilo-ohm, then the other resistor will be
(a) 1.403 kilo-ohm (b) 2.0 kilo-ohm (c) 3.403 kilo-ohm (d) 4.70 kilo-ohm
(e) None of the above/More than one of the above
Answer: (d) 4.70 kilo-ohm. For resistors in parallel, $1/R = 1/R1 + 1/R2$; the total is below the smallest one

BPSC 67th Which of the following is not correctly matched?
(a) Voltmeter : Potential difference (b) Ammeter : Electric current (c) Potentiometer : Electromotive force
(d) Galvanometer : Electric resistance (e) None of the above/More than one of the above
Answer: (d) Galvanometer : Electric resistance. Ammeter measures current, voltmeter potential difference, potentiometer emf; A galvanometer detects small currents; an ohmmeter measures resistance

BPSC 67th re-exam Due to temperature variation along a conductor, potential variation occurs along it. This phenomenon is known as
(a) Peltier effect (b) Thomson effect (c) Joule effect (d) Seebeck effect
(e) None of the above/More than one of the above
Answer: (b) Thomson effect. Thomson effect: a temperature gradient along one conductor sets up an emf in it; Seebeck effect: junctions of two metals at different temperatures produce an emf

BPSC 69th Which of the following liquids is a bad conductor of electricity?
(a) Salted water (b) Orange juice (c) Lemon juice (d) None of the above
Answer: (d) None of the above. Liquids with dissolved ions, such as salt water and fruit juices, conduct electricity

BPSC 70th Which of the following is the resistance of the wire ?
(a) $R = I/(2V)$ (b) $R = IV$ (c) $R = I/V$ (d) $R = V/I$
Answer: (d) $R = V/I$. Ohm's law: $V = IR$, so resistance $R = V/I$

BPSC 70th re-exam Reactance of a capacitor is
(a) Inversely proportional to frequency (b) Directly proportional to frequency
(c) Inversely proportional to sq. root of frequency (d) None of the above
Answer: (a) Inversely proportional to frequency. Capacitive reactance $Xc = 1/(2\pi fC)$ falls as frequency rises; Inductive reactance $XL = 2\pi fL$ rises in proportion to frequency

BPSC 71st Which term in the following does not denote the electric power in electric circuit?
(a) I^2R (b) IR^2 (c) VI (d) V^2/R
Answer: (b) IR^2. Electric power $P = VI = I^2R = V^2/R$, using Ohm's law $V = IR$

BPSC 71st In short circuit, the value of electric current in a time circuit :
(a) Very low (b) Do not change (c) Increases very high (d) Continuously changing
Answer: (c) Increases very high. In a short circuit resistance falls to almost zero, so current becomes very large

BPSC 71st What is the device to protect equipments from the electric shock?
(a) Fuse (b) Generator (c) Motor (d) Current controller
Answer: (a) Fuse. A fuse melts and breaks the circuit when current exceeds a safe limit

Test yourself (13)

1. Three resistors of 6 Ω each are connected in parallel. The equivalent resistance is
(a) 18 Ω (b) 2 Ω (c) 3 Ω (d) 6 Ω

2. A 60 W bulb and a 100 W bulb (both rated 230 V) are joined in series to the mains. Which glows brighter?
(a) The 60 W bulb (b) The 100 W bulb (c) Both equally (d) Neither glows

3. An electric iron of 1000 W is used for 30 minutes every day for 30 days. Energy used is
(a) 30 units (b) 15 units (c) 1.5 units (d) 300 units

4. Which of these materials is used for the filament of an incandescent bulb?
(a) Nichrome (b) Tin-lead alloy (c) Tungsten (d) Copper

5. A copper wire is stretched to double its length with no change in volume. Its resistance becomes
(a) Half (b) Double (c) Unchanged (d) Four times

6. Consider the statements: 1. Resistance of a metal increases with temperature. 2. Resistance of a semiconductor increases with temperature. Which is/are correct?
(a) 1 only (b) 2 only (c) Both 1 and 2 (d) Neither 1 nor 2

7. The earth pin of a three-pin plug is made longer so that it
(a) carries the full load current of the appliance (b) connects first and disconnects last
(c) reduces the electricity bill slightly (d) acts as a fuse when the current rises

8. The device that converts AC into DC is called
(a) Rectifier (b) Inverter (c) Transformer (d) Rheostat

9. A bird sitting on a single high-voltage wire does not get a shock because
(a) its feet and claws act as good insulators of electricity (b) the current in an overhead wire is AC, not DC
(c) there is no potential difference across its body (d) the wire carries very little current

10. Which effect produces an emf when the two junctions of two different metals are kept at different temperatures?
(a) Peltier effect (b) Thomson effect (c) Joule effect (d) Seebeck effect

11. Consider the following statements:
1. An ammeter is connected in parallel with a component and has a very high resistance.
2. A voltmeter is connected in parallel with a component and has a very high resistance.
3. A potentiometer measures the emf of a cell accurately because it draws no current at balance.
Which of the statements given above is/are correct?
(a) 1 only (b) 1 and 2 only (c) 2 and 3 only (d) 1, 2 and 3

12. Consider the following statements about household electricity:
1. Fuse wire is made of a tin-lead alloy because of its low melting point.
2. The heating coil of an electric iron is made of tungsten.
3. The fuse and the switches are placed on the live wire.
How many of the above statements are correct?
(a) Only one (b) Only two (c) All three (d) None

13. A shopkeeper replaces 10 filament bulbs of 60 W with 10 LED bulbs of 9 W that give about the same light. Each bulb runs 5 hours a day. How much electricity does he save in 30 days?
(a) 2.55 units (b) 13.5 units (c) 90 units (d) 76.5 units

Answers: 1. (b) n equal resistors in parallel give R/n = 6/3 = 2 Ω. · 2. (a) The 60 W bulb has higher resistance; with the same current it gets more power (I^2R). · 3. (b) 1 kW × 0.5 h × 30 = 15 kWh = 15 units. · 4. (c) Tungsten has the highest melting point of metals (3422 °C). · 5. (d) Length doubles and area halves, so R = ρL/A becomes 2 × 2 = 4 times. · 6. (a) Metals' resistance rises with heat; semiconductors' falls because heat frees more carriers. · 7. (b) Longer pin makes the safety earth connection before live and breaks it after live. · 8. (a) A rectifier (diodes) turns AC into DC; an inverter does the reverse. · 9. (c) Both feet are at the same potential, so no current passes through the bird. · 10. (d) Seebeck effect is the principle of the thermocouple. · 11. (c) A voltmeter sits in parallel with a high resistance and a potentiometer draws no current at balance; statement 1 is wrong because an ammeter goes in series with a very low resistance. · 12. (b) Statements 1 and 3 are correct; the iron's coil is nichrome (high resistivity, no oxidation when red-hot), while tungsten is used for bulb filaments. · 13. (d) Saving = 10 × (60 − 9) W × 5 h × 30 = 76.5 kWh; 90 units is the old bulbs' whole use, 13.5 units the LEDs' use and 2.55 units only one day's saving.