

UPPSC PRELIMS

QRS

**QUICK
REVISION
SERIES**

Last-Minute Revision Notes

SCIENCE & TECHNOLOGY

Physics • Chemistry • Biology • Technology

106 topics • concise tables • key points for quick recall

01 Physics • 23 topics

02 Chemistry • 23 topics

03 Biology • 38 topics

04 Science & Technology • 22 topics

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PART 01

Physics

Mechanics, heat, waves, optics, electricity, magnetism, modern physics • topics 1–23

1. Measurement and SI units

Quantity	SI unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Derived quantity	Unit	Relation
Force	newton	kg m/s^2
Pressure	pascal	N/m^2
Energy and work	joule	N m
Power	watt	J/s
Electric charge	coulomb	A s
Potential difference	volt	J/C
Resistance	ohm	V/A
Frequency	hertz	s^{-1}

KEY POINTS

- SI has seven base units; the remaining units are derived from them.
- Unit symbols are not pluralised. A space separates a numerical value from its unit.
- The kilogram is defined using the fixed Planck constant, rather than a metal prototype.
- Kelvin is written without a degree sign. A temperature interval of 1 K equals an interval of 1 °C.

2. Scientific instruments

Instrument	Measures or detects	Operating feature
Ammeter	Electric current	Connected in series; low resistance
Voltmeter	Potential difference	Connected in parallel; high resistance
Galvanometer	Small electric current	Deflection of a coil
Barometer	Atmospheric pressure	Mercury column or aneroid capsule
Manometer	Pressure difference	Difference between fluid levels
Hydrometer	Relative density of a liquid	Flotation
Lactometer	Relative density of milk	A specialised hydrometer
Hygrometer	Humidity	Response to moisture
Anemometer	Wind speed	Rotating cups or other sensors
Seismograph	Ground vibrations	Records seismic waves

Instrument	Measures or detects	Operating feature
Altimeter	Altitude	Pressure or radio measurement
Thermometer	Temperature	Thermal response of a material

Instrument	Principal use
Sphygmomanometer	Measurement of blood pressure
Stethoscope	Listening to internal body sounds
Spectrometer	Analysis of a spectrum
Refractometer	Measurement of refractive index
Sonar	Underwater ranging using sound
Radar	Ranging using radio waves

KEY POINTS

- A device that records a quantity is not necessarily the same as its unit of measurement.
- A rain gauge measures precipitation; it does not measure humidity.
- A pyrometer measures high temperatures without requiring direct contact in many designs.

3. Scales and physical quantities

Quantity or scale	Relationship	Meaning
Celsius to kelvin	$K = ^\circ C + 273.15$	Absolute temperature conversion
Celsius to Fahrenheit	$^{\circ}F = 9^{\circ}C/5 + 32$	Different zero points and intervals
Absolute zero	$0\text{ K} = -273.15\text{ }^{\circ}C$	Lower limit of thermodynamic temperature
Astronomical unit	About $1.496 \times 10^{11}\text{ m}$	A unit used within the Solar System
Light year	About $9.46 \times 10^{15}\text{ m}$	Distance travelled by light in one year
Parsec	About 3.26 light years	Astronomical distance unit
Angstrom	10^{-10} m	Atomic scale length
Nanometre	10^{-9} m	Nanoscale length

Scalar	Vector
Mass	Displacement
Time	Velocity
Distance	Acceleration
Speed	Force
Energy	Momentum
Temperature	Weight

KEY POINTS

- Scalars have magnitude; vectors have both magnitude and direction.
- Distance is total path length. Displacement joins the initial and final positions.
- Relative density has no unit because it is a ratio of two densities.
- Celsius and Fahrenheit have the same numerical reading at -40 degrees.

4. Motion and graphs

Term	Definition or relation	Key consequence
Average speed	Total distance / total time	Depends on the complete journey
Average velocity	Displacement / total time	Can be zero during a round trip

Term	Definition or relation	Key consequence
Acceleration	Change in velocity / time	Unit is m/s ²
Uniform motion	Equal distances in equal time intervals	Speed stays constant
Uniform acceleration	Equal velocity changes in equal intervals	Velocity changes linearly with time
Circular motion	Motion along a circular path	Velocity changes because direction changes
Distance time graph	Slope gives speed	A steeper line indicates greater speed
Velocity time graph	Slope gives acceleration	Area gives displacement

Equation	Condition
$v = u + at$	Constant acceleration
$s = ut + \frac{1}{2}at^2$	Constant acceleration
$v^2 = u^2 + 2as$	Constant acceleration
Centripetal acceleration = v^2/r	Uniform circular motion

KEY POINTS

- An object can have constant speed but changing velocity in circular motion.
- A horizontal velocity time line represents constant velocity, not zero velocity.
- Negative acceleration means acceleration opposite to the chosen positive direction; it need not always mean slowing down.

5. Newton laws and momentum

Law or quantity	Statement	Everyday application
First law	Motion changes only when a net external force acts	Inertia during sudden braking
Second law	Force equals the rate of change of momentum	$F = ma$ for constant mass
Third law	Interaction forces are equal and opposite	Rocket thrust and recoil
Momentum	$p = mv$	Depends on mass and velocity
Impulse	Force $\times$ time = momentum change	Airbags increase stopping time
Inertia	Resistance to a change in motion	Greater mass means greater inertia
Conservation of momentum	Total momentum is constant without net external force	Collisions in an isolated system

Situation	Explanation
Passenger moves forward during braking	The body tends to retain its initial motion
Dust leaves a beaten carpet	Dust resists the sudden motion of the carpet
A gun recoils	The gun and bullet gain opposite momenta
A swimmer moves ahead	Water exerts a reaction force on the swimmer
A rocket works in vacuum	It expels its own propellant; air is not required
Seat belt reduces injury	It restrains the body during rapid deceleration

KEY POINTS

- Action and reaction act on different bodies, so they do not cancel on one body.
- Balanced forces produce zero acceleration; they do not require zero velocity.
- Momentum is a vector quantity. Its SI unit is kg m/s.

6. Friction and circular motion

Type or term	Feature	Application
Static friction	Acts before surfaces start sliding	Walking without slipping
Limiting friction	Maximum static friction	Threshold for sliding
Sliding friction	Acts during relative sliding	Brake pads on a disc
Rolling resistance	Opposes rolling	Wheels reduce resistance compared with sliding
Fluid resistance	Opposes motion through a fluid	Streamlined vehicles reduce drag
Centripetal force	Directed towards the centre	Keeps an object in a circular path
Banking of roads	Inclined road surface supplies part of centripetal force	Safer turning at designed speed

Method	Effect on friction
Lubrication	Reduces direct contact between rough surfaces
Ball bearings	Replace much sliding with rolling
Treaded tyres	Improve grip under suitable conditions
Rough shoe soles	Increase available grip
Streamlining	Reduces fluid drag
Sand on a slippery surface	Improves traction

KEY POINTS

- Friction helps walking, writing and braking, but also causes heating and wear.
- The centripetal force is supplied by an existing force such as tension, gravity or friction.
- A satellite is kept in orbit by gravity; no continuous engine thrust is required for an ideal stable orbit.
- Increasing speed increases the centripetal force required at the same radius.

7. Gravitation and satellites

Concept	Relation or fact	Distinction
Universal gravitation	$F = Gm_1m_2/r^2$	Acts between all masses
Acceleration due to gravity	About 9.8 m/s^2 near Earth's surface	Varies with location
Weight	$W = mg$	A force measured in newtons
Mass	Amount associated with inertia	Measured in kilograms
Free fall	Motion under gravity alone	All bodies have the same acceleration without air drag
Escape speed	About 11.2 km/s at Earth's surface	Ignores air resistance and Earth's rotation
Orbital speed	About 7.9 km/s close to Earth's surface	Ideal circular orbit
Weightlessness	Absence of support force during free fall	Gravity can still be present

Location or change	Effect on g
Pole compared with equator	Effective g is generally greater at the pole
Increasing height	g decreases
Going deep below the surface	g generally decreases; it is zero at the centre in a symmetric model
Moon compared with Earth	Surface gravity is about one sixth
Increasing the body's mass	Its acceleration in free fall remains unchanged

Location or change	Effect on g
Doubling separation between two masses	Their gravitational force becomes one fourth

KEY POINTS

- G is the universal gravitational constant; g is local acceleration due to gravity.
- Earth attracts the Moon and the Moon attracts Earth with equal force magnitudes.
- A geostationary satellite must orbit over the equator in the direction of Earth's rotation.

8. Work energy and power

Quantity	Relation	Unit or condition
Work	$W = Fs \cos \theta$	Joule
Kinetic energy	$\frac{1}{2}mv^2$	Energy of motion
Gravitational potential energy	mgh	Near Earth's surface
Power	Work / time	Watt
Efficiency	Useful output / total input $\times 100$	Cannot exceed 100% for energy conversion
Mechanical energy	Kinetic + potential energy	Conserved when only conservative forces act
Kilowatt hour	$3.6 \times 10^6 \text{ J}$	Unit of energy
Horsepower	Approximately 746 W	Unit of power

Energy transformation	Example
Electrical to mechanical	Electric motor
Mechanical to electrical	Generator
Chemical to electrical	Battery
Electrical to heat	Resistance heater
Radiant to electrical	Solar photovoltaic cell
Chemical to mechanical	Internal combustion engine
Potential to kinetic	Falling water
Nuclear to thermal	Fission reactor

KEY POINTS

- Force can act without doing work when displacement is zero.
- The centripetal force does no work in uniform circular motion because it is perpendicular to velocity.
- Doubling speed makes kinetic energy four times as large at the same mass.
- One commercial electricity unit is 1 kWh, not 1 kW.

9. Machines and equilibrium

Term or machine	Principle	Example
Mechanical advantage	Load / effort	Measures force multiplication
Velocity ratio	Effort distance / load distance	Determined by machine geometry
Lever	Moments balance around a fulcrum	Crowbar
First class lever	Fulcrum lies between effort and load	Scissors; seesaw
Second class lever	Load lies between fulcrum and effort	Wheelbarrow; nutcracker
Third class lever	Effort lies between fulcrum and load	Human forearm; tweezers
Fixed pulley	Changes the direction of effort	Drawing water from a well
Movable pulley	Can multiply force	Lifting systems

Term or machine	Principle	Example
Inclined plane	Reduces effort by increasing travel distance	Ramp
Screw	An inclined plane wound around a cylinder	Screw jack
Wedge	Converts applied force into separating forces	Knife; axe

Equilibrium requirement	Meaning
Zero net force	No translational acceleration
Zero net torque	No angular acceleration
Torque = force × perpendicular distance	Turning effect of force
Lower centre of gravity	Usually increases stability
Wider base	Usually increases stability

KEY POINTS

- Simple machines trade force against distance; they do not create energy.
- Efficiency equals mechanical advantage divided by velocity ratio, multiplied by 100.
- A force passing through the pivot has zero moment about that pivot.

10. Pressure and buoyancy

Principle	Statement	Application
Pressure	Force / area	Sharp tools exert high pressure
Liquid pressure	$p = \rho gh$	Increases with depth
Pascal law	An applied pressure change is transmitted through a confined fluid	Hydraulic brakes
Archimedes principle	Upthrust equals the weight of displaced fluid	Ships and hydrometers
Flotation	A floating body displaces its own weight of fluid	A ship floats at equilibrium
Atmospheric pressure	Pressure exerted by the atmosphere	Drinking through a straw
Density	Mass / volume	Unit is kg/m^3
Relative density	Density / reference density	Dimensionless

Observation	Reason
A broad school bag strap is comfortable	It spreads force over a larger area
A dam is thicker near its base	Water pressure is greater at greater depth
A steel ship floats	Its average density including air spaces is low enough
An object seems lighter in water	Buoyant force reduces apparent weight
Sea water provides greater buoyancy than fresh water	Sea water is generally denser
A hydraulic jack multiplies force	The same pressure acts over a larger output area

KEY POINTS

- Upthrust depends on the fluid density and displaced volume.

- A body can float while partly submerged when its average density is below the fluid density.
- Liquid pressure at the same depth is independent of the shape of the container.

11. Surface tension viscosity and elasticity

Property	Meaning	Application
Surface tension	Liquid surface tends to minimise area	Small drops become nearly spherical
Capillarity	Rise or fall in narrow tubes	Water movement in porous materials
Viscosity	Resistance to relative flow between fluid layers	Oil flows more slowly than water under similar conditions
Elasticity	Ability to regain shape after removal of deforming force	Springs
Soap bubble	Internal pressure exceeds outside pressure	Surface tension creates the pressure difference
Hooke law	Extension is proportional to force within the elastic range	Spring balance
Stress	Force / area	Internal force per unit area
Strain	Change in dimension / original dimension	Dimensionless
Young modulus	Longitudinal stress / longitudinal strain	Measures stiffness

Observation	Reason
A needle may rest on water	Surface tension can support it if placed carefully
Soap improves wetting	It reduces water's surface tension
Water rises in a clean glass capillary	Adhesion to glass exceeds cohesion in the relevant balance
Mercury falls in a glass capillary	Its contact angle is greater than 90 degrees
Rain drops are rounded	Surface tension favours small surface area
Hot lubricating oil flows more readily	Liquid viscosity generally decreases with temperature
Rubber can stretch greatly	Large elastic deformation is possible over a range

KEY POINTS

- Surface tension is force per unit length and is measured in N/m.
- Steel has a higher Young modulus than rubber; stiffness differs from the size of reversible deformation.
- An elastic material can fail to recover if its elastic limit is exceeded.

12. Heat temperature and expansion

Term	Meaning	Unit or example
Heat	Energy transferred because of temperature difference	Joule
Temperature	Measures thermal state	Kelvin in SI
Specific heat capacity	Heat needed per unit mass per unit temperature rise	J/(kg K)
Thermal expansion	Increase in dimensions with heating	Expansion gaps in bridges
Linear expansion	Change in length	Metal rods
Volume expansion	Change in volume	Liquids and gases
Bimetallic strip	Two metals expand by different amounts	Thermostat

Term	Meaning	Unit or example
Anomalous expansion of water	Water expands on cooling below 4 °C	Ice floats on liquid water

Fact	Consequence
Water has maximum density near 4 °C	Cold lakes can retain liquid water below surface ice
Ice is less dense than liquid water	It floats
Water has a high specific heat capacity	It moderates temperature changes
Metals generally expand on heating	Rails require provision for expansion
A liquid thermometer uses thermal expansion	The liquid level changes with temperature
Kelvin temperature is absolute	Gas law temperatures are expressed in kelvin

KEY POINTS

- Heat and temperature are different quantities; a large cool object can contain more internal energy than a small hot object.
- A metal lid can loosen on warming because its dimensions increase.
- Internal energy includes microscopic kinetic and potential energies.

13. Heat transfer and change of state

Process	How energy moves	Example
Conduction	Through microscopic interactions without bulk flow	Heating a metal spoon
Convection	Through bulk motion of a fluid	Circulation in boiling water
Radiation	Through electromagnetic waves	Heat received from the Sun
Melting	Solid becomes liquid	Ice melts
Vaporisation	Liquid becomes gas	Boiling water
Condensation	Gas becomes liquid	Water drops on a cold glass
Sublimation	Solid changes directly to gas	Dry ice
Deposition	Gas changes directly to solid	Frost formation

Observation	Explanation
Sweating cools the body	Evaporation takes latent heat from the skin
A pressure cooker cooks faster	Higher pressure raises the boiling temperature of water
Water boils at lower temperature on a mountain	Atmospheric pressure is lower
Steam can cause severe burns	Condensation releases latent heat
A vacuum flask reduces heat transfer	Vacuum limits conduction and convection; reflective surfaces limit radiation
White clothing absorbs less solar radiation	It reflects a larger fraction of incident visible radiation

KEY POINTS

- During a phase change at constant pressure, added heat can change the state without raising temperature.
- Evaporation occurs at a liquid's surface below its boiling point.
- Faster airflow, greater exposed area and lower humidity usually increase evaporation.

14. Waves and electromagnetic spectrum

Wave type	Medium requirement	Examples
Mechanical wave	Requires matter	Sound; waves on a string
Electromagnetic wave	Can travel through vacuum	Light; radio waves
Longitudinal wave	Particle vibration is parallel to propagation	Sound in air
Transverse wave	Particle vibration is perpendicular to propagation	Light; waves on a stretched string
Frequency	Oscillations per second	Measured in hertz
Wavelength	Distance between corresponding points	Measured in metres
Wave speed	$v = \text{frequency} \times \text{wavelength}$	Depends on wave and medium

Band in increasing frequency	Typical use
Radio	Broadcasting and communication
Microwave	Radar; satellite links; ovens
Infrared	Thermal imaging; remote controls
Visible	Vision and photography
Ultraviolet	Disinfection; fluorescence
X ray	Medical imaging; security inspection
Gamma ray	Radiotherapy; nuclear phenomena

KEY POINTS

- All electromagnetic waves travel at the same speed in vacuum, about 3×10^8 m/s.
- Higher frequency means shorter wavelength in the same medium.
- Electromagnetic waves carry energy and momentum.
- X rays and gamma rays overlap in energy; their names also reflect their origins.

15. Sound and hearing

Property	Physical basis	Perception or use
Pitch	Mainly frequency	Higher frequency means higher pitch
Loudness	Related to intensity and ear response	Sound level commonly expressed in decibels
Quality or timbre	Waveform and harmonics	Distinguishes instruments
Infrasound	Below about 20 Hz	Used in studies of elephants and seismic phenomena
Audible range	About 20 Hz to 20 kHz for a young healthy person	Range narrows with age
Ultrasound	Above about 20 kHz	Imaging; cleaning; sonar
Echo	Reflection of sound heard separately	Distance measurement
Reverberation	Persistence due to repeated reflections	Controlled by absorbing surfaces

Fact	Implication
Sound cannot propagate in vacuum	It is a mechanical wave
Sound generally travels faster in solids than in gases	Elastic properties and density determine speed
Sound speed in air increases with temperature	Distance calculations depend on conditions
Ultrasound imaging uses reflected pulses	It does not use ionising radiation
Sonar distance = $\text{speed} \times \text{round trip time} / 2$	The pulse travels to the target and back
Bats use echolocation	Reflected sound helps locate objects

KEY POINTS

- Frequency remains unchanged when a wave crosses a stationary boundary; speed and wavelength can change.
- Doppler effect is a change in observed frequency due to relative motion of source and observer.
- Sound intensity and subjective loudness are related but are not identical quantities.

16. Reflection and mirrors

Mirror or term	Image or feature	Use
Plane mirror	Virtual, erect and same size	Ordinary looking mirror
Concave mirror	Converging mirror	Shaving and dental mirrors; reflectors
Convex mirror	Diverging mirror; virtual and diminished image	Vehicle rear view mirror
Pole	Centre of the reflecting surface	Reference point
Principal focus	Parallel rays converge or appear to diverge	Defines focal length
Radius of curvature	Twice the focal length for a spherical mirror	$R = 2f$
Law of reflection	Angle of incidence equals angle of reflection	Angles measured from the normal

Object position for concave mirror	Image
Beyond centre of curvature	Real, inverted and diminished
At centre of curvature	Real, inverted and same size
Between centre and focus	Real, inverted and enlarged
At focus	Reflected rays are parallel in the ideal model
Between focus and pole	Virtual, erect and enlarged
Convex mirror at any finite object distance	Virtual, erect and diminished

KEY POINTS

- A real image can be formed on a screen; a virtual image cannot be directly projected on a screen.
- A plane mirror reverses the direction perpendicular to its surface; lateral inversion is the familiar observed effect.
- Convex mirrors provide a wider field of view than comparable plane mirrors.

17. Refraction lenses and optical fibres

Concept	Meaning	Application
Refraction	Change in direction when wave speed changes across a boundary	A submerged pencil appears bent
Refractive index	$n = c/v$	Usually greater than 1 for transparent materials in visible light
Snell law	$n_1 \sin i = n_2 \sin r$	Predicts refraction
Convex lens	Converges parallel light	Magnifier; camera
Concave lens	Diverges parallel light	Correction of myopia
Lens power	$P = 1/f$ with f in metres	Unit is dioptre
Total internal reflection	Complete reflection above the critical angle	Optical fibres
Critical angle	Angle giving a refracted angle of 90°	Light must approach a lower index medium

Observation	Explanation
A coin in water appears raised	Refraction at the water air boundary
A diamond sparkles	High refractive index and internal reflection
A mirage forms	Refraction through air layers of differing temperature
Optical fibres guide light	Repeated total internal reflection in the core
A prism disperses white light	Refractive index depends on wavelength
A convex lens has positive power	It is converging under the usual sign convention
A concave lens has negative power	It is diverging under the usual sign convention

KEY POINTS

- Total internal reflection requires travel from higher to lower refractive index.
- Light entering normally changes speed but does not change direction.
- Optical fibre cladding has a lower refractive index than the core.

18. Human eye colour and atmospheric optics

Structure or defect	Role or cause	Correction or fact
Cornea	Major refraction at the eye's front surface	Transparent
Iris	Controls pupil size	Regulates incoming light
Lens	Fine focusing through accommodation	Changes curvature
Retina	Contains light sensitive cells	Receives the image
Rods	Sensitive in dim light	Limited colour discrimination
Cones	Colour vision in bright light	Different spectral sensitivities
Myopia	Distant image forms before the retina	Concave lens
Hypermetropia	Near image would form behind the retina	Convex lens
Presbyopia	Accommodation declines with age	Suitable near vision correction
Astigmatism	Unequal curvature produces unequal focusing	Cylindrical correction

Phenomenon	Reason
Blue sky	Shorter visible wavelengths are scattered more strongly
Red sunset	Long path removes much shorter wavelength light
Rainbow	Refraction, dispersion and internal reflection in droplets
Stars twinkle	Changing atmospheric refraction
Sun appears before geometric sunrise	Atmospheric refraction
Primary light colours	Red, green and blue combine additively

KEY POINTS

- The retinal image is real and inverted; visual processing produces the perceived scene.
- A normal eye's near point is conventionally taken as about 25 cm in basic optics.
- Colour blindness often involves altered cone function; it is not corrected by an ordinary spherical lens.

19. Electric charge and circuits

Quantity	Relation	SI unit
Charge	$Q = It$	Coulomb
Current	$I = Q/t$	Ampere
Potential difference	$V = W/Q$	Volt
Resistance	$R = V/I$ for an ohmic element	Ohm
Resistivity	$R = \rho L/A$	Ohm metre
Conductance	$1/R$	Siemens
Electric field	Force per unit positive test charge	N/C
Capacitance	Charge / potential difference	Farad

Circuit feature	Result
Resistors in series	$R = R_1 + R_2 + \dots$
Resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
Series circuit	Same current flows through each component
Parallel circuit	Each branch has the same potential difference
Longer wire of the same material and area	Greater resistance
Thicker wire of the same material and length	Lower resistance
Ammeter connection	Series
Voltmeter connection	Parallel

KEY POINTS

- Conventional current direction is opposite to electron drift in a metal.
- Ohm law applies when physical conditions such as temperature remain constant for an ohmic material.
- Resistivity is a material property; resistance also depends on dimensions.

20. Electric power safety and cells

Concept	Relation or feature	Use
Electrical power	$P = VI$	Rate of energy transfer
Resistor power	I^2R or V^2/R	For a resistive element

Concept	Relation or feature	Use
Electrical energy	$E = Pt$	Commercially measured in kWh
Heating effect	$H = I^2Rt$	Heaters and fuses
Fuse	Melts when excessive current flows	Connected in series in the live conductor
MCB	Trips on excessive current	Can be reset
Earthing	Provides a low resistance fault path	Protects exposed metal parts
RCD or RCCB	Detects imbalance between outgoing and returning current	Earth leakage protection

Device or material	Feature
Nichrome heater	High resistivity and good high temperature performance
Tungsten filament	High melting point
Dry cell	Chemical energy becomes electrical energy
Lead acid battery	Rechargeable; used in many vehicles
Lithium ion battery	Rechargeable; lithium ions move between electrodes
Solar cell	Photovoltaic conversion
Short circuit	Unintended low resistance path produces large current
Overloading	Demand exceeds a circuit's safe current capacity

KEY POINTS

- Household appliances are connected in parallel so that each receives the supply voltage and can operate independently.
- A fuse alone does not detect every small leakage current; an RCD performs a different function.
- A battery stores chemical energy, not a reservoir of free electricity.

21. Magnetism and electromagnetic induction

Concept or device	Principle	Application
Magnetic field	Region of magnetic influence	Compass response
Field lines	Closed curves; outside a magnet run north to south	Show field direction
Solenoid	Current produces a bar magnet like field	Electromagnet
Electromagnet	Coil with a suitable core	Relays; lifting magnets
Motor	Magnetic force on a current carrying conductor	Electrical to mechanical energy
Generator	Changing magnetic flux induces emf	Mechanical to electrical energy
Transformer	Mutual induction between coils	Changes AC voltage
Induced current	Results when magnetic flux changes in a closed circuit	Faraday law
Lenz law	Induced effect opposes the change causing it	Energy conservation

Comparison	Distinction
AC and DC	AC changes direction; DC is unidirectional
Step up transformer	Raises voltage and lowers current ideally
Step down transformer	Lowers voltage and raises current ideally
Soft iron core	Magnetises and demagnetises easily

Comparison	Distinction
Permanent magnet material	Retains substantial magnetisation
Fleming left hand rule	Direction of motor force
Fleming right hand rule	Direction of induced current in generator situations

KEY POINTS

- A transformer requires changing magnetic flux; steady DC does not sustain ordinary transformer action.
- Higher transmission voltage reduces current and resistive losses for the same transmitted power.
- Magnetic poles occur together in ordinary magnets; cutting a magnet produces smaller magnets with both poles.

22. Semiconductors and electronic devices

Material or device	Feature	Application
Conductor	Many mobile charge carriers	Copper wiring
Insulator	Very low conductivity under ordinary conditions	Plastic covering
Semiconductor	Conductivity can be controlled	Silicon chips
Intrinsic semiconductor	Undoped semiconductor	Electrons and holes are thermally generated
n type semiconductor	Donor doping gives electron majority carriers	Phosphorus doped silicon
p type semiconductor	Acceptor doping gives hole majority carriers	Boron doped silicon
Diode	Conducts preferentially in one direction	Rectification
LED	Emits light under suitable forward bias	Lighting and displays
Photodiode	Responds to light	Optical detection
Transistor	Controls current or acts as a switch	Amplifiers and logic circuits
Integrated circuit	Many components fabricated together	Processors and memory

Comparison	Distinction
Electron and hole	Negative charge carrier and effective positive carrier
Rectifier and inverter	AC to DC conversion and DC to AC conversion
LED and filament lamp	Electronic light emission and thermal light emission
Microprocessor and sensor	Computes instructions and detects a physical input
Silicon and silicon dioxide	Semiconductor and important insulating material

KEY POINTS

- Doped semiconductors are electrically neutral overall; n type does not mean the entire material is negatively charged.
- Semiconductor conductivity generally rises with temperature, unlike that of typical metals.
- A chip's manufacturing node is a technology designation and is not a literal measurement of every feature.

23. Atomic physics radiation and applications

Radiation or term	Nature	Important property
Alpha particle	Two protons and two neutrons	Strong ionisation; low penetration
Beta minus particle	Electron emitted in nuclear decay	Moderate penetration

Radiation or term	Nature	Important property
Gamma radiation	High energy electromagnetic radiation	High penetration
Half life	Time for half the undecayed nuclei to decay	Characteristic of a radionuclide
Radioactivity	Spontaneous transformation of unstable nuclei	Activity measured in becquerels
Fission	A heavy nucleus splits	Can sustain a chain reaction
Fusion	Light nuclei combine	Powers the Sun
Mass energy relation	$E = mc^2$	Small mass differences correspond to large energies

Use	Principle
Carbon dating	Decay of carbon 14 in once living material
Radiotherapy	Ionising radiation damages target cells
Food irradiation	Reduces microorganisms or pests without making food radioactive under approved conditions
Radiotracer	Tracks movement through a system
Smoke detector	Some designs use americium 241
Medical isotope imaging	Detects emitted radiation from a tracer

KEY POINTS

- Chemical reactions rearrange electrons; nuclear reactions alter nuclei.
- Half life is not the time for all nuclei to disappear.
- External alpha radiation is easily stopped, but an alpha emitting substance inside the body can be hazardous.
- Non-ionising radiation includes radio waves and visible light; ionising radiation can remove electrons from atoms.

PART 02

Chemistry

Matter, atoms, reactions, acids-bases, metals, carbon compounds, everyday chemistry • topics 24–46

24. Matter and separation methods

Form of matter	Composition or property	Example
Element	One type of atom	Iron; oxygen
Compound	Elements chemically combined in a fixed proportion	Water; sodium chloride
Mixture	Variable composition; components retain many properties	Air; sea water
Homogeneous mixture	Uniform composition at the relevant scale	Salt solution
Heterogeneous mixture	Non-uniform composition	Sand in water
Solid	Usually fixed shape and volume	Ice
Liquid	Fixed volume; takes container shape	Water
Gas	Neither fixed shape nor fixed volume	Oxygen

Separation method	Property used	Example
Filtration	Particle size	Insoluble sand from water
Evaporation	Volatility	Salt from a solution
Distillation	Boiling and condensation	Water from dissolved nonvolatile salts
Fractional distillation	Different boiling ranges	Petroleum fractions
Sublimation	Direct solid to gas change	Ammonium chloride from suitable mixtures
Centrifugation	Different sedimentation behaviour	Blood components
Chromatography	Different distribution between phases	Pigments
Magnetic separation	Magnetic behaviour	Iron particles from sand

KEY POINTS

- A compound has properties different from those of its constituent elements.
- Dissolved salt passes through ordinary filter paper; filtration does not remove it.
- Liquefaction of a gas involves suitable cooling and pressure conditions.

25. Solutions colloids and suspensions

Property	True solution	Colloid	Suspension
Typical particle scale	Below about 1 nm	About 1 to 1000 nm	Usually larger than colloidal particles
Visibility of particles	Not individually visible	Not individually visible to unaided eyes	Often visible
Settling on standing	No	Usually no	Often yes
Ordinary filtration	Particles pass through	Particles usually pass through	Particles can be retained
Tyndall effect	Normally absent	Present	Scattering can occur

Property	True solution	Colloid	Suspension
Example	Salt in water	Milk; fog	Muddy water

Term	Meaning
Solute	The substance dissolved
Solvent	The dissolving medium
Saturated solution	Contains the equilibrium maximum amount of dissolved solute at given conditions
Solubility	Amount that dissolves at specified temperature and pressure
Emulsion	Liquid droplets dispersed in another liquid
Aerosol	Solid or liquid particles dispersed in gas
Foam	Gas dispersed in a liquid or solid
Gel	Liquid held within a solid-like network

KEY POINTS

- The Tyndall effect is scattering of light by dispersed particles.
- Increasing temperature increases the solubility of many solids, but there are exceptions.
- Gas solubility in water commonly decreases with rising temperature and increases with gas pressure.
- Alloy composition can be homogeneous at an appropriate scale; an alloy is not automatically a chemical compound.

26. Atoms isotopes and ions

Particle or number	Meaning	Charge or relation
Proton	Particle in the nucleus	+1 elementary charge
Neutron	Particle in the nucleus	Zero charge
Electron	Particle outside the nucleus	-1 elementary charge
Atomic number Z	Number of protons	Identifies the element
Mass number A	Protons plus neutrons	$A = Z + N$
Isotope	Same Z, different neutron number	Carbon 12 and carbon 14
Isobar	Same A, different Z	Argon 40 and calcium 40
Isotone	Same neutron number	Carbon 14 and nitrogen 15
Cation	Positively charged ion	Usually formed by electron loss
Anion	Negatively charged ion	Usually formed by electron gain

Species	Protons	Neutrons	Electrons
Carbon 12 atom	6	6	6
Carbon 14 atom	6	8	6
Sodium 23 atom	11	12	11
Sodium ion Na^+	11	12	10
Chlorine 35 atom	17	18	17
Chloride ion Cl^-	17	18	18

KEY POINTS

- Ion formation changes electron number, not the identity of the element's nucleus.
- Isotopes have similar chemical behaviour but can differ in mass and nuclear stability.
- Atomic mass is not always an integer because natural elements can contain several isotopes.

27. Electron configuration and periodic table

Feature	Meaning	Pattern
Period	Horizontal row	Related to occupied electron shells
Group	Vertical column	Similar valence configurations and many chemical properties
Group 1	Alkali metals except hydrogen	Usually form +1 ions
Group 2	Alkaline earth metals	Usually form +2 ions
Group 17	Halogens	Often form -1 ions
Group 18	Noble gases	Low chemical reactivity under ordinary conditions
Transition elements	d block elements	Often show variable oxidation states
Lanthanides and actinides	f block series	Placed separately in most table layouts

Trend	Across a period generally	Down a group generally
Atomic radius	Decreases	Increases
Ionisation energy	Increases	Decreases
Metallic character	Decreases	Increases
Electronegativity	Increases	Decreases
Valence electron pattern in main groups	Changes systematically	Remains similar

KEY POINTS

- The modern periodic table is arranged by atomic number, not atomic mass.
- Fluorine is the most electronegative element on the usual Pauling scale.
- Trends are general patterns with exceptions; transition elements need separate treatment.
- Hydrogen has a distinctive position and does not share all properties of alkali metals.

28. Chemical bonding and the mole

Bond or interaction	Formation	Example
Ionic bond	Electrostatic attraction between oppositely charged ions	Sodium chloride
Covalent bond	Sharing of electron pairs	Hydrogen; water
Metallic bonding	Metal ions interact with delocalised electrons	Copper
Hydrogen bonding	Attraction involving hydrogen bonded to an electronegative atom	Water molecules
Single covalent bond	One shared pair	H ₂
Double covalent bond	Two shared pairs	O ₂
Triple covalent bond	Three shared pairs	N ₂

Quantity	Relation or fact
Mole	Exactly $6.02214076 \times 10^{23}$ specified entities
Avogadro constant	$6.02214076 \times 10^{23} \text{ mol}^{-1}$
Molar mass	Mass of one mole; often expressed in g/mol
Water molar mass	Approximately 18 g/mol
Carbon dioxide molar mass	Approximately 44 g/mol

Quantity	Relation or fact
Amount of substance	Mass / molar mass
One mole of oxygen molecules	Contains two moles of oxygen atoms

KEY POINTS

- Ionic solids usually conduct when molten or dissolved if their ions are mobile.
- Most simple covalent substances do not conduct electricity well; graphite is an important exception.
- A mole specifies the counted entities, which can be atoms, molecules, ions or other particles.
- Gas volume per mole depends on temperature and pressure; it is not a universal fixed volume.

29. Chemical reactions and equations

Reaction type	General change	Example
Combination	Two or more reactants form one product	$\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2$
Decomposition	One substance forms simpler substances	$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$ on heating
Displacement	One element replaces another	$\text{Zn} + \text{CuSO}_4 \rightarrow \text{ZnSO}_4 + \text{Cu}$
Double displacement	Ions exchange partners	$\text{Na}_2\text{SO}_4 + \text{BaCl}_2 \rightarrow \text{BaSO}_4 + 2\text{NaCl}$
Precipitation	An insoluble solid forms	Barium sulphate precipitate
Combustion	Reaction with an oxidant releases energy	Methane burns in oxygen
Neutralisation	Acid and base react	$\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$

Observation	Possible evidence of reaction
Gas evolution	Carbon dioxide from acid and carbonate
Precipitate formation	Insoluble solid appears
Colour change	A metal displacement reaction changes solution colour
Temperature change	Energy is released or absorbed
Light emission	Certain combustion reactions
New odour	Formation of a different volatile substance

KEY POINTS

- A balanced equation conserves the number of atoms of each element.
- Balancing changes coefficients, not the formulas of substances.
- Physical state symbols distinguish solid, liquid, gas and aqueous solution.
- Every observable change is not a chemical reaction; melting is usually a physical change.

30. Oxidation reduction and corrosion

Term	Meaning	Illustration
Oxidation	Loss of electrons; often gain of oxygen	$\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$
Reduction	Gain of electrons; often loss of oxygen	$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$
Oxidising agent	Accepts electrons; is itself reduced	Oxygen in many combustion reactions
Reducing agent	Donates electrons; is itself oxidised	Carbon in some metal extractions
Redox reaction	Oxidation and reduction occur together	Metal displacement
Corrosion	Chemical or electrochemical deterioration	Rusting of iron
Rancidity	Deterioration of fats and oils, often by oxidation	Stale oily food

Protection method	How it helps
Painting	Blocks contact with the environment
Oiling or greasing	Limits moisture and oxygen access
Galvanising	Zinc coating protects iron, including sacrificial action
Alloying	Can improve corrosion resistance
Cathodic protection	Makes the protected metal a cathode
Airtight food packaging	Reduces oxygen exposure
Antioxidants in food	Slow oxidation
Refrigeration	Slows many deterioration reactions

KEY POINTS

- Rusting requires suitable moisture and oxygen; dissolved salts can accelerate it.
- Rust is hydrated iron oxide and does not form a reliably protective layer.
- Aluminium's oxide film is relatively protective.
- Silver tarnish commonly contains silver sulphide; copper develops a green surface patina in moist air.

31. Acids bases and indicators

Acid or base	Formula or source	Key fact
Hydrochloric acid	HCl	Strong acid in aqueous solution
Sulphuric acid	H ₂ SO ₄	Strong mineral acid; highly corrosive
Nitric acid	HNO ₃	Strong acid and oxidising agent
Acetic acid	CH ₃ COOH	Weak acid in vinegar
Citric acid	Citrus fruits	Organic acid
Lactic acid	Curd and fermentation	Organic acid
Sodium hydroxide	NaOH	Strong base; caustic soda
Calcium hydroxide	Ca(OH) ₂	Slaked lime
Ammonia solution	NH ₃ in water	Weak base

Indicator	Acidic medium	Basic medium
Litmus	Blue litmus turns red	Red litmus turns blue
Phenolphthalein	Colourless	Pink in its usual working range
Methyl orange	Red in strongly acidic conditions	Yellow above its transition range
Turmeric	Yellow	Reddish brown with alkali
Universal indicator	Colour depends on pH	Colour depends on pH

KEY POINTS

- Acids provide hydrogen ions in aqueous solution; bases increase hydroxide ion concentration in the basic school model.
- Strong and concentrated mean different things: strength concerns ionisation, while concentration concerns amount per volume.
- A base soluble in water is called an alkali; not every base is an alkali.
- Acid dilution releases heat; acid is added slowly to water in standard laboratory practice.

32. pH and salts

pH relation or example	Meaning
pH = $-\log_{10}$ hydrogen ion activity	A logarithmic measure of acidity

pH relation or example	Meaning
pH below 7 at 25 °C	Acidic aqueous solution
pH equal to 7 at 25 °C	Neutral water in the basic model
pH above 7 at 25 °C	Basic aqueous solution
One unit decrease in pH	Tenfold increase in hydrogen ion activity
Buffer	Resists pH change when small amounts of acid or base are added
Tooth enamel demineralisation	Promoted by sufficiently acidic conditions
Antacid	Neutralises excess stomach acidity

Salt type	Example	Usual aqueous behaviour
Strong acid and strong base	NaCl	Approximately neutral
Strong acid and weak base	NH ₄ Cl	Acidic
Weak acid and strong base	Sodium acetate	Basic
Carbonate salt	Na ₂ CO ₃	Basic solution
Bicarbonate salt	NaHCO ₃	Mildly basic solution
Copper sulphate	CuSO ₄	Aqueous solution is acidic

KEY POINTS

- Neutral pH changes with temperature; the statement pH 7 is neutral is tied to about 25 °C.
- A salt is an ionic compound; salts are not all neutral or edible.
- Natural rain is slightly acidic because carbon dioxide dissolves in it.
- Blood pH is tightly regulated; ordinary dietary claims cannot replace that physiological control.

33. Important salts and lime

Substance	Formula	Use or distinction
Common salt	NaCl	Food; industrial raw material
Baking soda	NaHCO ₃	Baking; mild alkali; some extinguishers
Washing soda	Na ₂ CO ₃ ·10H ₂ O	Cleaning; water softening
Soda ash	Na ₂ CO ₃	Glass and chemical manufacture
Quicklime	CaO	Cement related processes; reacts exothermically with water
Slaked lime	Ca(OH) ₂	Whitewashing; lime water
Limestone	CaCO ₃	Cement and lime manufacture
Gypsum	CaSO ₄ ·2H ₂ O	Cement setting control; plaster manufacture
Plaster of Paris	CaSO ₄ ·½H ₂ O	Casts and moulds
Bleaching powder	Common school representation CaOCl ₂	Bleaching and disinfection; commercial material is a mixture

Change	Outcome
Quicklime plus water	Slaked lime forms and heat is released
CO ₂ passed into lime water	Milky calcium carbonate precipitate forms
Excess CO ₂ in lime water	Precipitate can dissolve as soluble bicarbonate forms
Heating gypsum carefully	Plaster of Paris forms

Change	Outcome
Plaster of Paris plus water	It sets to gypsum
Baking soda on heating	Sodium carbonate, carbon dioxide and water form

KEY POINTS

- Baking powder contains baking soda with an edible acid, often along with a filler.
- Water of crystallisation forms part of a crystalline compound's structure.
- Washing soda and baking soda have different formulas and uses.

34. Metals and reactivity

Metal group or property	Behaviour	Example
Highly reactive metals	React readily; require electrolysis for extraction from suitable compounds	Sodium; calcium; aluminium
Moderately reactive metals	Often extracted by reduction after suitable treatment	Zinc; iron
Less reactive metals	May occur native or need simpler extraction	Copper; silver; gold
Malleability	Can be hammered into sheets	Gold; aluminium
Ductility	Can be drawn into wires	Copper
Electrical conductivity	Mobile electrons carry charge	Copper; silver
Amphoteric oxide	Reacts with acids and bases	Al ₂ O ₃ ; ZnO

Reactivity sequence	Representative metal
Higher reactivity	Potassium
Next	Sodium
Next	Calcium
Next	Magnesium
Next	Aluminium
Next	Zinc
Next	Iron
Reference	Hydrogen
Lower than hydrogen	Copper
Still lower	Silver
Very low	Gold

KEY POINTS

- A more reactive metal can displace a less reactive metal from an appropriate salt solution.
- Copper does not release hydrogen from dilute hydrochloric acid under ordinary conditions.
- Mercury is a liquid metal near room temperature; bromine is a liquid non-metal.
- Sodium and potassium are stored away from air and water because they react readily.

35. Ores metallurgy and alloys

Metal	Important ore or mineral	Characteristic
Aluminium	Bauxite	Mixture rich in hydrated aluminium oxides
Iron	Haematite	Fe ₂ O ₃
Iron	Magnetite	Fe ₃ O ₄

Metal	Important ore or mineral	Characteristic
Zinc	Zinc blende	ZnS
Lead	Galena	PbS
Copper	Copper pyrites	CuFeS ₂
Tin	Cassiterite	SnO ₂
Mercury	Cinnabar	HgS

Alloy	Main constituents	Use
Brass	Copper and zinc	Fittings; instruments
Bronze	Copper and tin	Castings; statues
Stainless steel	Iron with chromium and other additions	Corrosion resistant articles
Solder	Often tin based; compositions vary	Joining electrical components
Duralumin	Aluminium with copper and other additions	Lightweight engineering
Nichrome	Nickel and chromium, often with iron	Heating elements

KEY POINTS

- An ore permits economically viable extraction under prevailing conditions; every mineral is not an ore.
- Roasting commonly heats sulphide ores in air; calcination heats ores with limited or no air.
- Flux reacts with impurities to form slag in suitable smelting processes.
- Alloying can change hardness, corrosion resistance and melting behaviour.

36. Carbon allotropes and nanomaterials

Allotrope	Structure	Property or use
Diamond	Three dimensional covalent network	Very hard; cutting tools
Graphite	Layered hexagonal sheets	Conducts electricity; lubricating behaviour
Graphene	A single carbon sheet	High strength and conductivity
Fullerene	Closed cage of carbon atoms	C ₆₀ is a well known example
Carbon nanotube	Tube-like carbon structure	High aspect ratio; functional properties depend on structure
Amorphous carbon	Lacks long range crystalline order	Charcoal; soot

Comparison	Diamond	Graphite
Bonding per carbon in ideal structure	Four neighbours	Three neighbours in a sheet
Electrical conduction	Normally poor	Good along layers
Mechanical behaviour	Very hard	Layers slide relatively easily
Typical use	Abrasives and jewellery	Electrodes and pencils

KEY POINTS

- Allotropes are different structural forms of the same element.
- Pencil material usually contains graphite and clay; it is not metallic lead.
- Activated carbon has a large internal surface area and adsorbs many substances.
- Nanomaterials are often described by dimensions of roughly 1 to 100 nm; nanoscale properties can differ from bulk properties.

37. Hydrogen oxygen and nitrogen

Gas	Formula	Key property or use
Hydrogen	H ₂	Light gas; fuel; ammonia manufacture
Oxygen	O ₂	Supports aerobic respiration and many combustion reactions
Ozone	O ₃	Strong oxidant; stratospheric UV absorption
Nitrogen	N ₂	About 78% of dry air by volume; relatively unreactive
Ammonia	NH ₃	Fertiliser manufacture; pungent gas
Nitrous oxide	N ₂ O	Greenhouse gas; anaesthetic use
Nitric oxide	NO	Signalling molecule; air pollution chemistry
Nitrogen dioxide	NO ₂	Reddish brown toxic gas

Process or fact	Explanation
Haber process	Nitrogen and hydrogen form ammonia under catalytic high pressure conditions
Electrolysis of water	Produces hydrogen and oxygen
Oxygen test	A glowing splint can relight in oxygen
Hydrogen test	A small suitable sample burns with a characteristic pop
Ozone layer	Absorbs much harmful solar ultraviolet radiation
Liquid nitrogen	Used for low temperature preservation and cooling

KEY POINTS

- Oxygen supports combustion but is not itself an ordinary combustible fuel.
- Hydrogen is not a primary energy source when produced using other energy; it acts as an energy carrier.
- Ground level ozone is a harmful pollutant even though stratospheric ozone is protective.
- Nitrogen fixation converts atmospheric nitrogen into biologically usable compounds.

38. Water hardness and purification

Term or method	Cause or action	Result
Hard water	Contains appreciable calcium and magnesium ions	Uses more soap and can form scale
Temporary hardness	Often due to calcium and magnesium bicarbonates	Can be reduced by boiling
Permanent hardness	Often due to sulphates or chlorides	Not removed simply by boiling
Distillation	Evaporates and condenses water	Removes most nonvolatile solutes
Reverse osmosis	Pressure drives water through a selective membrane	Reduces many dissolved substances
Ion exchange	Exchanges unwanted ions with other ions	Softening or deionisation
Chlorination	Chemical disinfection	Inactivates susceptible microorganisms
UV treatment	Radiation damages microbial genetic material	Does not remove dissolved salts

Characteristic	Fact
Pure water	Poor conductor compared with salt water
Boiling	Kills many pathogens but does not remove dissolved salts
Potable water	Suitable for drinking; need not be chemically pure

Characteristic	Fact
Heavy water	D ₂ O; contains deuterium
Water electrolysis volume ratio	Hydrogen to oxygen is 2 to 1 under matching conditions
Turbidity	Cloudiness due to suspended matter

KEY POINTS

- Clear water is not necessarily free of pathogens or dissolved contaminants.
- Hardness is different from salinity; sodium salts can make water saline without causing conventional hardness.
- Reverse osmosis produces a reject stream as well as treated water.
- Softening alone does not necessarily make water microbiologically safe.

39. Organic compounds and functional groups

Class	Functional feature	Example
Alkane	Carbon carbon single bonds in an acyclic saturated series	Methane; ethane
Alkene	Carbon carbon double bond	Ethene
Alkyne	Carbon carbon triple bond	Ethyne
Alcohol	Hydroxyl group on suitable carbon	Ethanol
Aldehyde	Terminal -CHO group	Ethanal
Ketone	Carbonyl group within a carbon chain	Propanone
Carboxylic acid	-COOH group	Ethanoic acid
Ester	-COO- linkage	Ethyl ethanoate

Term	Meaning
Catenation	An element forms chains or rings with itself
Tetravalency of carbon	Carbon commonly forms four covalent bonds
Homologous series	Related compounds with the same functional group and a systematic formula pattern
Isomerism	Same molecular formula but different arrangement
Saturated hydrocarbon	Contains only single carbon carbon bonds
Unsaturated hydrocarbon	Contains a carbon carbon double or triple bond
Fermentation	Microbial conversion of sugars into products such as ethanol

KEY POINTS

- Methanol is highly toxic; it is different from ethanol.
- Ethanoic acid is the systematic name for acetic acid.
- Functional groups largely determine characteristic chemical reactions.
- Consecutive members of many homologous series differ by a CH₂ unit.

40. Fuels combustion and petroleum

Fuel or material	Main feature	Use or limitation
LPG	Mainly propane and butane	Cooking fuel stored liquefied under pressure
CNG	Compressed natural gas, mainly methane	Vehicle fuel
LNG	Natural gas liquefied by cooling	Transport and storage
Biogas	Methane with carbon dioxide and other gases	Produced by anaerobic digestion

Fuel or material	Main feature	Use or limitation
Coal	Carbon rich fossil fuel	Power and industry
Petrol	Mixture of volatile hydrocarbons	Spark ignition engines
Diesel	Less volatile petroleum fraction	Compression ignition engines
Kerosene	Intermediate petroleum fraction	Fuel and aviation related applications
Hydrogen	Produces water during clean combustion with oxygen	Storage and production remain important issues

Term	Meaning
Calorific value	Heat released by complete combustion per unit amount of fuel
Complete combustion	Usually produces CO ₂ and water from hydrocarbons
Incomplete combustion	Can produce toxic CO and soot
Octane rating	Resistance to knocking in petrol engines
Cetane rating	Ignition quality of diesel fuel
Fractional distillation	Separates crude oil into boiling range fractions

KEY POINTS

- Carbon monoxide binds strongly to haemoglobin and interferes with oxygen transport.
- LPG has an added odorant so that leaks can be detected by smell.
- Burning a fuel does not establish that its entire life cycle has zero emissions.

41. Polymers fibres and plastics

Material	Type or building unit	Use
Polyethylene	Addition polymer of ethene	Packaging; containers
PVC	Polymer of vinyl chloride	Pipes; cable insulation
PTFE	Fluoropolymer	Non-stick and chemical resistant applications
Polystyrene	Polymer of styrene	Packaging and insulation
Nylon	Polyamide	Fibres and engineering components
Polyester	Ester linked polymer	Clothing; PET bottles
Bakelite	Cross linked phenol formaldehyde resin	Heat resistant electrical fittings
Melamine resin	Thermosetting resin	Laminates and tableware
Natural rubber	Polymer based mainly on isoprene	Elastic products

Category	Behaviour	Example
Thermoplastic	Can soften on heating and be remoulded within limits	Polyethylene; PVC
Thermoset	Cross linked structure does not remelt into a mouldable liquid	Bakelite
Natural fibre	Obtained from biological sources	Cotton; silk; wool
Regenerated fibre	Processed from a natural polymer	Viscose rayon
Synthetic fibre	Made from synthesised polymers	Nylon; polyester

KEY POINTS

- Vulcanisation creates cross links in rubber and improves useful mechanical properties.
- Cotton is mainly cellulose; wool and silk are protein based.
- Biodegradable does not mean instantaneous decomposition in every environment.
- Microplastics are small plastic particles, commonly defined as below 5 mm.

42. Soaps detergents and household chemicals

Substance or process	Nature	Use
Soap	Sodium or potassium salts of long chain fatty acids	Cleansing
Detergent	Synthetic surfactant formulation	Cleaning, including many hard water applications
Saponification	Alkaline hydrolysis of fats or oils	Soap formation
Micelle	Cluster with hydrophobic interiors in water	Helps carry oily dirt
Bleach	Oxidising or other bleaching agent	Colour removal and disinfection in suitable products
Disinfectant	Reduces microorganisms on inanimate surfaces	Surface treatment
Antiseptic	Used on living tissue in suitable concentrations	Wound related care
Baking soda	Sodium bicarbonate	Mild cleaning and food uses

Comparison	Soap	Many synthetic detergents
Hard water	Forms insoluble scum with calcium or magnesium	Often retains cleaning action
Origin	Commonly made from fats and oils	Produced through chemical synthesis
Functional behaviour	Surface active	Surface active
Environmental behaviour	Depends on formulation	Depends on formulation and biodegradability

KEY POINTS

- A surfactant has a water attracting part and a water repelling part.
- Cleansing is not identical to sterilisation; removing dirt need not eliminate all microorganisms.
- Bleach should not be mixed with acids or ammonia because dangerous gases can form.
- Glycerol is a useful product associated with the manufacture of soap from fats.

43. Fertilisers pesticides and food chemistry

Material	Important component or role	Fact
Urea	Nitrogen fertiliser	$\text{CO}(\text{NH}_2)_2$
Ammonium sulphate	Nitrogen and sulphur	A chemical fertiliser
DAP	Diammonium phosphate	Supplies nitrogen and phosphorus
Superphosphate	Phosphate fertiliser	Contains calcium phosphate related compounds
Potash fertiliser	Potassium source	Often based on potassium chloride
Biofertiliser	Living microorganisms	Helps nutrient availability under suitable conditions
Insecticide	Controls insects	Target differs from a herbicide
Herbicide	Controls unwanted plants	Not an insecticide
Fungicide	Controls fungi	Used against suitable fungal diseases

Food constituent or additive	Role
Carbohydrate	Major energy source
Protein	Growth, repair and many cellular functions

Food constituent or additive	Role
Fat	Energy storage and membrane components
Preservative	Slows spoilage under specified conditions
Emulsifier	Helps stabilise mixtures of oil and water
Antioxidant	Slows oxidation
Iodised salt	Supplies iodine in a suitable iodine compound

KEY POINTS

- Excess nutrient runoff can promote eutrophication of water bodies.
- Organic farming can use biological and selected permitted inputs; it does not mean absence of all pest control.
- Fertilisers supply nutrients; they do not directly replace all functions of soil organic matter.
- Food additive safety depends on substance, amount and permitted use.

44. Chemical pollution and everyday reactions

Pollutant or process	Source or formation	Effect or application
Sulphur dioxide	Sulphur containing fuel combustion	Acid deposition; respiratory irritation
Nitrogen oxides	High temperature combustion and other sources	Smog and acid deposition chemistry
Carbon monoxide	Incomplete combustion	Impairs oxygen transport
Carbon dioxide	Respiration; combustion	Greenhouse gas
CFCs	Older refrigerants and other historical uses	Stratospheric ozone depletion
Lead	Contaminated dust and industrial sources	Neurotoxic metal
Mercury	Some industrial emissions and contaminated food webs	Toxicity depends on chemical form
Arsenic	Geogenic groundwater contamination in some areas	Toxic exposure

Everyday change	Chemical explanation
Lime water turns milky	Calcium carbonate precipitates
Cut fruit browns	Enzyme mediated oxidation reactions
Milk becomes curd	Bacterial acid production coagulates proteins
Iron rusts	Electrochemical oxidation in suitable moist conditions
A silver article tarnishes	Reaction with sulphur containing substances
A lead acid battery discharges	Redox reactions convert chemical energy

KEY POINTS

- Acid rain commonly involves sulphuric and nitric acids formed from atmospheric precursors.
- Photochemical smog depends on sunlight driven chemistry involving nitrogen oxides and volatile organic compounds.
- Adsorption occurs at a surface; absorption involves uptake into a bulk phase.
- The presence of a chemical is not itself a measure of risk; exposure and toxicity both matter.

45. Electrochemistry and industrial processes

Process	Input or principle	Main product or application
Chlor alkali process	Electrolysis of brine	Chlorine, hydrogen and sodium hydroxide
Electroplating	Deposition using electric current	Thin protective or decorative metal coating
Electrorefining	Impure metal anode and suitable electrolyte	Purified metal at the cathode
Hall Heroult process	Electrolysis of alumina dissolved in molten cryolite	Aluminium
Blast furnace	Reduction of iron oxides with carbon monoxide and related reactions	Iron
Haber process	Catalytic reaction of nitrogen and hydrogen	Ammonia
Contact process	Catalytic oxidation of sulphur dioxide	Sulphuric acid manufacture
Solvay process	Uses brine, ammonia and carbon dioxide in a cycle	Sodium carbonate

Electrode concept	Electrochemical rule
Anode	Oxidation occurs here
Cathode	Reduction occurs here
Galvanic cell anode	Negative terminal during spontaneous discharge
Galvanic cell cathode	Positive terminal during spontaneous discharge
Electrolytic cell anode	Connected to the positive supply terminal
Electrolytic cell cathode	Connected to the negative supply terminal
Electrolyte	Conducts through mobile ions

KEY POINTS

- Electrode names depend on reaction type, while their signs depend on the kind of cell.
- Cryolite lowers the effective operating temperature and assists alumina electrolysis.
- An electrochemical cell converts chemical and electrical energy in opposite directions during discharge and charging when rechargeable.

46. Glass cement and useful materials

Material	Composition or structural feature	Use or property
Ordinary soda lime glass	Silica with sodium and calcium compounds	Windows and containers
Borosilicate glass	Contains boron oxide with silica	Better resistance to thermal shock
Fused silica	Very high silica content	Special optical and thermal applications
Cement	Calcium silicates and related compounds	Binding material after hydration
Concrete	Cement, water and aggregates	Construction
Reinforced concrete	Concrete with steel reinforcement	Combines compression and tensile support
Ceramics	Inorganic non-metallic materials processed with heat	Tiles; insulators
Silica gel	Porous silicon dioxide based material	Moisture adsorption
Activated carbon	Porous carbon	Adsorption and filtration

Material distinction	Explanation
Glass and crystal	Common glass lacks long range crystalline order

Material distinction	Explanation
Cement and concrete	Cement is one component of concrete
Setting of cement	Involves hydration reactions, not merely drying
Gypsum in cement	Helps regulate setting
Composite	Combines distinct components for useful properties
Refractory material	Resists high temperatures in service

KEY POINTS

- Silicon is an element; silica is silicon dioxide; silicone is a class of synthetic polymers.
- Tempered glass is processed to improve strength and alter its fracture behaviour.
- A desiccant removes moisture; it is not necessarily a disinfectant.
- Materials are selected for combined properties, including strength, weight, chemical resistance and temperature tolerance.

PART 03

Biology

Cells, nutrition, human physiology, genetics, diseases, plants, animals, ecology • topics 47–84

47. Branches of biology and classification

Branch	Study of
Botany	Plants
Zoology	Animals
Microbiology	Microorganisms
Cytology	Cells
Histology	Tissues
Anatomy	Structure of organisms
Physiology	Functions of organisms
Genetics	Heredity and variation
Taxonomy	Identification, naming and classification
Ecology	Organisms and their environment
Immunology	Immune systems
Entomology	Insects
Ornithology	Birds
Mycology	Fungi

Classification term	Meaning
Species	Basic unit of conventional biological classification
Genus	Groups closely related species
Family	Groups related genera
Binomial name	Genus followed by specific epithet
Homo sapiens	Scientific name of humans
Five kingdom scheme	Monera, Protista, Fungi, Plantae and Animalia
Three domain scheme	Bacteria, Archaea and Eukarya

KEY POINTS

- Scientific genus names start with a capital letter; specific epithets start with a lower case letter.
- Classification systems can change as evolutionary evidence improves.
- Viruses are not cellular organisms and are not included as a kingdom in the classic five kingdom scheme.

48. Cells and organelles

Structure	Principal role	Important feature
Plasma membrane	Controls movement into and out of the cell	Selectively permeable
Cell wall	Support and protection	Present in plants; composition differs among groups
Nucleus	Contains most nuclear genetic material	Present in eukaryotic cells

Structure	Principal role	Important feature
Mitochondrion	Aerobic energy metabolism	Has its own DNA and ribosomes
Chloroplast	Photosynthesis	Contains chlorophyll and its own DNA
Ribosome	Protein synthesis	Not membrane bound
Endoplasmic reticulum	Protein and lipid related processing	Rough ER bears ribosomes
Golgi apparatus	Modifies and sorts cellular products	Forms transport vesicles
Lysosome	Intracellular digestion and recycling	Contains hydrolytic enzymes
Vacuole	Storage and osmotic functions	Large central vacuole in many plant cells

Comparison	Prokaryotic cell	Eukaryotic cell
Membrane bound nucleus	Absent	Present
Membrane bound organelles	Absent	Present
Examples	Bacteria and archaea	Plants, animals, fungi and protists
Typical ribosomes	70S	80S in the cytoplasm

KEY POINTS

- Mature human red blood cells lack a nucleus and mitochondria.
- The cell is the basic structural and functional unit of cellular life.
- Plant cells have mitochondria as well as chloroplasts in photosynthetic tissues.

49. Membranes tissues and cell division

Process or tissue	Function	Example
Diffusion	Net movement down a concentration gradient	Gas exchange
Osmosis	Water moves across a selectively permeable membrane according to water potential	Water uptake by cells
Active transport	Moves substances using energy, often against a gradient	Ion pumps
Epithelial tissue	Covers and lines surfaces	Skin surface; intestinal lining
Connective tissue	Support, binding and transport	Bone; cartilage; blood
Muscle tissue	Contraction	Skeletal; smooth; cardiac muscle
Nervous tissue	Rapid communication	Neurons and supporting cells

Feature	Mitosis	Meiosis
Main role	Growth, repair and many asexual processes	Formation of haploid cells in sexual life cycles
Number of divisions	One	Two
Usual daughter cell number	Two	Four
Chromosome number	Usually maintained	Reduced by half
Homologous pairing and crossing over	Normally absent	Occur in prophase I
Genetic products	Usually similar	Usually varied

KEY POINTS

- A hypertonic external solution causes many cells to lose water.
- Plasmolysis is withdrawal of the living cell contents from the wall after water loss in plant cells.
- Meiosis and fertilisation alternate to maintain chromosome number across generations.
- Crossing over exchanges segments between non-sister chromatids of homologous chromosomes.

50. Biomolecules enzymes and energy

Biomolecule	Building units or nature	Main role
Carbohydrates	Sugars and related compounds	Energy; structural roles
Proteins	Amino acids	Enzymes; structure; transport
Lipids	Diverse hydrophobic compounds	Membranes; energy storage
DNA	Deoxyribonucleotides	Hereditary information in cellular organisms
RNA	Ribonucleotides	Gene expression and other functions
ATP	Adenosine triphosphate	Immediate energy coupling molecule
Enzyme	Usually a protein; some RNA molecules are catalytic	Speeds a reaction

Factor or term	Effect or meaning
Activation energy	Energy barrier lowered by a catalyst
Substrate	Reactant acted upon by an enzyme
Active site	Region binding and processing substrate
Temperature	Changes reaction rate; excessive heat can denature enzymes
pH	Each enzyme has a suitable range
Denaturation	Loss of normal three dimensional structure
Cofactor	Non-protein component needed by some enzymes

KEY POINTS

- Enzymes are not consumed in the overall reaction they catalyse.
- Enzymes do not change the equilibrium position of a reaction; they change how rapidly it is approached.
- ATP is used continuously and regenerated; it is not the body's principal long term energy store.
- Essential amino acids must be supplied adequately through diet because the body cannot synthesise enough of them.

51. Nutrition and balanced diet

Nutrient	Major functions	Representative sources
Carbohydrate	Energy for metabolism	Cereals; potatoes
Protein	Growth, repair and functional molecules	Pulses; eggs; dairy; meat
Fat	Energy; membranes; absorption of fat soluble vitamins	Oils; nuts; seeds
Dietary fibre	Supports bowel function and has other metabolic benefits	Whole grains; fruits; vegetables
Water	Solvent; transport; temperature control	Water and water rich foods
Minerals	Structural and regulatory functions	Varied foods
Vitamins	Essential micronutrient roles	Varied foods

Condition or concept	Distinction
Undernutrition	Inadequate energy or nutrients

Condition or concept	Distinction
Protein energy malnutrition	Deficiency involving protein and energy
Marasmus	Severe wasting associated with inadequate intake
Kwashiorkor	Severe malnutrition commonly associated with oedema
Obesity	Excess adiposity; influenced by multiple factors
Balanced diet	Supplies required nutrients and energy in appropriate amounts

KEY POINTS

- A food's energy content does not by itself establish its nutritional quality.
- Proteins provide about 4 kcal/g, carbohydrates about 4 kcal/g and fats about 9 kcal/g as standard dietary energy estimates.
- Requirements vary with age, activity, pregnancy and health.
- Body mass index is mass in kilograms divided by height in metres squared; it has limitations for individual assessment.

52. Vitamins and deficiency diseases

Vitamin	Major role	Deficiency association
A	Vision and epithelial function	Night blindness; xerophthalmia
B₁ thiamine	Carbohydrate metabolism and nerve function	Beriberi
B₂ riboflavin	Cellular oxidation reduction coenzymes	Cheilosis and related signs
B₃ niacin	NAD and NADP related metabolism	Pellagra
B₆ pyridoxine	Amino acid metabolism	Neurological and haematological problems
B₉ folate	DNA synthesis and cell division	Megaloblastic anaemia; fetal neural tube risk with inadequate maternal intake
B₁₂ cobalamin	Blood formation and neurological function	Megaloblastic anaemia; neurological damage
C ascorbic acid	Collagen formation and antioxidant functions	Scurvy
D	Calcium and phosphate homeostasis	Rickets in children; osteomalacia in adults
E	Antioxidant functions	Deficiency can affect nerves and red blood cells
K	Activation of clotting related proteins	Bleeding tendency

Classification	Vitamins	Characteristic
Fat soluble	A, D, E and K	Can be stored substantially; excess intake can be harmful
Water soluble	B group and C	Storage varies; B ₁₂ is an important storage exception

Source relationship	Fact
Sunlight and vitamin D	UVB exposure can enable vitamin D synthesis in skin
Citrus fruits and amla	Good vitamin C sources
Animal products and B₁₂	Important dietary sources; fortified foods can also supply it

KEY POINTS

- Vitamins do not directly supply appreciable dietary energy.
- Pellagra is classically associated with dermatitis, diarrhoea and dementia.
- Vitamin names refer to groups of compounds in some cases, not a single universal chemical.

53. Minerals and human health

Mineral	Major role	Deficiency or excess association
Iron	Haemoglobin and other proteins	Iron deficiency anaemia
Iodine	Thyroid hormone synthesis	Iodine deficiency disorders; goitre can have other causes too
Calcium	Bones, muscle and signalling	Poor skeletal health when inadequate
Phosphorus	Bones, nucleic acids and ATP	Essential structural and metabolic roles
Sodium	Fluid balance and nerve function	Excess intake can contribute to high blood pressure
Potassium	Cellular electrical function	Disturbance affects muscle and heart function
Zinc	Enzymes, growth and immunity	Impaired growth and healing when deficient
Fluoride	Can reduce tooth decay at appropriate exposure	Excess causes fluorosis
Magnesium	Enzyme functions and muscle physiology	Deficiency can affect nerves and muscles

Condition	Important distinction
Anaemia	Low haemoglobin; causes include iron deficiency and many other disorders
Goitre	Enlarged thyroid; it is not always due to iodine deficiency
Dental fluorosis	Results from excessive fluoride exposure during tooth development
Osteoporosis	Reduced bone strength; multiple risk factors
Dehydration	Loss of water, often with electrolyte disturbance
ORS	Glucose and electrolytes support intestinal water absorption

KEY POINTS

- Trace elements are needed in small amounts but are not unimportant.
- Iron from animal foods and non-haem iron from plant foods differ in absorption characteristics.
- Vitamin C can improve absorption of non-haem iron in a meal.
- Iodisation supplies iodine; it does not convert salt into a treatment for every thyroid disorder.

54. Human digestion

Organ or secretion	Function	Important substance
Mouth	Chewing and initial starch digestion	Salivary amylase
Oesophagus	Moves food by peristalsis	Muscular tube
Stomach	Mixes food; starts substantial protein digestion	Hydrochloric acid; pepsin
Liver	Produces bile	Bile salts
Gall bladder	Stores and concentrates bile	Releases bile into the intestine
Pancreas	Provides digestive enzymes and bicarbonate	Amylase; lipase; proteases
Small intestine	Most digestion and nutrient absorption	Villi increase surface area
Large intestine	Water absorption and faecal processing	Contains abundant microbiota

Nutrient	Main final absorbable products
Starch and many other carbohydrates	Simple sugars
Proteins	Amino acids and some small peptides
Fats	Fatty acids and monoacylglycerols after digestion

Enzyme	Acts chiefly on
Amylase	Starch
Pepsin and trypsin	Proteins
Lipase	Fats

KEY POINTS

- Bile helps emulsify fats but does not contain a digestive enzyme for splitting fat molecules.
- The liver is the largest internal organ and a major gland.
- Villi and microvilli enlarge absorptive area; they are not digestive glands themselves.
- Peristalsis is coordinated muscular movement along the alimentary canal.

55. Respiration and gas exchange

Term or structure	Role	Important fact
Breathing	Ventilation of the lungs	Moves air in and out
Cellular respiration	Releases usable energy from substrates	Occurs in cells
Nasal passages	Filter, warm and moisten incoming air	Mucus and cilia help protection
Trachea	Air passage	Supported by cartilage rings
Bronchi and bronchioles	Distribute air	Branch within lungs
Alveoli	Principal gas exchange surfaces	Thin walls and extensive capillaries
Diaphragm	Major breathing muscle	Contraction increases thoracic volume
Haemoglobin	Transports most blood oxygen	Located in red blood cells

Comparison	Aerobic respiration	Anaerobic processes
Oxygen requirement	Uses oxygen as final electron acceptor	Do not require oxygen in the relevant pathway
Energy yield	Generally greater per glucose	Lower for fermentation
Major human example	Mitochondrial oxidation	Lactate production under suitable conditions
Yeast example	Respiration when oxygen is available	Ethanol fermentation

KEY POINTS

- Oxygen enters blood and carbon dioxide leaves it by diffusion according to partial pressure gradients.
- Much carbon dioxide is transported in blood as bicarbonate.
- Lungs do not convert carbon dioxide into oxygen; plants can fix carbon dioxide during photosynthesis.
- Breathing rate and heart rate are different measurements.

56. Blood and its components

Component	Principal function	Feature
Plasma	Transports dissolved substances	Contains water, proteins and solutes
Red blood cell	Oxygen transport	Human mature cells lack a nucleus
Haemoglobin	Binds oxygen reversibly	Iron containing protein
White blood cell	Immune defence	Several distinct cell types
Platelet	Haemostasis and clot formation	Cell fragment derived from megakaryocytes
Fibrinogen	Precursor of fibrin	Soluble plasma protein
Fibrin	Forms a clot network	Produced during coagulation

Blood group term	Basis
ABO group	Presence or absence of A and B antigens on red cells
Group A	A antigen; usually anti-B antibodies in plasma
Group B	B antigen; usually anti-A antibodies in plasma
Group AB	A and B antigens; no usual anti-A or anti-B antibodies
Group O	Neither A nor B antigen; usually both antibody types
Rh positive	Relevant Rh D antigen is present
Crossmatching	Tests compatibility for transfusion

KEY POINTS

- O negative red cells are often used in emergencies, but compatibility depends on more than ABO and Rh D.
- AB plasma has a different compatibility pattern from AB red cells.
- Serum is the liquid remaining after blood clots; it differs from plasma.
- Adult red blood cells typically circulate for about 120 days.

57. Heart circulation and lymph

Structure	Role	Blood flow relationship
Right atrium	Receives systemic venous blood	From venae cavae
Right ventricle	Pumps blood to lungs	Through pulmonary artery
Left atrium	Receives blood from lungs	Through pulmonary veins
Left ventricle	Pumps to systemic circulation	Through aorta
Artery	Carries blood away from the heart	Usually high pressure
Vein	Carries blood towards the heart	Many have valves
Capillary	Exchange between blood and tissues	Very thin wall
Lymphatic vessel	Returns interstitial fluid and supports immunity	Carries lymph

Term	Meaning
Double circulation	Blood passes through the heart in pulmonary and systemic circuits
Systole	Contraction phase
Diastole	Relaxation phase
Blood pressure	Commonly reported as systolic / diastolic pressure
Coronary arteries	Supply the heart muscle
Pacemaker region	Sinoatrial node normally initiates cardiac rhythm

KEY POINTS

- Pulmonary arteries carry oxygen poor blood and pulmonary veins carry oxygen rich blood in normal postnatal circulation.
- Artery and vein names depend on direction of flow, not oxygen content.
- Lymphatic lacteals in intestinal villi help absorb dietary lipids.
- A reading near 120/80 mmHg is a familiar adult reference, not a universal value for every person.

58. Excretion and the kidney

Structure or process	Function	Important fact
Kidney	Regulates water, electrolytes and waste elimination	Contains nephrons
Nephron	Functional unit of the kidney	Includes filtering and tubular portions

Structure or process	Function	Important fact
Glomerulus	Filters plasma water and small solutes	Retains most cells and large proteins
Bowman capsule	Collects filtrate	Surrounds the glomerulus
Tubules	Reabsorb and secrete substances	Modify filtrate composition
Ureter	Carries urine to the bladder	One from each kidney
Urinary bladder	Stores urine	Muscular organ
Urethra	Carries urine outside	Different from a ureter

Waste or control	Relationship
Urea	Produced mainly in the liver from nitrogen metabolism
Carbon dioxide	Removed mainly through the lungs
Sweat	Helps temperature regulation; contains water and salts
ADH	Promotes water reabsorption in the kidney
Dialysis	Removes selected wastes and excess fluid across a membrane
Kidney transplantation	Replaces lost renal function with a donor organ

KEY POINTS

- Excretion removes metabolic wastes; egestion removes undigested food through the digestive tract.
- Most filtered water and useful solutes are reabsorbed; urine is not simply unchanged blood filtrate.
- Dialysis does not reproduce every hormonal and regulatory function of a healthy kidney.
- Kidney function is essential for internal chemical balance, not only waste removal.

59. Nervous system and reflexes

Part	Role	Feature
Neuron	Receives and transmits signals	Dendrites, cell body and axon
Dendrite	Commonly receives input	Branched extension
Axon	Carries output away from cell body	Can be myelinated
Synapse	Communication junction	Often uses neurotransmitters
Cerebrum	Higher cognition and voluntary processing	Largest part of the human brain
Cerebellum	Coordination and balance	Fine control of movement
Medulla	Controls several vital involuntary functions	Part of brainstem
Spinal cord	Signal pathway and reflex integration	Protected by vertebral column

System or pathway	Function
Central nervous system	Brain and spinal cord
Peripheral nervous system	Nerves outside the central system
Somatic system	Voluntary skeletal muscle control and related sensory input
Autonomic system	Regulates many internal organs
Sympathetic division	Supports mobilisation during stress
Parasympathetic division	Supports many rest and digestive functions
Reflex arc	Receptor, sensory neuron, integration, motor neuron and effector

KEY POINTS

- Reflex responses are rapid and can be integrated in the spinal cord without initial conscious deliberation.
- Brain activity can still receive information about a spinal reflex.

- Nerve impulses and chemical transmission at synapses are distinct stages of communication.
- Myelin increases the efficiency and speed of conduction along many axons.

60. Endocrine glands and hormones

Gland or tissue	Hormone	Principal role
Pituitary	Growth hormone	Growth and metabolic regulation
Pituitary	TSH	Stimulates thyroid activity
Thyroid	Thyroxine and related hormones	Metabolic regulation
Parathyroid	Parathyroid hormone	Calcium balance
Pancreatic beta cells	Insulin	Lowers blood glucose through several actions
Pancreatic alpha cells	Glucagon	Raises blood glucose through several actions
Adrenal medulla	Adrenaline	Acute stress response
Adrenal cortex	Cortisol; aldosterone	Stress metabolism; salt balance
Testes	Testosterone	Male reproductive development and function
Ovaries	Oestrogens; progesterone	Reproductive cycles and pregnancy related roles
Pineal gland	Melatonin	Circadian timing

Disorder or concept	Relationship
Diabetes mellitus	Inadequate insulin action causes chronic high blood glucose
Type 1 diabetes	Usually autoimmune destruction of insulin producing cells
Type 2 diabetes	Insulin resistance with relative insulin deficiency
Diabetes insipidus	Water balance disorder involving ADH function; not the same as diabetes mellitus
Acromegaly	Excess growth hormone after skeletal growth plates close

KEY POINTS

- Endocrine glands release hormones into circulation; exocrine glands use ducts.
- The hypothalamus controls much pituitary activity.
- ADH and oxytocin are synthesised in the hypothalamus and released from the posterior pituitary.
- Hormone regulation commonly uses negative feedback.

61. Skeleton muscles skin and senses

Structure	Role	Fact
Bone	Support, protection and mineral storage	Living tissue
Cartilage	Flexible support and joint surfaces	Less rigid than bone
Tendon	Connects muscle to bone	Transmits muscular force
Ligament	Connects bones at joints	Helps stability
Skeletal muscle	Movement of the skeleton	Usually voluntary; striated
Smooth muscle	Movement in internal organs	Involuntary; non-striated
Cardiac muscle	Pumping action of the heart	Involuntary; striated
Skin	Barrier, sensation and thermal regulation	Contains several gland and receptor types

Sensory structure	Function
Cochlea	Hearing
Semicircular canals	Sense rotational head movement
Taste receptors	Chemical detection in the mouth

Sensory structure	Function
Olfactory receptors	Smell
Sweat glands	Cooling through evaporation
Melanin	Pigment with a protective role against UV exposure

KEY POINTS

- An adult human skeleton typically has 206 bones, with individual variation.
- The femur is the longest major bone in the human body.
- Muscles contract to pull; opposite movements often require antagonistic muscle groups.
- The smallest bones are the auditory ossicles of the middle ear; the stapes is the smallest of them.

62. Human reproduction and development

Structure or process	Role	Important distinction
Testes	Produce sperm and testosterone	Located in the scrotum
Ovaries	Produce oocytes and reproductive hormones	Paired organs
Fallopian tube	Transport and usual site of fertilisation	Also called oviduct
Uterus	Supports implantation and development	Muscular organ
Sperm	Male gamete	Normally carries X or Y chromosome
Oocyte	Female gamete	Normally carries X chromosome
Fertilisation	Fusion of gametes	Restores diploid chromosome number
Implantation	Embryo attaches within uterine lining	Follows early development
Placenta	Exchange and endocrine interface	Maternal and fetal circulations remain largely separate

Term	Meaning
Ovulation	Release of an oocyte from the ovary
Menstruation	Shedding of uterine lining without established pregnancy
Gestation	Pregnancy duration
Puberty	Maturation of reproductive capacity
Identical twins	Usually arise from one zygote
Fraternal twins	Arise from separate fertilised oocytes

KEY POINTS

- The menstrual cycle varies; 28 days is a conventional example, not a fixed rule for every individual.
- Biological sex in the standard XX/XY model depends on the sex chromosome carried by the fertilising sperm.
- Contraceptive methods differ in mechanism; barrier methods can also reduce transmission of several infections.
- Lactation provides nutrition and immune related components to infants.

63. DNA RNA and protein synthesis

Feature	DNA	RNA
Sugar	Deoxyribose	Ribose
Bases	A, T, G and C	A, U, G and C
Usual structure	Double stranded	Often single stranded
Major role	Long term genetic information	Multiple gene expression and regulatory roles
Base pairing	A with T; G with C	A with U; G with C when paired

Process or molecule	Role
Replication	Copies DNA
Transcription	Produces RNA from a DNA template
Translation	Produces a polypeptide from an mRNA sequence
mRNA	Carries coding information to ribosomes
tRNA	Brings amino acids during translation
rRNA	Structural and catalytic part of ribosomes
Codon	A three nucleotide unit in mRNA
Gene	DNA sequence with a functional product in the usual cellular model
Genome	Complete genetic material of an organism or cell

KEY POINTS

- The genetic code has 64 codons, including three standard stop codons.
- AUG usually functions as a start codon and codes for methionine.
- A change in DNA sequence is a mutation; its effects can be harmful, neutral or beneficial in context.
- Reverse transcription makes DNA from an RNA template and occurs in retroviruses and other systems.

64. Mendelian inheritance and human genetics

Concept	Meaning	Example or relation
Allele	Alternative form of a gene at a locus	Different trait variants
Genotype	Genetic constitution	AA; Aa; aa in a simple model
Phenotype	Observable trait	Influenced by genotype and environment
Dominant allele	Expressed in a heterozygote in a simple dominance model	Does not mean more common
Recessive allele	Masked in that heterozygote	Can appear in homozygotes
Segregation	Allele copies separate during gamete formation	Gametes carry one copy at a locus
Independent assortment	Unlinked loci assort independently	Linkage limits this rule
Test cross	Cross with a suitable recessive genotype	Helps infer an unknown genotype

Human genetics fact	Detail
Usual somatic chromosome number	46; organised into 23 pairs
Usual gamete chromosome number	23
Autosome pairs	22 in a typical human somatic cell
Down syndrome	Usually trisomy 21
Turner syndrome	Commonly associated with a single X chromosome
Klinefelter syndrome	Commonly XXY
Haemophilia A and red green colour vision deficiency	Often show X linked recessive inheritance

KEY POINTS

- A simple monohybrid cross $Aa \times Aa$ gives a 1:2:1 genotype ratio and 3:1 phenotype ratio with complete dominance.
- Mendel studied garden pea plants.

- Many human traits are polygenic; they do not follow a single simple dominant recessive pattern.

65. Evolution and adaptation

Concept	Meaning	Example
Natural selection	Heritable differences affect survival and reproduction	Drug resistant populations under selection
Adaptation	Heritable trait improving fitness in a given environment	Camouflage
Homologous structures	Shared evolutionary origin with possible different functions	Vertebrate forelimbs
Analogous structures	Similar function with different evolutionary origin	Bird and insect wings
Vestigial structure	Reduced ancestral feature	Has an evolutionary history; may retain functions
Speciation	Formation of distinct species	Can follow reproductive isolation
Genetic drift	Random change in allele frequencies	Strong effects in small populations
Gene flow	Movement of alleles between populations	Migration and breeding

Evidence	Contribution
Fossils	Records of past organisms
Comparative anatomy	Structural relationships
Molecular sequences	Genetic evidence of relatedness
Biogeography	Distribution patterns
Embryology	Developmental similarities interpreted with other evidence
Artificial selection	Humans select inherited traits

KEY POINTS

- Evolution occurs in populations across generations, not through an individual deciding to change.
- Mutations arise without anticipating future needs; selection acts on variation.
- Antibiotics select resistant organisms rather than making every exposed bacterium deliberately adapt.
- Modern evolutionary theory combines selection with genetics and additional population processes.

66. Bacteria viruses fungi and protozoa

Group	Organisation	Important feature
Bacteria	Prokaryotic cells	Often reproduce by binary fission
Archaea	Prokaryotic cells	Distinct from bacteria; include methanogens
Fungi	Eukaryotic organisms	Cell walls commonly contain chitin
Protozoa	Diverse single celled eukaryotes	Some are parasitic
Virus	Acellular genetic material within a protective structure	Replicates using host cells
Bacteriophage	Virus infecting bacteria	Useful in molecular biology
Viroid	Small infectious RNA without a conventional protein coat	Known plant pathogens
Prion	Infectious misfolded protein	Associated with particular neurodegenerative diseases

Organism	Useful or disease related association
Lactobacillus	Fermented foods
Saccharomyces	Bread and alcoholic fermentation
Rhizobium	Symbiotic nitrogen fixation in legumes
Penicillium	Some species produce penicillin
Plasmodium	Malaria
Entamoeba histolytica	Amoebiasis

KEY POINTS

- Antibiotics act on susceptible bacteria and do not treat viral infections directly.
- Not all microorganisms are pathogens; many are essential to ecosystems and industry.
- A virus's genome can be DNA or RNA, depending on the virus.
- Fungi lack chlorophyll and obtain nutrients through absorption.

67. Immunity vaccines and medicines

Term	Meaning	Example
Innate immunity	Immediate general defence mechanisms	Skin; phagocytes
Adaptive immunity	Antigen specific response with memory	B and T cell responses
Antibody	Protein binding a specific antigen feature	Produced by plasma cells
Antigen	Material recognised by adaptive immune receptors	Microbial surface component
Active immunity	The body generates its own adaptive response	Infection or vaccination
Passive immunity	Ready formed antibodies are transferred	Maternal antibodies; immunoglobulin injection
Vaccine	Prepares immune responses against a target	Several technology platforms exist
Antibiotic	Acts against susceptible bacteria	Penicillin
Antiviral	Acts on specific viral processes	Not interchangeable with antibiotics

Comparison	Active immunity	Passive immunity
Onset	Usually requires time	Can provide immediate protection
Memory	Often develops	Does not itself generate lasting immune memory
Duration	Often longer	Usually limited by antibody persistence

Concept	Fact
Herd protection	Reduced transmission can indirectly protect others when immunity and pathogen conditions permit
Allergy	Inappropriate or excessive immune response to a substance
Autoimmunity	Immune attack on the body's own components

KEY POINTS

- Vaccination does not guarantee zero infections; protection differs by disease, product and outcome.
- Antibiotic resistance belongs to microbes, not to a patient becoming immune to the medicine.
- Immunisation is the process of acquiring protection; vaccination is administration of a vaccine.

68. Bacterial diseases

Disease	Causative agent	Major route or association
Tuberculosis	Mycobacterium tuberculosis	Airborne transmission
Cholera	Vibrio cholerae	Contaminated water or food
Typhoid fever	Salmonella Typhi	Faecal oral transmission
Tetanus	Clostridium tetani toxin	Contaminated wounds; not ordinary person to person spread
Diphtheria	Toxigenic Corynebacterium diphtheriae	Respiratory or close contact spread
Whooping cough	Bordetella pertussis	Respiratory spread
Leprosy	Mainly Mycobacterium leprae	Prolonged close exposure is important
Plague	Yersinia pestis	Often flea associated; pneumonic form can spread by droplets
Anthrax	Bacillus anthracis	Exposure to infected animals or contaminated products

Prevention approach	Relevant example
Safe water and sanitation	Cholera and typhoid control
Vaccination	Several bacterial diseases have vaccines
Ventilation and early detection	Tuberculosis control
Wound care and immunisation	Tetanus prevention
Food hygiene	Many intestinal infections
Appropriate antibiotic use	Treatment and resistance control

KEY POINTS

- BCG is a tuberculosis vaccine; its protection is particularly important against severe childhood forms.
- Tetanus results from a toxin affecting the nervous system.
- Cholera can cause severe dehydration; rehydration is central to treatment.
- A disease name, causative organism and route of spread are separate facts.

69. Viral diseases

Disease	Virus or group	Major transmission relationship
Polio	Poliovirus	Mainly faecal oral
Measles	Measles virus	Airborne spread
Mumps	Mumps virus	Respiratory and close contact spread
Rabies	Rabies virus	Usually saliva through bites or scratches
Influenza	Influenza viruses	Respiratory spread
Dengue	Dengue viruses	Aedes mosquitoes
Chikungunya	Chikungunya virus	Aedes mosquitoes
Japanese encephalitis	Japanese encephalitis virus	Mosquito borne; animal transmission cycle
Hepatitis A and E	Respective hepatitis viruses	Primarily faecal oral
Hepatitis B and C	Respective hepatitis viruses	Blood and other specific exposure routes
HIV infection	Human immunodeficiency virus	Sexual, blood and vertical transmission
COVID-19	SARS-CoV-2	Primarily respiratory transmission

Fact	Distinction
AIDS	Advanced syndrome related to HIV infection
Common cold	Can be caused by several viruses
Avian influenza	Influenza infections associated with birds; several subtypes exist
Smallpox	Eradicated globally; caused by variola virus

KEY POINTS

- HIV is not spread by ordinary social contact, sharing a classroom or mosquito bites.
- Hepatitis is liver inflammation and can also have non-viral causes.
- Dengue and malaria have different causative organisms and mosquito associations.
- Rabies prevention after exposure is time sensitive; vaccination history affects the medical response.

70. Parasitic fungal and vector borne diseases

Disease	Agent	Vector or source
Malaria	Plasmodium species	Female Anopheles mosquito
Lymphatic filariasis	Filarial worms	Mosquitoes; species and vectors vary
Kala azar	Leishmania donovani in the Indian setting	Sand fly
Sleeping sickness	Trypanosoma brucei group	Tsetse fly
Amoebiasis	Entamoeba histolytica	Contaminated food or water
Giardiasis	Giardia duodenalis	Faecal oral exposure
Ascariasis	Ascaris lumbricoides	Ingestion of eggs from contaminated soil or food
Taeniasis	Taenia tapeworms	Undercooked infected meat
Ringworm	Dermatophyte fungi	Contact related spread
Candidiasis	Candida species	Opportunistic fungal infection

Vector	Important association
Aedes	Dengue, chikungunya and Zika
Anopheles	Malaria
Sand fly	Leishmaniasis
Tsetse fly	African sleeping sickness
Rat flea	Bubonic plague association

KEY POINTS

- Only female mosquitoes take blood meals in the familiar disease vector examples.
- Malaria is a protozoan disease, not a viral disease.
- Ringworm is fungal despite its name; it is not caused by a worm.
- Vector control includes source reduction and appropriate control methods, not only spraying.

71. Noncommunicable diseases and diagnostics

Condition	Main feature	Relevant distinction
Hypertension	Persistently elevated blood pressure	Often has no early obvious symptoms
Diabetes mellitus	Chronic elevated blood glucose	Different from diabetes insipidus
Cancer	Uncontrolled growth with other malignant features	Not one single disease

Condition	Main feature	Relevant distinction
Coronary artery disease	Reduced blood supply through coronary vessels	Can cause heart attack
Stroke	Brain injury due to blood flow interruption or bleeding	Different from heart attack
Asthma	Variable airway narrowing and inflammation	Not an infection itself
Osteoporosis	Reduced bone strength	Raises fracture risk

Test or technology	Measures or detects	Physical basis
ECG	Electrical activity of the heart	Surface electrodes
EEG	Electrical activity related to the brain	Scalp electrodes
X ray imaging	Internal structures	Ionising electromagnetic radiation
CT	Cross sectional anatomy	Computer processed X rays
MRI	Tissue imaging	Magnetic fields and radiofrequency signals
Ultrasound	Internal structures and flow in suitable examinations	High frequency sound
PCR based test	Specific nucleic acid target	Amplification of genetic material

KEY POINTS

- An ECG records electrical activity; it does not directly image heart anatomy.
- MRI and diagnostic ultrasound do not use ionising radiation.
- A screening result is not always a definitive diagnosis.
- Tumours can be benign or malignant; cancer refers to malignant disease.

72. Plant tissues and transport

Tissue or structure	Role	Characteristic
Apical meristem	Growth in length	At shoot and root tips
Lateral meristem	Growth in thickness	Includes vascular cambium
Parenchyma	Storage and basic functions	Usually living cells
Collenchyma	Flexible support	Uneven wall thickening
Sclerenchyma	Mechanical strength	Often dead at maturity with thick walls
Xylem	Water and mineral transport	Also supports the plant
Phloem	Transport of sugars and other organic substances	Source to sink transport
Root hair	Water and mineral uptake	Increases surface area
Stoma	Gas exchange and transpiration	Opening controlled by guard cells

Process	Meaning
Transpiration	Water vapour loss from aerial plant surfaces
Translocation	Movement of organic substances in phloem
Root pressure	Positive pressure generated through root processes
Cohesion tension mechanism	Important explanation of water ascent in xylem
Guttation	Liquid water loss through hydathodes

KEY POINTS

- Phloem transport can be in different directions in different sieve tubes according to sources and sinks.

- Stomatal opening balances carbon dioxide uptake against water loss.
- The endodermis helps regulate entry into the vascular system of roots.
- Most xylem conducting elements are dead at maturity; phloem conducting systems include living cells.

73. Photosynthesis and plant respiration

Component or stage	Function	Location or feature
Chlorophyll	Absorbs light	In photosynthetic membranes
Light reactions	Produce ATP and reducing power; release oxygen	Thylakoid membranes
Carbon fixation	Incorporates CO ₂ into organic compounds	Calvin cycle in chloroplast stroma in the standard model
Water	Source of released oxygen	Split during light reactions
Carbon dioxide	Carbon source for carbohydrates	Enters mainly through stomata
Rubisco	Catalyses initial fixation in the Calvin cycle	Also has oxygenase activity
C₄ pathway	Concentrates CO ₂ around fixation machinery	Maize; sugarcane
CAM pathway	Temporally separates initial CO ₂ uptake and fixation	Many succulents

Comparison	Photosynthesis	Cellular respiration
Energy relationship	Stores energy in organic compounds	Releases usable energy from substrates
Carbon dioxide relationship	Consumes it during fixation	Often releases it during oxidation
Oxygen relationship	Oxygenic photosynthesis releases it	Aerobic respiration consumes it
Occurrence in plants	Photosynthetic tissues with suitable light	Living cells continuously

KEY POINTS

- Plants respire in darkness as well as in light.
- The oxygen released in oxygenic photosynthesis comes from water, not directly from carbon dioxide.
- Light, carbon dioxide, temperature and water availability can limit photosynthesis.
- The simplified equation is $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$, with light energy; actual pathways involve many steps.

74. Plant hormones nutrition and movements

Hormone	Major role	Application or example
Auxin	Cell elongation and directional growth	Rooting; apical dominance
Gibberellin	Stem growth and seed germination processes	Can overcome dormancy in suitable seeds
Cytokinin	Promotes cell division in suitable contexts	Shoot formation in tissue culture
Abscisic acid	Stress responses and dormancy	Stomatal closure under water stress
Ethylene	Gaseous hormone; ripening and other responses	Fruit ripening

Movement or nutrient	Meaning
Phototropism	Directional growth response to light
Geotropism or gravitropism	Directional growth response to gravity

Movement or nutrient	Meaning
Hydrotropism	Directional response to water gradients
Thigmotropism	Directional growth response to contact
Nastic movement	Movement whose direction is not determined by stimulus direction
Nitrogen	Required for amino acids, nucleic acids and other compounds
Magnesium	Central ion in chlorophyll
Phosphorus	Required in ATP, nucleic acids and other compounds
Potassium	Important in enzyme function and osmotic regulation

KEY POINTS

- Roots generally show positive gravitropism; shoots generally show negative gravitropism.
- The folding of Mimosa leaves is a touch induced nastic response, not ordinary directional growth.
- Plants obtain mineral nutrients from their environment; photosynthesis does not manufacture mineral elements.
- Nutrient deficiency symptoms depend on mobility, species and growth conditions.

75. Flowers pollination seeds and fruits

Structure or process	Role	Fact
Stamen	Male reproductive structure	Anther and filament
Anther	Produces pollen	Pollen contains male gametophyte components
Carpel or pistil	Female reproductive structure	Stigma, style and ovary
Ovule	Contains the embryo sac	Usually becomes a seed after fertilisation
Ovary	Contains ovules	Usually develops into fruit
Pollination	Transfer of pollen to a receptive stigma	Precedes fertilisation
Double fertilisation	Two fusion events in flowering plants	Forms zygote and primary endosperm nucleus
Embryo	Young developing sporophyte	Contained within seed
Endosperm	Nutritional tissue	Commonly triploid in the standard angiosperm model

Pollination mode	Typical feature
Wind pollination	Light abundant pollen; suitable exposed floral structures
Insect pollination	Often scent, nectar or conspicuous flowers
Self pollination	Pollen transfer within the same plant under the relevant definition
Cross pollination	Pollen transfer between different plants of the same species
Seed dispersal	Can use wind, water, animals or mechanical release

KEY POINTS

- Pollination and fertilisation are different events.
- A fruit is not always sweet; its botanical definition concerns development and structure.
- Vegetative propagation can produce plants genetically similar to the parent.
- Seed germination usually requires suitable moisture, oxygen and temperature; requirements vary among species.

76. Useful plants microbes and agriculture

Organism or product	Association	Use
Rhizobium	Legume root nodules	Symbiotic nitrogen fixation
Azotobacter	Free living bacterium	Nitrogen fixation related use

Organism or product	Association	Use
Cyanobacteria	Certain rice field systems	Nitrogen fixation
Mycorrhiza	Fungus root association	Improves nutrient uptake in many plants
Lactobacillus	Lactic acid fermentation	Curd and fermented foods
Saccharomyces cerevisiae	Yeast	Bread; ethanol production
Methanogens	Anaerobic environments	Methane production in biogas systems
Bacillus thuringiensis	Produces insecticidal proteins	Biological pest control and Bt crop technology

Plant or crop	Product or fact
Cinchona	Source of quinine historically
Papaver somniferum	Opium alkaloids
Hevea brasiliensis	Natural rubber
Jute	Bast fibre
Cotton	Seed hair fibre
Tea	Processed leaves of <i>Camellia sinensis</i>
Coffee	Processed seeds of <i>Coffea</i> species

KEY POINTS

- Biological nitrogen fixation uses nitrogenase and is performed by certain prokaryotes, not by the legume plant alone.
- Biofertilisers and biopesticides have different primary functions.
- Hybrid vigour concerns performance of particular crosses; hybrids are not automatically genetically modified organisms.
- Plant breeding selects or combines inherited variation for useful traits.

77. Ecosystems food chains and cycles

Term	Meaning	Example
Producer	Synthesises organic matter from inorganic sources	Green plant
Consumer	Obtains organic matter from other organisms	Animal
Decomposer	Breaks down dead organic matter	Many fungi and bacteria
Food chain	Linear feeding relationship	Grass → deer → tiger
Food web	Interconnected feeding relationships	Multiple linked chains
Trophic level	Position in an energy transfer sequence	Primary consumer
Ecological pyramid	Representation of number, biomass or energy	Energy pyramid is upright
Biomagnification	Increase in certain contaminant concentrations up a food chain	Persistent pollutants

Cycle	Key processes
Water cycle	Evaporation, condensation, precipitation and flow
Carbon cycle	Photosynthesis, respiration, decomposition and combustion
Nitrogen cycle	Fixation, assimilation, ammonification, nitrification and denitrification
Phosphorus cycle	Weathering, uptake, transfer and sedimentation

Concept	Fact
Energy flow	Directional; energy is dissipated as heat
Nutrient cycling	Matter can circulate between organisms and environment

KEY POINTS

- The 10% law is a rough educational rule for energy transfer, not an exact constant for every ecosystem.
- Biomass pyramids can be inverted in some aquatic systems; energy pyramids remain upright over a suitable interval.
- Decomposition returns nutrients and is influenced by moisture, temperature and substrate quality.

78. Biodiversity pollution and conservation

Term or issue	Meaning	Relevant distinction
Genetic diversity	Variation within a species	Important for adaptation and breeding
Species diversity	Variety of species	Different from species abundance alone
Ecosystem diversity	Variety of ecological systems	Forests, wetlands and grasslands
In situ conservation	Protection in natural habitats	Protected areas
Ex situ conservation	Protection outside natural habitats	Seed banks; botanical gardens
Eutrophication	Nutrient enrichment promotes excessive growth	Can lead to oxygen depletion
BOD	Biochemical oxygen demand	Reflects microbial oxygen use under specified test conditions
Bioaccumulation	Build-up within an organism	Different from biomagnification

Problem	Scientific relationship
Habitat loss	Reduces space and resources for species
Invasive alien species	Can alter native ecosystems
Overexploitation	Removal exceeds sustainable regeneration
Ozone depletion	Increased harmful UV exposure
Climate change	Changes temperature, rainfall and ecological conditions
Sewage treatment	Microbial processes reduce organic load

KEY POINTS

- Biodiversity is not restricted to large animals; microorganisms and genetic variation are also included.
- Seed banks preserve suitable seeds; not every species has seeds that tolerate standard storage.
- High BOD can indicate substantial biodegradable organic pollution, but testing conditions matter.
- Gene banks preserve suitable seeds, tissues, gametes or other genetic material using appropriate protocols.

79. Plant groups and life cycles

Group	Organisation	Reproductive feature
Green algae	Diverse aquatic and other forms	Several life cycle patterns
Bryophytes	Nonvascular land plants	Water is needed for motile sperm fertilisation
Pteridophytes	Vascular plants without seeds	Reproduce through spores
Gymnosperms	Seed plants with unenclosed ovules	Seeds are not enclosed in an ovary-derived fruit
Angiosperms	Flowering plants	Seeds develop within fruit in the usual pattern
Monocots	One cotyledon	Often parallel leaf venation and fibrous roots
Eudicots	Two cotyledons	Often net-like venation and a taproot system

Organism or structure	Association
Spirogyra	Filamentous green alga with spiral chloroplasts
Funaria	A moss
Marchantia	A liverwort
Fern	A seedless vascular plant
Cycas	A gymnosperm
Pinus	A gymnosperm
Wheat and maize	Monocots
Pea and mustard	Eudicots

KEY POINTS

- Bryophytes are often called amphibians of the plant kingdom because fertilisation requires water, although they are not animals.
- Spores and seeds are different reproductive structures.
- Alternation of generations involves multicellular haploid gametophyte and diploid sporophyte phases.
- Venation and root patterns are useful general comparisons, but individual exceptions occur.

80. Animal phyla and body organisation

Group	Characteristic	Example
Porifera	Pore bearing animals with a canal system	Sponges
Cnidaria	Stinging cells and a gastrovascular cavity	Hydra; jellyfish; corals
Platyhelminthes	Flatworms	Planaria; tapeworm
Nematoda	Unsegmented roundworms	Ascaris
Annelida	Segmented worms	Earthworm; leech
Arthropoda	Jointed appendages and chitinous exoskeleton	Insects; spiders; crustaceans
Mollusca	Soft body; mantle; muscular foot in many forms	Snail; octopus
Echinodermata	Marine animals with a water vascular system	Starfish; sea urchin
Chordata	Notochord at some developmental stage	Vertebrates and related groups

Body feature	Meaning
Bilateral symmetry	A single principal plane divides mirror-like left and right halves
Radial symmetry	Body parts arranged around an axis
Coelom	Body cavity lined by mesoderm in the relevant classification
Segmentation	Body organisation into repeated units
Exoskeleton	Support external to soft tissues
Endoskeleton	Internal supporting framework

KEY POINTS

- Arthropoda is the largest animal phylum by described species number.
- Adult echinoderms are commonly radially organised, while their larvae show bilateral symmetry.
- A notochord and vertebral column are different structures; chordates do not all have vertebrae.
- Insects have three pairs of legs; spiders have four pairs.

81. Vertebrates and comparative physiology

Group	Typical features	Example
Fishes	Aquatic vertebrates; gills; fins	Rohu; shark
Amphibians	Life cycles often involve water and land	Frog; toad
Reptiles	Amniotic development; scales in typical forms	Lizard; snake; crocodile
Birds	Feathers; endothermy	Pigeon; ostrich
Mammals	Mammary glands; hair at some stage	Human; whale; bat

Comparison	Standard textbook pattern
Fish heart	Two main chambers
Amphibian heart	Three main chambers
Most reptile hearts	Three main chambers with varying ventricular separation
Crocodilian heart	Four chambers
Bird and mammal hearts	Four chambers
Fish respiration	Gills in most familiar adult forms
Adult frog respiration	Lungs and skin are important
Insect respiration	Tracheal system
Earthworm respiration	Moist body surface
Whale respiration	Lungs; whales are mammals

Animal	Special distinction
Bat	A mammal capable of sustained powered flight
Platypus	Egg laying mammal
Penguin	Flightless bird adapted for swimming

KEY POINTS

- Endothermy concerns heat production and regulation; it does not mean body temperature is perfectly constant under all conditions.
- Crocodiles are reptiles despite their four chambered hearts.
- Whales and dolphins are mammals, not fishes.
- The categories of warm blooded and cold blooded are simplified school terms for more complex thermal physiology.

82. Reproduction and adaptations in animals

Process or adaptation	Meaning	Example
Binary fission	Division into two individuals	Amoeba
Multiple fission	Several offspring arise from one parent cell	Stages in Plasmodium
Budding	New individual develops as an outgrowth	Hydra; yeast
Fragmentation	Parts form new individuals in suitable organisms	Some simple organisms
Regeneration	Restoration of lost parts	Can support reproduction in certain animals
Oviparity	Egg laying	Most birds
Viviparity	Live birth	Most mammals
Metamorphosis	Marked developmental transformation	Butterfly; frog

Process or adaptation	Meaning	Example
Camouflage	Reduced detectability in a setting	Background matching
Mimicry	Resemblance with protective or other effects	Several insect examples

Relationship	Meaning
Parasitism	One organism benefits while harming the host
Mutualism	Both partners benefit under the relevant conditions
Commensalism	One benefits with no major effect on the other in the simplified model
Predation	One organism consumes another
Hibernation	Seasonal reduced activity and metabolism in suitable animals
Migration	Regular movement between regions

KEY POINTS

- Asexual reproduction usually has one parental source without gamete fusion.
- Regeneration is not identical to reproduction; repairing a limb need not create a new animal.
- A tadpole and adult frog differ in several respiratory and ecological features.
- Adaptations are interpreted in relation to an environment and evolutionary history.

83. Human physiological facts and disease distinctions

Fact or condition	Accurate relationship
Largest organ of the body	Skin by conventional overall organ description
Largest internal solid organ	Liver
Largest artery	Aorta
Longest major bone	Femur
Smallest bone	Stapes
Major mature human red blood cell feature	No nucleus or mitochondria
Usual adult dentition	32 permanent teeth when all third molars are present
Typical milk dentition	20 teeth
Haemophilia	Inherited deficiency in a clotting factor in common forms
Sickle cell disease	Inherited haemoglobin disorder
Thalassaemia	Inherited reduced synthesis of particular globin chains
Jaundice	Yellow discolouration related to bilirubin; a sign with multiple causes

Comparison	Distinction
Heart attack and cardiac arrest	Injury from reduced blood supply and failure of effective pumping are different events
Infection and inflammation	Microbial invasion and a tissue response are different concepts
Communicable and hereditary disease	Transmission between hosts and genetic inheritance are different mechanisms
Deficiency and infectious disease	Inadequate nutrient availability and pathogen involvement differ
Antigen and antibody	Recognised target and immune binding protein differ

KEY POINTS

- A textbook average such as pulse rate is not a universal fixed measurement.

- Haemophilia causes impaired clotting; it is not a deficiency of haemoglobin.
- Jaundice does not identify one specific pathogen.
- The body's physiological systems work together; one symptom can have several causes.

84. Discoveries and biological techniques

Scientist or development	Association	Important detail
Robert Hooke	Described cells in cork	Published in Micrographia in 1665
Antonie van Leeuwenhoek	Early observations of microorganisms	Used powerful simple microscopes
Robert Brown	Description of the cell nucleus	Important contribution to cell biology
Schleiden and Schwann	Cell theory	Plants and animals are composed of cells
Rudolf Virchow	Cells arise from pre-existing cells	Associated with extension of cell theory
Gregor Mendel	Laws of inheritance	Pea experiments
Charles Darwin	Natural selection	On the Origin of Species published in 1859
Edward Jenner	Smallpox vaccination	Cowpox related approach
Louis Pasteur	Microbial research and vaccination	Pasteurisation is named after him
Alexander Fleming	Discovery of penicillin's antibacterial effect	Later development required other researchers

Technique	Purpose
Pasteurisation	Controlled heating reduces pathogens and spoilage organisms
Sterilisation	Eliminates viable microorganisms to a defined standard
Aseptic technique	Prevents unwanted microbial contamination
Microscopy	Observes small structures using suitable magnification and resolution
Gram staining	Differentiates bacterial staining patterns related to cell envelope properties
Culture	Grows organisms or cells under controlled conditions

KEY POINTS

- Pasteurisation is different from sterilisation and does not necessarily destroy all spores.
- Magnification enlarges an image; resolution distinguishes nearby details.
- Discovery and development can involve different people and stages.

PART 04

Science & Technology

Biotechnology, space, nuclear, energy, IT, AI, defence, institutions • topics 85–106

85. Recombinant DNA and genetic engineering

Tool or step	Role	Important distinction
Restriction endonuclease	Cuts DNA at specific recognition sequences	A molecular cutting tool
DNA ligase	Joins DNA fragments	Forms phosphodiester bonds
Vector	Carries DNA into a host	Plasmid is a common example
Plasmid	Often circular extrachromosomal DNA	Can carry engineered genes
Selectable marker	Helps identify cells with a desired vector	May confer a selectable phenotype
Host cell	Receives and expresses introduced material	Often a bacterium or other cultured cell
Recombinant DNA	Contains joined DNA from different sources	Can be propagated in a host
Bioreactor	Provides controlled biological production conditions	Temperature, pH and aeration can be managed

Application	Scientific basis
Recombinant insulin	Human insulin components produced using engineered organisms
Industrial enzyme production	Selected genes expressed in production hosts
Transgenic organism	Contains introduced genetic material
Gene cloning	Makes copies of a specific DNA sequence
Molecular diagnosis	Detects genetic or pathogen related targets
Downstream processing	Purification and formulation after biological production

KEY POINTS

- Genetic engineering changes genetic material using molecular methods; selective breeding uses reproductive selection.
- Introducing a gene does not guarantee its useful expression; regulatory sequences and host conditions matter.
- Recombinant products can be identical or closely related to naturally occurring molecules.

86. PCR sequencing and DNA profiling

Technology	What it does	Main element
PCR	Amplifies a selected DNA region	Primers, polymerase and thermal cycling
RT-PCR in reverse transcription usage	Converts RNA to DNA before PCR	Reverse transcriptase
Real time PCR	Monitors amplification as it proceeds	Fluorescent signal
DNA sequencing	Determines nucleotide order	Several technology platforms exist
DNA profiling	Compares variable DNA markers	Often uses short tandem repeats

Technology	What it does	Main element
Gel electrophoresis	Separates molecules by migration in an electric field	DNA usually moves towards the positive electrode
ELISA	Detects antigen or antibody using enzyme linked assays	Immunological detection
Biosensor	Converts a biological recognition event into a measurable signal	Recognition element plus transducer

PCR phase	Event
Denaturation	Double stranded DNA separates on heating
Annealing	Primers bind complementary sequences
Extension	Polymerase synthesises new DNA
Repeated cycling	Target copies accumulate

Application	Use
Forensic identification	Comparison of biological samples
Paternity analysis	Comparison of inherited marker patterns
Pathogen testing	Detection of specific genetic targets
Genetic research	Study of variation and sequence

KEY POINTS

- PCR copies DNA; sequencing reads its base order. They are different operations.
- RT-PCR abbreviations can be used differently; reverse transcription and real time detection should be distinguished explicitly.
- DNA profiling does not routinely read every base of a person's genome.
- Contamination and sample quality can affect molecular test interpretation.

87. Genome editing stem cells and cloning

Technology or cell type	Meaning	Key distinction
CRISPR Cas system	Guide dependent targeting of nucleic acids	Adapted from microbial defence systems
Cas9	A DNA cutting protein in a widely used editing system	Works with a guide RNA
Gene editing	Targeted alteration of genetic sequences	Need not always add foreign DNA
Gene therapy	Uses genetic material or genetic modification for treatment	Can be delivered in different ways
Somatic editing	Changes non-reproductive cells	Not normally inherited by offspring
Germline editing	Changes material that can enter inheritance	Raises distinct biological and ethical issues
Stem cell	Can self renew and generate differentiated cells	Potency varies
Embryonic stem cell	Pluripotent cell derived from an early embryo	Can form many body cell types
Adult stem cell	Stem cell in developed tissues	Often has a more limited range
Induced pluripotent stem cell	Somatic cell reprogrammed to pluripotency	Does not require derivation from an embryo

Cloning term	Meaning
Molecular cloning	Copies a DNA sequence

Cloning term	Meaning
Reproductive cloning	Attempts to produce a whole organism with a closely matched nuclear genome
Therapeutic cloning concept	Produces cells or tissues for research or potential treatment
Dolly	Sheep produced through somatic cell nuclear transfer

KEY POINTS

- A clone need not be identical in every trait because environment and other biological factors affect phenotype.
- Gene editing can produce off-target changes and other unintended effects.
- Stem cell therapy is not an established cure for every degenerative disease.
- Pluripotent and totipotent describe different developmental capacities.

88. Agricultural biotechnology

Technology	Purpose	Example or limitation
Bt crop	Expresses selected insecticidal proteins	Bt cotton targets susceptible insect pests
Tissue culture	Grows plant cells or tissues under controlled conditions	Micropropagation
Totipotency	Capacity of a cell to generate a complete plant under suitable conditions	Basis of many plant culture methods
Biofortification	Improves nutrient content or availability	Can use breeding or biotechnology
Marker assisted selection	Uses genetic markers to aid breeding	Does not inherently create a transgenic plant
RNA interference	Sequence dependent suppression of gene expression	Research and selected applications
Somatic hybridisation	Fusion of somatic cells or protoplasts	Combines material without ordinary sexual crossing
Cryopreservation	Storage at very low temperature	Conservation of suitable biological material

Comparison	Distinction
GM crop and hybrid crop	Molecular genetic modification and controlled breeding are different concepts
Insect resistance and herbicide tolerance	Different engineered traits
Biofortification and food fortification	Nutrient improvement in the crop and addition during processing
Biofertiliser and chemical fertiliser	Microbial product and nutrient chemical input
Plant tissue culture and seed sowing	In vitro propagation and conventional seed development

KEY POINTS

- Bt toxins are not active against every insect; their effects depend on protein and target species.
- Resistance management is important because pest populations can evolve.
- Tissue culture can multiply selected plants rapidly, but contamination control is essential.
- A genetically modified crop should be assessed by its particular trait and evidence, rather than by the label alone.

89. Vaccine platforms and precision medicine

Platform	What is delivered	Immune response basis
Live attenuated vaccine	Weakened organism	Limited replication stimulates immunity
Inactivated vaccine	Inactivated pathogen	Antigens stimulate immunity without pathogen replication
Subunit vaccine	Selected pathogen components	Targeted antigen exposure
Toxoid vaccine	Inactivated toxin	Protection against toxin effects
Viral vector vaccine	Modified carrier virus with target instructions	Cells produce a target antigen
mRNA vaccine	Messenger RNA instructions	Cells transiently produce antigen
DNA vaccine	DNA instructions	Expression of a target antigen

Technology	Meaning
Monoclonal antibody	Antibody preparation targeting a specific antigen feature
CAR T cell therapy	Patient or donor T cells engineered with a chimeric antigen receptor
Precision medicine	Uses relevant individual variation to guide care
Pharmacogenomics	Studies genetic influences on medicine response
Liquid biopsy	Studies biomarkers in body fluids, including circulating tumour material
Organoid	Three dimensional culture modelling selected tissue features

KEY POINTS

- mRNA vaccines do not need to alter nuclear DNA to work.
- Different vaccine platforms have different storage, dosing and suitability requirements.
- CAR T cell therapy is used for selected indications; it is not a universal treatment for all cancers.
- A biological medicine is produced through biological systems or contains biological components; it differs from a simple generic chemical in important ways.

90. Indian biotechnology initiatives

Initiative or institution	Core purpose	Key fact
GenomeIndia	Characterise genetic diversity in Indian populations	The project generated 10,000 whole genome sequences in its initial major dataset
BioE3 policy	High performance biomanufacturing	Economy, Environment and Employment
DBT	Department of Biotechnology	Government support for biotechnology research and development
BIRAC	Biotechnology Industry Research Assistance Council	Supports biotechnology innovation and industry development
Biofoundry	Automated biological design and testing capability	Links engineering with biological systems
Biomanufacturing	Uses biological systems to make products	Includes chemicals, materials and therapeutics

BioE3 thematic area	Focus
Bio-based chemicals and enzymes	Industrial production using biological routes
Functional foods and smart proteins	Nutrition and sustainable protein applications
Precision biotherapeutics	Advanced biological treatments

BioE3 thematic area	Focus
Climate resilient agriculture	Biological tools for resilience
Carbon capture and utilisation	Biological approaches to carbon management
Marine and space research	Emerging biological applications

KEY POINTS

- BioE3 was approved in August 2024; it is a policy framework, not a single vaccine programme.
- A population genome resource supports research; it does not itself provide a medical diagnosis for every participant.
- Genomics studies whole genetic systems; genetics can also focus on individual genes and inheritance.
- Personal genomic data require careful consent, security and interpretation.

91. Space science and orbital terms

Term	Meaning	Application
Low Earth orbit	Orbit relatively close to Earth	Many imaging and human spaceflight missions
Geostationary orbit	Circular equatorial orbit matching Earth's rotation	A satellite appears fixed in the sky
Geosynchronous orbit	Period equals Earth's sidereal rotation period	Not necessarily stationary in the sky
Polar orbit	Passes near Earth's polar regions	Broad surface coverage
Sun synchronous orbit	Orbital plane precesses to keep a similar local solar time	Earth observation
Apogee	Farthest point from Earth	Elliptical Earth orbit
Perigee	Nearest point to Earth	Elliptical Earth orbit
Escape trajectory	Sufficient energy to leave a body's gravitationally bound orbit	Interplanetary flight
Lagrange point	Equilibrium related location in a rotating two-body system	Space observatory placement

Concept	Fact
Geostationary altitude	About 35,786 km above the equator
Orbital motion	Continuous gravitational free fall around a body
Microgravity	Very small apparent weight in a freely falling system
Payload	The useful mission equipment or spacecraft carried
Launch vehicle	Rocket placing a payload on a trajectory
Space debris	Non-functional human made objects or fragments in space

KEY POINTS

- Geostationary is a special case of geosynchronous.
- Being in space does not mean gravity has become zero.
- L1 and L2 mission spacecraft usually operate in suitable orbits around those points, rather than sitting perfectly motionless.

92. Indian launch vehicles and rocket engines

Vehicle	Principal character	Important feature
PSLV	Versatile launch vehicle widely used for polar missions	Uses solid and liquid stages

Vehicle	Principal character	Important feature
GSLV Mk II	Vehicle with a cryogenic upper stage	Used for suitable heavier orbital missions
LVM3	Heavy lift Indian launch vehicle	Formerly called GSLV Mk III
SSLV	Small Satellite Launch Vehicle	Designed for small payload missions
Sounding rocket	Carries experiments on a suborbital trajectory	Does not necessarily enter orbit
Human rated launch vehicle	Designed and qualified for crew safety needs	Used in human spaceflight programmes

Propulsion type	Feature	Example
Solid propulsion	Fuel and oxidiser are in a solid propellant	Boosters
Liquid propulsion	Propellants are supplied to a chamber	Controllable engines
Cryogenic propulsion	Uses very cold propellants	Liquid hydrogen and liquid oxygen combination
Semi-cryogenic concept	One propellant is cryogenic and the other is not	Liquid oxygen with kerosene
Electric propulsion	Accelerates particles using electrical energy	Efficient thrust for some in-space tasks

KEY POINTS

- Rocket thrust follows momentum conservation and Newton's third law.
- A launch vehicle and the satellite it carries are different systems.
- Cryogenic refers to very low temperature storage and operation, not nuclear propulsion.
- The LVM3 configuration has solid boosters, a liquid core and a cryogenic upper stage.

93. Indian lunar and planetary missions

Mission	Year or milestone	Main fact
Chandrayaan-1	Launched in 2008	India's first lunar mission; contributed to evidence of lunar water or hydroxyl
Chandrayaan-2	Launched in 2019	Orbiter mission with a lander and rover attempt
Chandrayaan-3	Soft landing on 23 August 2023	Demonstrated landing and roving near the lunar south polar region
Mars Orbiter Mission	Entered Mars orbit in 2014	Also called Mangalyaan
Vikram	Chandrayaan lander name	Used for Chandrayaan-2 and Chandrayaan-3 landers
Pragyan	Rover name	Lunar surface mobility

Chandrayaan-3 instrument	Purpose
ChaSTE	Studies surface thermophysical properties
ILSA	Measures seismic activity around the landing site
RAMBHA Langmuir probe	Studies near-surface plasma
APXS	Elemental analysis from the rover
LIBS	Laser induced breakdown spectroscopy for elemental study
SHAPE	Spectro-polarimetry of Earth from the propulsion module

KEY POINTS

- Chandrayaan-3 landed in the south polar region, not exactly at the geographic south pole.
- An orbiter, lander and rover perform different tasks.
- A soft landing reduces touchdown speed to a survivable level.
- National Space Day in India is observed on 23 August, marking the Chandrayaan-3 landing.

94. Solar astronomy and space observatories

Mission or concept	Purpose	Important detail
Aditya-L1	Studies the Sun and its environment	Operates in a halo orbit around Sun Earth L1
Sun Earth L1	Located towards the Sun from Earth	About 1.5 million km from Earth
AstroSat	Indian multiwavelength astronomy observatory	Launched in 2015
XPoSat	Studies X ray polarisation	Indian X ray astronomy mission launched in 2024
James Webb Space Telescope	Primarily infrared astronomy	Operates near Sun Earth L2
Hubble Space Telescope	Astronomy across several wavelength bands	Earth orbiting observatory

Aditya-L1 payload	Main focus
VELC	Solar corona
SUIT	Solar ultraviolet imaging
SoLEXS	Soft X ray spectroscopy
HEL1OS	Hard X ray spectroscopy
ASPEX	Solar wind particles
PAPA	Plasma analysis
Magnetometers	Magnetic field measurements

KEY POINTS

- Aditya-L1 does not land on the Sun or orbit close to its visible surface.
- Solar corona is the outer atmosphere; it differs from the photosphere.
- A solar flare, solar wind and coronal mass ejection are related but distinct phenomena.
- Polarisation provides information beyond ordinary intensity and wavelength measurements.

95. Earth observation navigation and NISAR

System or mission	Principal role	Important feature
INSAT and GSAT systems	Communication and related services	Several missions also support meteorology
IRS related missions	Earth observation	Remote sensing applications
Cartosat	Cartographic imaging	Mapping related missions
Resourcesat	Resource monitoring	Agriculture and land studies
Oceansat	Ocean observations	Ocean related data
NavIC	Indian regional satellite navigation system	Navigation with Indian coverage and surrounding region
GPS	United States navigation system	Global system
NISAR	NASA ISRO Synthetic Aperture Radar	Dual L band and S band radar

NISAR attribute	Fact
Launch	30 July 2025 on GSLV-F16
NASA contribution	L band radar and associated systems
ISRO contribution	S band radar, spacecraft related systems and launch responsibilities
Observations	Land deformation, ice and ecosystem changes
Radar feature	Active microwave sensing supports day and night observation

Remote sensing term	Meaning
Spatial resolution	Size of distinguishable surface detail
Spectral resolution	Ability to distinguish wavelength bands
Temporal resolution	Revisit or observation frequency

KEY POINTS

- Navigation, communication and imaging satellites have different principal functions.
- Radar can observe through many cloud conditions, but penetration and measurement depend on wavelength and target.
- NISAR is an Earth observation mission, not a communication or crewed spacecraft.

96. Human spaceflight and docking

System or mission	Role	Important fact
Gaganyaan	Indian human spaceflight programme	Develops crew launch, survival and recovery capabilities
Crew module	Habitable crew space	Requires environmental control and safe re-entry
Service module	Supports spacecraft functions	Propulsion and other services
Crew escape system	Moves crew away from a failing launch vehicle	A critical safety capability
Space suit	Supports and protects the wearer	Depends on mission environment
SpaDeX	Space Docking Experiment	Two spacecraft demonstrate rendezvous and docking
International Space Station	Crewed orbital research platform	International collaboration

Milestone or process	Fact
SpaDeX launch	30 December 2024 on PSLV-C60
First SpaDeX docking	16 January 2025
SpaDeX undocking	13 March 2025
Rendezvous	Spacecraft approach with matched relative motion
Docking	Spacecraft physically connect in a controlled manner
Re-entry	A spacecraft returns through the atmosphere
Ablative heat shield	Sacrificial material helps manage re-entry heating

KEY POINTS

- Docking supports station assembly, servicing and complex multi-launch missions.
- Orbital rendezvous requires close control of relative position and velocity between spacecraft.
- Microgravity affects fluid distribution, muscles and bones during extended stays.
- Life support must manage oxygen, carbon dioxide, temperature, pressure and other conditions.

97. Nuclear reactors and fuel cycle

Component or process	Role	Example or fact
Nuclear fuel	Contains fissile material	Uranium 235; plutonium 239
Fission chain reaction	Neutrons trigger further fissions	Controlled in a power reactor
Moderator	Slows neutrons in suitable reactors	Water; heavy water; graphite
Control rods	Absorb neutrons	Help regulate reactor power

Component or process	Role	Example or fact
Coolant	Carries heat away	Water; gas; liquid metal in different designs
Steam turbine	Converts steam energy to rotation	Drives a generator
Containment	Restricts release during specified conditions	Major safety barrier
Spent fuel	Fuel removed after irradiation	Contains remaining fuel and radioactive products

Comparison	Meaning
Fissile material	Can sustain fission with low energy neutrons under suitable conditions
Fertile material	Can be converted into fissile material
Uranium 238	Fertile precursor to plutonium 239
Thorium 232	Fertile precursor to uranium 233
Heavy water	Can serve as moderator in suitable reactors
Fast reactor	Uses a fast neutron spectrum; no moderator in the usual design
FBTR at Kalpakkam	Uses liquid sodium as coolant

KEY POINTS

- A reactor produces heat; the generator produces electricity.
- Moderators and control rods have different functions.
- Radiation exposure, contamination and reactor power are different concepts.
- A nuclear power plant does not operate as an ordinary explosive chain reaction device.

98. Indian nuclear energy and radiation technology

Institution or programme	Role	Location or fact
Department of Atomic Energy	Atomic energy programme administration	Government of India
BARC	Bhabha Atomic Research Centre	Mumbai region
IGCAR	Indira Gandhi Centre for Atomic Research	Kalpakkam, Tamil Nadu
NPCIL	Nuclear Power Corporation of India Limited	Operates major civilian nuclear power facilities
AERB	Atomic Energy Regulatory Board	Safety regulation within its mandate
Narora Atomic Power Station	Nuclear electricity generation	Uttar Pradesh
Three stage programme	Long term utilisation of uranium and thorium resources	Stages use different fuel and reactor concepts

Stage concept	Fuel cycle relationship
First stage	Pressurised heavy water reactors use natural uranium and generate plutonium in spent fuel
Second stage	Fast breeder reactor concept uses plutonium and breeds additional fissile material
Third stage	Thorium based cycle aims to use uranium 233

Radiation application	Purpose
Agriculture	Mutation breeding; pest management applications
Medicine	Diagnosis and treatment

Radiation application	Purpose
Industry	Non-destructive inspection; thickness gauges
Food processing	Approved irradiation for specified purposes

KEY POINTS

- Thorium is fertile rather than directly fissile in the usual reactor terminology.
- The three stage programme describes a development strategy, not three reactors of identical type.
- Radiation sterilisation and food irradiation do not mean the treated material becomes a radioactive source.
- Natural uranium consists mainly of uranium 238 with a small fraction of uranium 235.

99. Renewable energy hydrogen and storage

Technology	Conversion or role	Important limit
Solar photovoltaic	Light to electricity	Output depends on sunlight and system conditions
Solar thermal	Solar radiation to heat	Different from photovoltaic conversion
Wind turbine	Wind kinetic energy to electricity	Output varies with wind conditions
Hydropower	Water energy to electricity	Depends on flow and available head
Biomass energy	Biological material supplies fuel	Sustainability depends on sourcing and use
Geothermal	Earth's internal heat	Location and resource conditions matter
Fuel cell	Electrochemical conversion of fuel and oxidant	Not ordinary combustion
Battery	Stores energy chemically	Cycle life and materials differ

Hydrogen term	Usual production meaning
Green hydrogen	Produced using renewable energy through specified pathways, commonly electrolysis
Grey hydrogen	Commonly fossil derived without carbon capture
Blue hydrogen	Fossil derived with carbon capture arrangements
Electrolyser	Splits water using electrical energy
Fuel cell vehicle	Converts stored fuel into electricity onboard
Pumped storage	Uses electricity to pump water upward and later generates power

KEY POINTS

- Colour names for hydrogen describe production routes and are not different colours of the gas.
- A fuel cell needs a continuing fuel supply; a rechargeable battery stores reactants internally within its operating design.
- Hydrogen's climate benefit depends on production, leakage, transport and end use.
- Energy storage supports variable renewable generation and grid balancing.

100. Computers data and digital systems

Component or concept	Role	Distinction
CPU	Executes instructions	Includes control and arithmetic logic functions
RAM	Working memory	Usually volatile
ROM	Nonvolatile stored information	Forms and update methods vary
SSD	Electronic nonvolatile storage	No spinning magnetic disc
Hard disk	Magnetic storage	Uses rotating platters
Operating system	Manages hardware and application resources	System software

Component or concept	Role	Distinction
Application software	Performs user tasks	Word processor; browser
Binary system	Uses digits 0 and 1	Bit is a binary digit
Byte	Normally eight bits	Basic data unit

Term	Meaning
Algorithm	Defined sequence of steps for a task
Database	Organised data with management facilities
Cloud computing	On-demand network access to shared computing resources
Edge computing	Processes data near its source or use
Internet of Things	Connected physical devices exchanging data
Sensor	Detects a physical or chemical property
Actuator	Produces an action in response to control

KEY POINTS

- Storage capacity and processing speed are different specifications.
- 1 kB is 1000 bytes in SI usage; 1 KiB is 1024 bytes in binary usage.
- Cloud computing uses physical infrastructure; cloud does not mean data has no storage location.
- A computer virus is a software threat, not a biological virus.

101. Internet communication and mobile technology

Term or technology	Role	Key distinction
Internet	Network of interconnected networks	Different from the World Wide Web
World Wide Web	Linked resources accessed using web protocols	One service on the Internet
IP address	Identifies a network interface in an IP system	IPv4 and IPv6 use different formats
DNS	Resolves names to network information	Supports domain name use
HTTP	Web transfer protocol	HTTPS adds transport protection through TLS
Wi-Fi	Wireless local networking	Not a synonym for the Internet
Bluetooth	Short range wireless communication	Different design from Wi-Fi
Optical fibre	Light based data transmission	High capacity with low attenuation
5G	Fifth generation mobile technology	Includes enhanced broadband and other service categories

Communication term	Meaning
Bandwidth	Capacity or frequency range, depending on context
Latency	Time delay
Upload	Data transfer from a client to a remote service
Download	Data transfer from a remote service to a client
Modem	Converts signals for a communication link
Router	Directs packets between networks
Satellite communication	Uses spacecraft links to relay signals

KEY POINTS

- Higher bandwidth does not automatically imply lower latency.
- Radio signals and optical signals are both electromagnetic, but operate in different frequency ranges.
- Mobile generations are technology families, not single frequency bands.

- HTTPS protects the connection but does not guarantee that the site's claims or intentions are trustworthy.

102. Artificial intelligence robotics and quantum technology

Technology	Meaning	Important limit
Artificial intelligence	Systems perform tasks associated with intelligent behaviour	Capabilities depend on design and data
Machine learning	Learns patterns from data for tasks	A subset of AI
Deep learning	Uses multi-layer neural networks	A subset of machine learning
Generative AI	Produces content from learned patterns	Can produce incorrect information
Computer vision	Processes images or visual input	Used in recognition and inspection
Robot	Programmable machine interacting with the physical world	May or may not use AI
Quantum computing	Uses quantum states for information processing	Does not speed up every task
Qubit	Quantum information unit	Can be in superposed states
Quantum entanglement	Correlations not explained by independent classical states	Does not allow unrestricted faster-than-light messaging

National Quantum Mission	Fact
Approval	April 2023
Period	2023-24 to 2030-31
Approved outlay	₹6003.65 crore
Main domains	Computing, communication, sensing and metrology, materials and devices
Computing objective	Development involving 50 to 1000 physical qubits across platforms

KEY POINTS

- Training learns model parameters; inference uses a trained model to produce outputs.
- Bias, privacy, explainability and robustness are important AI issues.
- Quantum key distribution is different from sending all ordinary data through a quantum computer.
- A robot's autonomy varies; remote operated machines and autonomous machines are distinct.

103. Cybersecurity blockchain and digital payments

Term	Meaning	Protection or limitation
Malware	Malicious software	Updates and appropriate security controls
Phishing	Deceptive attempt to obtain information or access	Verify requests and links
Ransomware	Malware that blocks access or threatens disclosure	Backups and prevention are important
Encryption	Converts readable data using a cryptographic method	Requires secure key management
Hash	Fixed-length digest from data in a specified algorithm	Not ordinary reversible encryption
Digital signature	Cryptographic authentication and integrity mechanism	Depends on private and public keys
Multi-factor authentication	Uses more than one factor type	Improves protection over a password alone
Blockchain	Linked records maintained under a consensus design	Not identical to cryptocurrency

Indian digital system	Role
UPI	Unified Payments Interface; interoperable payment system
NPCI	National Payments Corporation of India
Aadhaar	Identity system administered by UIDAI
DigiLocker	Digital document platform
CBDC	Central bank digital currency; digital form of central bank money
CERT-In	Indian Computer Emergency Response Team

Threat distinction	Fact
Data breach	Unauthorised access or disclosure
Denial of service	Disruption of availability

KEY POINTS

- Blockchain does not make every input true; external data can still be incorrect.
- A digital signature is not just a scanned handwritten signature.
- An OTP is sensitive authentication information; sharing it can defeat account protection.
- Digital currency, online banking and a cryptocurrency are different concepts.

104. Advanced materials lasers and manufacturing

Technology or material	Principle	Use
Laser	Stimulated emission gives a coherent beam	Communication; machining; medicine
LED	Light from an electronic junction	Lighting and displays
Superconductor	Zero electrical resistance under suitable conditions	Magnets; specialised electronics
Meissner effect	Expulsion of magnetic flux in the superconducting state	Distinctive superconducting behaviour
Nanotechnology	Uses nanoscale structures and properties	Materials; sensing; medicine
3D printing	Builds objects layer by layer	Additive manufacturing
Composite material	Combines components with different roles	Carbon fibre reinforced polymer
Smart material	Responds to an external stimulus	Shape memory alloys
MEMS	Microelectromechanical systems	Small sensors and actuators

Manufacturing term	Meaning
Additive process	Material is added to form a component
Subtractive process	Material is removed, as in machining
Semiconductor fabrication	Layered processing of electronic structures
Photolithography	Transfers patterned information using light sensitive processes
Metamaterial	Engineered structure with designed wave interactions

KEY POINTS

- Laser light is not always visible; lasers operate across different wavelength ranges.
- Nanoparticle behaviour depends on composition, size, surface and exposure.
- Superconductivity generally requires specific temperature and other conditions; all good conductors are not superconductors.
- 3D printing can use polymers, metals and other materials; it is not restricted to plastic.

105. Defence transport and ocean technology

Technology	Core principle	Distinction
Ballistic missile	Powered boost followed by a largely ballistic flight segment	Trajectory differs from a cruise missile
Cruise missile	Sustained aerodynamic flight with propulsion	Often flies at relatively low altitude
Guided missile	Uses a guidance system	Guidance does not define its trajectory type alone
Radar	Uses reflected radio waves	Range and tracking
Sonar	Uses sound underwater	Active and passive forms
UAV or drone	Aircraft without an onboard human pilot	Can be remotely piloted or autonomous
BrahMos	Supersonic cruise missile programme	India Russia collaboration
Akash	Surface to air missile system	Air defence
Agni	Ballistic missile family	Different versions have different specifications

Technology	Purpose
Electric vehicle	Uses electric motor propulsion
Regenerative braking	Recovers part of kinetic energy into storage
Maglev	Magnetic levitation and propulsion concepts
Autonomous underwater vehicle	Underwater tasks without continuous human control
Deep Ocean Mission	Ocean exploration and technology programme
Matsya 6000	Human occupied submersible development under Samudrayaan; designed for a 6000 m depth capability

KEY POINTS

- Hypersonic commonly means speeds of Mach 5 or more; Mach number is speed divided by local sound speed.
- A development target is different from a completed operational capability.
- Passive sonar listens; active sonar transmits a pulse and detects returns.

106. Indian scientific institutions and contributions

Institution	Location	Main field
CSIR Central Drug Research Institute	Lucknow	Drug research
CSIR Indian Institute of Toxicology Research	Lucknow	Toxicology and environmental health
CSIR National Botanical Research Institute	Lucknow	Plant science
CSIR Central Institute of Medicinal and Aromatic Plants	Lucknow	Medicinal and aromatic plants
Birbal Sahni Institute of Palaeosciences	Lucknow	Palaeosciences
CSIR National Physical Laboratory	New Delhi	Measurement standards
Indian Institute of Science	Bengaluru	Research and higher education

Institution	Location	Main field
Indian Agricultural Research Institute	New Delhi	Agricultural research
Vikram Sarabhai Space Centre	Thiruvananthapuram	Launch vehicle research
Satish Dhawan Space Centre	Sriharikota	Space launch operations

Scientist	Contribution or association
C V Raman	Raman scattering; Nobel Prize in Physics in 1930
S N Bose	Quantum statistics underlying Bose Einstein statistics
Meghnad Saha	Thermal ionisation equation in astrophysics
Jagadish Chandra Bose	Research in radio waves and plant responses
Homi J Bhabha	Major role in India's atomic energy programme
Vikram Sarabhai	Major role in India's space programme
A P J Abdul Kalam	Aerospace and missile programme contributions

KEY POINTS

- CSIR is the Council of Scientific and Industrial Research, which supports a network of research laboratories.
- The Raman effect concerns inelastic light scattering and is not ordinary reflection.
- National Science Day is observed on 28 February in India, commemorating the discovery of the Raman effect.