Let's Map It

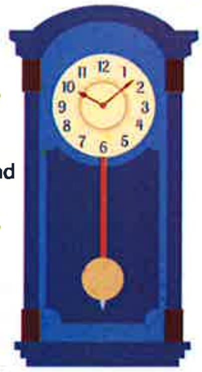
PHYSICAL QUANTITIES

examples with SI units

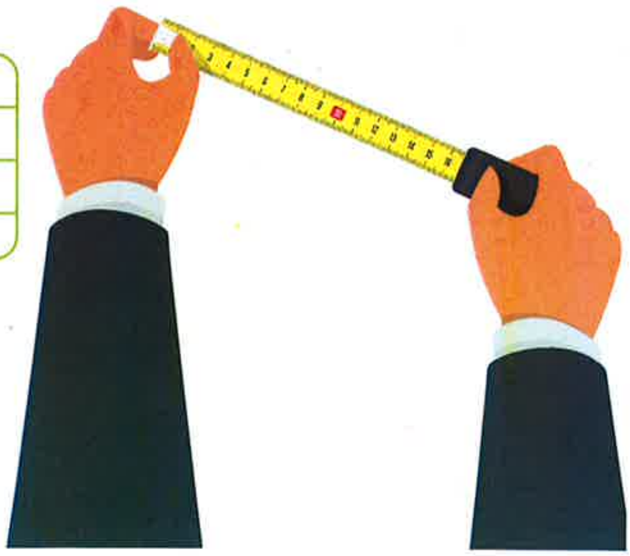
- **Length (m)**: can be measured using
- **Volume (m³)**: can be measured using
  - Measuring cylinder for liquids and small irregular solids
  - Formulae for regular solids
  - Displacement method for large irregular solids
- **Time (s)**: can be measured using
  - Clocks and digital timers (e.g. pendulum clocks and stopwatches)
  - based on: Periodic motions called oscillations

can be classified into

- **S Scalar quantities**: have only
  - S Magnitude
- **S Vector quantities**: have both
  - S Magnitude
  - S Direction
  - S Represented by vector diagrams
  - S Addition of two vectors to give the resultant vector can be determined graphically or by calculation.



Instrument	Precision	Measuring range
Measuring tape	1 mm	Several metres
Metre rule	1 mm	Several cm to1 m
Vernier calipers	0.1 mm	1 cm to 15 cm



Let's Map It

MOTION

is described in terms of

Speed (m/s)
- scalar

involves
- Distance (m)

can be found by
- Area under speed–time graph

can be found by
- Speed = $\frac{\text{distance travelled}}{\text{time taken}}$
- Average speed = $\frac{\text{total distance travelled}}{\text{total time taken}}$
- Gradient of distance–time graph

Velocity (m/s)
- vector

involves
- Displacement (m)

can be found by
- Velocity = $\frac{\text{displacement}}{\text{time taken}}$

Acceleration (m/s²)
- vector

can be found by
- (S) Acceleration = $\frac{\text{change in velocity}}{\text{time}}$
- (S) Gradient of speed–time graph

example
- Acceleration of free fall, $g = 9.8$ m/s²
  - (S) without air resistance, object falls with constant acceleration
  - (S) with air resistance, object falls with decreasing acceleration and may reach terminal velocity

Let's Map It

MASS m (SI unit: kg)

- **is defined as** → A measure of the quantity of matter in an object at rest relative to the observer
- **values may be compared using** →
  - Electronic balance
  - Beam balance
- **is related to** → WEIGHT W and DENSITY ρ

WEIGHT W (SI unit: N)

- **values may be compared using** → Electronic balance; Beam balance
- **is defined as** → A gravitational force on an object that has mass
  - → $W = m \times g$
  - **where** → Gravitational field strength g is the force per unit mass.
  - **which is equivalent to** → Acceleration of free fall g
- **can be described as** → (S) The effect of a gravitational field on a mass

DENSITY ρ (SI unit: kg/m^3)

- **is defined as** → Mass per unit volume
  - → $\rho = \frac{m}{V}$
  - → Based on density data, we can determine
    - whether an object floats;
    - (S) whether one liquid will float on another liquid, given the two liquids do not mix.

Let's Map It

FORCES *F*
(SI unit: N)

- **cause** → Objects to change in size and/or shape
  - **such as** → A spring
    - **whose spring constant *k* is a ratio given by** → Ⓢ $k = \frac{F}{x}$ where F = load, x = extension
      - **represented using** → Ⓢ Load-extension graph within the limit of proportionality

- **affect** → Motion
  - **described by** → Ⓢ Resulant force F (N) = mass (kg) × accelleration (m/s)
    - **applies to**
      - Balanced forces (Resultant F = 0 N)
        - **for an object**
          - At rest
          - Moving at a constant velocity
      - Unbalanced forces (Resultant $F \neq$ 0 N)
        - **for an object**
          - Ⓢ Moving in a circle
          - Accelerating due to a push or pull
          - Decelerating due to friction or drag

- **produce** → Turning effect known as moment of a force (SI unit: N m)
  - **defined as** → Moment (N m) = force (N) × perpendicular distance of the force from the pivot
    - **can be**
      - Anticlockwise
      - Clockwise
        - **for an object in equilibrium** → Principle of moments: Sum of clockwise moments = sum of anticlockwise moments
          - **which relate to** → Stability of an object
            - **affected by its**
              - Base area
              - Centre of gravity

Let's Map It

MOMENTUM *p*

SI unit: kg m/s

Vector quantity

is defined as

The product of mass and velocity

$p = mv$

where

p = momentum

m = mass

v = velocity

is related to

Impulse

where

Impulse = change in momentum

$F\Delta t = \Delta p$

Force

where

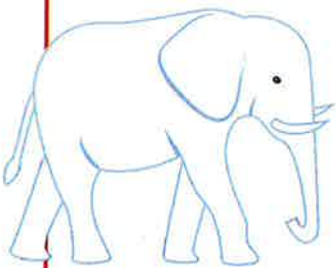
Resultant force $F = \frac{\Delta p}{\Delta t}$

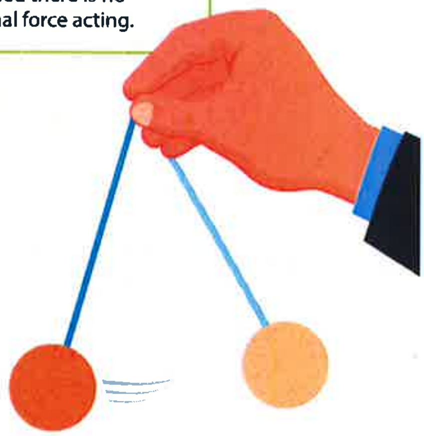
is conserved in collisions between objects governed by

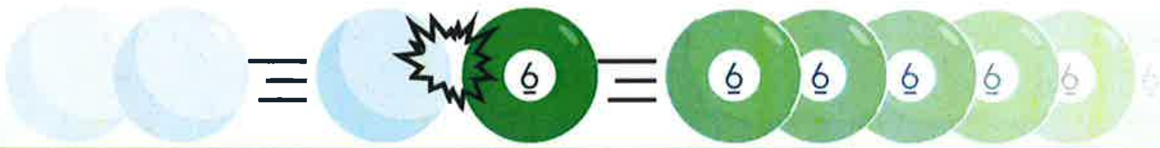
The principle of conservation of momentum

which states that

When objects collide, the total momentum of the objects before a collision is the same as the total momentum of the objects after the collision, provided there is no external force acting.







Let's Map It

ENERGY E (SI unit: J) — is the capacity to do → **WORK W** (SI unit: J)

ENERGY E and WORK W are related to → **POWER P** (SI unit: W)

ENERGY E is governed by → The principle of conservation of energy

The principle of conservation of energy states that → Energy cannot be created or destroyed but can be converted from one form to another.

WORK W is defined as → **S** $W = F \times s$
where
F = force
s = distance moved in the direction of the force

POWER P is defined as → **S** $P = \frac{W}{t} = \frac{E}{t}$
where
W = work done
E = energy converted

examples of forms of energy:

- **Potential energy**
  - Chemical potential energy
  - Elastic (strain) energy
  - Electrostatic potential energy
  - Magnetic potential energy
  - Nuclear energy
  - Gravitational potential energy
  - **S** $E_p = mgh$
- **Kinetic energy**
  - **S** $E_k = \frac{1}{2}mv^2$
  - Electrical energy
  - Thermal energy
  - Light
  - Sound

produced from major energy resources:

- Fuel
- Biofuel
- Water
- Geothermal resources
- Nuclear fission
- Sun
  - energy release by nuclear fusion
  - **S** source of most of our energy
- Wind

converted into useful energy by machines depending on their

Efficiency

- Where some of the energy input is converted to useful energy and some into wasted energy such as heat and sound
- **S** Can be calculated using the following formulae:

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{useful power output}}{\text{total energy input}} \times 100\%$$

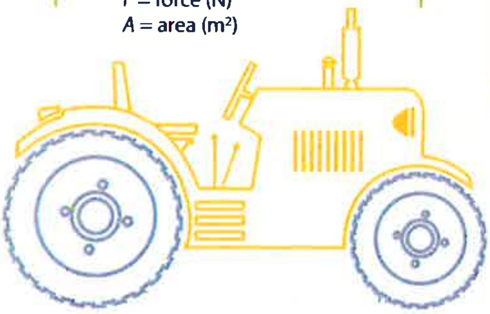
Let's Map It

PRESSURE
(SI unit: Pa)

is defined as → **Force per unit area**

$p = \frac{F}{A}$

where
p = pressure (Pa or N/m^2)
F = force (N)
A = area (m^2)



depends on →

Force
- For the same area, the greater the force, the greater the pressure.

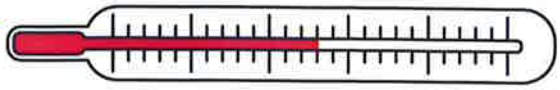
Area
- For the same force, the smaller the area, the greater the pressure.

example → **Pressure in liquids**

Pressure in liquids increases with
- Depth (height measured from surface of liquid)
- Density

Ⓢ Change in pressure is given by
$\Delta p = \rho g \Delta h$

where
ρ = density of liquid (kg/m^3)
g = gravitational field strength (N/kg)
h = height of liquid column (m)



Let's Map It

KINETIC PARTICLE MODEL OF MATTER

is proven by → **Brownian motion**

states that → **Matter is made of tiny particles that are in continuous random motion.**

where
- Particles have greater kinetic energy at higher temperature
- Particles have least energy at absolute zero

  which
  - 0K in kelvin
  - –273°C in degree Celsius

  converted using the equation
  T (in K) = θ (in °C) + 273

which exist in three states known as

Solids
- Particles are closely packed
- Arranged in a regular pattern
- Large number of particles per unit volume
- Particles vibrate about fixed positions
- S Attractive forces between particles are very strong

melting →
← freezing/ solidifying

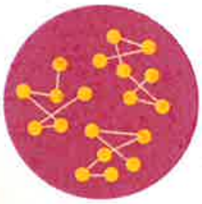
Liquids
- Particles are slightly further apart
- Randomly arranged
- Slightly smaller number of particles per unit volume
- Particles can move freely within the liquid
- S Attractive forces between particles are moderately strong

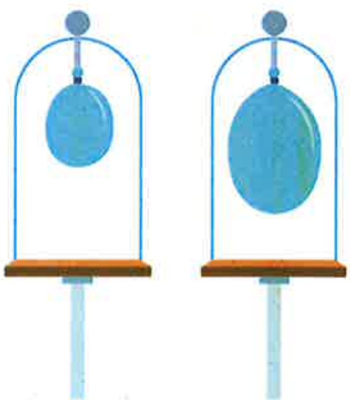
boiling →
← condensing

Gases
- Particles are far apart
- Randomly arranged
- Small number of particles per unit volume
- Particles move randomly at high speeds
- S Attractive forces between particles are negligible

where → **Gas pressure is due to the collision of gas particles with the walls of the container**

- which increases with → Temperature at constant volume
- which decreases with → Volume at constant temperature
  - its equation is given by → S $pV = k$





Let's Map It

THERMAL ENERGY

THERMAL ENERGY — causes → Thermal expansion

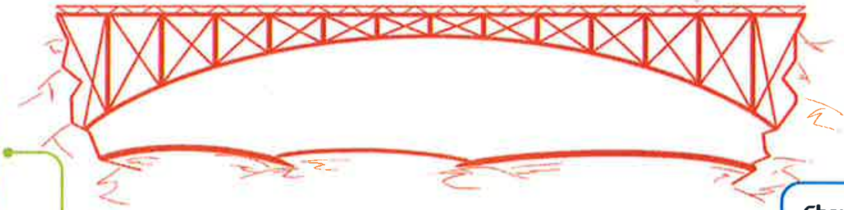
THERMAL ENERGY — increases → Internal energy

Internal energy — causes → Temperature rise; Changes of state

Thermal expansion
- Particles move further apart
- Gases expand more than liquids
- Liquids expand more than solids

Applications
- Shrink fitting to join metals
- Liquid-in-glass thermometers

E ects
- Expansion of bridges
- Expansion of rails

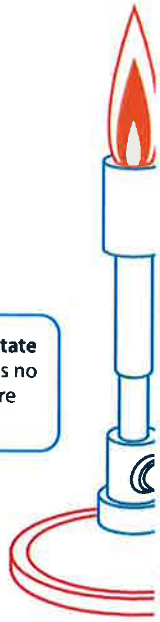


Temperature rise
- S which depends on the specific heat capacity of a substance:
  $c = \frac{\Delta E}{m\Delta\theta}$

can be used to

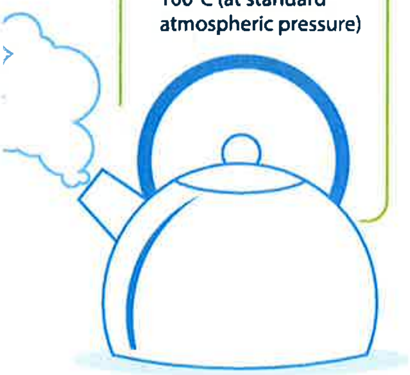
S Measure specific heat capacity of solids and liquids

Changes of state (when there is no temperature change)



Melting
- Solid to liquid
- Requires energy
- Melting point of pure water = 0°C (at standard atmospheric pressure)

Boiling
- Liquid to gas
- Requires energy
- Occurs at boiling point
- Boiling point of pure water = 100°C (at standard atmospheric pressure)

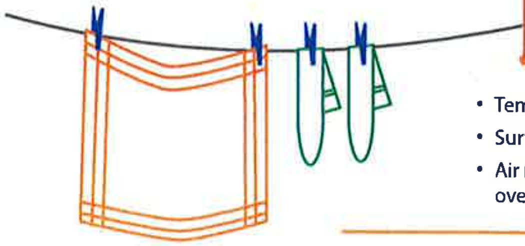


Condensation
- Gas to liquid
- Gives out energy

Solidiÿcation
- Liquid to solid
- Gives out energy

Evaporation
- Liquid to gas
- Requires energy
- Occurs at any temperature
- Causes cooling

affected by
- Temperature
- Surface area
- Air movement over a surface



Let's Map It

THERMAL ENERGY

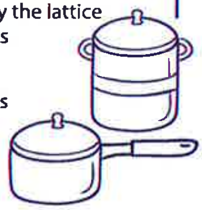
is transferred from

A region of higher temperature to a region of lower temperature until thermal equilibrium is reached.

by the processes of

Conduction

- Through contact between two surfaces
- Requires a medium
- (S) In non-metals, by the lattice vibration of particles
- (S) In metals, by the vibration of particles and free electron diffusion



Convection

- Through bulk movement of fluids (liquid or gas), forming convection currents
- Requires a medium
- Convection currents form due to changes in the density of the fluid

Radiation

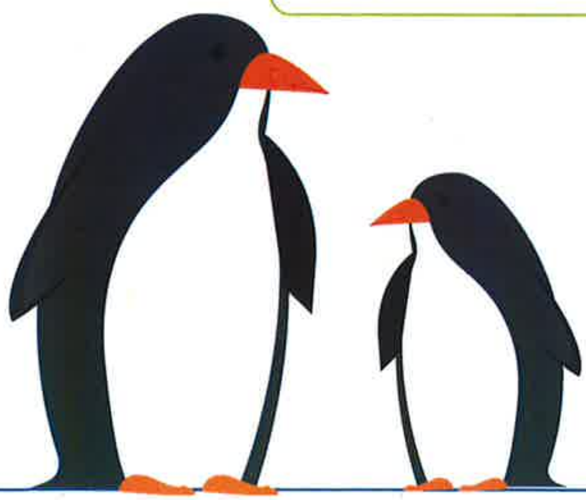
- Through transfer of thermal energy in the form of infrared radiation
- Does not require a medium
- Absorbed and emitted by all objects

which can be applied in

- Cooking utensils
- Soldering irons
- Double-glazed windows
- Electric kettle
- Air conditioners
- Hot water radiators
- Greenhouse
- (S) Car radiators

where the rate of thermal energy transfer is affected by

- Surface colour and texture
- (S) Surface temperature
- (S) Surface area



Let's Map It

WAVES

Transfer energy without transferring matter

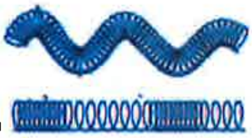
Wave motion is made up of periodic motion or motion repeated at regular intervals.

Transverse wave

- Direction of vibration is perpendicular to direction of propagation

Longitudinal wave

- Direction of vibration is parallel to direction of propagation



Wave behaviour

Refle tion

- Waves bounce off the plane surface without changing shape.

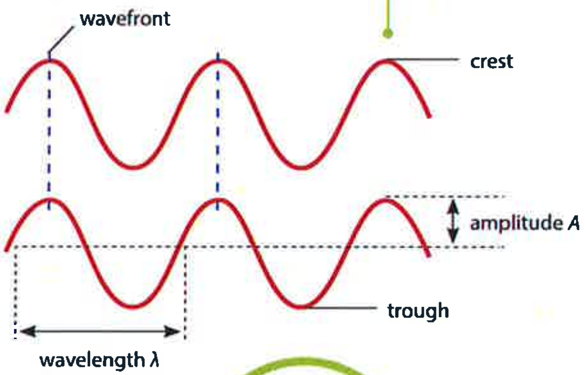
Refraction

- Waves change direction when pass from one medium to another; usually accompanied by a change in speed of the waves.

Diff action

- Waves spread out when they encounter gaps and edges.

Wave features



Can be plotted on a

- displacement–distance graph
- displacement–time graph

Frequency f is the number of complete waves produced per second.

Period T is the time taken to produce one complete wave.

Wave speed is the distance travelled by a wave per second and given by:

$$v = f\lambda$$

Let's Map It

LIGHT

LIGHT undergoes **Reflection**

LIGHT undergoes **Refraction**

Reflection / Refraction — of which image position can be located by **Ray diagrams**

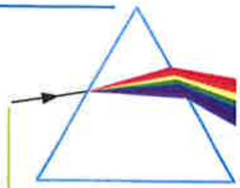
Ray diagrams — described by terms such as:
- Incident ray
- Reflected/ refracted ray
- Point of incidence
- Normal
- Angle of incidence
- Angle of reflection/ refraction

Reflection — is governed by **Law of re ection**
Angle of incidence i = angle of reflection r

Reflection — by a plane mirror — Image formed
- is the same size as the object
- is laterally inverted
- is upright
- is virtual
- has the same distance from the mirror as the object

Refraction causes **Dispersion**

Dispersion produces — Seven colours of the visible spectrum



Refraction is governed by — (S) **Law of refraction** (Snell's law)
$\frac{\sin i}{\sin r}$ = constant

Law of refraction defines — (S) **Refractive index**

$n = \frac{\text{sin (angle of incidence in vacuum)}}{\text{sin (angle of refraction in medium)}}$

$= \frac{\text{(speed of light in vacuum)}}{\text{(speed of light in medium)}}$

Law of refraction explains — **Total internal re ection**

Total internal re ection occurs when
- Light travels from an optically denser medium to an optically less dense medium.
- Angle of incidence in the optically denser medium is greater than the critical angle c.

(S) $\sin c = \frac{1}{n}$

Applications
- glass prism
- (S) optical fibre

Law of refraction — apply to refraction in — **Thin converging lens**

Thin converging lens — described by terms such as
- focal length
- principal axis
- optical centre
- focal point
- focal plane

(S) Applications
- magnifying glass
- spectacle lenses

Let's Map It

ELECTROMAGNETIC SPECTRUM

consists of the following main regions

- Radio waves
- Microwaves
- Infrared radiation
- Visible light
- Ultraviolet radiation
- X-rays
- Gamma rays

Increasing f ↑ Increasing λ ↓

with the following common property

All electromagnetic waves travel at the same high speed in a vacuum.

S The speed of electromagnetic waves in a vacuum is 3.0×10^8 m/s and is approximately the same in air.

has

Harmful effects
- Damage to body cells leading to cancer
- Damage to eyes
- Skin burns

has

Uses
- In medical field: sterilisation, medical diagnosis, scanning, treatment
- In communications: radio and TV transmissions, remote controllers, optical fibres, mobile phones
- In security: security marking, baggage scanners, detection of fake notes
- In other applications: heating, cooking, thermal imaging, photography

relied upon by

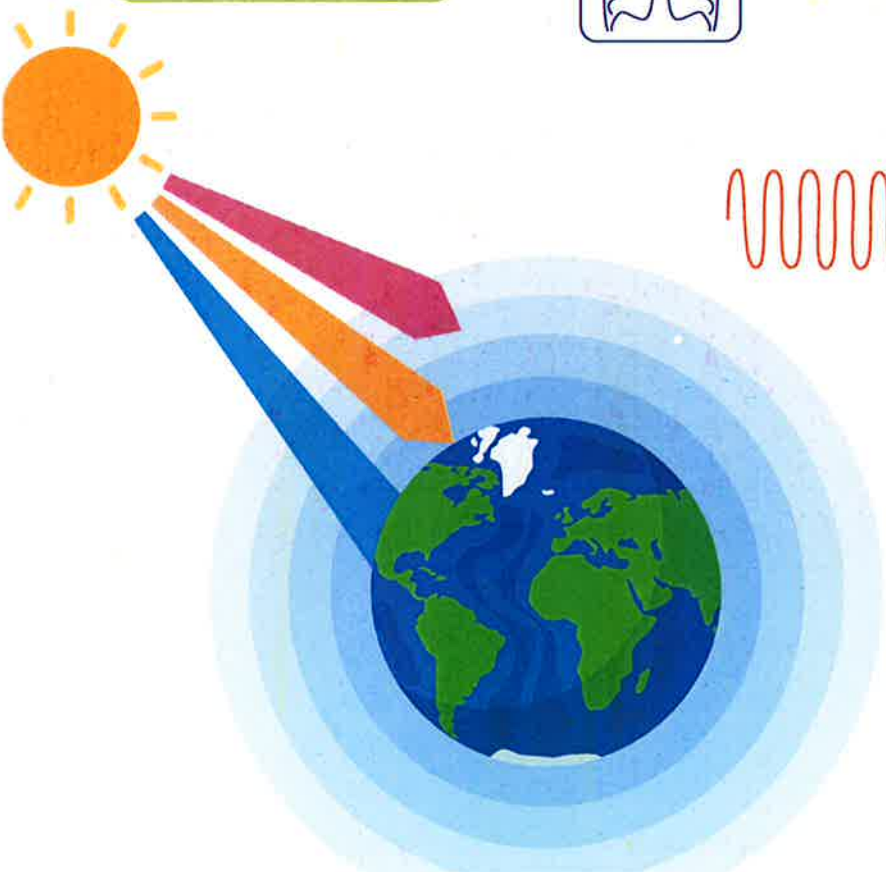
S Communication systems
- Involve the use of mobile phones, wireless Internet, Bluetooth and optical fibres

transmit signals in two forms

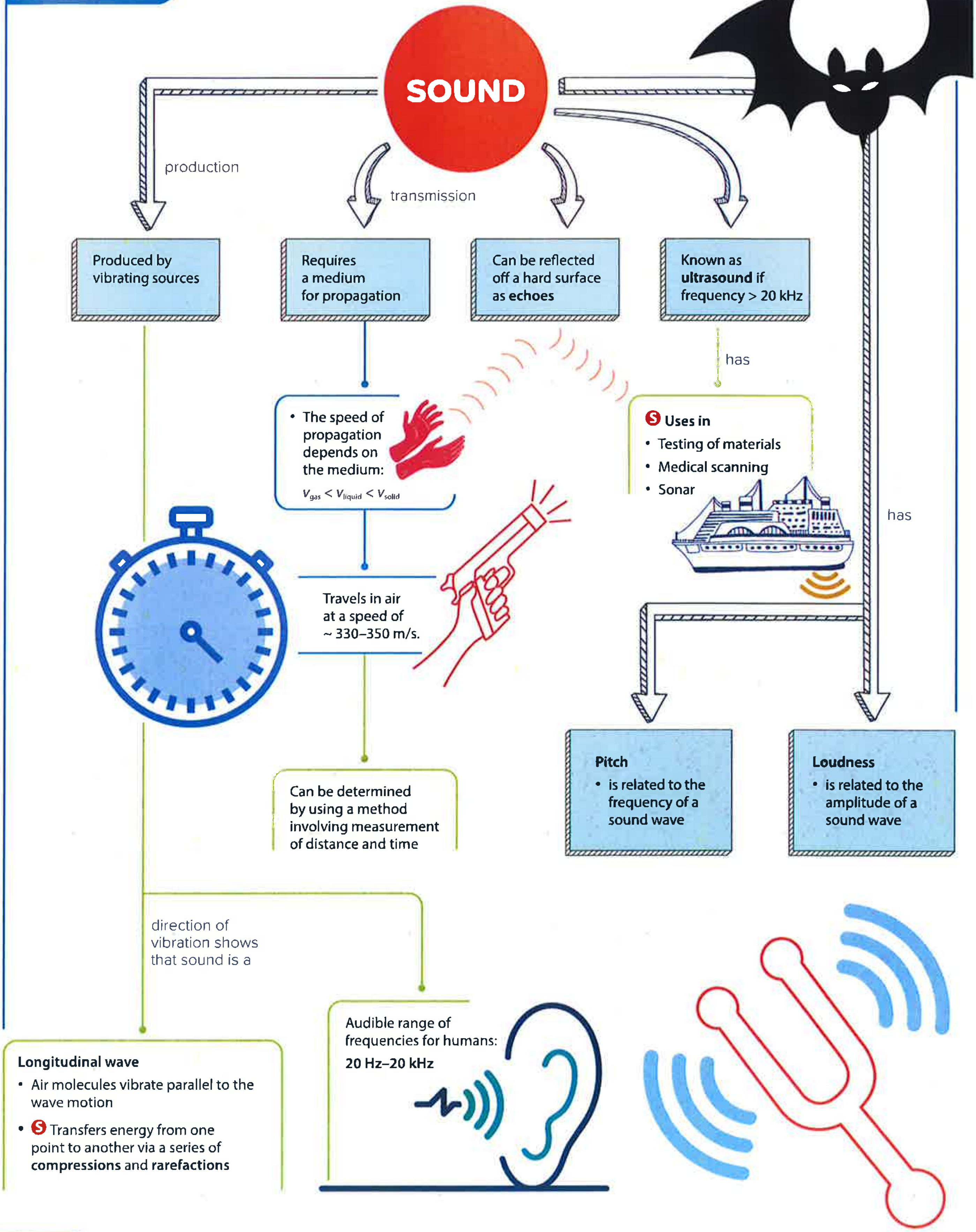
S Analogue signals
- Have continuous values

S Digital signals
- Have fixed values

- S Increased rate of transmission of data
- S Increased range of transmission

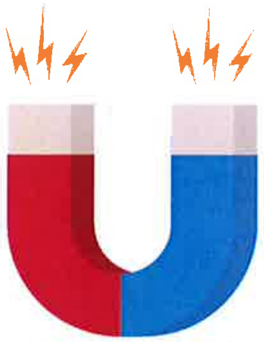


Let's Map It


SOUND
production
transmission
Produced by vibrating sources
Requires a medium for propagation
Can be reflected off a hard surface as **echoes**
Known as **ultrasound** if frequency > 20 kHz
has
S Uses in
• Testing of materials
• Medical scanning
• Sonar
has
• The speed of propagation depends on the medium:
$v_{gas} < v_{liquid} < v_{solid}$
Travels in air at a speed of ~ 330–350 m/s.
Can be determined by using a method involving measurement of distance and time
Pitch
• is related to the frequency of a sound wave
Loudness
• is related to the amplitude of a sound wave
direction of vibration shows that sound is a
Longitudinal wave
• Air molecules vibrate parallel to the wave motion
• S Transfers energy from one point to another via a series of **compressions** and **rarefactions**
Audible range of frequencies for humans:
20 Hz–20 kHz

Let's Map It

MAGNETISM



Magnet

have the following properties

- Attract magnetic materials
- Have a north pole and a south pole, with the strongest magnetic force
- When suspended freely, rest in north-south direction
- Obey the laws of magnetism (like poles repel, unlike poles attract)

due to

Magnetic force

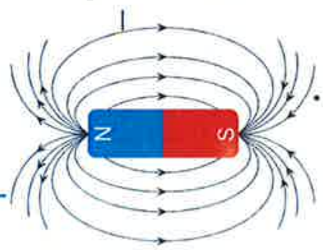
caused by

S Interactions between magnetic fields

which is

Visualised using plotting compass

magnetic field line



where

- The direction of the magnetic field lines at a point is the direction of the force on the N pole of a magnet at that point.
- **S** The relative strength of the magnetic force is dependent on how closely packed the magnetic field lines are.

Magnetic materials

- **Hard magnetic materials** which are difficult to magnetise through
- **Soft magnetic materials** which are easy to magnetise through

Induced magnetism

to form

- **Permanent magnets** used in
  - Magnetic door catches
  - Maglev trains
- **Temporary magnets** used in
  - Maglev trains
  - Electromagnets

Let's Map It

CHARGE Q
(SI unit: C)

can be categorised into → **Positive and negative charges**

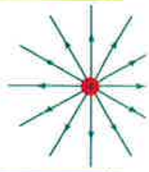
interacts as follows

⊕ ⊕ (repel) ⊖ ⊖ (repel) ⊕ ⊖ (attract)

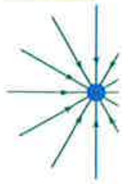
- Like charges repel
- Unlike charges attract

generates → **Electric field**

- Is a region in which an electric charge experiences a force



Electric field lines
- Directed away from a positive charge
- Directed towards a negative charge



moving charges produce → **Electric current I (SI unit: A)**

where

$I=\frac{Q}{t}$
where
t = time

Electricity

Electrical energy
$E=IVt$

Power
$P=IV$

non-moving charges produce → **Static electricity**

is due to the build up of charges on the surfaces of

Electrical insulators

for example through

Friction

related to

Electromotive force E
(SI unit: V)

where

$E=\frac{W}{Q}$
where
W = work done by source to drive a unit charge around the circuit

Potential difference V
(SI unit: V)

where

$V=\frac{W}{Q}$
where
W = work done to drive a unit charge through a component

Related to

Resistance R
(SI unit: Ω)

- Resistance is directly proportional to the length of the conductor
- Resistance is inversely proportional to the cross-sectional area of the conductor

where

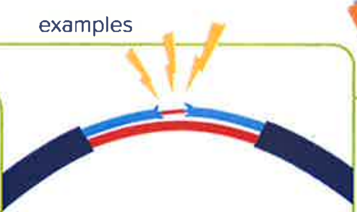
$R=\frac{V}{I}$

Let's Map It

ELECTRICAL CIRCUITS

- can be represented by → Circuit diagrams
- includes → Circuit components
  - examples: Cells, batteries, power supplies, generators, potential dividers, switches, resistors (fixed and variable), heaters, NTC thermistors, light-dependent resistors (LDRs), lamps, motors, ammeters, voltmeters, magnetising coils, transformers, fuses and relays, **S** diodes, **S** light-emitting diodes (LEDs)

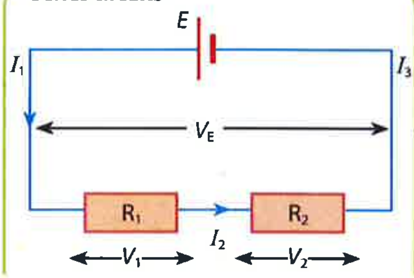
- can cause → **Electrical hazards**
  - Damaged insulation
  - Overheating cables
  - Damp conditions
  - Excess current from overloading



- can be avoided by using → **Safety features**
  - Trip switches
  - Fuses
  - Switches
  - Earthing
  - Three-pin plugs
  - Double insulation

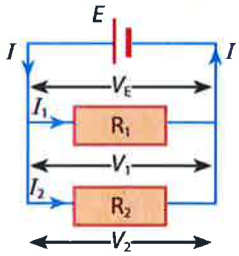
- examples

Series circuits



- Current: $I_1 = I_2 = I_3$
- Potential difference: $V_E = V_1 + V_2$
- Combined resistance: $R = R_1 + R_2$

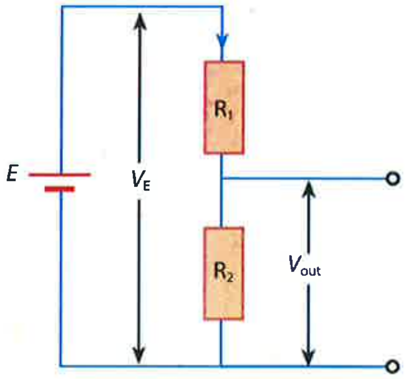
Parallel circuits



- Current: $I = I_1 + I_2$
- Potential difference: $V_E = V_1 = V_2$
- **S** Combined resistance: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

Potential divider circuit with fixed resistors

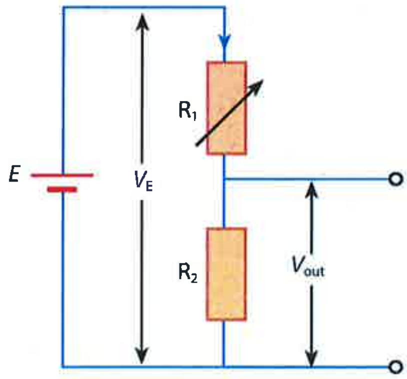
- Fixed R_1 and fixed R_2



S $V_{out} = \frac{R_2}{R_1 + R_2} \times V_E$

Variable potential divider circuit with rheostat

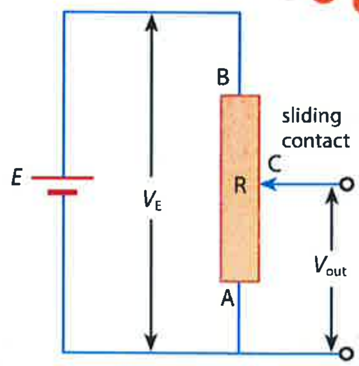
- Variable R_1 and fixed R_2



S In general: $\frac{R_1}{R_2} = \frac{V_1}{V_2}$

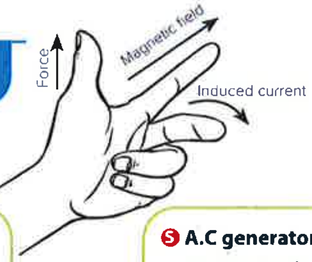
Variable potential divider circuit with potentiometer

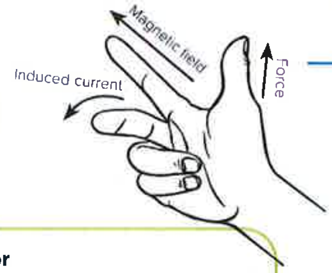
- Variable R_1 and variable R_2



S $V_{out} = \frac{R_{AC}}{R_{AB}} \times V_E$

Let's Map It





ELECTROMAGNETIC EFFECTS

S D.C. motors
- Convert electrical energy into mechanical energy
- Direction of resultant force can be found using **Fleming's left-hand rule**

applied in

Turning effect — produces → Current-carrying conductor in an external magnetic field

Turning effect can be increased by increasing:
- The number of turns on the coil
- The current
- The strength of the magnetic field

S Beams of charged particles in a magnetic field

S Two parallel current-carrying conductors in a magnetic field

acts on

Resultant force

Electromagnetism

involves interaction of

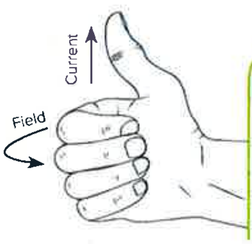
Interact to produce

External magnetic fields

Magnetic fields — produces — **Electric current**

Electric current applied in:
- Relays
- Loudspeakers

Field patterns can be deduced using the **right-hand grip rule**.



- Magnetic field strength can be increased by increasing the magnitude of the current
- Magnetic field direction can be reversed by reversing the direction of the current

S A.C generator
- Convert mechanical energy into electrical energy
- Direction of induced current in the coil can be found using **Fleming's right-hand rule**

applied in

Electromagnetic induction
- A process in which an induced e.m.f. is produced in a conductor due to a changing magnetic field.

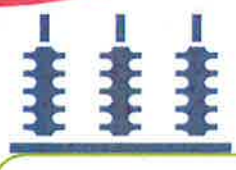
governed by

S Lenz's law
- The direction of an induced e.m.f. opposes the change that is causing it.

Faraday's law
- The magnitude of the induced e.m.f. in a circuit is directly proportional to the rate of change of magnetic flux in the circuit .

Factors affecting the magnitude of an induced e.m
- Number of turns in the current-carrying coil
- Strength of the magnet
- Speed at which the magnet moves with respect to the current-carrying conductor

applied in



Transformer
- Change a high alternating voltage (at low current) to a low alternating voltage (at high current) or vice versa

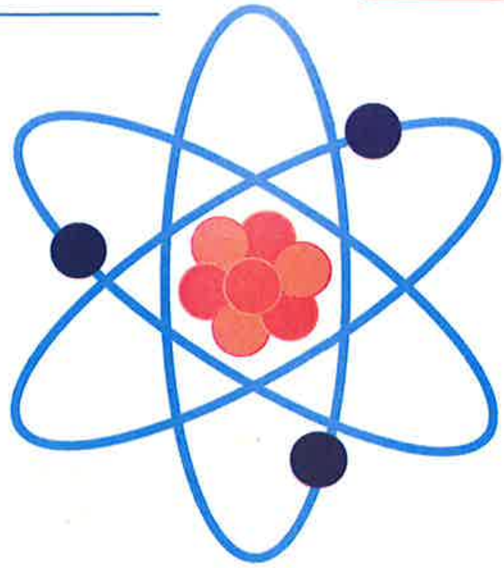
used for

High voltage transmission of electricity
- Reduce power losses (more efficient)

  S $P_{loss} = I^2R = (\frac{P_{out}}{V})^2R$
- Lower cable and construction costs

- Turns ratio $\frac{V_p}{V_s} = \frac{N_p}{N_s}$ where p means primary and s means secondary
- **S** For an ideal transformer (100% efficiency), $I_p V_p = I_s V_s$

Let's Map It



Geiger and Marsden experiment (Rutherford's scattering)

provides insights into

THE NUCLEAR ATOM

can / consists of

Negatively charged electrons

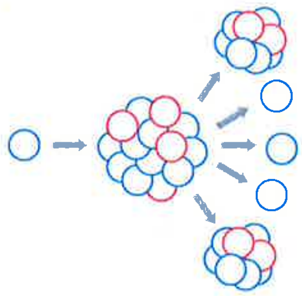
Positively charged nucleus

contains

Nucleons
- 2 types of particles, protons and neutrons
- Nucleon number A

Protons
- Positively charged
- Proton number Z

Neutrons
- No charge
- Number of neutrons (A-Z)



Nuclide notation

$$^{A}_{Z}X$$

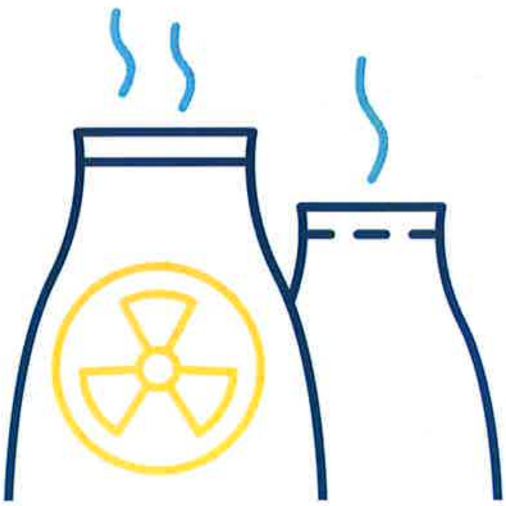
- Element *X*
- Nucleus has *Z* protons and *A* – *Z* neutrons

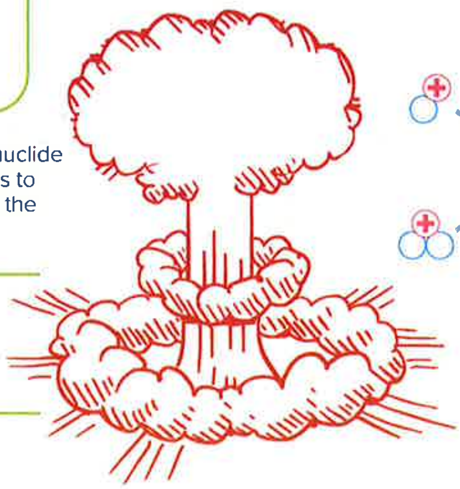
used to represent

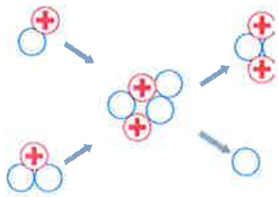
Isotopes of elements
- Same proton number Z
- Different nucleon number A

used in nuclide equations to describe the

Nuclear processes of
- Nuclear fission
- Nuclear fusion







Let's Map It

RADIOACTIVITY

Background radiation from sources including
- radon gas in the air
- rocks and buildings
- food and drink
- cosmic rays

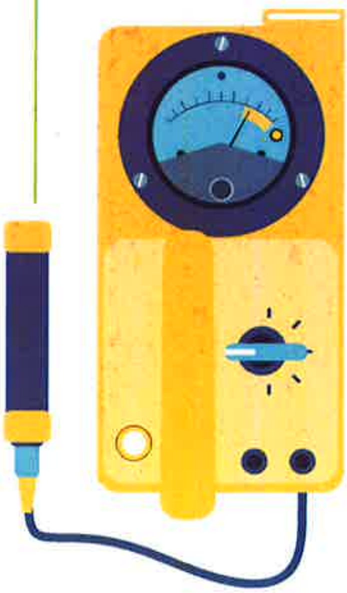
causes

Safety precautions
- Reduce exposure time
- Increase distance from source
- Shield from source

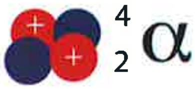
can be measured using

Electronic detector connected to a counter

- Measures count rate in **counts/s** or **counts/min**
- S **Corrected count rate** = count rate - background count rate



Three types of nuclear emission



- **Alpha (α-) particle:** two protons and two neutrons
- **Beta (β-) particle:** fast-moving electron
- **Gamma (γ-) ray:** electromagnetic radiation

- Spontaneous and random emission
- Relative penetrative power
- S Relative ionisation power
- S Deflection in electric and magnetic fields

Radioactive decay from unstable nucleus

S Decay equations
- **α-decay**

  $^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$
- **β-decay**

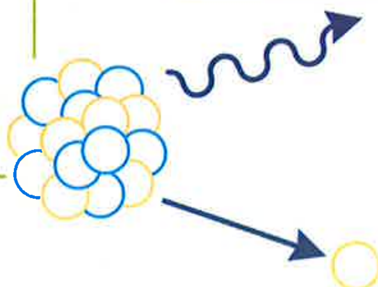
  $^{A}_{Z}X \longrightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}\beta$
- **γ-emission**

  $^{Am}_{Z}X \longrightarrow {}^{A}_{Z}X + \gamma$

  Or

  $^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + \gamma$

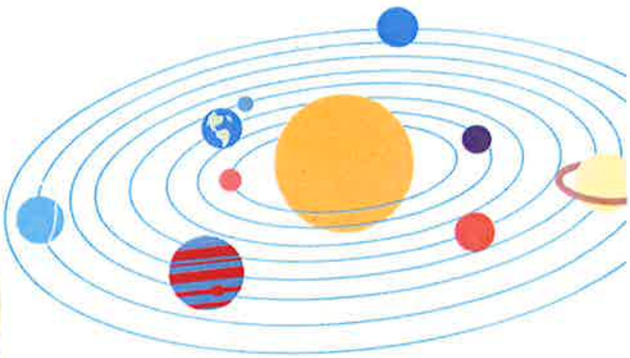
Half-life
- Time taken for half the nuclei of that isotope in any sample to decay.



Let's Map It

Cloud of dust and gas
- Mainly hydrogen and helium plus assorted heavier elements

the force of gravity causes matter to collect together—accretion—to form



SOLAR SYSTEM

consists of

Main planets
- Mercury
- Venus
- Earth
- Mars

(rocky and small)

- Jupiter
- Saturn
- Uranus
- Neptune

(gaseous and large)

The Sun
- A star
- Massive size produces strong gravitational field
- Gives out energy

- Dwarf planets
- Moons
- Asteroids
- Comets

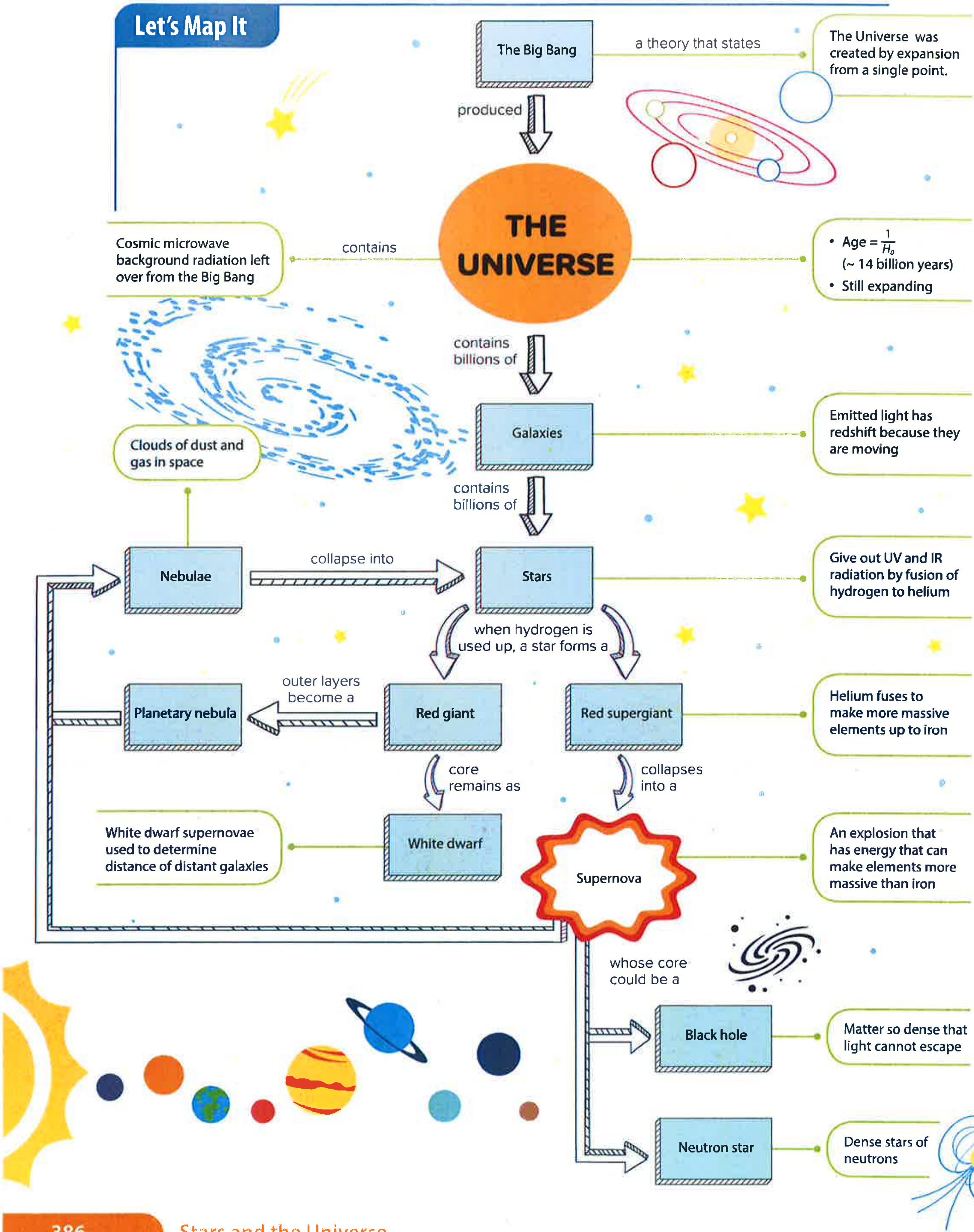
(S) Gravitational field strength
- Increases with mass
- Decreases with distance from planet

The Earth
- Spins once every 24 hours to give **night and day**
- Orbits the Sun every year (~365 days) on its tilted axis to give **seasons**

The Moon
- Earth's natural satellite
- Orbits the Earth every 27 days
- Appearance changes with position in orbit **(Moon phases)**

Orbits
- Kept in orbit by the Sun's gravitational attraction
- (S) Elliptical orbit with the Sun at one focus
- (S) Orbital speed $v = \frac{2\pi r}{T}$
- Time to orbit increases as distance from the Sun increases

Let's Map It


The Big Bang
a theory that states
The Universe was created by expansion from a single point.
produced
THE UNIVERSE
contains
Cosmic microwave background radiation left over from the Big Bang
• Age = $\frac{1}{H_0}$ (~ 14 billion years)
• Still expanding
contains billions of
Galaxies
Emitted light has redshift because they are moving
contains billions of
Stars
Give out UV and IR radiation by fusion of hydrogen to helium
Clouds of dust and gas in space
Nebulae
collapse into
when hydrogen is used up, a star forms a
Red giant
Red supergiant
Helium fuses to make more massive elements up to iron
outer layers become a
Planetary nebula
core remains as
White dwarf
White dwarf supernovae used to determine distance of distant galaxies
collapses into a
Supernova
An explosion that has energy that can make elements more massive than iron
whose core could be a
Black hole
Matter so dense that light cannot escape
Neutron star
Dense stars of neutrons