# Lesson 1 – Matter

## States of Matter

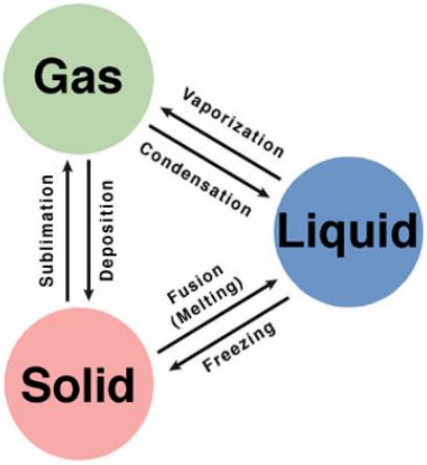
What is matter? Matter is anything that has mass and occupies space. The three basic properties of matter are mass, volume, and shape. Mass is the internal composition of a body while weight is how much that body weighs (they do not mean the same thing). Volume is amount of space that matter takes up. The three states of matter are solids, liquids, and gases. The following table summarizes some important concepts to remember about these states of matter.

| | **Solids** | **Liquids** | **Gases** |
|---|---|---|---|
| Characteristics | Has definite shape.<br>Has definite volume.<br>Cannot be compressed. | No definite shape.<br>Has definite volume.<br>Can be slightly compressed. | No definite shape.<br>No definite volume.<br>Can be easily compressed. |
| Molecules | Molecules are tightly packed.<br>This is why solids have a definite shape. | Molecules are not tightly packed.<br>This is why liquids can flow and take the shape of their containers. | Molecules are very loose.<br>This is why gases are freely abounding in the atmosphere. |
| Expansion | Expands slightly when heated. Can contract back to original size. | Expands more visibly when frozen. Can contract back to initial size. | Easily expands and contracts. |

For visual explanations, watch this video on states of matter: States of Matter - Solids, Liquids, Gases & Plasma - Chemistry (youtube.com)

## Phase Changes of Matter

Phase change means when a state of matter is converted into another state of matter. For example, solids can be converted to liquids, liquids to gases. Gases can also be converted to liquids, and liquids to solids. The figure[1] below helps to visualize the phase change process and necessary vocabulary to know and remember.




[1] The figure was snipped from Lesson on Phase Diagrams - Hydrogen Fuel Cells (weebly.com) website.

Examples of:

- Solid to liquid is ice cubes melting.
- Liquid to solid is water to ice.
- Liquid to gas is boiling water in a pot.
- Gas to liquid is when rain falls.
- Solid to gas is dry ice changing directly to gas.
- Gas to solid is water vapour changing to ice.

Something is common to all these changes. There is an external influence that causes these changes, which is heat (change in temperature). Some important definitions to remember:

- The boiling point of a liquid is the temperature at which that liquid begins to change state to gas.
- The melting point is the temperature at which a solid begins to change state into a liquid.
- The freezing point is the temperature at which a liquid changes state into a solid.

Solids have high melting points and very high boiling points because a reasonable amount of heat will be needed to break the strong bonds between the atoms. Gases have low boiling points and freezing points because the atoms are loosely bonded.
This video provides explanation on phase changes of matter: CHANGES IN STATES OF MATTER || FREEZING, MELTING, CONDENSATION, EVAPORATION, SUBLIMATION, DEPOSITION (youtube.com)

**Physical And Chemical Properties of Matter**

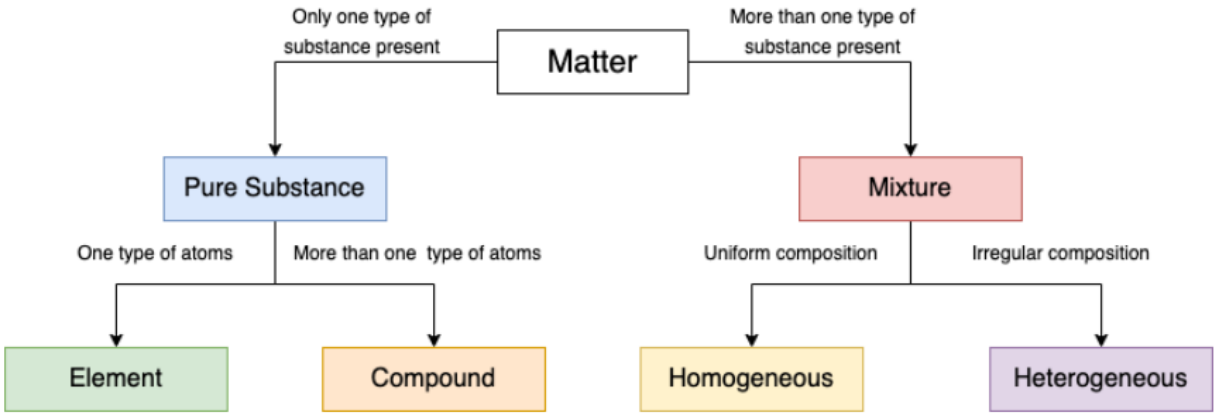
Properties are characteristics that enable us to distinguish one state of matter from another or one substance from another. There are two types of properties, and we will briefly discuss both.

Physical properties are properties that are observable or can be measured. They can be measured as internal or external properties. They are usually reversible reactions. Some examples of physical properties include density, colour, hardness, melting and boiling points, and electrical conductivity. Physical changes are changes affecting the form of a chemical substance, but not its chemical composition. It is a reversible reaction that affects the physical properties of a substance, e.g., size or shape.

Chemical properties are properties that describe how a substance reacts with another substance to form an entirely new substance. They are mostly irreversible reactions. Some examples of chemical properties include flammability, toxicity, acidity, reactivity, and heat of combustion. Chemical changes occur when a substance's composition is changed to form an entirely new substance. It is usually classified as an irreversible reaction that forms a new substance with different properties.
This video provides more explanation on physical and chemical changes: Physical and Chemical Properties (youtube.com)

## Lesson 2 – Matter

Matter is anything that has mass and occupies space. Matter can be classified into two main categories, which are pure substances and mixtures. The figure[1] below helps us to visualize the further subcategories.




An atom is a particle of matter that uniquely defines a chemical element. Atoms can be further divided into electrons (negatively charged particles), neutrons (neutrally charged particles) and protons (positively charged particles). The center of an atom is called the nucleus, and it contains the neutrons and protons of the atoms, while the electrons orbit around the nucleus like the planets orbiting around the sun.

Isotopes are atoms with the same number of protons but different numbers of neutrons e.g. carbon 12 has 6 neutrons and 6 protons (which makes 12 atomic mass). Carbon 13 has 7 neutrons (and 6 protons making 13) and carbon 14 has 8 neutrons.

Allotropes are chemical elements that exist in two or more different forms e.g. Carbon existing naturally as graphite and diamond. Oxygen exists as the breathable harmless air ($O_2$) while Ozone ($O_3$) is deadly.

Mixtures are substances made from the combination of two or more different substances. The mixtures are usually a physical combination that retains the properties of the combined substances.

Homogeneous mixture means all samples of that mixture are the same. Examples are salt and water, brass (alloy of copper and zinc).

Heterogeneous mixture means not all samples of that mixture are the same. Examples are oil and water, salt and pepper, water and gasoline, vinegar, and oil.

The particle theory of matter states that matter is formed of tiny particles. The particles are constantly randomly moving about. The particles can be arranged regularly or randomly. The particles are held together by weak or strong forces. The particles have empty spaces between them.

[1]Figure was snipped from the 1.3: Classification of Matter - Chemistry LibreTexts website.

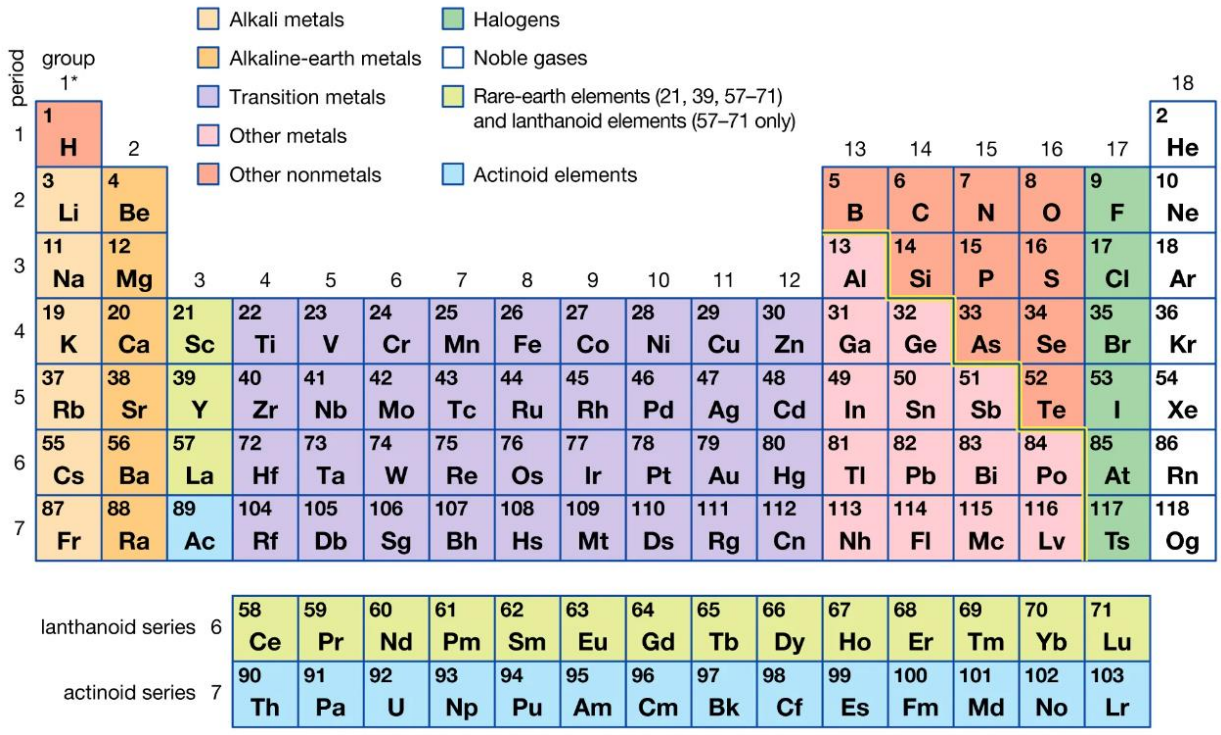
An element is a substance that cannot be broken down into another substance. Examples of element includes oxygen ($O_2$), hydrogen ($H_2$), chlorine ($Cl$), iron ($Fe$).

A compound is the chemical combination of two or more elements. A prominent example of a compound is water ($H_2O$). It is the chemical combination of two molecules of hydrogen and one molecule of oxygen. Another example is salt (sodium chloride, $NaCl$).

A molecule is a group of two or more atoms that form the smallest identifiable unit into which a pure substance can be broken down into.

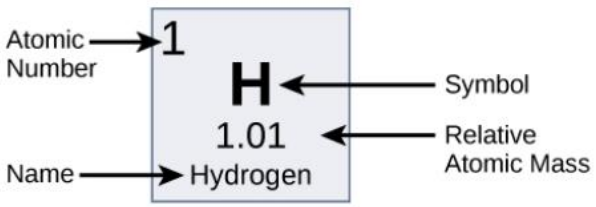
The periodic table[2] is an organized array of elements with increasing atomic number. Each row is called a period, and each column is called a group.

**Periodic table of the elements**




*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC). © Encyclopædia Britannica, Inc.

Atomic number is the number of protons present in an element. The atomic mass is the average number of protons plus neutrons in the element. For any given element, the atomic number is usually the smaller number while the atomic mass is the larger number written as a decimal. The figure[3] presents an illustration of the numbers.




[2] The periodic table figure was snipped from Periodic table | Definition, Elements, Groups, Charges, Trends, & Facts | Britannica website.

[3] The figure was snipped from The Periodic Table of Elements | Biology for Majors I (lumenlearning.com) website.

# Lesson 3 – Motion

## One-dimensional motion

Motion describes the movement of objects or how they change positions. Linear motion is one-dimensional motion. This means an object moving in a straight line (from right to left or left to right). The two broad categories that classify the measurements of an object in motion are vector and scalar quantities.

Scalar quantities are quantities that have magnitude and no direction. Examples are time, distance, speed, mass.

Vector quantities are quantities that have both magnitude and direction. Examples are displacement, velocity, acceleration, and force.

Velocity is the change in displacement per unit time while speed is the change in distance per unit time. The SI unit of both quantities is $m/s$.

Acceleration is the change in velocity per unit time. Its SI unit is $m/s^2$.

Acceleration due to gravity is the acceleration experienced by a body due to free fall near the surface of a massive surface. Denoted as $g$, acceleration due to gravity near the surface of the earth is given as $\boldsymbol{g = 9.81\ m/s^2}$. This value increases when a body is close to the earth's surface and decreases as the body gets farther away from the earth's surface.

The SI unit (International System of Units) is a standardized set of units for measuring physical quantities. Helpful video to provide more concept explanation: Speed, Velocity, and Acceleration | Physics of Motion Explained (youtube.com)

## Force

Force is a push or pull on an object resulting from the object's interaction with another object. The SI unit of force is Newtons.

Friction is a force that opposes or resists motion. It is a resultant force from the motion between any two surfaces. The SI unit of friction is Newtons.

Attractive force brings two objects to come closer to each other while Repulsive force causes two objects to move away from each other. Examples are mechanics, electricity, magnetism, gravity.

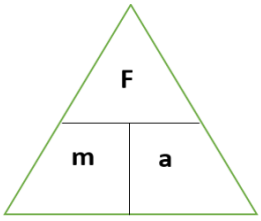
This video has explanations on concepts of force: What is Force? | Contact Force and Non-Contact Force | Science Lesson for Kids (youtube.com)
Real life examples of Friction (youtube.com)

## Newton's laws of motion

Newton's first law of motion states that a body remains at rest, or a body in motion remains in motion, unless acted upon by a force.

Newton's second law of motion states that the force acting on a body is directly proportional to its acceleration.

$$F = ma$$



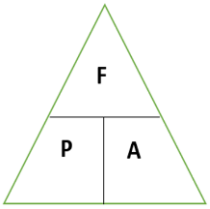

Newton's third law of motion states that to every action, there is an equal but opposite reaction. Watch this video for visual explanations on Newton's laws: Newton's 3 Laws of Motion for Kids: Three Physical Laws of Mechanics for Children - FreeSchool (youtube.com)

**Pressure**

Pressure is the perpendicular force per unit area.

$$Pressure = \frac{Force}{Area}$$

It has $N/m^2$ as its SI unit (or Pascals).



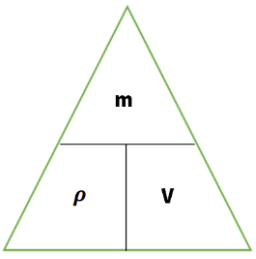

Watch this video for explanations and more information on pressure: Pressure Calculations on Maximum and Minimum pressure (youtube.com)

**Density**

Density is mass per unit volume. It is the amount of matter packed into a space. Solids are denser than liquids and liquids are denser than gases.

$$\rho = \frac{mass}{Volume}$$

Density is important because it helps in determining whether an object sinks or floats in a fluid.




This video will provide more explanation on the concept of density: Density Practice Problems – Tyler DeWitt (youtube.com)

# Lesson 4 – Fluids

**Fluids**

A fluid is defined as a substance that can flow and it doesn't maintain a fixed shape. Gases and liquids are usually considered as fluids. The characteristics of fluids are compressibility, pressure, buoyancy, viscosity, and surface tension.

Cohesive forces are forces binding molecules of the same substance together (particles within a fluid being strongly attracted to each other). Cohesion is strong in solids but weak in gases. Cohesion is strong enough in liquids to keep the particles together but weak enough to allow the molecules slide past each other. This enables liquids to take the shape of their container.

Adhesive forces bind molecules of different substances together (particles of different substances are strongly attracted to each other). Do watch this video for a visual explanation: Adhesion, Cohesion and Surface Tension Part 10 (youtube.com)

**Surface Tension**

Surface tension is a contractive tendency of the surface of a liquid that allows it to resist an external force. Examples are the ability of some insects to run on water's surface, needle and plant leaf resting on water. Watch this video for a visual explanation: What is Surface Tension? | Richard Hammond's Invisible Worlds | Earth Science (youtube.com)

**Viscosity**

This is simply the measure of a fluid's resistance to flow. It is the internal friction of liquids. It can also be how strongly a fluid's cohesive forces will affect the movement of its molecules. The stronger the cohesive force, the stronger the viscosity and the slower the fluid will flow. Watch this video for a visual explanation: What is Viscosity | Understanding Resistance to Flow (youtube.com)

**Buoyancy**

Buoyant force is the net upward force on any object in any fluid due to the pressure difference at different depths. Any object which is partially or totally submerged in a liquid has a buoyant force acting on it which pushes the object up. Watch this video for a visual explanation: What is Buoyancy? | Physics | Don't Memorise (youtube.com)

**Archimedes Principle**

Archimedes principle states that anybody completely or partially submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the body. Mathematically,

$$F_B = W_{fluid}$$

$F_B$ is the magnitude of the buoyant force, $W_{fluid}$ is the weight of the fluid.

$$F_B = \rho g V$$

where $\rho$ is the density of the fluid, $g$ is acceleration due to gravity and $V$ is the volume of the object. The following video explains Archimedes principle: Archimedes principle & buoyancy | fluids | Physics | Khan Academy (youtube.com)

An object immersed into a liquid will either float, be partially submerged or totally submerged (and sink).

- The object will rise to the surface and float if the buoyant force is greater than the object's weight.
- The object will sink if the buoyant force is less than the object's weight.
- The object will remain submerged (or suspended) in the liquid if the buoyant force equals the object's weight.

An object floats if it is less dense than the fluid it is immersed in. An object sinks if it is denser than the fluid. This video helps with visual explanation: Density & Floating: Why Some Objects Float While Others Sink (youtube.com)

**Apparent Weight and Specific Gravity**

Apparent weight is the weight that an object appears to have. This is not the actual weight of the object. The apparent weight differs from the actual weight when the force of gravity acting on the object is not balanced by an equal but opposite force. The apparent weight also differs from weight when an object is "partially or completely immersed in a fluid".

$$Apparent\ weight = weight\ of\ object\ - Bouyant\ force$$

Specific gravity is the measure of the density of a substance in comparison to the density of water.

$$Specific\ gravity\ = \frac{Density\ of\ substance}{Density\ of\ water}$$

# Lesson 5 – Gases and properties of gases

**Pressure For Fluids.**

Pressure was previously defined as force applied perpendicular to the surface of an object per unit area.

$$Pressure = \frac{Force}{Area}$$

This formula relates to solids. To obtain the formula for pressure of liquids, we replace force with mass times acceleration and mass with density times volume. We also replace volume with area times height. Simplify that expression results to,

$$Pressure = \rho gh$$

where $\rho$ is the density of the fluid, $g$ is acceleration due to gravity and $h$ is the height of the fluid above the object.

**Some Necessary Definitions.**

Atmospheric pressure is the pressure exerted by the atmosphere and is denoted by $P_{atm}$.

Gauge pressure is the pressure of a system above atmospheric pressure. The readings from gauge pressure includes the weight of the atmosphere.

Pneumatic pressure is the pressure exerted by a pressurized gas. Pneumatic systems work by compressing the gas and increasing pressure.

Hydraulic pressure is the pressure that is generated by a hydraulic fluid in a confined space when it is subjected to an external force.

Hydrostatic pressure is the pressure exerted by a liquid at rest due to the force of gravity acting on it.

$$P_H = \rho gh$$

The following videos will help to understand the defined concepts above:

Absolute pressure, Gauge pressure, Atmospheric pressure Explained. Absolute pressure Gauge. English - YouTube

Pressure: Atmospheric & Hydrostatic Pressure and Fluids – Physics | Lecturio - YouTube

**Ideal Gas**

An ideal gas is a gas which obeys the ideal gas laws at all pressures and temperatures.

The ideal gas law is a relation between the pressure P, volume V, and temperature T of a gas in the limit of low pressures and high temperatures. Mathematically:

$$PV = nRT$$

where $P$ is the pressure, $V$ is the volume and $n$ is the number of moles of gas, $R$ is the ideal gas constant and $T$ is the temperature in Kelvin. Simply put, the ideal gas law states that the pressure of a gas is inversely proportional to volume and directly proportional to temperature.

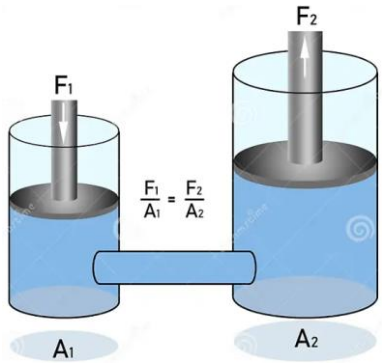
Watch this video for more explanations: Ideal Gas Law - YouTube

**Pascal's principle**

Pascal's principle states that when a change in pressure is applied to an enclosed fluid, it is transmitted undiminished to all portions of the fluid and to the walls of its container.

$$P = \frac{F_1}{A_1}, \qquad P = \frac{F_2}{A_2}$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$




The figure[1] provides a visualization of Pascal's principle. This YouTube video illustrates the Pascal's principle: Pascal's law - Animated and explained with 3d program (youtube.com).

**Pressure and Altitude (or Height)**

The higher the altitude of an object, the lower the pressure exerted on that object. The lower the altitude of that object, the higher the pressure exerted on the object. The pressure on a mountain top is lower than the pressure at sea level. Pressure is inversely proportional to altitude.

$$P\ \alpha\ \frac{1}{h}$$

This is the reason why the boiling point of water is lower at the top of the mountain (due to lower pressure) and higher at sea level. Watch this video for more information: Atmospheric Pressure and Boiling - YouTube.

[1]The figure was snipped from Pascals Law for (principle of Transmission of Fluid Pressure Stock Illustration - Illustration of water, automotive: 281662369 (dreamstime.com) website.

# Lesson 6 – Intro to Mechanical Science

**Energy.**

Energy is defined as the ability to do work. The SI unit of energy is Joules. There are six different forms of energy which are chemical, electrical, mechanical, radiant, thermal, and nuclear energy. These forms of energy can be classified into two broad types of energy:

1. Kinetic energy is the energy of motion.

$$K.E. = \frac{1}{2}mv^2$$

2. Potential energy is the internal energy a body possesses (or stored energy in a body).

$$P.E. = mgh$$

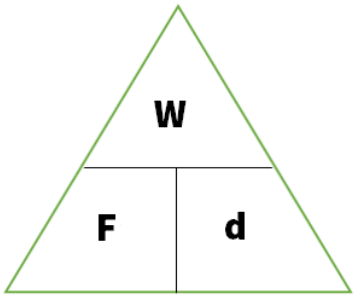
It is essential to remember that the weight of an object is the force exerted on the object by gravity, $W = mg$.

The law of conservation of energy states that energy can neither be created nor destroyed but can be changed from one form to another or can be transformed from one system to another.

**Work.**

Work is the product of the force applied on an object and the distance the object is moved, i.e.,

$$W = Force \times displacement$$




Work is the transfer of energy (in or out of a system). The SI unit of work is also Joules.

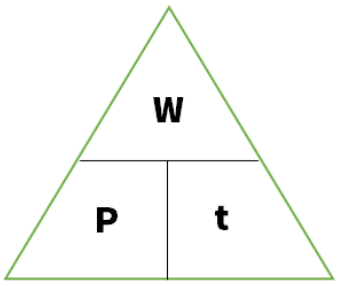
**Relationship Between Work and Energy**

Work is the transfer of energy from one object to another. Work is performed when a force is applied in moving an object over a certain distance. This results in the change in energy of the object. Energy is the capacity to do the work in moving that object over the distance.

**Power.**

Power is the rate at which work is done or the rate at which energy is transferred or converted. The SI unit of power is Watts. It is also measured in $J/s$ or $kW$ or $ft\ lb\ \sec^{-1}$.

$$P = \frac{Work}{time} = \frac{Force \times distance}{time}$$




Horsepower is another unit of measuring power. An important conversion to take note of is:

$$1\ Hp = 746\ Watts$$

**Efficiency**.
The efficiency of a machine is the measure of how much input power is available as actual output power.

$$Efficiency = \frac{Power\ output}{Power\ input} \times 100\%$$

Efficiency tells us how efficient the machine is. If the efficiency is equal to 100%, then the machine is perfectly efficient. This means all the power used to drive it goes to the output of the machine with no energy losses). If the efficiency is 0%, then all the input power is lost in the machine and the machine cannot output any energy.

For example, if a machine has an efficiency of 80%, it means that 80% of the power input is converted into useful work, while the remaining 20% is lost as waste heat, friction, or other inefficiencies.

# Lesson 7 – Classical Mechanics

Classical Mechanics is the field of physics that studies the motion of large objects. It also deals with the motion of bodies under the influence of forces or with the equilibrium of forces when all forces are balanced.

**Forces**

A force is simply defined as a push or pull action on an object. It could also be explained as any action that influences an object to change its velocity. This action on the object tends to maintain or alter the motion of the object. We now know from Newton's second law of motion that force is defined as the mass of an object multiplied by the acceleration of the object. Mass is a scalar quantity, but acceleration is a vector quantity. This means force is a vector quantity because it has a defined direction.

There are two types of force: Contact and non-contact forces. Contact forces implies that there is physical contact between the objects. An example of contact force is friction. Non-contact force means there is no contact between the objects. Examples are electrical force, magnetic force, and gravitational force. Watch this video for more information: Types Of Forces (youtube.com)

**Mechanical Equilibrium**

Mechanical equilibrium is the condition where the balance between opposing forces acting on an object is equal to zero.

**Velocity and Acceleration as Vector Quantities**

Let us recall the definitions of vector and scalar quantities:
Scalar quantities are quantities that only have magnitude (or size). Vector quantities are quantities having both magnitude and direction.

Velocity is defined as displacement (not distance) divided by time. Since displacement is a vector quantity, velocity is also a vector quantity. From the definition of acceleration, we understand that it is the change in velocity divided by time. We just concluded that velocity is a vector quantity. That makes acceleration …? You guessed right! Acceleration is also a vector quantity.

It is important to note that exam questions on science mostly test your knowledge of the concept. If you can fully grasp the concept behind the topics, you will do very well in the exams.

# Lesson 8 – Heat/Thermal Energy

**Thermal Energy and Temperature**
Temperature is the measure of the average kinetic energy of particles. Temperature can also simply be defined as the measurement of how cold or hot an object is. The constant random motion of particles is called thermal energy.

Heat is the transfer of energy between objects at different temperatures. Heat energy always travels from a hotter object to a cooler object. Thermal equilibrium occurs when there is no difference in temperature.

From the definitions above, we can understand that heat and temperature are not the same. When heat transfer occurs between two objects, the temperature of the objects will change.

Watch this video for more explanation related to the above definitions:
Heat transfer | Thermodynamics | High school physics | Khan Academy (youtube.com)
Heat Energy & How We Use It *COOL* Science for Kids! (youtube.com)

**Sources of Heat**
The main source of heat on earth is the sun. Other sources of heat are from common appliances around us. Examples are geyser, furnace, oven/gas cooker, pressing iron. Watch this video for more explanation on sources of heat:
sources heat - YouTube

**Changes of State**
We have previously dealt with changing states of matter in Lesson 1 under the Phase Changes of State section. We will briefly introduce them in this lesson. Matter exists in three states, which are solids, liquids, and gases. These states can be changed/transformed into the other states by a change in temperature and/or pressure. This video provides a summary explanation of the changes of state of matter:
Changes of State | Matter | Physics | FuseSchool (youtube.com)

Thermal expansion is used to describe the expansion of most materials when the temperature is increased. It is the increase in the dimensions of a body (area, volume, density, mass) due to the increase in its temperature.

**Heat Transfer: Conduction, Convection and Radiation**
Heat transfers can happen in three ways: conduction, convection, and radiation. We will briefly consider each of them.

Conduction is the transfer of thermal energy between objects that are in direct contact with each other. It is the transfer of kinetic energy between the molecules of a solid object. An example is touching a hot object with your bare hands.

Convection is the transfer of energy due to motion of mass from one region of space to another. Heat convection occurs when bulk flow of a fluid (gas or liquid) carries heat along with the flow of matter to other parts of the fluid. An example is how water starts to boil from the lower parts (bubbles rise from the bottom) and spreads all through the other parts.

Radiation is the transfer of heat through electromagnetic waves and does not require direct contact between two or more bodies. An example is you feel hot while walking under the sun.

In summary, conduction is the transfer of thermal energy through direct contact, convection is the transfer of thermal energy through the movement of heated particles in a liquid or gas while radiation is the transfer of thermal energy through thermal emission. Watch these videos for more information on heat transfer:
Thermal conduction, convection, and radiation | Thermodynamics | Physics | Khan Academy (youtube.com)
Heat Transfer - Conduction, Convection, and Radiation (youtube.com)

**Measuring Temperature**
Temperature is measured in degrees using thermometers that are calibrated in Celsius degrees (denoted as $℃$) or Fahrenheit degrees (denoted as $℉$). The metric system measure temperature using the Celsius and Kelvin scales defined by the relationship:

$$K = ℃ + 273.15$$

where $K$ is Kelvin and $℃$ represents Celsius. The imperial system uses the Fahrenheit and Rankine scales to measure temperature. The relationship between Celsius and Fahrenheit is defined as:

$$℉ = \frac{9}{5}℃ + 32$$

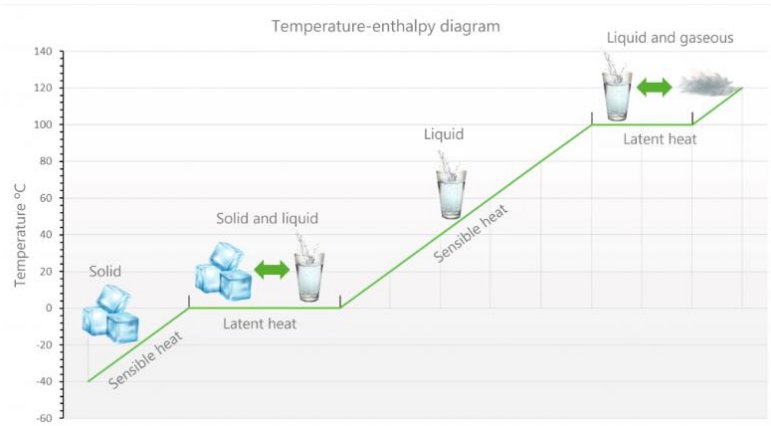
Water has a boiling point of $100℃$ and a freezing point of $0℃$. Its melting point is $0℃$

Bimetallic strips are made up of two metals that expand and contract at different rates, when heated or cooled. They measure a wider range of temperatures compared to thermometers and are commonly used in thermostats. The different expansion rates of the metals to make them causes the bimetallic strip to bend when heated or cooled. When the temperature is increased, the metal with the higher thermal expansion will expand first, causing the bimetallic strip to bend. When the temperature is decreased, the metal with the lower thermal expansion will expand first. This video illustrates how the bimetallic strip works:
Thermal Expansion Demo: Bimetallic Strip (youtube.com)

# Lesson 9 – Heat/Thermal Energy cont'd

## Sensible Heat and Latent Heat

In simple terms, sensible heat refers to the change in temperature of a substance while latent heat is the phase change of that substance to another. For sensible heat, the temperature is increased but no phase change occurs. For latent heat, the temperature is constant while the substance experiences phase change. The figure[1] below gives a visual explanation of the difference between sensible and latent heat.




The formula for calculating sensible heat is:

$$Q = m\, c\, \Delta t$$

where $m$ is the mass of the body, $c$ is the specific heat coefficient of the body and $\Delta t$ is the change in temperature. The formula for calculating latent heat is:

$$Q = n\, \Delta H$$

where $n$ is the number of moles, and $\Delta H$ is the phase change (could be fusion or vaporization).

## Conversion between Celsius and Fahrenheit

To convert from Celsius to Fahrenheit, the following formula is used:

$$°\mathrm{F} = \frac{9}{5}°\mathrm{C} + 32$$

To convert from Fahrenheit to Celsius, the following formula is used:

$$°\mathrm{C} = \frac{5}{9}(°\mathrm{F} - 32)$$

Absolute zero temperature is the temperature at which atoms in an object stops moving completely and the temperature can't go any lower. It occurs at $0$ Kelvin or $-273.15°\mathrm{C}$.

The following videos will help to explain the concepts above:
Sensible and latent heat calculations (youtube.com) (stop at 2:28 minutes)
Heat From Latent and Sensible Heat (youtube.com)
Converting Between Temperature Scales (Celsius, Fahrenheit, and Kelvin) (youtube.com)

[1] The figure was snipped from Sensible and Latent Heat - Keyter website.

## Lesson 10 – Machines

A machine is any device that helps us to do work. A simple machine is a mechanical device that helps us in performing work by multiplying or transforming the force. It is called simple because the machines operate on basic principles that involves one movement. Examples of simple machines are knife, bottle opener, axe etc. There are six types of simple machines:

1. Inclined plane (examples include ramps, escalators, stairs).
2. Wedge (examples include are saw, knife).
3. Screw (examples include jar lid, corkscrew).
4. Lever (examples include scissors, wheelbarrow).
5. Pulley (examples include elevators, garage doors).
6. Wheel and axle (examples include electric fan, drill).

A compound machine is a combination of more than one simple machines. Examples include a car engine, tractors operating on a farm etc.

Mechanical advantage is the ratio of the force output (load) to the force input (effort applied to the load). A value greater than 1 means that the effort is multiplied (less force is needed). A value less than 1 means the speed is multiplied but greater force is required.

$$\text{M. A.} = \frac{\text{Force output}}{\text{Force input}}$$

Mechanical advantage simply measures the efficiency of a machine. It could also be related to the distance through the formula:

$$\text{M. A.} = \frac{\text{Effort arm}}{\text{Load arm}}$$

These two formulas can be combined into one formula which is useful for solving problems related to levers.

$$\frac{\text{Resistance force (load)}}{\text{Effort force}} = \frac{\text{effort distance}}{\text{resistance distance}}$$

A gear is a wheel (circle-like object) with teeth. The teeth used to connect two or more gears helps to ensure they don't fall off the other. The gear that is forced to move is called the driver gear. The gear that moves because of the first gear is called the follower (or driven) gear. Gear ratio is the ratio of the driven (follower) gear to the driver gear. It indicates how many times a gear must turn for another gear to turn once. Gear ratios reduces the torque by increasing the speed and vice versa.

$$\text{Gear Ratio} = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driver gear}} = \frac{\text{Number of turns on driven gear}}{\text{Number of turns on driver gear}}$$

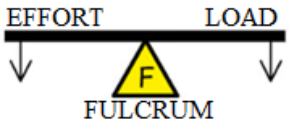
Gear ratio is the mechanical advantage for gears.

# Lesson 11 – Machines

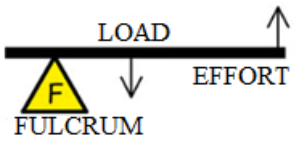
## Levers

A lever is a simple machine that is used to increase the force applied in doing work on a load. It can also be used to increase the amount of movement/speed about a fixed point. The fixed point is called the fulcrum. The force (effort) is applied on one end on a load. There are three classes of lever and their images[1] are presented below:

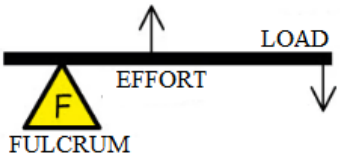
- First class levers: The fulcrum is between the load and effort (or force applied). The mechanical advantage (MA) can either be less than 1 or greater than 1. This means there is a gain in force (effort arm longer) or gain in speed (effort arm shorter). Examples include seesaw, pry bar, scissors.




- Second class levers: The load is between the fulcrum and the effort. MA is always greater than 1. This means there is gain in force but loss in speed. Examples include wheelbarrow, nutcracker, staplers.




- Third class levers: The effort is between the fulcrum and the load. The MA is always less than 1. This means there is gain in speed but loss in force. Examples include fishing rod, baseball bat, tweezers.




The MA of levers is calculated using the formulas:

$$MA = \frac{\text{Resistance force (load)}}{\text{Effort applied}}$$

$$MA = \frac{\text{effort distance}}{\text{load distance}}$$

Most times both formulas are combined to solve a particular problem related to levers.

## Inclined Planes

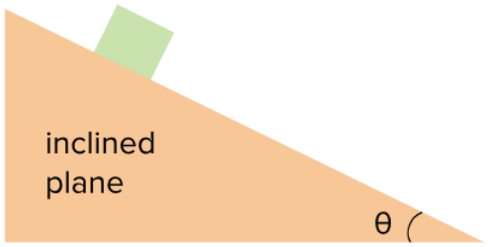
These are simply ramps designed to move load from the horizontal plane to an intended height. Inclined planes basically are right triangles we previously studied. The mechanical advantage of inclined planes is calculated as the ratio of the distance covered in moving the load to the vertical distance the load is lifted. Mathematically,

[1] The images were snipped from Requirements for Movement (HL) | HL IB Biology Revision Notes 2025 | Save My Exams website. The wordings were edited and adjusted to the vocabulary used in this handout.

$$MA = \frac{\text{Resistance force (load)}}{\text{Effort applied}}$$

or

$$MA = \frac{\text{distance load is moved}}{\text{load height}}$$




In instances where the angle of inclination of the inclined plane is given (like the image above[2]), we use:

$$MA = \frac{\text{Resistance force (load)}}{\text{Effort applied}} = \frac{\text{distance load is moved}}{\text{load height}} = \frac{1}{\sin\theta}$$

**Efficiency**

Efficiency of a simple machine is calculated as follows:

$$Eff = \frac{MA}{VR} \times 100\%$$

where *MA* is mechanical advantage and *VR* is the velocity ratio. The velocity ratio is simply the distance to be covered by the load to the load height.

[2] The figure was snipped from What are inclines? (article) | Khan Academy website.

# Lesson 12 – Basic Electricity

## Introduction to Electricity

Electricity is the flow/movement of electric charges (electrons) through a conductor. There are positive (protons) and negative (electrons) electric charges. Positive and positive or negative and negative charges (like charges) repel each other. Opposite charges attract each other. Electricity can either be static or dynamic.

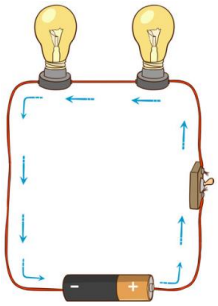
## Electric Circuits

An electrical circuit can be defined as a pathway through which electric current flows. A simple circuit is a circuit that has only a battery and a resistor. There are two types of simple circuits which will be briefly explained below.

A series circuit is a circuit where current flows in only one direction. The total resistance (effective resistance) is the sum of all the resistors.

$$R = R_1 + R_2 + R_3$$

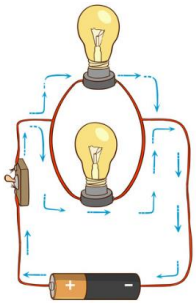
The series circuit is illustrated in the figure[1] below.



A parallel circuit is a circuit where current flows in more than one path. The total resistance is the sum of the reciprocal of each resistor.

$$R = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The figure[2] illustrates a parallel circuit.



## Other Important Definitions

An electrical load is an electrical component or portion of a circuit that consumes (active) electric power. Some examples of electric loads are appliances and lights.

A switch is a device that can break the path of electricity in an electric circuit. Electric current can be of two types: Direct Current or Alternating Current.

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[1]The figure was snipped from An In-Depth Dive Into Series vs. Parallel Circuits | Advanced PCB Design Blog | Cadence website.

[2] This figure was also snipped from An In-Depth Dive Into Series vs. Parallel Circuits | Advanced PCB Design Blog | Cadence website.

# Lesson 13 – Electricity: Formulas and Calculations

**Ohm's Law**

Voltage is the difference in electric potential between two points. It also determines how much current will flow through a circuit. It is usually represented as *V* and its unit is the Volts, *V*.

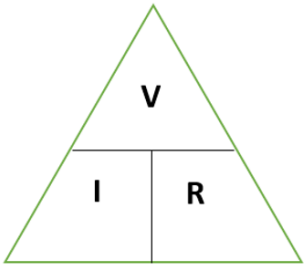
An electric current is a flow of charged particles such as electrons or ions moving through an electrical conductor. It is usually represented as *I* and its unit is Amperes, *A*.

Electrical resistance is a property of a material that opposes the flow of electric current through it. The unit of resistance is Ohms represented by the Greek symbol, Ω.

Ohm's law states that the current passing through a conductor between two points is directly proportional to voltage across the two points.

Mathematically,

$$V = IR$$




**Electrical Power**

This is defined as the rate of energy use, or the amount of energy used per unit time. Electrical power is measured in Watts. Electrical power can be calculated by multiplying the voltage and the current.

$$P = VI$$

Electrical power can also be calculated using the formula (from the above definition):

$$Power\ (W) = \frac{Energy\ (J)}{Time\ (s)}$$

One Watt is equal to one Joule per second.

$$1\ Watt = \frac{1\ Joule}{Second}$$

**Cost of Electrical Usage**

The formula used to calculate electrical usage cost is the rate multiplied by the energy.

$$Cost = Rate \times Energy$$

The cost is measured in cents, the rate is measured in cents per kilowatts hour and the energy is measured in kilowatts hour (kWh).