‘O’-Level Physics Notes

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Abstract

These notes are for the ‘O’-Level Physics syllabus [6091]. They might be similar in content to other physics courses too, though structured differently.

These notes are written by myself, which means they are prone to typos and errors. If you find errata, do contact me so I can remedy. or give you access to the GitHub repository for you to push any changes.

Some code (especially the `tcolorboxes`) are copied from 4yn’s a-lv-notes repository[1].

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Use these notes with caution.

Contents

Part I

Measurement

1 Physical Quantities, Units and Measurement

Preamble

Measurement is a tool that we use in physics a lot. It is difficult to get fully accurate measurements due to how well we can create instruments, control random errors, and other factors. Nonetheless we try to minimise these errors by practising proper measurement techniques. We use measurements to determine physical quantities, and these quantities are communicated with units.

1.1 Physical Quantities

Definition 1.1.1: Physical Quantity

A physical quantity is a quantity consisting of a numerical and a unit.

The numerical magnitude tells us the size of the quantity, and the unit tells us what the quantity is expressed in.

Physical quantities can be either a **basic quantity**):

Physical Quantity		SI Unit	
mass	m	kilogram	kg
time	t	second	s
temperature	T	kelvin	K
length	l	metre	m
current	I	ampere	A
amount	n	mole	mol

or a **derived quantity**, which are derived from basic quantities.

1.1.1 Dimensional Analysis

This is not explicitly taught in syllabus, but it is a very important tool to help you if you are stuck in a problem.

The main idea is to treat units like **algebraic terms**, and manipulate them accordingly to get the right derived unit for the quantity. Usually, a single unit is written in square brackets [ ] to avoid confusion with units with multiple letters (*e.g.* [mol] and [m]).

1.2 Prefixes, Standard Form, and Order of Magnitude

If a number is too large or too small, it will get very annoying to write a lot of digits. That is what prefixes and standard form aim to solve. The former will be written with the unit, while the latter will be written with the numerical magnitude.

A number is expressed in standard form as

$$\underbrace{A}_{\text{base}} \times \underbrace{10^N}_{\text{factor}}$$

where $1 \leqslant A < 10$ and $N \in \mathbb{Z}$.

A unit can be rewritten with any of these prefixes preceding its symbol:

Prefix	Symbol	Factor	Order of Magnitude
tera	T	10^{12}	12
giga	G	10^{9}	9
mega	M	10^{6}	6
kilo	k	10^{3}	3
deci	d	10^{-1}	-1
centi	c	10^{-2}	-2
milli	m	10^{-3}	-3
micro	μ	10^{-6}	-6
nano	n	10^{-9}	-9
pico	p	10^{-12}	-12

1.3 Scalars and Vectors

Definition 1.3.1: Scalar Quantity

A scalar quantity has a magnitude but no direction.

Definition 1.3.2: Vector Quantity

A vector quantity has a magnitude and direction.

1.4 Vector Analysis

Vectors can be added by using the trigonometric method or the graphical method.

Equation 1.4.1: Components

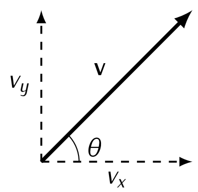
A two-dimensional vector $\mathbf{v}$ can be broken down into components v_x and v_y, with magnitudes of

$$v_x = |\mathbf{v}| \cos\theta, \; v_y = |\mathbf{v}| \sin\theta$$

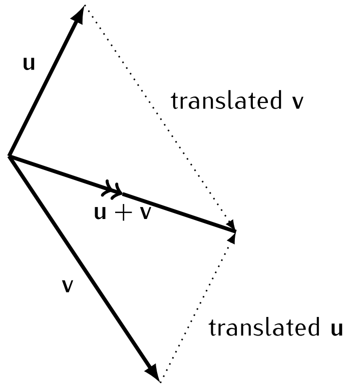
Equation 1.4.2: Magnitude of Vectors

The magnitude of a vector $\mathbf{v}$ with components v_x and v_y is given by

$$|\mathbf{v}| = \sqrt{v_x^2 + v_y^2}$$



Observer that when you add the two components together, they form the vector itself.



Bring a protractor with you to the examination.

1.5 Measurement

1.5.1 Precision and Accuracy

Definition 1.5.1: Precision

Precision is how well a set of readings of the same physical quantity agree with each other.

Definition 1.5.2: Accuracy

Accuracy is how close the set of readings are to the true value.

1.5.2 Measurement of Lengths

Parallax error should be avoided when measuring lengths. In the case of a measuring tape or a metre rule, the object needs to be **in contact** with the measuring instrument.

Vernier Callipers

Accuracy: $\pm 0.01\,\text{cm}$

1. Check for zero error. This error is Δx.
2. Place the object to be measured at the appropriate measurement site (internal jaws, external jaws, or tail).
3. Slide the vernier scale so that the jaws or tail measure the entirety of the object.
4. On the main scale (with $0.1\,\text{cm}$ subdivisions), take the reading that is on or left of the '0' mark of the vernier scale, x_{main}.
5. On the vernier scale (with $0.01\,\text{cm}$ subdivisions), read the mark that coincides with a mark on the main scale, x_{vernier}.
6. The measurement is the sum of the reading on the main scale and vernier scale, and then subtracting the zero error, $x - \Delta x$.

Micrometer Screw Gauge

Accuracy: $\pm 0.001\,\text{cm}$

1. Check for zero error. This error is Δx.
2. Place the object in between the anvil and the spindle.
3. Close the jaws on the micrometer screw gauge until the object is in contact. Turn the ratchet until a 'click' sound is heard.
4. On the datum line (with $0.5\,\text{mm}$ subdivisions), take the reading that is on the left of the circular scale, x_{datum}.
5. On the circular scale (with $0.01\,\text{mm}$ subdivisions), take the reading that coincides with the datum line, x_{circular}.
6. The measurement is the sum of the reading on the datum line and circular scale, and then subtracting the zero error, $x - \Delta x$.

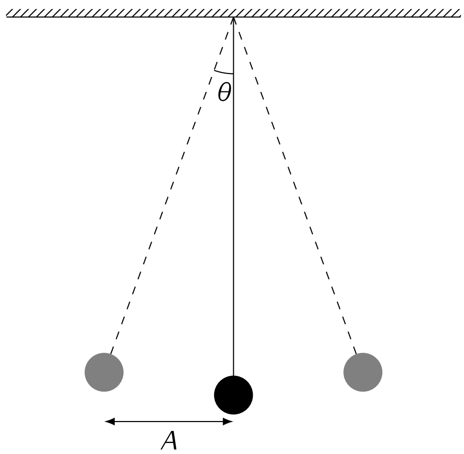
1.5.3 Simple Pendulum

A simple pendulum is one on the premises that the string is massless, and the bob is a point mass.

Equation 1.5.1: Period of Simple Pendulum

Using the approximation $\cos\theta \approx 1 - \frac{\theta^2}{2}$, for a reasonably small θ (angle of release),

$$T = 2\pi\sqrt{\frac{L}{g}}$$



Part II

Newtonian Mechanics

2 Kinematics

Preamble

Kinematics is the study of the motion of objects. It can describe the way a thing moves in space over time. We will only cover one-dimensional motion in this chapter.

2.1 Distance and Displacement

Definition 2.1.1: Distance

The distance traversed by an object in some time is the entire distance regardless of the direction of motion. The SI unit of distance is the metre [m].

Distances are a *scalar* quantity.

Definition 2.1.2: Displacement

The displacement of an object is the **net change in position** of an object. The SI unit of displacement is the meter [m].

Displacements are a *vector* quantity. When reporting the displacement of an object, it is important to also state the **direction** from the origin point.

2.2 Average Speed, Average Velocity, and Instantaneous Velocity

Equation 2.2.1: Average Speed

The average speed of an object is given as

$$\text{average speed} = \frac{\text{total distance}}{\text{total time}}$$

Speed is a *scalar* quantity.

Definition 2.2.1: Average Velocity

The average velocity of an object is the change in displacement of the object from the origin point. The SI unit of velocity is metre per second [$\mathrm{m\,s^{-1}}$].

Equation 2.2.2: Average Velocity

The average velocity of an object can be computed as

$$\langle v \rangle = \frac{\Sigma s}{\Sigma t}$$

Definition 2.2.2: Instantaneous Velocity

The instantaneous velocity of an object is the rate of change of displacement of the object at **some specific time**. Mathematically, it is the derivative of the displacement function.

Equation 2.2.3: Instantaneous Velocity

The instantaneous velocity at a time t is computed as

$$v(t) = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t}$$

Velocity is a *vector* quantity. When reporting the velocity of an object, it is important to also state the **direction** from the origin point.

2.3 Acceleration

Definition 2.3.1: Acceleration

Acceleration is the rate of change of velocity.

Equation 2.3.1: Acceleration

The acceleration of an object is computed as

$$a = \frac{\Delta v}{\Delta t}$$

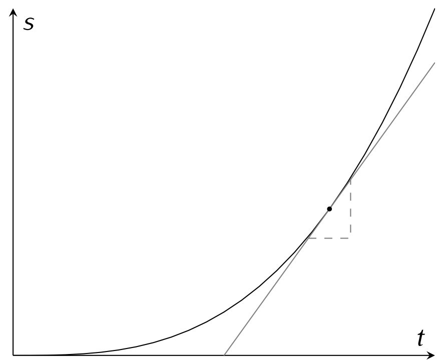
Acceleration is a *vector* quantity. When reporting the acceleration of an object, the direction from the origin point must be stated.

2.4 Kinematic Graphs

A kinematic graph is a visual representation of the state of motion of the object over a period of time. A kinematic graph is useful in many situations, and should be drawn when you are stuck in a kinematics problem.

2.4.1 Displacement-time Graph

The displacement-time graph records the displacement of an object over a time period. The displacement is recorded on the vertical axis, the time is recorded on the horizontal axis.

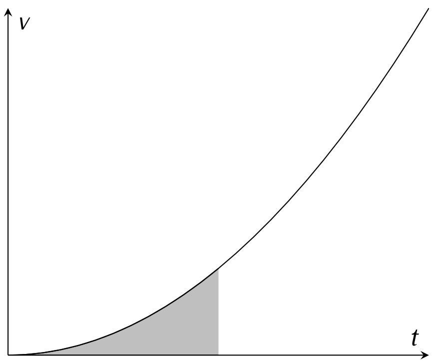


The gradient of the tangent to the displacement-time graph is the velocity at that time only.

The gradient of a displacement-time graph tells us its **velocity**.

2.4.2 Velocity-time Graph

The velocity-time graph records the velocity of an object over a time period. The velocity is recorded on the vertical axis, the time is recorded on the horizontal axis.



Usually the graph would be made out of straight lines and calculating area shouldn't be a problem. If the graph is curved, count squares.

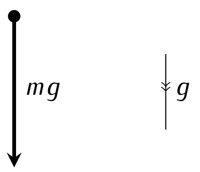
The gradient of a velocity-time graph tells us its **acceleration**; the area under a velocity-time graph tells us the **displacement**. s

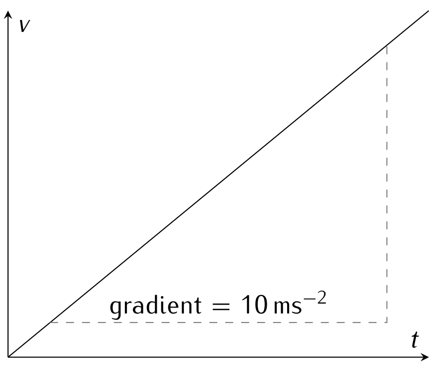
2.5 Freefall

Definition 2.5.1: Freefall

An object is in freefall when the only force acting on it is due to gravity.

This means that the acceleration due to freefall is always equal to the local acceleration g, and all other forces like air drag do not exist.





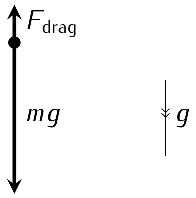
2.6 Air drag

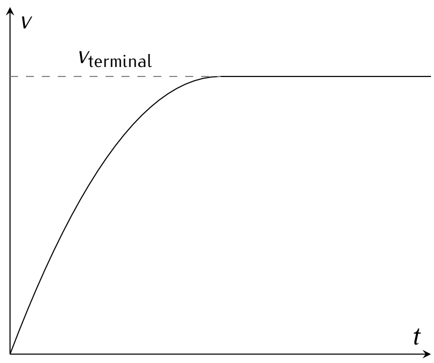
In real situations, air drag, or air resistance, is a resistive force that works against the weight of an object when falling. Air drag is **proportional to the square of the velocity** of an object.

As an object falls, its velocity increases. Air drag then also increases. The acceleration of the object slowly decreases as the net force acting on the object is decreasing.

This continues until a point where the air drag is equal and opposite to the weight of the object. The object then experiences zero net force, and has zero acceleration, maintaining a constant velocity.

This constant velocity is **terminal velocity**.





3 Dynamics

Preamble

In physics, forces change the state of motion of an object. Studying forces allow us to talk about the effects on the object and predict the motions of the object. In this chapter, we will look at two-dimensional dynamics.

3.1 Forces

Definition 3.1.1: Force

A force is a push or pull on a body. The SI unit of force is the newton [N].

3.2 Newton's Laws of Motion

The three laws of motion are:

Definition 3.2.1: First Law

Newton's first law states that every object will continue in its state of rest or uniform motion in a straight line unless a resultant force acts on it.

Definition 3.2.2: Second Law

Newton's second law states that when a resultant force acts on an object of a constant mass, the object will accelerate in the direct ion of the resultant force. The product of the mass m and acceleration a_{net} of the object gives the resultant force.

$$F_{\text{net}} = ma_{\text{net}}$$

Definition 3.2.3: Third Law

Newton's third law states that if body A exerts a force F_{AB} on body B, body B will exert an equal and opposite force F_{BA} on body A.

3.3 Effects of Forces

From the first law, we know that a force can accelerate a body (*i.e.* change velocity). This can be done by either changing the magnitude or direction of the velocity vector of the body.

3.3.1 Static System

Definition 3.3.1: Equilibrium

A body is said to be in equilibrium if the net force on the body is zero. This is sometimes called a static system, where no net acceleration takes place.

When resolving statics problems, it is important to ensure all force vectors add up to zero. Graphically, all these vectors when placed tip to tail should end where they started.

3.3.2 Unbalanced System

If the net force on a body is not zero, the object is not in translational equilibrium, and that means its velocity is changing.

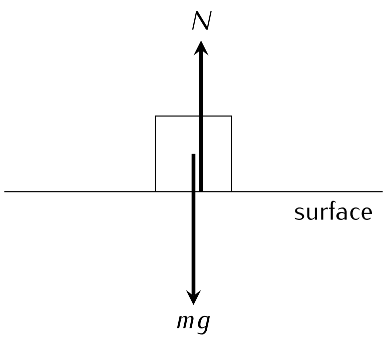
3.4 Types of Forces

It is not sufficient to just describe forces as "push" and "pull" forces. Different names for forces are designated for different contexts. In this syllabus, only friction is required, but I will add common forces as well. Refer to chapter 4 for weight.

3.4.1 Normal Force

Definition 3.4.1: Normal Force

The normal force is the force perpendicular to a surface that the surface applies to a body due to its compression.



3.4.2 Tension

Definition 3.4.2: Tension

Tension is the force exerted in a body when it is pulled on.

On a massless string, the tension on the two ends are equal.

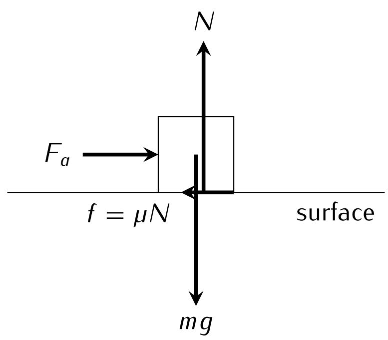
3.4.3 Friction

Definition 3.4.3: Friction

is the contact force that opposes or tends to oppose motion between surfaces in contact.

Friction is a resistive force, that works against a force applied. There are two types of friction: kinetic and static friction.

Kinetic friction deals with two objects moving on each other, and exists when an object is moving, while static friction deals with two objects that are stationary. The maximum static friction is the minimum force to be applied to allow an object to start moving on a surface.

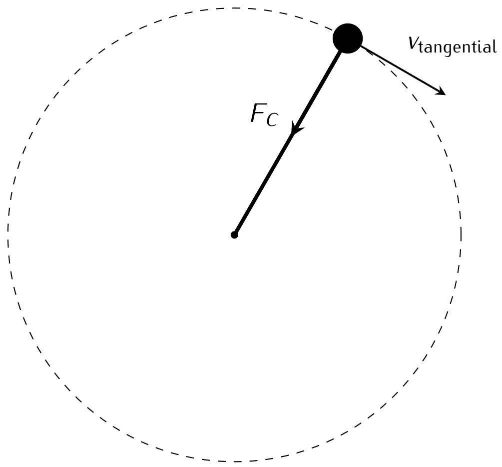


3.4.4 Centripetal Force

Definition 3.4.4: Centripetal Force

(It's not really in syllabus but you need to know this is a thing.) A centripetal force accelerates a body by changing the direction of the body's velocity without changing the body's speed.

This force arises in uniform circular motion. Centripetal force "pulls" the object back to the centre, allowing it to constantly change direction. Centripetal force can be the force of a string pulling a rotating object or the gravitational force acting on a planet orbiting around a star.



$$F_C = \frac{m v_{\text{tangential}}^2}{r}$$

The magnitude of $v_{\text{tangential}}$ stays constant, but the direction is constantly changing. That means the object is accelerating. This acceleration is called centripetal acceleration.

4 Mass, Weight, and Density

Preamble

Matter is anything that takes up space and has mass. The three quantities we are exploring today will allow us to describe matter in different ways.

4.1 Mass

Definition 4.1.1: Mass

Mass is the **amount of matter** in a body. The SI unit of mass is the kilogram [kg].

The magnitude of mass depends on the number of atoms in the body.

Mass is a **scalar** quantity. It can be measured with an **electronic mass balance**.

Definition 4.1.2: Inertia

The inertia of an object refers to the reluctance of the object to change its state of rest or motion, due to its mass.

4.2 Weight

Definition 4.2.1: Weight

The weight of an object is defined as the **gravitational force acting on it** due to gravity. The weight of an object w with mass m is equal to

$$w = mg$$

where g is the local gravitational field strength. The SI unit of weight is the newton [N].

Weight is a force, therefore it is a **vector** quantity. It can be measured with a **spring balance**.

Definition 4.2.2: Gravitational Field

A gravitational field is a region in which a mass experiences a force due to gravitational attraction. The gravitational field strength is the gravitational force acting per unit mass. On Earth, is equal to

$$g = 10\,\mathrm{m\,s^{-2}} = 10\,\mathrm{N\,kg^{-1}}$$

4.3 Density

Definition 4.3.1: Density

The density of an object is its mass per unit volume. The density of an object ρ with mass m and volume V is equal to

$$\rho = \frac{m}{V}$$

The SI unit of density is kilogram per cubic metre [$\mathrm{kg\,m^{-3}}$].

When an object is placed in a liquid,

$$\text{the object will} \begin{cases} \text{float} & \rho_{\text{object}} < \rho_{\text{liquid}} \\ \text{suspend} & \rho_{\text{object}} = \rho_{\text{liquid}} \\ \text{sink} & \rho_{\text{object}} > \rho_{\text{liquid}} \end{cases}$$

5 Turning Effect of Forces

Preamble

Objects do not only move in a straight line, they can also move in curves and circles and all kinds of funny shapes. In this chapter we will explore how we can make an object turn by applying a force.

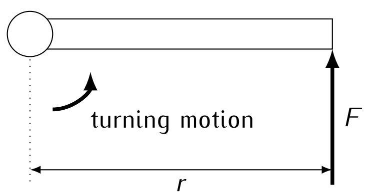
5.1 Moment

Definition 5.1.1: Moment

The moment of a force is the product of the force F and the perpendicular distance from the pivot to the line of action of the force r

$$M_O = r \times F$$

The SI unit of moment is newton metre [N m].



Definition 5.1.2: Principle of Moments

The principle of moments states that when a body is in equilibrium, the sum of clockwise moments about a pivot is equal to the sum of anticlockwise moments about the same pivot..

5.2 Centre of Gravity

Definition 5.2.1: Centre of Gravity

The centre of gravity, or centre of mass, is a point where the weight of an object seems to be acting on. The centre of gravity can lie outside an object.

5.3 Stability

Definition 5.3.1: Stability

The stability of an object is a measure of its ability to return to its original position after it is s lightly displaced.

An object can be in stable, unstable, or neutral equilibrium.

Type of equilibrium	Stable	Unstable	Neutral
Centre of gravity	Low	High	
Base area	Large	Narrow	A line of contact points with surface
Slight displacement	Return to equilibrium	Topple over	Stay in new position

An object's stability can be increased by lowering the height of the centre of gravity, or increasing the base area of the object.

6 Pressure

Preamble

These preambles are feeling more dreadful to write because pressure is building up.

6.1 Pressure

Definition 6.1.1: Pressure

Pressure is defined as the amount of force per unit area. It is given as

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

The SI unit of pressure is the pascal [Pa].

6.2 Pressure of Fluids

Equation 6.2.1: Pressure due to a Fluid Column

Fluids of a density ρ can exert pressure p at a height h equal to

$$p = \rho g h$$

Equation 6.2.2: Transfer of Pressure

Pressure is constant in an incompressible liquid,

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

Equation 6.2.3: Work Done

Energy is conserved by the first law of thermodynamics (which is useful to keep in mind when solving hydraulic press problems):

$$F_1 d_1 = F_2 d_2$$

6.3 Atmospheric Pressure

Equation 6.3.1: Atmospheric Pressure

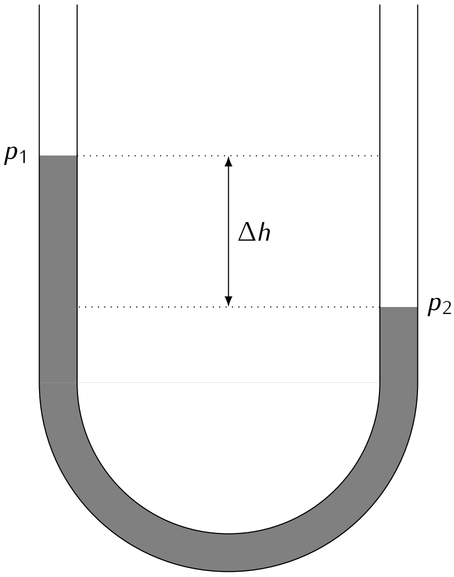
Atmospheric pressure at sea level is said to be 1 atm. It is equal to 101 325 Pa.

$$p_0 = 101\,325\,\mathrm{Pa} = 760\,\mathrm{mmHg}$$

Equation 6.3.2: Pressure Difference

A manometer can be used to measure pressure differences. It measures a Δh which corresponds to a pressure difference of

$$\Delta p = \rho g \Delta h$$



$$\Delta p = |p_2 - p_1| = \rho g \Delta h$$

7 Energy, Work, and Power

Preamble

The study of energy and matter form the basis of physics. In this chapter we will look at the concept of energy, work done, power, and other relevant quantities.

7.1 Energy

Definition 7.1.1: Energy

Energy is the capacity to do work.

Definition 7.1.2: Principle of Conservation of Energy

Energy cannot be created nor destroyed, but can be converted from one form to another. The total energy in an isolated system is constant. i.e.

$$\Delta E_T = 0$$

Definition 7.1.3: Kinetic Energy

Kinetic energy is the energy an object possesses when it is moving. It is given as

$$E_K = \frac{1}{2}mv^2$$

The SI unit of kinetic energy is the joule [J].

Definition 7.1.4: Gravitational Potential Energy

Gravitational potential energy is defined as how much work can be done by the gravitational force from a height h away. It is given as

$$E_P = mgh$$

The SI unit of gravitational potential energy is the joule [J].

Definition 7.1.5: Mechanical Energy

The mechanical energy of an object is the sum of its kinetic energy and its gravitational potential energy:

$$E_T = E_K + E_P$$

7.2 Work

Definition 7.2.1: Work Done

The work done by a constant force on an object is the product of the force F and the distance moved by the object in the direction of the force (actually displacement s).

$$W = Fs$$

The SI unit of work done is the joule [J].

Equation 7.2.1: Efficiency

Efficiency is calculated by

$$\eta = \frac{\text{output}}{\text{input}} \times 100\%$$

7.3 Power

Definition 7.3.1: Power

Power is defined as the rate of work done or rate of energy conversion. It is calculated as

$$P = \frac{W}{t}$$

The SI unit of power is the watt [W].

Part III

Thermal Physics

8 Kinetic Model of Matter

Preamble

Matter is made up of small particles that behave in certain ways under different conditions. In this chapter we will accurately describe the particulate nature of matter and how it behaves under different temperature and pressure conditions.

8.1 Three States of Matter

Property	Solid	Liquid	Gas
Shape	fixed	not fixed	not fixed
Volume	fixed	fixed	not fixed
Compressible?	no	no	yes

When prompted to describe a state, you might want to talk about its:

- arrangement of particles
- forces between particles
- kinetic energy of particles
- motion of particles

as written like in the next few subsections.

8.1.1 Solids

Solids are

- closely packed in an orderly manner
- held together by strong forces of attraction
- have enough energy to only vibrate and rotate about their fixed positions
- cannot move around freely

8.1.2 Liquids

Liquids are

- arranged in a disorderly manner
- have weaker forces of attraction than the particles of a solid
- have more kinetic energy than particles of the substance in the solid state, and are not held in fixed positions
- can move freely throughout the liquid

8.1.3 Gases

Gases are

- spread far apart from one another
- have weaker forces of attraction than the particles of a liquid
- have a lot of kinetic energy and are not held in fixed positions
- can move about rapidly in any direction

Definition 8.1.1: Brownian Motion

Particles are in constant random motion. Brownian motion arises due to these random motions of particles in a fluid.

8.2 Gas Laws

There are three gas laws.

Definition 8.2.1: Ideal Gas Law

As a result of the three gas laws to be presented below, the relationship for an ideal gas between its temperature, pressure, and volume can be expressed as

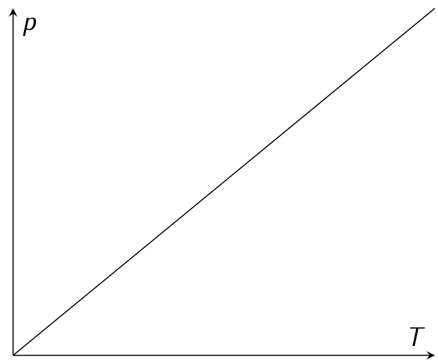
$$pV = nRT$$

where nR is some constant.

Equation 8.2.1: Charles Law

Charles Law states that the pressure of a gas is directly proportional to its temperature *if the volume stays constant (isochoric)*. Mathematically,

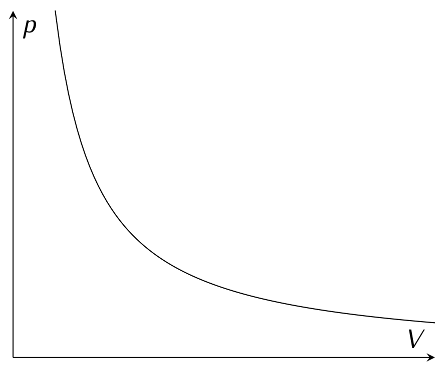
$$p \propto T$$



Equation 8.2.2: Boyle's Law

Boyle's law states that the pressure of a gas is inversely proportional to the volume of the gas *if the temperature stays constant (isothermic)*. Mathematically,

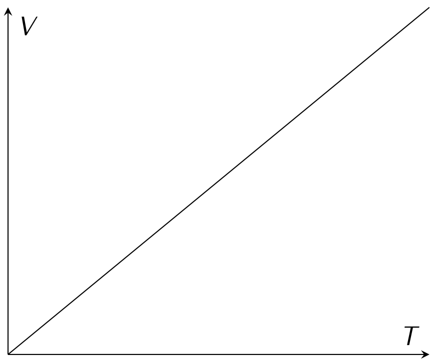
$$p \propto \frac{1}{V}$$



Equation 8.2.3: Gay-Lussac's Law

Gay-Lussac's Law states that the volume of a gas is directly proportional to its temperature *if the pressure stays constant (isobaric).* Mathematically,

$$V \propto T$$



Equation 8.2.4: Avogadro's Law

(*This is not in this syllabus but it is in O-Level Chemistry so I'll put it here.*) Avogadro's law states that the amount of gas is directly proportional to the volume of the gas. Mathematically,

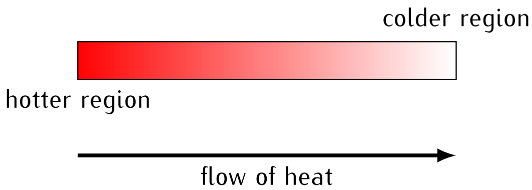
$$n \propto V$$

9 Transfer of Thermal Energy

Preamble

Heat can be transferred in multiple ways. In this chapter we will look at three different methods for heat transfer.

Heat always flows from a region of higher temperature to a region of lower temperature. Net flow of thermal energy occurs only when there is a difference in temperature.



9.1 Methods of Heat Transfer

Definition 9.1.1: Conduction

Conduction is the process whereby particles within a medium without the movement of the medium itself.

Particles collide with neighbouring particles and that energy gets transferred down the entire object, causing the object to increase in temperature.

Metals can conduct heat better due to **electron diffusion**.

Definition 9.1.2: Convection

Convection is the transfer of thermal energy by means of convection currents in a fluid due to a difference in density.

Definition 9.1.3: Radiation

Radiation is the transfer of thermal energy in the form of electromagnetic waves such as infrared radiation without the aid of a medium.

Factors that affect the rate of radiation include:

- **Colour:** darker objects radiate heat better than lighter objects (see emissivity)
- **Surface:** rougher surfaces radiate heat better than smoother surfaces (due to higher surface area)
- **Surface Temperature:** higher surface temperatures allow for faster radiation.

Further reading: Radiation is modelled by the Stefan-Boltzmann Law:

$$P = A\varepsilon\sigma T^4$$

where ε is the emissivity and σ is the Stefan-Boltzmann constant, $5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$.

10 Temperature

Preamble

In this chapter we will learn how to make a thermometer because you can't buy one in practical exam.

10.1 Temperature and Heat

Definition 10.1.1: Temperature

Temperature (or thermodynamic temperature) refers to how hot or cold an object is.

Definition 10.1.2: Heat

Heat is the amount of thermal energy that is being transferred from a hotter to a colder region.

Equation 10.1.1: Temperature Conversion

To convert from degrees celsius [°C] to kelvin [K],

$$[\mathrm{K}] = [^\circ\mathrm{C}] + 273.15$$

10.2 Thermometer Calibration

Definition 10.2.1: Ice Point

The ice point is the temperature of pure melting ice at one atmosphere, and is assigned a value of 0 °C.

Definition 10.2.2: Steam Point

The steam point is the temperature of pure boiling water at one atmosphere, and is assigned a value of 100 °C.

Definition 10.2.3: Thermometric Property

A thermometric property is a property of matter that varies continuously and linearly with temperature.

Some examples of this include the volume of an object, the electromotive force of a thermocouple, and the height of a liquid column.

Equation 10.2.1: Thermometry Formula

To make a thermometer, you need some thermometric property X at temperatures 0 °C, 100 °C, and some temperature θ °C. Then you plug them into this formula

$$\theta\,°\mathrm{C} = \frac{X_\theta - X_0}{X_{100} - X_0} \times 100\,°\mathrm{C}$$

11 Thermal Properties of Matter

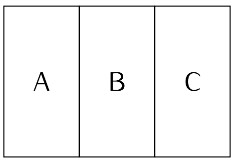
Preamble

Matter has some properties when it comes to heat. These preambles are also getting difficult to write because I'm running out of ideas.

11.1 Heat Energy

Definition 11.1.1: Zeroth Law of Thermodynamics

(*This isn't in syllabus.*) The zeroth law of thermodynamics states that if object A, B, and C are in thermal contact with each other, and if the temperature of object A is equal to that of B, and the temperature of object B is equal to that of C, then the temperature of object A must equal to that of C.



if $T_A = T_B$ and $T_B = T_C$ then

$$T_A = T_B = T_C$$

Definition 11.1.2: Heat Capacity

Heat capacity C is the amount of heat energy required to raise the temperature of an object by 1 K. Its relationship can be expressed as

$$Q = C\Delta T$$

The SI unit of heat capacity is joule per kelvin [J K^{-1}].

Definition 11.1.3: Specific Heat Capacity

Specific heat capacity c is the amount of heat energy required to raise the temperature of a unit mass of an object by 1 K. Its relationship can be expressed as

$$Q = mc\Delta T$$

The SI unit of heat capacity is joule per kelvin per kilogram [J K^{-1} kg^{-1}].

Definition 11.1.4: Latent Heat

Latent heat is the energy released or absorbed by a substance during a change of state, without a change in its temperature. In general,

$$Q_{f/v} = ml_{f/v}$$

where $l_{f/v}$ is the specific latent heat of fusion/vaporisation, the heat energy required to melt or freeze/vaporise or condense a unit mass. The SI unit of specific latent heat is joule per kilogram [J kg^{-1}].

11.2 Vaporisation

Definition 11.2.1: Evaporation

Evaporation is the process whereby a liquid vaporises at the surface because it has the energy equal or more than that of the latent heat of vaporisation, allowing it to escape into the atmosphere.

Evaporation can happen at any temperature. The temperature can vary during evaporation. It is also slower than boiling.

Definition 11.2.2: Boiling

Boiling is the process where a liquid reaches boiling point and the particles have enough energy to vaporise.

Boiling only happens at boiling point (*i.e.* temperature stays constant during boiling). It happens quite quickly.

Part IV

Waves

12 General Wave Properties

Preamble

Waves are a fundamental method of describing the nature of matter and how it interacts with energy. In this chapter we will be covering general wave properties that would be helpful.

12.1 Definitions

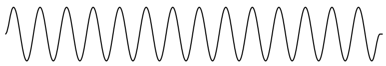
Definition 12.1.1: Wave

A wave is made up of periodic motion. A wave is a disturbance that transfers energy from one place to another without transfer of matter.

Definition 12.1.2: Transverse Wave

A transverse wave is when the particles oscillate perpendicular to the direction of propagation.

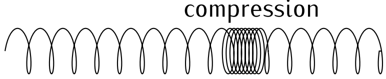
An example of a transverse wave is electromagnetic waves.



Definition 12.1.3: Longitudinal Wave

A longitudinal wave is when the particles oscillate parallel to the direction of propagation.

An example of a longitudinal wave is sound waves.



12.2 Parts of a Wave

12.2.1 Common Quantities

Definition 12.2.1: Amplitude

The amplitude of a wave is the maximum displacement of a particle in a wave. It is usually represented by the letter A. The most common unit for amplitude is the metre [m]; though keep in mind other physical quantities like voltage can exhibit periodic wave-like behaviour.

Definition 12.2.2: Wavelength

The wavelength of a wave is the displacement between two successive in-phase points. It is usually represented by the Greek letter λ. The SI unit for wavelength is the metre [m].

Definition 12.2.3: Wavefront

A wavefront is an imaginary line on a wave that joins all adjacent points that are in phase.

12.2.2 Time-based Quantities

Definition 12.2.4: Period

The period of a wave is the time taken for a particle to complete one oscillation. It is usually represented by the letter T. The SI unit for period is the second [s].

Definition 12.2.5: Frequency

The frequency of a wave is the number of times a particle completes one oscillation in one second. It is usually represented by the letter f. The SI unit for frequency is the hertz [Hz].

Equation 12.2.1: Period and Frequency

Period and frequency are reciprocals of each other,

$$f = \frac{1}{T} \Leftrightarrow T = \frac{1}{f}$$

12.2.3 Some Things Specific to Longitudinal Waves

Definition 12.2.6: Compression

A compression in a longitudinal wave is where there are more particles around that region than in equilibrium.

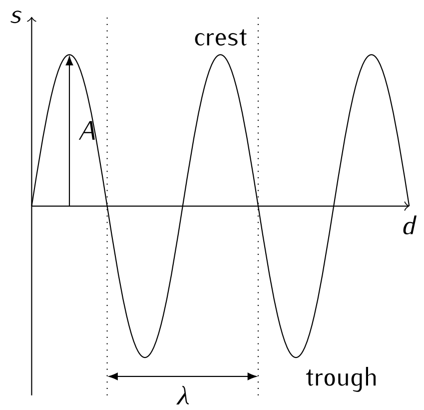
Definition 12.2.7: Rarefaction

A rarefaction in a longitudinal wave is where there are less particles around that region than in equilibrium.

12.3 Graphs

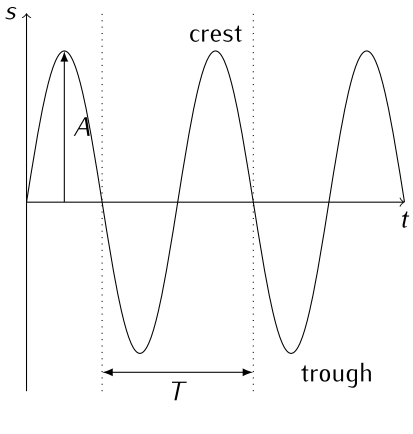
12.3.1 Displacement-distance Graph

This is also known as a snapshot graph. The snapshot graph shows a wave's particles **at a certain time**. The horizontal axis shows distance; the vertical axis shows the particle at that distance's displacement from its equilibrium position.



12.3.2 Displacement-time Graph

This is also known as a history graph. The history graph shows one particle of a wave **over a certain time**. The horizontal axis shows time; the vertical axis shows the particle's displacement from its equilibrium position at that time.



12.4 Wave Speed

Equation 12.4.1: Wave Speed

For a wave with frequency f and wavelength λ, the velocity v it is travelling at is equal to

$$v = f\lambda$$

13 Light

Preamble

Light can be studied as a wave. In this chapter we will look at how light interacts with matter.

13.1 Reflection

Definition 13.1.1: Normal

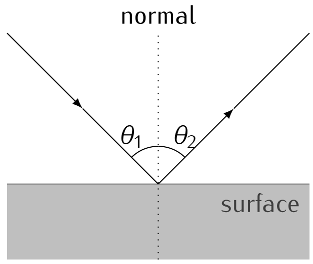
The normal is an imaginary line draw perpendicular to the surface that reflection is taking place at.

Definition 13.1.2: Angle of Incidence

The angle of incidence is the angle between the incident ray and the normal.

Definition 13.1.3: Angle of Reflection

The angle of reflection is the angle between the reflected ray and the normal.



Definition 13.1.4: First Law of Reflection

The incident ray, reflected ray, and the normal lie on the same plane.

Definition 13.1.5: Second Law of Reflection

In reflection, the angle of incidence is equal to the angle of reflection.

$$\theta_1 = \theta_2$$

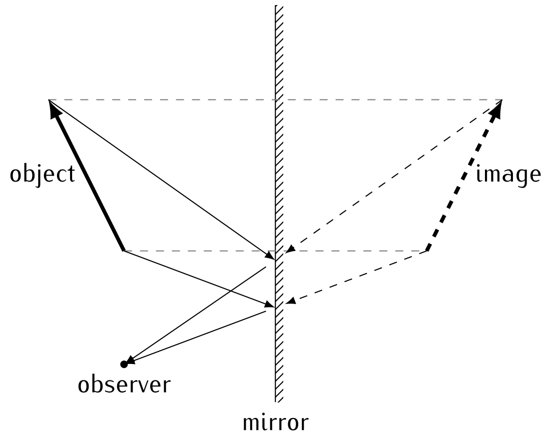
I have chosen to name the angles θ_1 and θ_2 due to the reversible nature of light. It does not matter which way the light goes; the angles will be preserved.

Definition 13.1.6: Virtual Image

A virtual image is an image that cannot be cast on a screen.

The properties of an reflected image are:

- same shape and size
- same distance from the mirror
- laterally inverted
- upright
- virtual



Virtual images or construction lines are drawn with **dotted** lines.

13.2 Refraction

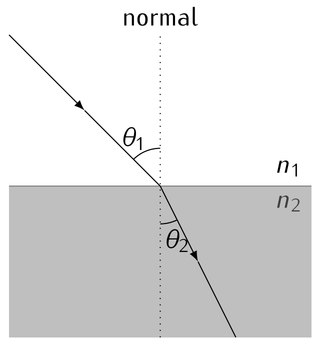
Definition 13.2.1: Refraction

Refraction is the bending of light as light passes from one optical medium to another, due to light changing speed.

13.2.1 Essentials

Definition 13.2.2: Angle of Refraction

The angle of refraction is the angle between the refracted ray and the normal.



Definition 13.2.3: First Law of Refraction

The incident ray, refracted ray, and the normal lie on the same plane.

Definition 13.2.4: Second Law of Refraction

For two given media, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

Equation 13.2.1: Refractive Index

The refractive index of a medium is the ratio of the speed of light in vacuum to the speed of light in the medium

$$n = \frac{c}{v}$$

Sometimes it might also be

$$n = \frac{\text{real depth}}{\text{apparent depth}}$$

.

Equation 13.2.2: Snell's Law

Snell's Law is the same thing as the second law of refraction, mathematically expressed as

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Definition 13.2.5: Critical Angle

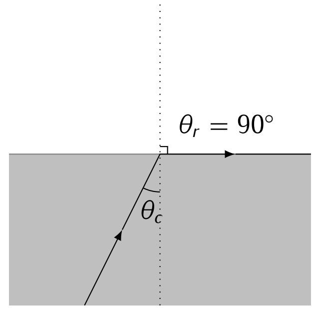
The critical angle is defined as the angle of incidence in an optically denser medium for which the angle of refraction in the optically less dense medium is 90°.

Derivation for critical angle formula for any refractive indices considering $n_1 > n_2$, from equation 13.2,

$$\begin{aligned} n_1 \sin \theta_c &= n_2 \sin 90^\circ \\ \sin \theta_c &= \frac{n_2(1)}{n_1} \\ \sin \theta_c &= \frac{n_2}{n_1} \\ \theta_c &= \boxed{\sin^{-1}\left(\frac{n_2}{n_1}\right)} \end{aligned}$$

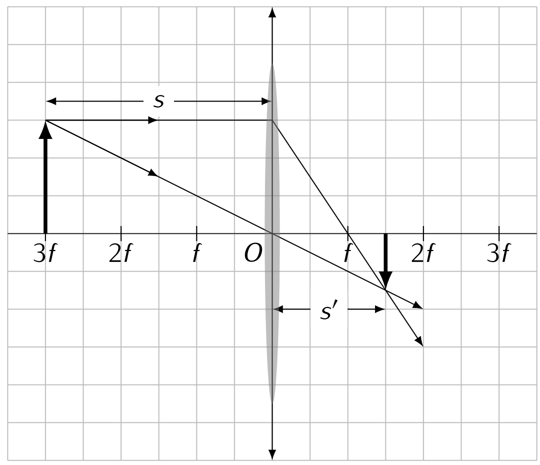
Definition 13.2.6: Total Internal Reflection

Total internal reflection is the complete reflection of a light ray inside an optically denser medium at its boundary with an optically less dense medium.



13.2.2 Lenses

For the most part of this section, we will consider a thin lens.



Real images are drawn with **solid** lines.

Definition 13.2.7: Principal Axis

The horizontal line passing through the optical centre of the lens is called the principal axis. The principal axis is perpendicular to the vertical plane of the lens.

Definition 13.2.8: Optical Centre

The optical centre is the midpoint between the lens' surface on the principal axis. Rays that travel through the optical centre are not deviated.

Definition 13.2.9: Focal Length

The focal length is the distance between the optical centre and the focal point.

Definition 13.2.10: Focal Plane

The focal plane is the plane that passes through the focal point f and is perpendicular to the principal axis.

s	Image is	s'	Uses
$s = \infty$	real	$s' = f$	telescope
$s > 2f$	real	$f < s' < 2f$	camera
$s = 2f$	real	$s' = 2f$	photocopier
$f < s < 2f$	real	$s' > 2f$	projector
$s = f$	virtual	$s' = -\infty$	eyepiece
$s < f$	virtual	$s' < 0$	microscope

Real images are inverted; virtual images are upright.

Equation 13.2.3: Thin Lens Equation

(*This is not in syllabus.*) For a thin lens, the focal length and the distances between the object and its image is

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

Equation 13.2.4: Magnification

(*This is not in syllabus.*) The magnification of a lens is given by

$$M = \frac{s'}{s}$$

14 Electromagnetic Spectrum

Preamble

The electromagnetic spectrum consists of electromagnetic waves of different frequencies. In this chapter we will explore these different frequencies and study some of their uses.

14.1 Electromagnetic Waves

Definition 14.1.1: Speed of Light

All electromagnetic waves travel at the speed of light c in a vacuum.

$$c = 3.0 \times 10^8\,\mathrm{m\,s^{-1}}$$

Some properties of electromagnetic waves:

- They do not require a medium to travel.
- They transfer energy from one place to another.
- They obey the laws of reflection and refraction.
- They do not change its frequency.
- They carry no electric charge.

14.2 Parts of the Electromagnetic Spectrum

In increasing frequency (i.e. decreasing wavelength), and their uses:

- Radio waves (e.g. radio and television communication)
- Microwaves (e.g. microwave oven and satellite television)
- Infra-red (e.g. infra-red remote controllers and intruder alarms)
- Visible light (e.g. optical fibres for medical uses and telecommunications)
- Ultra-violet (e.g. sunbeds and sterilisation)
- X-rays (e.g. radiological and engineering applications)
- Gamma rays (e.g. medical treatment)

14.3 Effects of the Electromagnetic Spectrum

When absorbing electromagnetic waves of various frequencies, different effects can be observed.

- Absorbing infrared rays can cause heating
- Higher frequencies such as x-rays can cause ionisation
- Overexposure to ultra-violet and higher frequency rays can lead to damage to living cells and tissue

15 Sound

Preamble

Sound is transferred in a form of a wave. In this chapter we will explore the different properties of sound and some of its applications.

15.1 Fundamentals

Some fundamental properties of sound:

- Sound is produced by a vibrating source.
- Sound exists in the form of a longitudinal wave.
- In different media, sound has different speeds. Generally, the higher the density, the faster the speed of sound.

gases → liquids → solids

increasing speed of sound

Equation 15.1.1: Speed of Sound

For a sound source from d away from an observer and capturing it after a time t, the speed of sound can be calculated as

$$v = \frac{s}{t}$$

15.2 Properties of Sound

Equation 15.2.1: Loudness

The loudness of a sound wave is directly proportional to the square of its amplitude

$$\text{loudness}\begin{cases}\text{louder} & \text{higher } A\\ \text{softer} & \text{softer } A\end{cases}$$

Equation 15.2.2: Pitch

The pitch of a sound is directly proportional to its frequency

$$\text{pitch}\begin{cases}\text{higher} & \text{higher } f\\ \text{lower} & \text{lower } f\end{cases}$$

The human ear can hear sounds from between 20 Hz to 20 kHz.

15.3 Applications of Sound

Definition 15.3.1: Echo

An echo is the repetition of a sound due to the reflection of sound.

Echo is used in distance measurement systems such as SONAR in ships.

Definition 15.3.2: Ultrasound

Ultrasound is sound with frequencies above the upper limit of the human range of audibility (i.e. 20 kHz).

Ultrasound is used in product quality control and prenatal scanning.

Part V

Electricity and Magnetism

16 Static Electricity

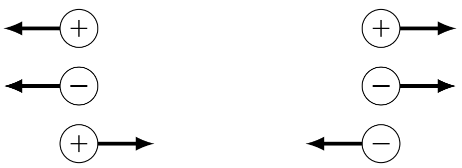
Preamble

Static electricity is the study of charges at rest. In this chapter we will explore that very concept.

Definition 16.0.1: Charge

Charge is measured in coulombs [C]. There are positive and negative charges.

Like charges repel, unlike charges attract.



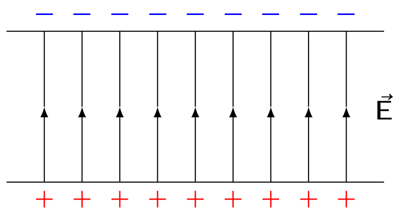
[2] physics.stackexchange.com

16.1 Electric Fields

Definition 16.1.1: Electric Field

An electric field is a region of space whereby a charge experiences an electric force.

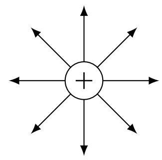
Electric field lines **cannot cross**.



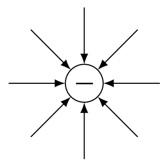
16.1.1 Isolated Charges

Field lines are the path a test charge would take within that electric field. The closer the field lines are, the stronger the electric field at that area, which means that the test charge would experience a stronger force.

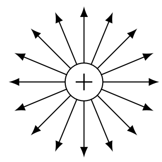
Field lines extend **out** from **positive** charges.



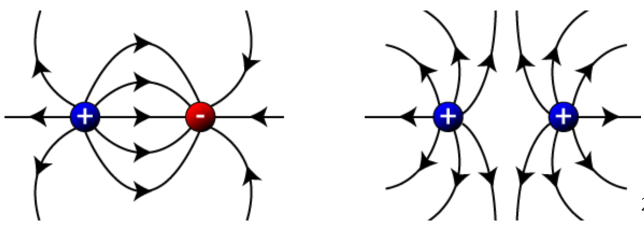
Field lines go **in** to **negative** charges.



If a charge is stronger, it gets more field lines (e.g. this one has twice the charge as the one above, so it should get more)



Drawing these in TikZ was too difficult so take these from some online website.



[2]

16.2 Charging

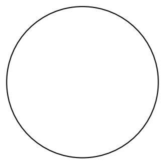
The two methods of charging are **rubbing** and **induction**.

16.2.1 Rubbing

Electrons (negative charges) can be transferred from one object to another through rubbing. There are no movement of positive charges.

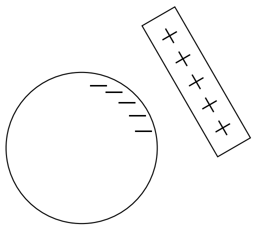
16.2.2 Induction

Charging with induction can be achieved for two conductors. The most classic example is the metal sphere case.

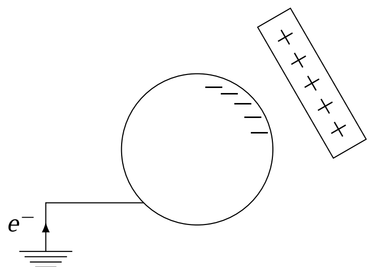


Suppose this sphere is overall neutral to begin with, and isolated from ground.

Now a positively charged rod is brought to the sphere. This causes the electrons in the sphere to move towards the positively charged rod.

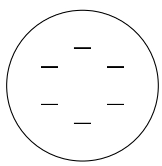


The sphere is then earthed. Electrons flow from earth up to the sphere.



Keep in mind the location of where the earth connection is made **does not matter**. These charged particles are not moving due to position, but moving due to lower energy states available.

The rod is then removed, leaving behind a negatively charged sphere.



16.3 Discharging

16.3.1 Insulators

Insulators can be discharged by **heating** or **providing humid conditions**.

16.3.2 Conductors

Conductors can be discharged through a process known as **earthing**. Earthing allows electrons to flow into (in the case of a positively charged object) and out of (in the case of a negatively charged object) the object.

16.4 Applications and Hazards of Electrostatic Charging

16.4.1 Applications

An application of electrostatics is in spray painting.

In spray painting, the object to be painted is charged. The paint will then be charged with the opposite charge, and allowing the paint to attract to the object's surface, allowing for a better coat and efficient painting.

16.4.2 Hazards

Lightning is a danger that is caused by electrostatic charging.

Charges build up in clouds due to friction between air and water molecules, which causes in ionised (charged) air which allows a conductive path between the charges built up in the clouds and ground, causing lightning.

This can be resolved by installing conductive lightning rods on high objects such as buildings to safely ground these large releases of electric energy.

17 Current of Electricity

Preamble

Current is the rate of flow of charge. When charges move there is current and hence we name this current electricity. In this chapter we will explore the fundamentals that govern current electricity.

17.1 Current

Definition 17.1.1: Current

Current is the rate of flow of charge.

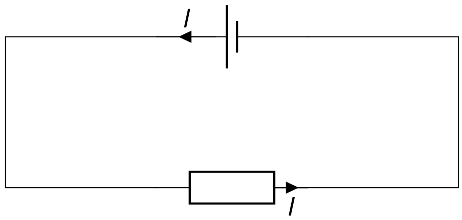
$$I = \frac{Q}{t}$$

The SI unit of current is ampere [A].

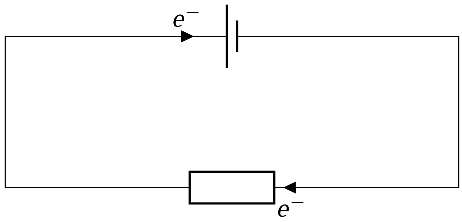
Current is measured with an ammeter.

17.1.1 Current Flow

Conventional current is where current flows from a higher voltage to a lower voltage.



Electron flow is the opposite of that.



In physics we mostly use conventional current. This document will do likewise.

17.2 Electromotive Force and Potential Difference

Definition 17.2.1: Electromotive Force

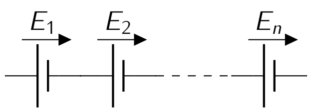
Electromotive force (e.m.f.) is the work done by a source in driving unit charge around a complete circuit.

$$E = \frac{W}{Q}$$

The SI unit of electromotive force is volt [V].

Equation 17.2.1: Electromotive Forces in Series

If multiple electromotive force sources are arranged in series



then the net electromotive force is

$$E_{\text{net}} = E_1 + E_2 + \cdots + E_n$$

Definition 17.2.2: Potential Difference

The potential difference (p.d.) (or voltage) across a component in a circuit as the work done to drive unit charge through the component.

$$V = \frac{W}{Q}$$

The SI unit of potential difference is volt [V].

17.3 Resistance

Definition 17.3.1: Resistance

The resistance of a component is the ratio of the potential difference across it to the current flowing through it.

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

The SI unit of resistance is ohm [Ω].

Definition 17.3.2: Ohm's Law

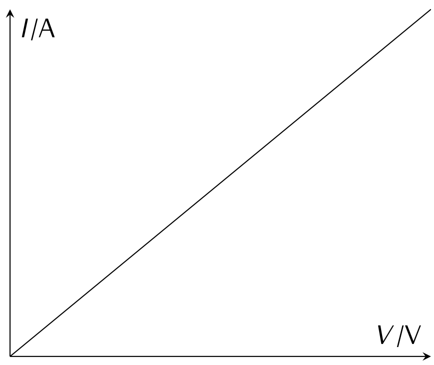
Ohm's Law states that the current passing through a metallic conductor is directly proportional lo the potential difference across it, provided that physical conditions (such as temperature) remain constant.

$$V = IR$$

Definition 17.3.3: Ohmic Conductors

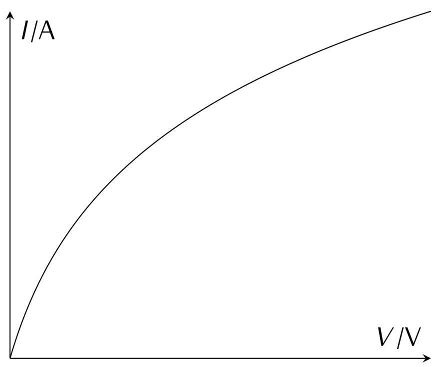
Ohmic conductors are conductors that obey Ohm's law.

An ohmic conductor might exhibit an $I - V$ graph as such:



Notice that the graph is **linear** and starts at the **origin**.

On the other hand, non-ohmic conductors may exhibit such a characteristic curve:



Notice that the graph is **not linear**.

17.4 Resistivity

Definition 17.4.1: Resistivity

Resistivity is the property of a material that determines its resistance when made into a wire or electrical component. The SI unit of resistivity is ohm metre [Ω m].

Equation 17.4.1: Resistance of a Wire

The resistance of the wire with length l, cross-sectional area A, and resistivity ρ is equal to

$$R = \frac{\rho l}{A}$$

Rewritring this equation making ρ the subject gives us

$$\rho = \frac{AR}{l}$$

Temperature affects resistance. The higher the temperature of a conductor, the higher its resistance.

$$R \begin{cases} \text{high} & \text{higher } T \\ \text{low} & \text{lower } T \end{cases}$$

This is not to be confused with the behaviour of a thermistor (chapter 18).

18 DC Circuits

Preamble

Most things at our homes run on direct current (DC). In this chapter we will explore how DC circuits behave and how it is used to make the many circuits and electronic devices around us.

Equation 18.0.1: Kirchhoff's Current Law

(This isn't in syllabus.) The current flowing in a junction must equal to the current flowing out of a junction.

$$\Sigma I_{\text{node}} = 0$$

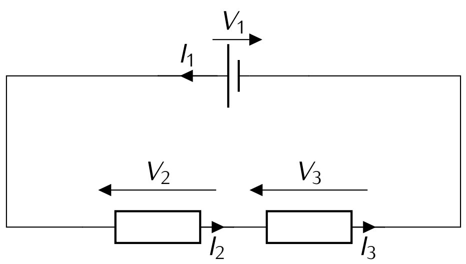
Equation 18.0.2: Kirchhoff's Voltage Law

(This isn't in syllabus.) The algebraic sum of voltages in a loop/mesh is equal to zero.

$$\Sigma V_{\text{mesh}} = 0$$

18.1 Series Circuits

We will look at this series circuit for this subsection.



18.1.1 Current

Current in a series circuit is always the same. In the case of the circuit above,

$$I_1 = I_2 = I_3$$

18.1.2 Voltage

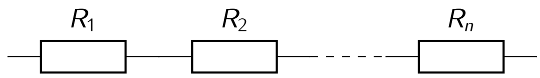
The sum of voltages across components in a series circuit is equal to the voltage across the entire circuit. In the case of the circuit above,

$$V_1 = V_2 + V_3$$

18.1.3 Resistance

Equation 18.1.1: Resistance in Series

If multiple resistors are arranged in series

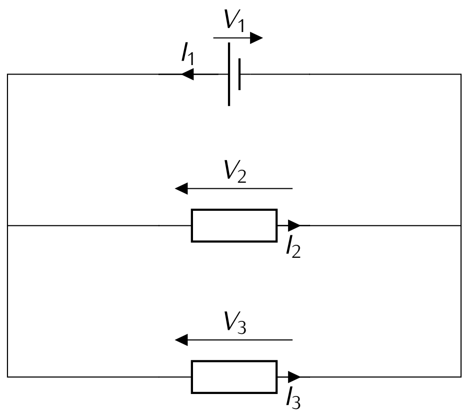


then the net resistance is

$$R_{\text{net}} = R_1 + R_2 + \cdots R_n$$

18.2 Parallel Circuits

We will look at this series circuit for this subsection.



18.2.1 Current

The sum of individual currents in each parallel branch is equal to the main current flowing into or out of parallel branches. In the case of this circuit,

$$I_1 = I_2 + I_3$$

18.2.2 Voltage

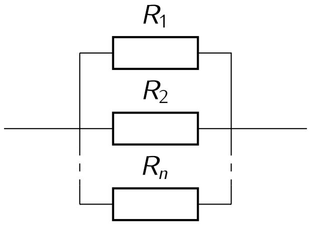
The voltages across parallel branches are the same. In the case of this circuit,

$$V_1 = V_2 = V_3$$

18.2.3 Resistance

Equation 18.2.1: Resistance in Parallel

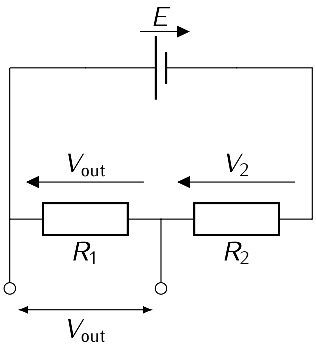
If multiple resistors are arranged in parallel



then the net resistance is

$$R_{\text{net}} = \left(R_1^{-1} + R_2^{-1} + \cdots + R_n^{-1}\right)^{-1}$$

18.3 Voltage Divider



$$V_{\text{out}} = \frac{R_1}{R_1 + R_2} \times E$$

Equation 18.3.1: Voltage Divider

For a resistor R_x in a series circuit with total resistance R_T, the voltage across the resistor R_x is

$$V_x = \frac{R_x}{R_T} \times E$$

18.4 Input and Output Transducers

Definition 18.4.1: Input Transducer

An input transducer is an electronic device that converts non-electrical energy into electrical energy.

We will look at two input transducers: (NTC-) thermistors and light dependent resistors (LDR).

Thermistors are devices which vary its resistance according to temperature. As the temperature increases, the resistance decreases.

$$R_{\text{TH}} \begin{cases} \uparrow & T \downarrow \\ \downarrow & T \uparrow \end{cases}$$

Light-dependent resistors (LDR) varies its resistance according to the light intensity shining on it. As the light intensity shining on it increases, the resistance decreases.

$$R_{\text{LDR}} \begin{cases} \uparrow & \text{light intensity} \downarrow \\ \downarrow & \text{light intensity} \uparrow \end{cases}$$

19 Practical Electricity

Preamble

In this chapter we will explore electricity in everyday life and electrical safety.

19.1 Electrical Energy and Power

Equation 19.1.1: Electrical Power

Electrical power can be calculated with the equations

$$P = IV = I^2R = \frac{V^2}{R}$$

Equation 19.1.2: Electrical Energy

Because $E = Pt$, we multiply all the above equations by t

$$E = IVt = I^2Rt = \frac{V^2}{R}t$$

Equation 19.1.3: Cost of Electricity Consumption

The cost of using some amount of electrical energy can be calculated in the equation

$$\text{cost} = E \times \text{rate}$$

Sometimes the preferred unit of electrical energy consumed is kilowatt hours [kW h] to make calculating cost easier.

19.2 Hazards of Electricity

Electricity can be powerful but dangerous. The following are notable examples where electricity can cause a hazard.

- **Damaged Insulation**
  - Damaged insulation can occur when the insulating material of a cable experiences wear and tear over time, leaving in exposed conducting wires.
  - These exposed conducting wires can cause electric shocks if touched.
- **Damp Environments**
  - Water is conductive, *even if it is pure.*
    * $H_2O\,(l) \rightleftharpoons \underbrace{H^+(aq) + OH^-(aq)}_{\text{mobile charges}}$

– Water coming into contact with uninsulated electrical wires provides a conducting path for current.

- **Overheating of Cables**
  - Overloading of sockets can cause too high of current draw.
  - Due to the heating effect of current, if the current exceeds the power rating of a wire or electrical component, it may damage the component or start an electrical fire.

19.3 Safety Features in Home Circuitries

19.3.1 Circuit Breakers

Definition 19.3.1: Circuit Breaker

A circuit breaker is a safety device that can switch off the electrical supply in a circuit when large currents flow through it.

Circuit breakers can be reset by the user.

19.3.2 Fuses

Definition 19.3.2: Fuse

A fuse is a safety device added to an electrical circuit to prevent excessive current flow.

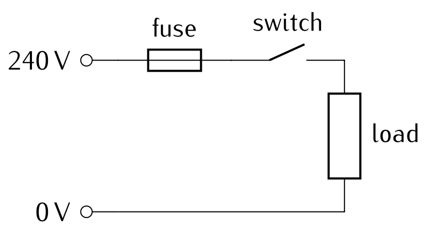
Fuses have a certain current rating which we will call I_0. The following shows what happens to the fuse if some current I is passed through it.

$$\text{fuse} \begin{cases} \text{not blown} & I \leqslant I_0 \\ \text{blown} & I > I_0 \end{cases}$$

19.3.3 Switches

Definition 19.3.3: Switches

Switches are designed to break or complete an electrical circuit. They should be fitted to the live wire of the appliance.



19.3.4 Earthing

Definition 19.3.4: Earthing

Earthing is the method of connecting a wire from the appliance to earth so that unsafe currents can safely flow to earth without hurting the user.

19.3.5 Three-pin Plugs

Definition 19.3.5: Three-pin Plugs

Three pin plugs contain three wires: earth, ground, and neutral. They also have a fuse.

The earth wire is **green** and **yellow**; the live wire is **brown**; the neutral wire is **blue**.

Viewing the three pin plug with its casing removed, the live (bRown) wire goes to the Right (→); the neutral (bLue) wire goes to the Left (←).

19.3.6 Double Insulation

Double insulation is used if the appliance uses a two pin plug. It provides two levels of insulation:

1. The electric cables are insulated from the internal components of the appliance.
2. The internal components are insulated from the external casing.

If double insulation is available, but a three-pin plug is present, the earth connector is most likely a dummy one just to allow the appliance to plug in.

20 Magnetism

Preamble

Magnets were discovered by who knows who at who knows when. All I know is we have to study them now thanks to lodestone sailor people.

20.1 Magnets

Definition 20.1.1: Magnetic Materials

Magnetic materials are materials that can be attracted to a magnet.

The four materials you probably remember from primary school are: iron, nickel, cobalt, and steel.

Definition 20.1.2: Non-magnetic Materials

Non-magnetic materials are materials that cannot be attracted to a magnet.

Definition 20.1.3: Law of Magnetic Poles

The law of magnetic poles states that like poles repel and unlike poles attract.

Some properties magnets exhibit are

- Magnets have two poles: north and south.
- Magnets point in the north-south direction when suspended.
- Like poles repel, unlike poles attract.

Using the property that magnets can repel, we can do the repulsion test to see if an object is a magnet or just a magnetic material.

20.2 Magnetic Induction

Definition 20.2.1: Magnetic Induction

Magnetic induction is the process whereby an object made of a magnetic material becomes a magnet when it is near or in contact with a magnet.

That means magnetic materials become magnets when in contact or near a magnet.

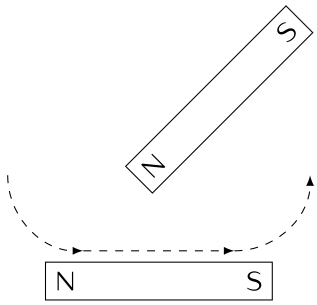
20.3 Magnetisation and Demagnetisation

Definition 20.3.1: Theory of Magnetism

(This is not in syllabus.) A magnet is made up of many magnetic domains which are made up of atoms that have a ferromagnetic property.

20.3.1 Magnetisation

You can make a magnet either by stroking it with another magnet, or using electricity to make an electromagnet.



The pole that touches the magnetic object first will be the pole of that magnetic object at that point.

For the electromagnet, refer to chapter 21.

20.3.2 Demagnetisation

To demagnetise a magnet you first have to orient it in the **east-west direction**. Then there are three ways to do this.

1. **Hammering:** Hammering a magnet placed in the east-west direction alters the alignment of the magnetic domains, causing the magnet to lose its magnetism.
2. **Heating:** Strongly heating a magnet and letting it cool in an east-west orientation will cause the magnet to lose its magnetism. The temperature to heat the magnet up to such that the atoms lose the magnetism is called the Curie temperature.
3. **Electrical Method:** Place a magnet in a solenoid in the east-west direction and connect an alternating current supply. Withdraw the magnet while the alternating current is flowing in the solenoid until it is some distance away.

20.4 Magnetic Fields

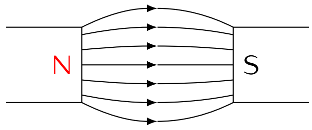
Definition 20.4.1: Magnetic Field

A magnetic field is the region surrounding a magnet, in which a body of magnetic material experiences a magnetic force.

Magnetic field lines **cannot cross**.

Magnetic monopoles **do not exist**.

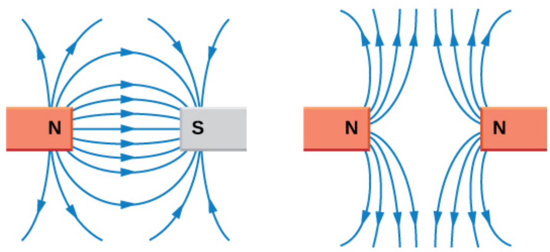
Field lines point from **north poles** to **south poles.** Like electric fields, the closer the field lines are, the stronger the magnetic field at that point.



The magnetic field of a magnet can be plotted by sprinkling iron filings around it, or plotting it with a plotting compass.

To use a plotting compass, align a magnet in the north-south direction first. Then using a plotting compass, from the north pole of the magnet, draw a point at where the compass points to. Then continue this and connect the lines. Remember that plotting compasses point in the direction of the field lines.

For attraction and repulsion of two magnetic poles use this lovely diagram that I could not draw so I had to source it online.



Magnetic field lines between unlike poles

Magnetic field lines between like poles [3]

20.5 Temporary and Permanent Magnets

Magnetic materials can either be "soft" or "hard". An example of a soft magnetic material is iron. An example of a hard magnetic material is steel.

- **Magnetisation**
  - Hard magnetic materials are difficult to magnetise and demagnetise.
  - Soft magnetic materials are easier to magnetise and demagnetise.
- **Uses**

[3] phys.libretexts.org

– Hard magnetic materials are used to make permanent magnets.

– Soft magnetic materials are used to make temporary magnets.

- **Interaction with Field Lines**

  – Hard magnetic materials do not allow magnetic fields to pass through it as easily as soft magnetic materials.

  – Soft magnetic materials allow magnetic fields to pass through it with ease.

21 Electromagnetism

Preamble

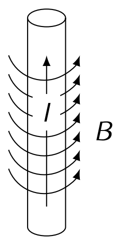
What happens when you combine electricity and magnetism? You get electromagnetism!

21.1 Induced Magnetic Fields

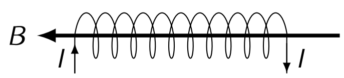
Definition 21.1.1: Induced Magnetic Field

A current-carrying conductor produces a magnetic field around it.

To identify the direction of the magnetic field or current, use the right-hand corkscrew rule.



It works for solenoids too. Just swap the current and magnetic field. Use the same hand, though.



Equation 21.1.1: Ampere's Law for Wires

The magnetic field strength of a current-carrying wire increases when the current is increased.

$$B \propto I$$

Equation 21.1.2: Ampere's Law for Solenoids

The magnetic field strength of a current-carrying solenoid increases when the current or the number of turns is increased.

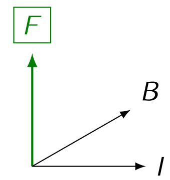
$$B \propto nI$$

21.2 The Motor Effect

Definition 21.2.1: The Motor Effect

When a current-carrying conductor is placed in a magnetic field, the conductor experiences a force. This effect on the conductor is called the motor effect.

The direction of the force can be determined with Fleming's left-hand rule.

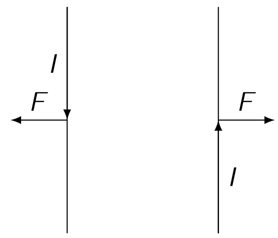


Left-hand rule is for induced force.

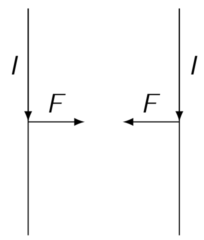
21.2.1 Two Wires

If we have two current-carrying wires, they can either attract or repel each other.

In the case of currents in the **opposite** direction, the two wires **repel** each other.



In the case of currents in the **same** direction, the two wires **attract** each other.



These results can be derived from Fleming's left-hand rule in the examination.

21.2.2 Charges in Magnetic Fields

First, some notation: $\odot$ means current is coming out of the paper, $\otimes$ means current is going in to the paper.

You should use Fleming's left-hand rule to determine where the charges would go. In the case of a positive charge, the current points **towards** where the positive charge is going; in the case of a negative charge, the current points **opposite** where the negative charge is going.

21.3 DC Motors

Some important parts of the DC motor:

- **Split-ring commutator:** to reverse the current every half revolution so that the motor can continue spinning.
- **Carbon brushes:** to ensure electrical contact between the split-ring commutator and the circuit.

The turning effect on a current-carrying coil in a DC motor can be increased by

- inserting a soft iron core into the coil;
- increasing the number of turns in the coil;
- increasing the current in the coil.

22 Electromagnetic Induction

Preamble

In the previous chapter we saw how a current can induce a magnetic field. In this chapter we will see the other side: how a magnetic field can induce a current.

22.1 Fundamentals

Definition 22.1.1: Electromagnetic Induction

Electromagnetic induction is the process through which an induced electromotive force is produced in a conductor due to a changing magnetic field.

The two laws of electromagnetic induction are:

Definition 22.1.2: Faraday's Law

Faraday's Law of electromagnetic induction states that the magnitude of the induced electromagnetic force is directly proportional to the rate of change of magnetic flux in the circuit.

$$\varepsilon \propto \frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

Keep in mind it is the **change** in magnetic flux. If you put a coil of wire in a magnetic field and there is **no change**, then there is **no induced electromotive force**.

Definition 22.1.3: Lenz's Law

Lenz's Law states that the direction of the induced electromotive force, and hence the induced current in a closed circuit, is always such that its magnetic effect opposes the motion or the change producing it.

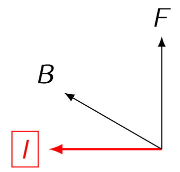
Equation 22.1.1: Faraday's Law for Solenoids

(This is not in syllabus.) Faraday's Law can be mathematically expressed as

$$\varepsilon = -N\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

22.2 AC Generators

The current flowing in the coil can be found using Fleming's right-hand rule.

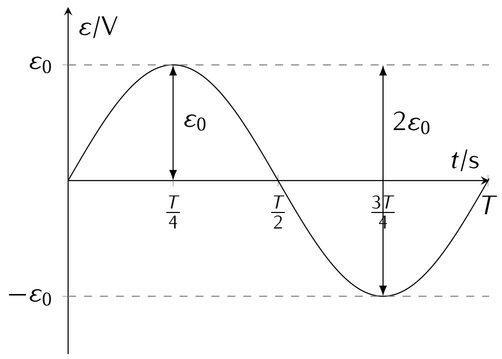


Right-hand rule is for induced current.

Some important parts of the AC generator:

- **Armature:** the coil of wire mounted on the axle.
- **Slip Rings:** to ensure that the induced current in the coil is transferred to the external circuit.

The output voltage is a sinusoidal wave.

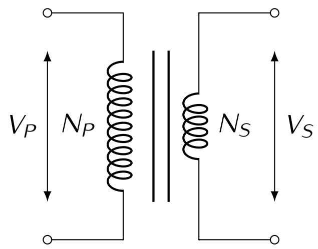


22.3 Transformers

Definition 22.3.1: Transformer

A transformer is a device that can change a high alternating voltage (at low current) to a low alternative voltage (at high current), or vice versa.

- **Primary coil:** connected to an alternating voltage V_P;
- **Secondary coil:** output of the induced voltage V_S;
- **Laminated soft iron core:** comprises of this sheets of soft iron. Because it is easily magnetised and demagnetised, this ensures better magnetic flux linkage between the two coils.



Equation 22.3.1: Turns Ratio

The turns ratio of a transformer is calculated by

$$\frac{N_P}{N_S} = \frac{V_P}{V_S}$$

The type of transformer can be determined from its turns ratio.

$$\text{type of transformer} \begin{cases} \text{step-up transformer} & N_S > N_P \\ \text{step-down transformer} & N_S < N_P \end{cases}$$

Equation 22.3.2: Conservation of Power

Power is conserved in an ideal transformer,

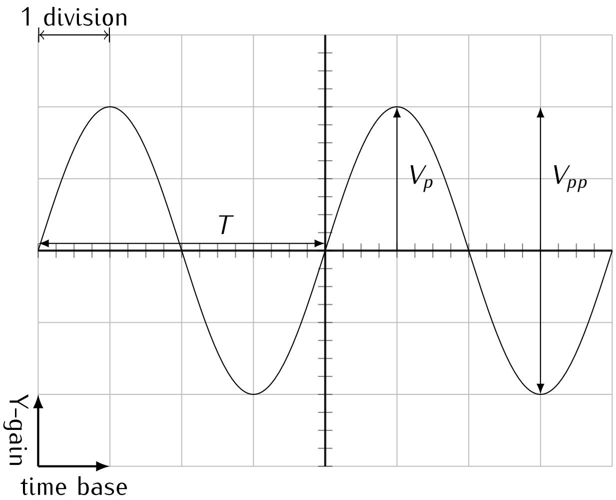
$$V_P I_P = V_S I_S$$

22.4 Cathode Ray Oscilloscopes

Definition 22.4.1: Oscilloscope

Oscilloscopes are instruments used to observe how a voltage varies over time.

The graphic below shows an example of what a voltage varying over time might look like.



Keep in mind that V_p, *peak* voltage does *not* necessarily refer to V_P, *primary* voltage. The p and P are different.

When reading an oscilloscope, always first identify the time base, in seconds/division [s/div], and the Y-gain, in volts/division [V/div].

Equation 22.4.1: Complete Cycles

The number of complete cycles of a voltage with frequency f_y shown in the oscilloscope with frequency of the time base $f_x = (\text{time base})^{-1}$ is given by the ratio

$$\frac{f_y}{f_x}$$

End of Document

Have fun studying and all the best for your examinations!

https://github.com/kangzhe3067/physicsNotes