# Physics Handout

## A handout for IBDP Physics

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*Wir müssen wissen,wir werden wissen*

*We must know, we would know*

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# Chapter 1 Uncertainty and measurement

## 1.1 Significant-figure

**Definition 1.1 (Significant-figure)**

***Significant figures***(s.f.) *of a number in positional notation are digits in the number that are reliable and necessary.[**enwiki:1125233395**] which follows the rules below:*

- *All non zero numbers are significant figures.*
- *All leading zeros are **not** significant figures. For example: 0.001 is 1 significant figure number.*
- *Trailing zeros when they are merely placeholders. For example: 0.12000 is 2 significant figures.*

♣

**Theorem 1.1 (Arithmetic with s.f.)**

*The Arithmetic with significant figures are separate into 2 kinds first is addition the second is multiplication such that satisfy:*

- *The result of **addition and subtraction** should have the same number of the smallest decimal places.*
- *The result of **multiplication and division** should have the same number of the least significant figures*

♡

## 1.2 Errors

### 1.2.1 Systemic error

**Definition 1.2 (Systemic error)**

*Systemic error is error which it is not a random event, in another way it is accurate but not*

♣

## 1.3 Uncertainty

**Definition 1.3 (Absolute uncertainty)**

♣

**Note** *Note that the absolute uncertainty only contains one s.f.*

**Definition 1.4 (Fractional uncertainty)**

♣

**Definition 1.5 (Percentage uncertainty)**

♣

**Theorem 1.2 (Calculation with uncertainty)**

♡

# Chapter 2 Mechanics

**Lemma 2.1 (Data booklet)**

*Data Booklet of this chapter:*

$$v = u + at \tag{2.1}$$

$$s = ut + \frac{1}{2}at^2 \tag{2.2}$$

$$v^2 = u^2 + 2as \tag{2.3}$$

$$s = \frac{v + u}{2t} \tag{2.4}$$

*where $s$ is the displacement, $v$ is final velocity, $u$ is initial velocity, and $a$ is acceleration, $t$ is time.* ♡

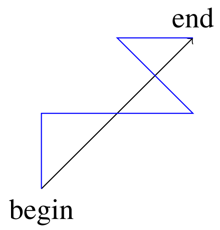
## 2.1 Displacement and Distance

The aim of this chapter is going to let us have a better understanding of what is motion and how we can describe or calculate the variables in motion using the concepts.

**Definition 2.1 (Distance)**

***Distance*** *is a measurement of how far does an object traveled without consider it's direction.* ♣

Therefore it's easy see that distance is depends on the route of object traveled. Please note that distance is a scalar rather than vector.




In the figure above, the blue line is the distance of an object moved from the begin to the end. And the black line is the displacement the object moved. Hence we can make the conclusion that the displacement of a motion only depends on its begin point and the end point.

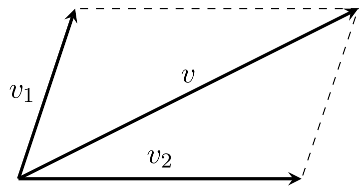
**Definition 2.2 (Displacement)**

***Displacement*** *is a vector whose length is the shortest distance from the initial to the final position.* ♣

**Note** *Please note that Displacement is a vector quantity.*

## 2.2 Speed, Velocity and Acceleration

**Note** *We use the law of parallelograms to represent the Synthesis and decomposition of velocity (or any vector)*




**Definition 2.3 (Speed)**

***Speed*** *is distance divided by time, with disregard to direction.*

$$speed = \frac{distance}{time} \tag{2.5}$$

♣

**Note** *Note that speed is a scalar.*

And the concept ”instantaneous speed” is different from the speed. From a mathematical point of view we can describe the instantaneous speed as the rate of change of position with respect to time.

**Remark** Instantaneous speed is the rate of change of position with respect to time.

**Definition 2.4 (Velocity)**

***Velocity*** *is a measure of how fast an object moves through a Displacement*

$$v = \frac{\Delta x}{\Delta t} = \frac{s}{t} \tag{2.6}$$

♣

**Note** *This vector $v$ has the same direction as $\Delta r$.*

**Corollary 2.1**

*We call the limit as $\Delta t$ approaches zero in the equation $v = \frac{\Delta x}{\Delta t}$ as the instantaneous velocity.*

♡

**Note** *Note that Instantaneous velocity is along the tangent to the path.*

Therefore we have a general idea of what is velocity. But in this case how can we measure the in-changing velocity? Hence we define a new physical quantity–acceleration.

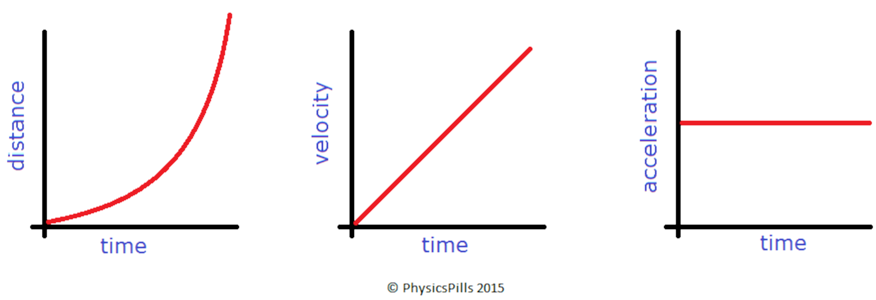
**Definition 2.5**

***Acceleration*** *is the change in velocity over time.*

$$a = \frac{\Delta v}{\Delta t} \tag{2.7}$$

♣

In this case we can easily guess that the identity of acceleration in a $v - t$ graph will be the gradient of v. Hence we can find out the relationship in one graph:




After discuss the ideal situation let’s first consider a question in the real life ”Whether a ball in the air which are dropping will reach a final velocity?” The answer is yes. In this case, the air resistance is not ignored therefore at the last the force of air resistance will be the **same** as the weight of the object but in opposite direction. We call the velocity when it does not change any more in the free fall motion as **terminal velocity**

**Definition 2.6**

*Terminal velocity is the maximum velocity (speed) attainable by an object as it falls through a fluid (air is the most common example).* ♣

When the acceleration is constant the motion of an object can be describe into 4 equations. I am not going to give out the prove these equations, you can find out these proof in the text book. (which first appear in the data booklet.)

**Corollary 2.2 (kinematic equations)**

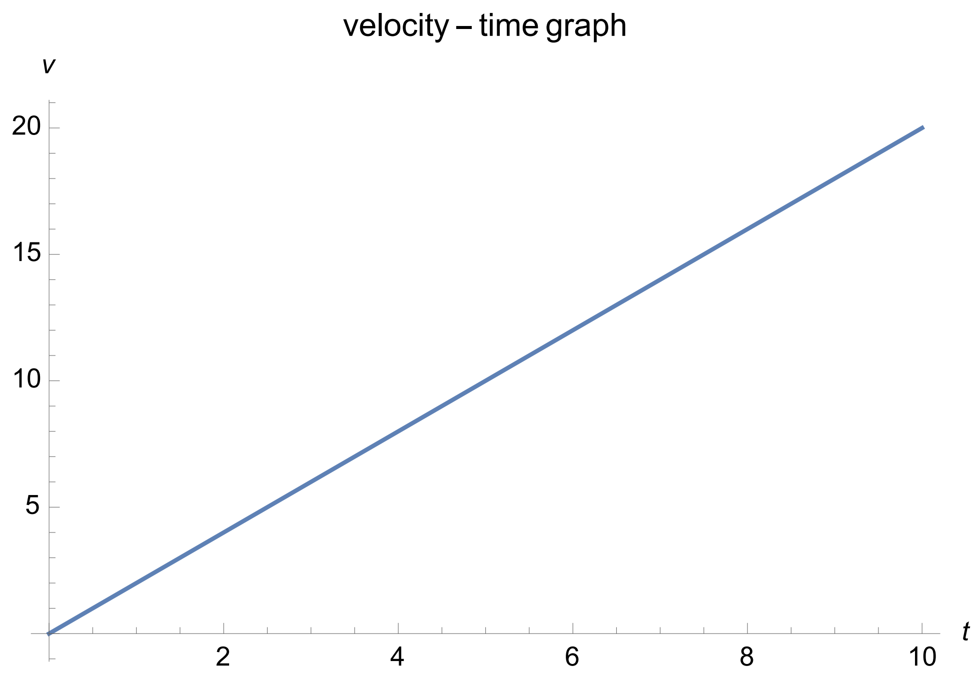
- $s = ut + \frac{1}{2}at^2$ *Displacement*
- $v = u + at$ *Velocity*
- $v^2 = u^2 + 2as$ *Timeless*
- $s = \frac{v+u}{2t}$ *Average displacement*

♡

**Note** *Note that these formulae can only be used when we have constant acceleration and motion on a straight line.*

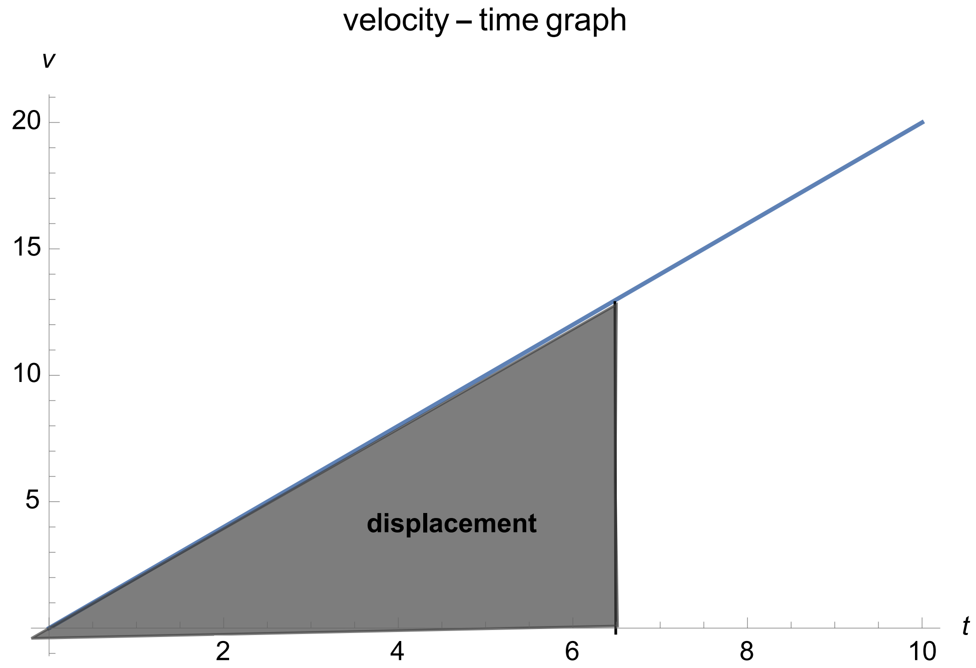
## 2.3 Analysis the graph

In the exam we are often given a graph of velocity vs. time which are similar like below. Hence we can using this kind of graph to find out very much informations which are very useful and help you better understand the concept.Let's have an example of a uniform motion.




By the concept of $displacement = velocity \times time$ we can inference that the area between the motion graph and $x - axis$ is the measurement of displacement.

**Theorem 2.1**
*The Displacement in a Velocity,time graph is the area between the motion graph and the $x - axis$* ♡

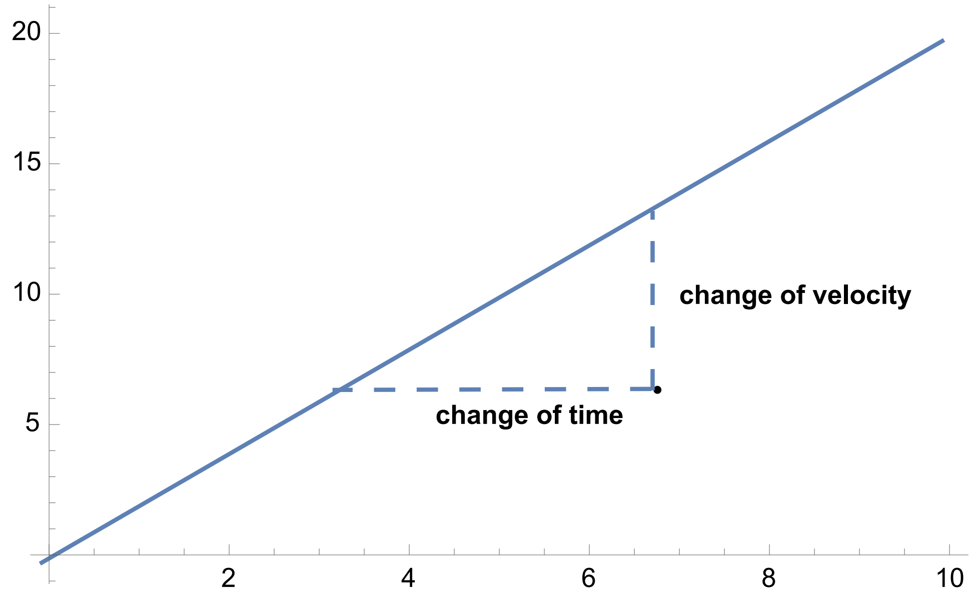



Now let's move our line of sight to the slope(gradient) of this graph.

**Definition 2.7**
*The **slope(velocity)** is a number that describes both the direction and the steepness of the line. Which give by equation:*

$$s = \frac{\Delta y}{\Delta x} \tag{2.8}$$

*where $\Delta$ means "change of"* ♣




The slope also represent a physical quantity. Which is acceleration of motion.

**Theorem 2.2 (slope-acceleration)**

*The **slope** of velocity & time graph represent the acceleration of this motion.*

**Proof** 2.2 We denote the slope of velocity & time graph as $a$. Hence the equation of slope is $a = \frac{\Delta y}{\Delta x} = \frac{\Delta v}{\Delta t}$2.2 review the concept of acceleration we found that it is the same expression of the slope. Hence the slope in velocity & time graph is same measure as acceleration.

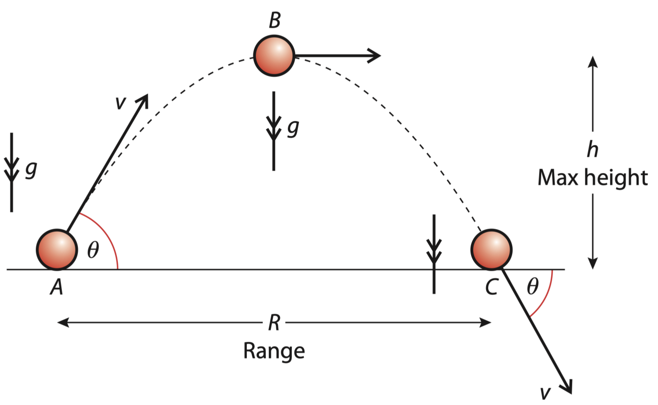
Analysis the graph is an important skill while having your exam. We change the abstract numbers into a visualize graph.

## 2.4 Projectile motion

A projectile is an object that has been given an initial velocity by some sort of short-lived force, and then moves through the air under the influence of gravity.

**Remark** Notice that the acceleration of vertical movement is a constant $g$ hence we can use the 4 equations.2.2

Lets give an example:




There are few special position which are A, B and C while you analysis the graph you can see that the acceleration($g$) never change but the direction of movement is changing.

**Property** *While the movement of a projectile motion is upwards then the acceleration in the equation should be negative. When it is downwards it should be positive.*

**Corollary 2.3**

*While the object is in the position of B*

- $0 = v^2 sin^2(\theta) - 2gh$
- $h = v \cdot sin(\theta)t - \frac{1}{2}g(\frac{t}{2})$

*While the object is in the position of C*

- $0 = vsin(\theta)t - \frac{1}{2}gt^2$

Hence you can use these equations to solve the questions.

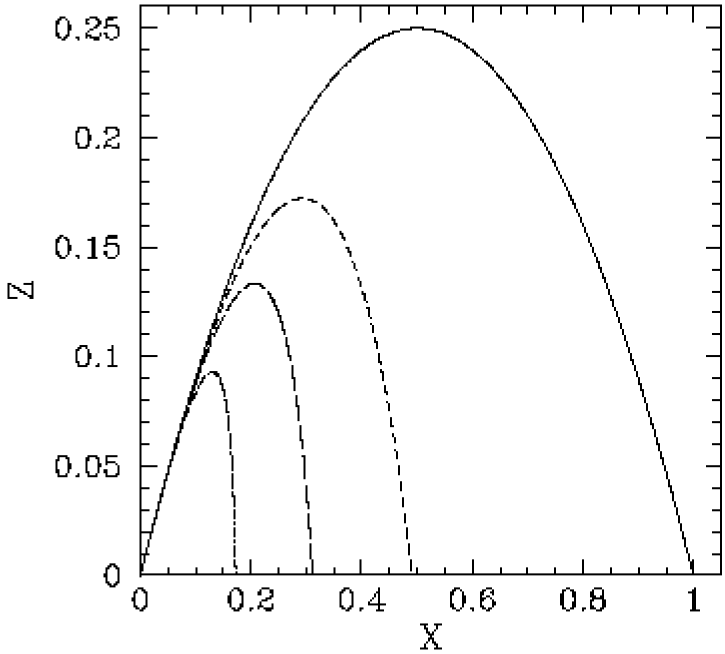
**Note** *Note that you are not forced to remember these formulas. In most of the cases, the 4 equations2.2 is more useful.*

### 2.4.1 Projectile motion with air resistance

For projectile motion in the unideal conditions one of the biggest factor is the air resistance.

**Theorem 2.3**
*The projectile motion with air resistance both the height and range are less. It is also no longer a parabola(quadratic function) – the way down is steeper than the way up.* ♡

For example in the graph




Notice that under the air resistance both the height and range are less. It is also no longer a parabola – the way down is steeper than the way up.

## 2.5 Force and Newton's Law

**Definition 2.8**
*Force is a vector quantity which describe a pull or a push with units in ($N$, Newton).* ♣

Force is a very abstract concept with many ways to describe.

**Example 2.1** Tension force —- If you attach a rope to a body and pull it, the rope is in tension. This is also the name of the force exerted on the body.

**Example 2.2** Gravitational force —- We know that all objects experience a force that pulls them downwards; we call this force the weight. The direction of this force is always towards the centre of the Earth.

### 2.5.1 Newton's 1st Law

**Definition 2.9 (Newton's 1st Law)**
*A body remains at rest, or in motion at a constant speed in a straight line, unless acted upon by a force.[1]* ♣

**Remark** In general, the Newton's 1st law state that an object's net force is zero when it's speed is constant.

$$F_{net} = 0N \tag{2.9}$$

Therefore we can see that the result force is zero if and only if the speed is zero or in a stationary speed.

### 2.5.2 Newton's 2nd Law

**Definition 2.10 (Newton's 2nd Law)**

*When a body is acted upon by a force, the time rate of change of its momentum equals the force.[1]* ♣

**Remark** In short, the Newton's 2nd law is saying that the force is proportion to the

### 2.5.3 Resolve the Force

**Example 2.3** Consider the question: What is the result(net) force on an object at a Sloping slopes.

**Solution** *The question can be shown in the graph.*

# Chapter 3 Circular Motion

A force applied perpendicular to a body's displacement can result in its circular motion.

**Lemma 3.1 (Data booklet)**

*The data booklet of this chapter:*

$$v = \omega r \tag{3.1}$$

$$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2} \tag{3.2}$$

$$F = \frac{mv^2}{r} = m\omega^2 r \tag{3.3}$$

♡

**Definition 3.1**

***Circular motion** is a movement of an object along the circumference of a circle or rotation along a circular path.*

♣

**Theorem 3.1**

***Uniform circular motion** is a motion of a particle travels in a circle (or arc) with constant speed $v$.* ♡

## 3.1 Centripetal Velocity, Acculturation and Force

The magnitude of the velocity vector $v$ is NOT changing, however the direction of the velocity is changing. Note that although the velocity is constant but the acceleration is NOT zero in the circular motion.

**Definition 3.2**

***Centripetal acceleration** is the acceleration which always have a direction to the center of the circle.*

$$a_c = \frac{v^2}{r} \tag{3.4}$$

♣

**Note** *Remember that the direction of the velocity is always perpendicular to the acceleration in the circular motion.*

Since we have learned the Newton's second law $F = ma$, similarly we define the force in circular motion

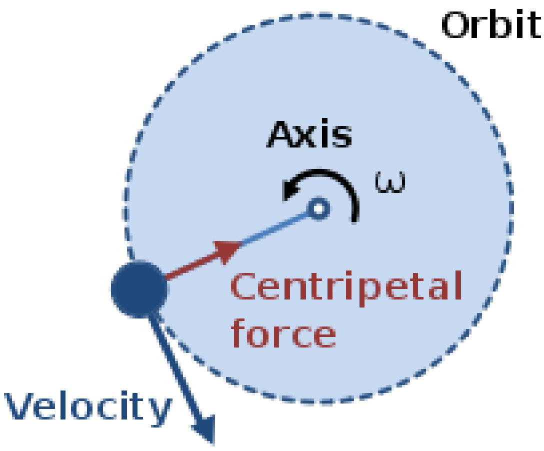
**Definition 3.3**

*The **centripetal force** is defined as*

$$F_c = ma_c \tag{3.5}$$

♣

**Note** *Please note that the Centripetal force is not a real force! Hence please DO NOT draw centripetal force on the graph. You can draw tension force, friction force, gravitational force, etc.*

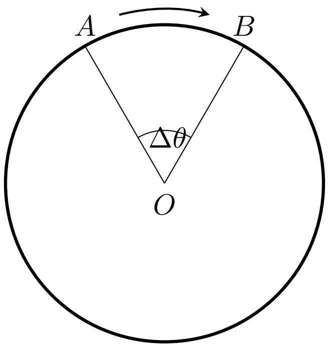



**Definition 3.4 (Frequency and period)**

*The **period** $T$ is the time for one complete revolution. And the **frequency** $f$ is defined as how many cycles (oscillations, repetitions, revolutions) occur each second. Therefore the relationship with this two quantities are:*

$$f = \frac{1}{T}\text{ , or } T = \frac{1}{f} \tag{3.6}$$

♣




## 3.2 Angular Velocity, Displacement and Momentum

**Definition 3.5**

*The **Angular displacement** $\theta$ of a body is the angle (in radians, degrees or revolutions) through which a point revolves around a centre or a specified axis in a specified sense.*
*For the length of the circle which in that angular displacement is defined as **Arc Length** $s$.*

♣

**Lemma 3.2 (Transformation of radian)**

*The relation of radian and angle is:*

$$Radian = \frac{angle}{360°} \times 2\pi \tag{3.7}$$

♡

In this case we have a new way to represent the displacement in the circular motion. Hence we will define a new quantity to represent the speed which called Angular Speed.

**Definition 3.6 (Angular velocity)**

***Angular speed*** *is defined as the rate of change of angular displacement per unit.(The magnitude of angular velocity)*

$$\omega = \frac{\theta}{t} = \frac{2\pi}{T} = 2\pi f \ \ (rads^{-1}) \tag{3.8}$$

♣

**Note** *Angular speed is also called angular frequency.*

We already know the relation between the displacement and the angular displacement (or the relation between angle and radian).

**Theorem 3.2**

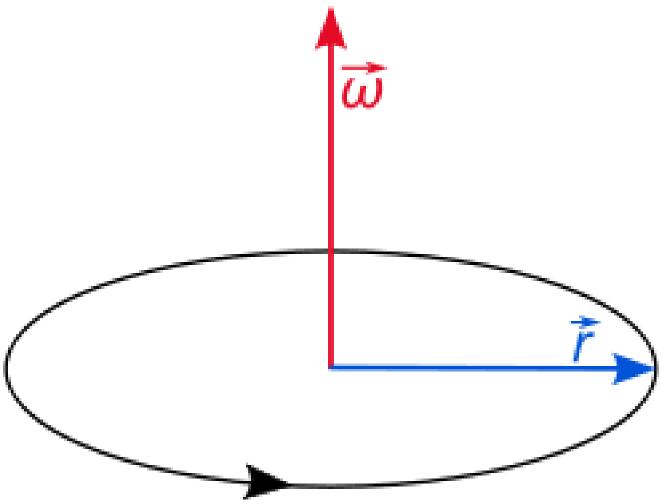
*The relation between the speed $v$ and $\omega$ is :*

$$v = \omega \cdot r \tag{3.9}$$

♡

As speed with a direction is called velocity, angular speed with a direction is called angular velocity.To assign a direction to a rotation we use a right hand rule as follows:

- Rest the heel of your right hand on the rotating object.
- Make sure your fingers are curled in the direction of rotation.
- Your extended thumb points in the direction of the angular velocity.




## 3.3 Banking

The benefit of banking is the horizontal component of the normal force will provide the centripetal force. No side way friction is needed.

# Chapter 4 Thermal Physics

## 4.1 Ideal gas

**Definition 4.1 (Ideal gas)**

*Ideal gas is an imaginary gas that is used to model real gases which follows:*

$$PV = nRT \tag{4.1}$$

*Where $P$ is pressure*
*$V$ is volume*
*$n$ is mole number*
*$R$ is gas constant $= 8.314JK^{-1}mol^{-1}$*
*$T$ is the temperature of the system.*

**Remark** Please do not worry about this equation, I would explain it later step by step.

**Property** *Ideal gas has the properties below:*

- *Molecules are identical perfect spheres*
- *Molecules are perfect elastic.(The momentum and kinetic energy is conserved)*
- *There are no intermolecular forces such as van dee wal force or hydrogen bonding.*
- *Ideal gas can not be liquefied*

**Note** *The real gas is similar to the ideal gas when pressure is low and the volume is large*

**Definition 4.2 (Pressure)**

*Pressure (symbol:$p$ or$P$) is the force applied perpendicular to the surface of an object per unit area over which that force is distributed.*

$$P = \frac{F}{A} \tag{4.2}$$

*where $P$ is pressure and $F$ is force $A$ is the area which force acting on.*

**Remark** Hence you can see that the pressure only depends on the force and the area.

**Theorem 4.1**

*The Pressure is proportion to the temperature. (when the number of particle and volume is constant)*

$$P \propto T \tag{4.3}$$

**Proof** The pressure increase with the increase of temperature because the force between collision with the walls and molecules increases. At the same time the number of collision is increase.

**Theorem 4.2 (Boyle's law)**

*The pressure is inverse proportional to the volume. (when the number of particle and temperature is constant)*

$$P \propto \frac{1}{V} \tag{4.4}$$

**Proof** For smaller volume the frequency of collision between molecules and wall and molecules increases.

**Definition 4.3 (Mole)**

*Mole is a unit to count the numbers of particles.*

$$n = \frac{N}{N_A} \tag{4.5}$$

*Where $n$ is mole number, $N$ is number of particles in the system, $N_A$ is Avogadro constant*

**Note** $N_A = 6.022 \times 10^{23}$

**Theorem 4.3 (Avogadro's law)**

*The volume is proportion to the mole number.(when pressure and temperature is constant)*

$$V \propto n \tag{4.6}$$

**Proof** It is an empirical formula

Hence by listing the theorem above we can combine them into one equation which the ideal gas equation.

### 4.1.1 Average Kinetic energy and Internal energy in ideal gas

**Definition 4.4 (Average K.E. in Ideal gas)**

$$\overline{E}_k = \frac{3}{2}\frac{R}{N_A}T \tag{4.7}$$

**Note** *It is average energy of one atom or molecule.*

**Theorem 4.4**

*In ideal gas the kinetic energy is equal to the internal energy, since the potential energy is zero.*

$$Internal\ energy = K.E. + P.E.(0) = K.E. \tag{4.8}$$

**Example 4.1** What's the Internal energy of $N$ molecules ideal gases?

$$\begin{aligned} E = N \cdot \overline{E_k} &= N(\frac{3}{2}\frac{R}{N_A}T) \\ &= \frac{3}{2}\frac{N}{N_A}RT \\ &= \frac{3}{2}nRT = \frac{3}{2}PV \end{aligned}$$

**Theorem 4.5 (Internal energy of ideal gas)**

$$E = \frac{3}{2}nRT = \frac{3}{2}PV \tag{4.9}$$

# Chapter 5 Wave phenomena(HL)

## 5.1 Oscillation

**Definition 5.1 (Oscillation)**

*Oscillation is vibration which repeat themselves.* ♣

## 5.2 Simple harmonic motion

Simple harmonic motion is a special type of periodic motion where the restoring force on the moving object is directly proportional to the magnitude of the object's displacement and acts towards the object's equilibrium position. Simple harmonic motion can serve as a mathematical model for a variety of motions, but is typified by the oscillation of a mass on a spring when it is subject to the linear elastic restoring force given by **Hooke's law**.

**Definition 5.2 (Simple Harmonic Motion Discriminating)**

$$a = -\omega^2 x \tag{5.1}$$

♣

**Remark** Where we can describe this equation by:

- Acceleration is in the opposite direction of displacement
- Acceleration is proportional to displacement

Therefore this leads to this most important inference.

**Theorem 5.1 (S.H.M.)**

*The acceleration in S.H.M. must be proportional and in the opposite direction to the displacement.* ♡

Oscillation is a kind of reciprocating motion(repeating motion), and the displacement of the Oscillation object can not continue to increase like uniform or variable speed linear motion, but has a maximum displacement, otherwise it will not be a vibration. The maximum distance that vibrating objects leave the equilibrium position is called the amplitude.

Hence we can define the amplitude

**Definition 5.3 (Amplitude)**

*Amplitude is the maxium displacement in an oscillation.* ♣

Therefore we are wondering other physical quantity in an oscillation. For example how long does it finish a whole oscillation. We name it "period"

**Definition 5.4 (Period)**

*Period is the time that finish a whole oscillation.* ♣

### 5.2.1 Single pendulum

## 5.3 Single-slit diffraction

### 5.3.1 Double-source interference

**Definition 5.5 (Interference)**

*Interference is a phenomenon in which two waves combine by adding their displacement together at every single point in space and time, to form a resultant wave of greater, lower, or the same amplitude.* ♣

Constructive and destructive interference result from the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency.[**enwiki:1123025965**]

**Theorem 5.2 (Constructive inteference)**

*Constructive interference occurs when*

$$PS_1 - PS_2 = n\lambda \tag{5.2}$$

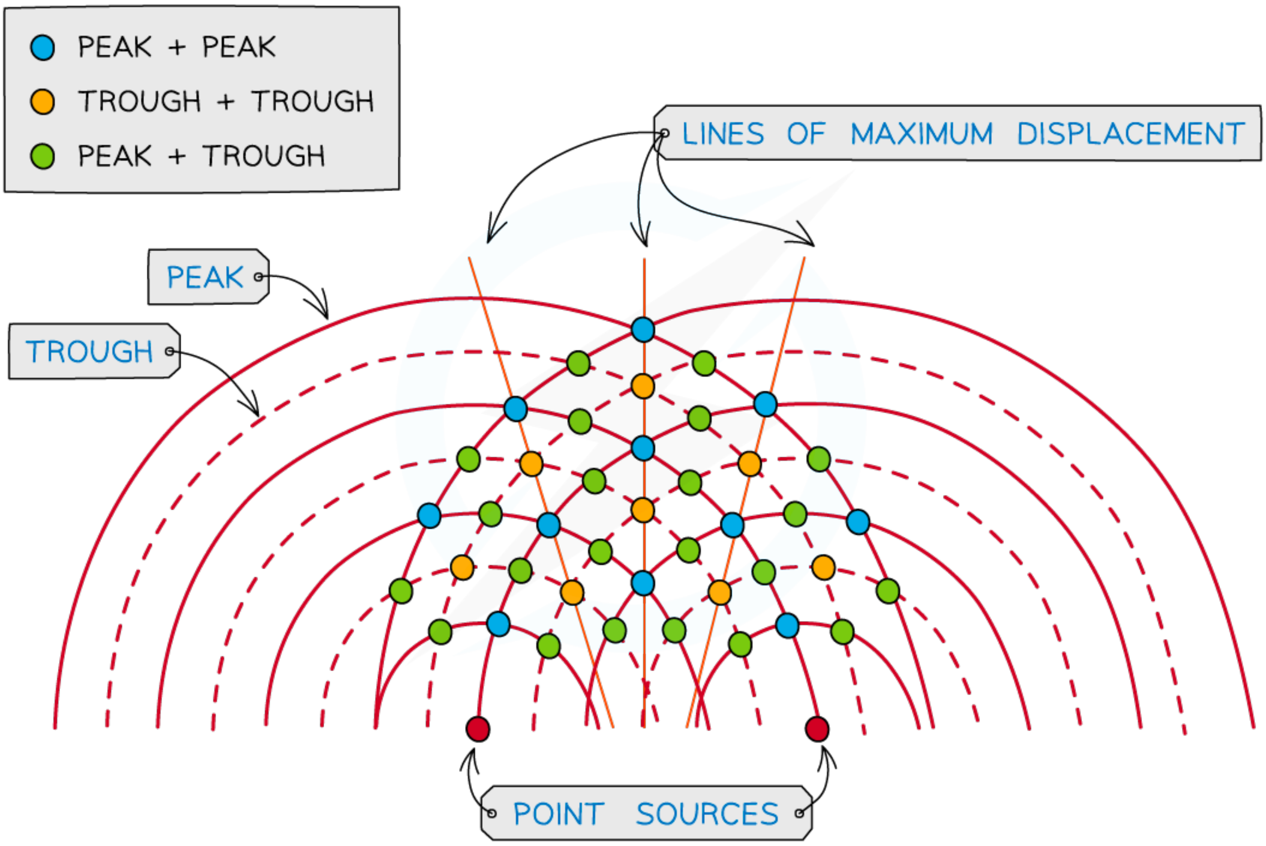
*Where $PS$ is the distance from a point to the resource of wave.* ♡

**Theorem 5.3 (Destructive interference)**

*Destructive interference occurs when*

$$PS_1 - PS_2 = (n - 0.5)\lambda \tag{5.3}$$

♡





### 5.3.2 Single-slit diffraction

In the single-slit diffraction experiment, we can observe the bending phenomenon of light or diffraction that causes light from a coherent source to interfere with itself and produce a distinctive pattern on the screen called the diffraction pattern.

**Theorem 5.4 (The angle of 1st minimum)**

*The angle of 1st minimum equation is defined as :*

$$\theta = \frac{\lambda}{b} \tag{5.4}$$

*Where*

- $\theta$: *angle(radian)*
- $\lambda$: *wavelength*
- $b$: *width of slit*

♡

# Chapter 6 Fields

Electric charges and masses each influence the space around them and that influence can be represented through the concept of fields.

**Lemma 6.1**

*The data booklet of this chapter is:*

| *GRAVITATIONAL* | *ELECTROSTATIC* |
|---|---|
| $g = -\frac{\Delta V_g}{\Delta r} = -G\frac{M}{r^2}$ | $E = k \cdot \frac{q}{r^2}$ |
| $V_g = -G\frac{M}{r}$ | $V = k \cdot \frac{q}{r}$ |
| $F_g = -G\frac{Mm}{r^2}$ | $F = k \cdot \frac{q_0 q}{r^2}$ |
| $P.E. = mV_g = -G\frac{Mm}{r}$ | $P.E. = qV = k \cdot \frac{qq_0}{r}$ |

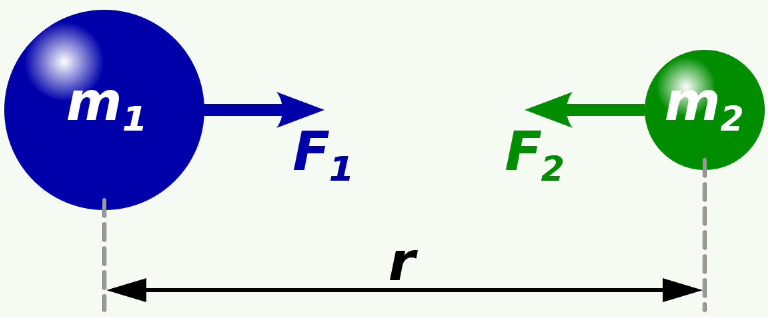
*where $k$, $G$ are both constant, $P.E.$ represent the potential energy.* ♡

**Definition 6.1**

*The **Gravitational Field Force** has formula :*

$$F_g = -G\frac{m_1 m_2}{r^2} \tag{6.1}$$

*where $G$ is gravitational constant, $m_1$ is the mass of the first object, $m_2$ is the second object in a system.*




♣

**Note** *Note that the reason of the negativity of Gravitational force is because the direction of this type of force is always attraction to each other.*

While we have learned the definition of energy and work of a force is $E(W) = Fd \cdot cos(\theta)$. In the similar way we are able to define the work done by gravitational force. Which we call it **Gravitational Potential Energy**.

**Definition 6.2**

*The **Gravitational Potential Energy** is:*

$$E_p(P.E.) = F_g \times r = -G\frac{m_1 m_2}{r} \tag{6.2}$$

Therefore we can define the potential of gravitational fields which is the **work done per unit mass to move a small object from infinite to a radii.**

**Definition 6.3**

*The Gravitational potential is the work done per unit mass to move a small object from infinite to a radii.*

$$V_g = -G\frac{M}{r} \tag{6.3}$$

**Note** *Note that Gravitational potential is derived from gravitational potential energy and is thus a scalar. There is no need to worry about vectors.*

Draw the Equipotential surface is the visualized way to represent the Gravitational Potential. And it is helpful for your "in mind 3D model" if you understand it.

**Definition 6.4**

*The Equipotential surface are imaginary surfaces at which the potential is the same.*

But in this case how do we describe the strength of gravitational field? Therefore we define g which represent the gradient of potential field

## 6.1 Celestial motion

For a satellite

## 6.2 Electrostatic

**Definition 6.5**

*The elementary charge* $e = 1.6 \times 10^{-19}C$