Physics Notes

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Abstract

These notes are written by myself, which means they are prone to typos and errors. If you find an error, do contact me so I can take remedial action, or give you access to the Github repository for you to push any changes.

Use these notes with caution.

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: Physical Quantity**
>
> A physical quantity is a quantity consisting of a **numerical magnitude** 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

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

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 1.2: Scalar Quantity**
>
> A scalar quantity has a magnitude, unit, but **no** direction.

> **Definition 1.3: Vector Quantity**
>
> A vector quantity has a magnitude, unit, and direction.

1.4 Vector Addition

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

> **Equation 1.1: Magnitude of Vectors**
>
> The magnitude of a vector $\vec{v}$ with components $\vec{v_x}$ and $\vec{v_y}$ is given by
>
> $$|\vec{v}| = \sqrt{|\vec{v_x}|^2 + |\vec{v_y}|^2}$$

1.5 Measurement

1.5.1 Precision and Accuracy

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

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: ± 0.01 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 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 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: ± 0.001 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 mm subdivisions), take the reading that is on the left of the circular scale, x_{datum}.

5. On the circular scale (with 0.01 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 1.2: Period of Simple Pendulum

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

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

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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: 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 2.2: 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

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Equation 2.1: Average Speed

The average speed of an object is given as

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

Soeed is a *scalar* quantity.

Definition 2.3: Average Velocity

The average velocity of an object is the change in rate of change of displacement of the object from the origin point.

Equation 2.2: Average Velocity

The average velocity of an object can be computed as

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

Definition 2.4: 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 2.3: 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 2.5: Acceleration

Acceleration is the rate of change of velocity.

Equation 2.4: 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.
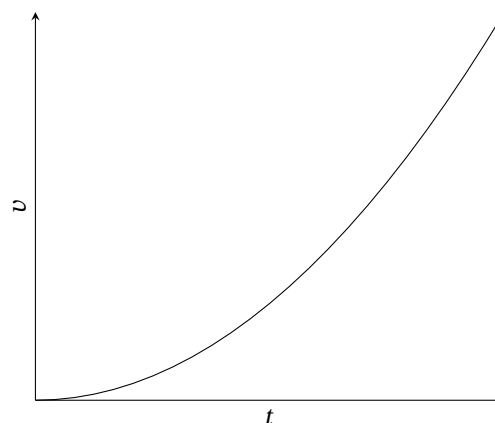
2.4.1 Displacement-time Graph

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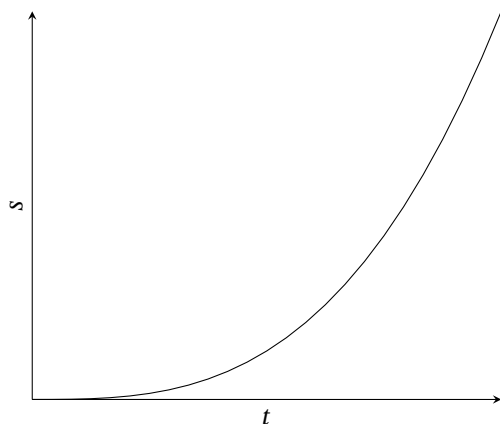
The gradient of a displacement-time graph tells us its **velocity**.

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.


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

2.5 Freefall

Definition 2.6: 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.
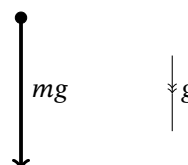
2.6 Air drag

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: 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: First Law**
>
> An object does not change its state of motion until being acted upon by a force. This is also known as the law of inertia.

> **Definition 3.3: Second Law**
>
> The net force F_{net} acting on a body is given by as
>
> $$F = ma_{net}$$
>
> where m is the mass of the body and a_{net} is the net acceleration of the body.

> **Definition 3.4: Third Law**
>
> When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

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

A body is said to be in translational 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 3.5: Normal Force**
>
> The normal force is the force perpendicular to a surface that the surface applies to a body due to its compression.
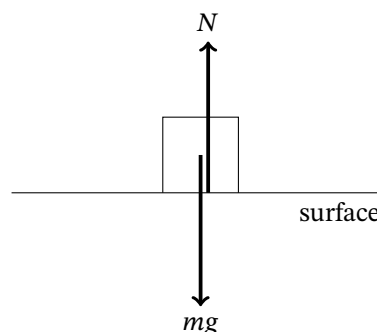
3.4.2 Tension

> **Definition 3.6: 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 3.7: Friction

Friction is the force parallel to a surface that a surface applies to an body due to its roughness.

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.