Contents

1 Measurements and their errors

1.0.1 Use of SI units and their prefixes

Base SI units

Second	**Time**	**Symbol**
metre	length	m
kilogram	mass	kg
ampere	electric current	A
kelvin	temperature	K
mole	amount of substance	mol

SI symbols

Prefix	**Symbol**	10^n	**Decimal**	**Name**
tera	T	10^{12}	1 000 000 000 000	trillion
giga	G	10^9	1 000 000 000	billion
mega	M	10^6	1 000 000	million
kilo	k	10^3	1 000	thousand
		10^0	1	one
milli	m	10^{-3}	0.001	thousanth
micro	μ	10^{-6}	0.000 0001	millionth
nano	n	10^{-9}	0.000 000 001	billionth
pico	p	10^{-12}	0.000 000 000 001	trillionth
fempto	f	10^{-15}	0.000 000 000 000 001	quadrillionth

1.0.2 Limitation of physical measurements

2 Particles and radiation

2.1 Particles

2.1.1 Constituents of the atom

The specific charge is the charge (C) per unit of mass (kg).

Isotopes of an atom have the same proton number, but a different mass number. The mass number of an element is the weighted mean of the relative atomic mass all of its isotopes.

2.1.2 Stable and unstable nuclei

The electromagnetic force causes protons to repel each other. The strong nuclear force holds the particles in the nucleus together. Strong nuclear force acts equally between all nucleons.

Distance (fm)	**Effect of strong nuclear force**
< 0.5	repulsive
> 0.5	attractive
> 1.5	equal
< 3	falls towards 0

Alpha α decay happens in atoms with too many nucleons as the nuclei is too big for the strong nuclear force to keep them stable. An alpha particle $^4_2\alpha$ is emitted from the nucleus.

$$^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X} \rightarrow ^{\mathrm{A-4}}_{\mathrm{Z-2}}\mathrm{Y} + ^4_2\alpha$$

Beta-mminus β^- decay happens in an atom that has too many neutrons. An electron and an antineutrino particle are emitted. When a nucleus ejects a beta particle, a neutron is changed into a proton. The antineutrino particle released carries some enegy and momentum.

$$^{\mathrm{A}}_{\mathrm{Z}}\mathrm{W} \rightarrow ^{\mathrm{A}}_{\mathrm{Z+1}}\mathrm{W} + ^0_{-1}\beta^- + \overline{\nu}_e$$

Beta particles have a greater range than alpha particles.

2.1.3 Particles, antiparticles and photons

For every type of particle there is a corresponding antiparticle.

Particle	**Antiparticle**
electron	positron
proton	antiproton
neutorn	antineutron
neutrino	antineutrino

Electromagnetic radiatiion can be released in packets of energy called photons. The energy carried by a photon is given by the following equations,

$$E = hf = \frac{hc}{\lambda}$$

Annihilation is the process where a particle and its antiparticle meet to form two photons.

Pair production is the process where a photon, with enough energy, converts to a particle and its antiparticle.

2.1.4 Particle interactions

The four fundemental interactions are,

- gravity
- electromagnetic
- weak nuclear
- strong nuclear

Exchange particles are used to transfer forces between elementary particles.

Interaction / Force	**Exchange particle**			**Particle**
Strong Nuclear	Gluons betwee quarks	Pions between Baryons		Hadrons
Weak Nuclear	W^+	W^-	Z^0	All particles
Electromagnetic	Virtual Photon			Charged particles
Gravitational	Graviton			Particless with mass

beta minus β^- decay happens when a nuclei has too many neutrons,

$$n \to p + e^- + \overline{\nu}_e$$

beta plus β^+ decay happens in nuclei with too many protons,

$$n \to p + e^+ + \nu_e$$

Electron captrue happens when a proton combines with an electron,

$$p + e^- \to n + \nu$$

2.1.5 Classification of particles

Hadrons are subject to strong interaction.

There are two classes of hadrons, baryons and mesons

Baryon	**Symbol**	**Composition**	**Charge (Q)**	**Baryon number (B)**	**Strangeness (S)**
Proton	p	uud	+1	+1	0
Anti proton	$\overline{\text{p}}$	$\overline{\text{uud}}$	-1	-1	0
Neutron	n	uud	0	+1	0
Anti neutron	$\overline{\text{n}}$	$\overline{\text{udd}}$	0	-1	0

Meson	**Symbol**	**Composition**	**Charge (Q)**	**Baryon number (B)**	**Strangeness (S)**
Pion plus	π^+	$\text{u}\overline{\text{d}}$	+1	0	0
Pion Minus	π^-	$\overline{\text{u}}\text{d}$	-1	0	0
Pion zero	π^0	$\text{u}\overline{\text{u}}$	0	0	0
Pion zero	π^0	$\text{d}\overline{\text{d}}$	0	0	0
Kaon plus	K^+	$\text{u}\overline{\text{s}}$	+1	0	+1
Kaon minus	K^-	$\overline{\text{u}}\text{s}$	-1	0	-1
Kaon zero	K^0	$\text{d}\overline{\text{s}}$	0	0	+1
Anti kaon zero	$\overline{\text{K}}^0$	$\overline{\text{d}}\text{s}$	0	0	-1

Baryon number is a quantum number wich is allways conserved.

The proton is the only stable baryon, all other decay.

Pions are the exchange particles of the strong nuclear force.

The kaon decays into pions.

Lepton	**Symbol**	**Charge (Q)**	**Electron lepton number (L)**
Electron	e	-1	+1
Electron neutrino	ν_{e}	0	+1
Positron	e^{+}	+1	-1
Anti electron neutrino	$\overline{\nu}_{\mathrm{e}}$	0	-1

Lepton	**Symbol**	**Charke (Q)**	**Muon lepton number (L)**
Muon	μ^{-}	-1	+1
Muon neutrino	ν_{μ}	0	+1
Anti muon	μ^{+}	+1	-1
Anti muon neutrino	$\overline{\nu}_{\mu}$	0	-1

Lepton number is a quantum number which is allways conserved.

Muons decay into electrons.

Strange particles are produced through the strong reaction and decay through the weak interaction.

Strangeness is a quantumn number and strange particlesa are allways created in pairs.

Strangeness is only conserved during strong reactions.

Strangeness can change by 0, +1 or -1 in weak reactions.

2.1.6 Quarks and antiquarks

Quark	**Charke (Q)**	**Baryon number (B)**	**Strangeness (S)**
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
$\overline{\mathrm{d}}$	$+\frac{1}{3}$	$-\frac{1}{3}$	0
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
$\overline{\mathrm{u}}$	$-\frac{2}{3}$	$-\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1
$\overline{\mathrm{s}}$	$+\frac{1}{3}$	$-\frac{1}{3}$	+1

2.1.7 Applications of conservation laws.

Energy and momentum are also conserved in particle interactions.

2.2 Electomagnetic radiation and quantumn phenomena

2.2.1 The photoelectric effect

The threshold frequency is the minimus frequency that would remove an electron from the surface of an a metal.

$$f_0 = \frac{\phi}{h}$$

The work function is the amount of energy required to remove an electron from the surface of a metal.

$$hf = \phi + E_{k\ \text{(max)}}$$

$E_{k\ \text{(max)}}$ is the maximum kinetic energy of the photoelectrons.

2.2.2 Collisions of electrons with atoms

Ionisation is where an electron gains enough energy to be completely removed from an atom. Exitation happens when an electron gains the exact amount of energy to move up one enrgy level.

One electron volt is equal to the energy gained by an electron of charge e, when it is accelerated through a potential difference of one volt.

2.2.3 Energy levels and photon emission

Atoms of the same element have the same energy levels. Each transition releases a photon with a fixed amount of energy, so the frequency and wavelength are also fixed. The wavelength of the light is responsible for its colour. Diffracton gratings can be used to seperate light into line spectra. Line spectra is evidence for transitions between energy levels in atoms.

$$hf = \Delta E$$

2.2.4 Wave-particle duality

Electron diffraction gratings suggest that particles possess wave properties. The photoelectric effect show that waves have a particle properties.

$$\lambda = \frac{h}{mv}$$

The amont of diffractions depends on a particles momentum as $p = mv$

3 Waves

3.1 Progressive and stationary waves

3.1.1 Progressive waves

Waves are caused by oscillations and all carry energy without transferring matter.

The amplitude of a wave is the maximum displacemnt of the particles from the equilibrum position.

The frequency is the amount of oscillations per unit of time.

The wavelength of a wave is the distance between two successive points with the same displacement.

The time period is the amound of time it takes for a wave to oscillate once.

$$c = f\lambda$$

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

Phase difference between two points is the faction of the wavelength between them.

3.1.2 Longitudinal and transverse waves

For longitudinal waves, oscillations are parallel to the direction of travel.

For transverse waves, oscillations are puprendicular to the direction of travel.

Polarisation restricts the oscillation of a wave to one plane. This can prove of electromagnetic waves as logntitudinal waves would not be restricted to one plane.

3.1.3 Principle of superposition of waves and formation of stationary waves

Superposition is the process by which two waves combine into a single wave form when they overlap. The graph of the two waves would be the sum of their displacements.

Standing waves form when two similar waves superimpose in opposite directions. Standing waves form nodes of zero displacement and antinodes of maximum displacement.

The frequency for the first harmonic is given by,

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

The frequncy of the second harmonic is double the frequency of the first harmonic. For all harmonics, the length of the string is double the wavelength. The wavelength of the second harmonic is half the frequency of the first harmonic.

3.2 Refraction, diffraction and interference

3.2.1 Interference

Coherent waves have the same;

- frequency
- wavelength
- polarisation
- amplitude

Interference is a case of superposition where the waves that combine are coherent. The waves overlap and form a repeating interference paten of maxima and minima areas. Constructive intereference is where the path difference between the waves is 2π radians, so the waves arrive in phase creating a larger waves. Destructive interference is where the path difference between waves is π radians, so the waves arrive out of phase to create no wave.

A laser is a coherant light source.

In Young's double-slit experiment, two coherent sources of light are used to create an interference pattern. Constructive interference make light fringes and areas of deconstructive interference create dark fringes. The fringe spacing is given by;

$$w = \frac{\lambda D}{s}$$

Interference can be demonstrated by the sound of two speakers connected to the same generator. Coherent sound waves will interfere with each other. Constructive interference creates loud fringes and deconstructive interference creates quiet fringes.

3.2.2 Diffraction

A diffraction grating is a series of narrow paralles slits. When light shines through a diffraction grating several bright sharp lines can be seen. The first bright line lies directly behind where the light shines on the grating. This is zero-order maximum where $n = 0$. At angle $n\theta$ is the n^{th} maximum. There are no lines between the maxima as the path difference is not an integar number of wavelength so waves arriave deconstructively.

$$d \sin\theta = n\lambda$$

3.2.3 Refraction at a plane surface

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

The refractive index in air is approximately 1.

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

$$sin\theta_C = \frac{n_2}{n_2}$$

An optical fibre is a thin piece of flexible glass which light can travel down because of total internal reflection. Cladding as added to the outside of optical fibre to reduce the amount of light that is lost. Cladding has a lower refractive index than glass.

Fibre optic cables are used in;

- phone and TV signals
- medical endoscopes

4 Mechanics and materials

4.1 Force energy and momentum

4.1.1 Scalars and vectors

Scalar quantities are measurements that only have magnitude. Vector quantities are measurements that have both magnitude and direction.

4.1.2 Moments

A moment is the force x puprendicular distance from the pivot. When in equilibrium the total anticlockwise moment is equal to the total clockwise moment.

4.1.3 Motion along a straight line

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

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

$$s = \frac{1}{2}(u + v)t$$

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

$$s = vt - \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

4.1.4 Projectile motion

4.1.5 Newton's laws of motion

$$F = ma$$

4.1.6 Momentum

$$p = mv$$

Momentum is allways conserved.

$$F = \frac{\Delta(mv)}{\Delta t}$$

$$F\Delta t = \Delta(mv)$$

The area under a force time graph is equal to the ... .
Eleastic collisions

4.1.7 Work, energy and power

$$W = Fs\cos\theta$$

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

The area under a force displacement graph is the word done.

$$\text{efficiency} = \frac{\text{usefull output power}}{\text{input power}}$$

4.1.8 Conservation of energy

Definition ...

$$\Delta E_p = mg\Delta h$$

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

4.2 Materials

4.2.1 Bulk properties of solids

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

Hooke's law, elastic limit

$$F = k\Delta L$$

Tensile strain, and tensile stress
Elastic strain, breaking stress

$$\text{energy stored} = \frac{1}{2}F\Delta L$$

Area under force-extension graph

Description of plastic behaviour, fracture and brittle behaviour linked to force–extension graphs.

Quantitative and qualitative application of energy conservation to examples involving elastic strain energy and energy to deform.

Spring energy transformed to kinetic and gravitational potential energy.

Interpretation of simple stress–strain curves.

4.2.2 The Young modulus

$$\text{Young modulus} = \frac{\epsilon}{\sigma} = \frac{FL}{A\Delta L}$$

The gradient of the *straight part* of a stress-strain curve is the Young's modulus of the material.

(One simple method of measurement is required.)

5 Electricity

5.1 Current electricity

5.1.1 Basics of electricity

Electric current is the rate of flow of charge carried by electrons. When the current is one ampere, one coulomb of charge passes in one second.

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

Potential difference is the work done per unit of charge. The potential difference between two points is defined as the work done to move one coulomb unit of charge between those two points.

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

If there is a potential difference across an electrical component than a current will flow. An electrical component's resistance measures how that device reduces the electrical current through it.

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

5.1.2 Current-voltage characteristics

Ohm's law states that provided physical conditions remain constant, the current through an ohmic conductor is directly proportional to the potential difference across it. An ohmic conductor is an electrical device that obay Ohm's law.

$$I \propto V$$

5.1.3 Resistivity

The resistivity of a material is defined as the resistance of a 1m long wire with a cross sectional area of 1m^2.

$$\rho = \frac{RA}{L}$$

Semiconductors are materials that are not as good conductors electricity as metals because they have fewer charge carriers available. If more energy is supplied, more charge carriers are release, decreasing the resistance.

An NTC thermistor's resistance decreases as temperature increases. Thermistors can be used as temperature sensors and resistance-temperature graphs. Warming a thermistor gives electrons more energy to escape the atoms and therefore be able to carry charge. As there are more charge carriers, the resistance decreases.

To investigate how a thermistor's resistance changes with temperature place a thermistor and a thermometer in a water beaker with boiling water. Measure the temperature, current and potential difference across the thermistor every 5C. Calculate the resistance of the thermometer for every change in temperature and plot resistance-temperature graph.

5.1.4 Circuits

5.1.5 Potential divider

A potential divider is circuit with a voltage source and a couple of resistors in series. The voltage is split across the resistors in the ratio of their resistances.

$$V_{out} = \frac{R_2}{R_1 + R_2} V_S$$

other equation

5.1.6 Electromotive force and internal resitance.

Batteries have an internal resistance which heats them up when they are used. The emf is the amount of electrical energy that the battery produces for every one coulomb of charge. Emf can be measured by either:

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

when there is no current running through the terminals, or

$$\epsilon = I(r + R)$$

The equation can be rearranged to $V = rI + \epsilon$ which is in the form $y = mx + c$, where:

- ϵ is the y intercept
- $-r$ is the gradient

6 Further mechanics and thermal physics

6.1 Periodic motion

6.1.1 Circular motion

When there is motion in a circular path at constant speed, there is an acceleration and requires a centrepetal force.

$$\omega = \frac{v}{r} = 2\pi f$$

One radian is the angle created where the arc length of a circle is equal to its radius.

$$a = \frac{v^2}{r} = \omega^2 r$$

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

6.1.2 Simple harmonic motion

An object moving in simple harmonic motion oscillates in equilibrium.

Simple harmonic motion is defined as:

$$a \propto -x$$

The acceleration of simple harmonic motion, $a = -\omega^2 r \cos\theta$ is the horizontal component of acceleration of circular motion $a = \omega^2 r$. Substituting $x = r\cos\theta$ gives,

$$a = -\omega^2 x$$

$$x = A\cos(\omega t)$$

$$v = \pm\omega\sqrt{(A^2 - x^2)}$$

$$\text{Maximum speed} = \omega A$$

$$\text{Maximum acceleration} = \omega^2 A$$

6.1.3 Simple harmonic systems

A mass spring system is a simple harmonic oscillator. When a mass is pushed or pulled from either side of the equilibrium postion, there's a restoring force exerted on it.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

A simple pendulum is a simple harmonic oscillator.

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

$$E_{k\ (max)} = E_{p\ (max)}$$

6.1.4 Forced vibrations and resonance

Free vibrations invovle no transfer of energy to or form the surroundings and oscillates at its resonant frequency. Forced vibrations happen when there's an external force. The frequency of a forced vibration is called the driving frequency.

A system is resonating when the driving frequency approaches the natural frequency. At resonance the phase difference between the driver and the oscillator is 90°. Damping forces cause oscillating systems to loose energy to their surroundnigs. Lightly damped systems take a long time to stop oscillating, heavily damped systems take a short time to stop oscillating. Critical dampening reduces the amplitude in the shortest possible time. Overdamped systems have heavier dampening than cirtically damped systems and take longer to return to equilibrium.

6.2 Thermal physics

6.2.1 Thermal energy transfer

6.2.2 Ideal gas

6.2.3 Molecular kinetic theory model

7 Feilds and their consequences

7.1 Fields

7.2 Gravitational fields

7.2.1 Newton's law

7.2.2 Gravitational field strength

7.2.3 Gravitational potential

7.2.4 Orbits of planets and satelites

7.3 Electric fields

7.3.1 Coulomb's law

7.3.2 Electric field strength

7.3.3 Electric potential

7.4 Capacitance

7.4.1 Capacitance

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

7.4.2 Parallel plate capacitor

$$C = \frac{A\varepsilon_0\varepsilon_1}{d}$$

Permittivity is a measure of how difficult it is to generate an elecric feild in a medium. Reletive permittivity is the ratio of permittivity of a material to the permittivity of free space. Reletive permittivity is also known as the dielectric constant.

Polar molecules rotate in an electric feild because the negative ends of the molecules are attracted to the positively charged plate.

7.4.3 Energy stored by a capacitor

The area under the graph of change against potential difference is the energy stored by the capacitor

$$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$

7.4.4 Capacitor chrage and discharge

$t = RC$ is known as the constant, τ, which is them time taken for the charge on a dischargnig capacitor Q to fall $\frac{1}{\mathrm{e}}$ of Q_0 or the charge of a charging capacitor to raise by $1 - \frac{1}{\mathrm{e}}$ of Q_0

The time constant can be calculated directly form a graph of a capacitor charging or discharging.

The time to half,$T_{\frac{1}{2}}$ is the time taken for the charge, current or potential difference of a discharging capacitor to decrease by half of its initial value. The time to halve is given by:

$$T_{\frac{1}{2}} = \ln(2)RC$$

Calculating the charge of a discharging capacitor:

$$Q = Q_0\mathrm{e}^{-\frac{t}{RC}}$$

Calculating the voltage of a discharging capacitor:

$$V = V_0\mathrm{e}^{-\frac{t}{RC}}$$

Calculating the current of a discharging capacitor:

$$I = I_0 \mathrm{e}^{-\frac{t}{RC}}$$

Calculating the charge of a charging capacitor:

$$Q = Q_0(1 - \mathrm{e}^{-\frac{t}{RC}})$$

Calculating the voltage of a charging capacitor:

$$V = V_0(1 - \mathrm{e}^{-\frac{t}{RC}})$$

Calculating the current of a charging capacitor:

$$I = I_0 \mathrm{e}^{-\frac{t}{RC}}$$

7.5 Magnetic fields

7.5.1 Magnetic flux density

7.5.2 Moving charges in a magnetic field

7.5.3 Magnetic flux and flux linkage

7.5.4 Electromagnetic induction

7.5.5 Alternating currents

7.5.6 The operation of a transformer

8 Nuclear physics

8.1 Radioactivity

8.1.1 Rutherford scattering

8.1.2 α , β and γ radiation

8.1.3 Radioactive decay

8.1.4 Nuclear instability

8.1.5 Nuclear radius

8.1.6 Mass and energy

8.1.7 Induced fission

8.1.8 Safety aspects