1. Mechanics of Particles

* Kinematics – position, displacement, velocity, acceleration, vectors

Position is described by displacement vector = **x** from a fixed point, origin

Velocity **v** = d**x**/dt

Acceleration **a = d**v/dt

* Motion of point mass

When considering translational motion, we can consider all forces acting on an object to be acting through its centre of mass

* Motion in 1d

These equations are derived by integrating a constant acceleration, a, using the limits where ti=0, tf=t, vi=u, vf=v. Clearly define the coordinate system ie which direction is positive before use

s=ut+1/2at^2

v^2=u^2+2as

v=u+at

* Motion in 2d

Motion in more than one dimension can be uniquely separated into its dimensions uniquely as long as they are orthogonal (perpendicular) to one another. Each dimension has its own set of intendent kinematic equations.

* Vector description of motion of a point mass

The motion of a point mass can be uniquely defined when its position and momentum (velocity) is known

* Relative velocity

In an inertial frame travelling at v1 relative to rest frame, the velocity of an object travelling at v2 in the rest frame appears to be **v**apparent= **v**2- **v**1

* Motion with constant acceleration (e.g. free fall) or with variable acceleration (e.g.

car on straight road)

Motion with constant acceleration is parabolic/quadratic

Consider graphical methods when the velocity of an object changes multiple times in a question.

* Motion with constant acceleration (e.g. projectile motion)
* Motion in a circle (involving centripetal acceleration)

For an object to undergo circular motion, the net force acting on the object must be

**F**net = m **a**centripetal = m v^2/r in the radial direction

Note: centripetal force isn’t a physical force, rather it is a condition for the net force acting on an object that is undergoing circular motion

* Dynamics – inertia, momentum, impulse, forces, energy

Inertia - a property of matter by which it continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force. Related to the mass of an object

Impulse **J** = delta**P= F**average delta t= m delta**v F**average = m **a**average = m delta**v**/deltat

Forces **F**=d**p**/dt =m**a** (for constant mass) Newton’s second law

* Newton’s laws of motion Application of Newton’s laws

Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This is normally taken as the definition of inertia. The key point here is that if there is no net force acting on an object (if all the external forces cancel each other out) then the object will maintain a constant velocity. If that velocity is zero, then the object remains at rest. If an external force is applied, the velocity will change because of the force.

The second law explains how the velocity of an object changes when it is subjected to an external force. The law defines a force to be equal to change in momentum (mass times velocity) per change in time. Newton also developed the calculus of mathematics, and the "changes" expressed in the second law are most accurately defined in differential forms. (Calculus can also be used to determine the velocity and location variations experienced by an object subjected to an external force.) For an object with a constant mass m, the second law states that the force F is the product of an object's mass and its acceleration a:

F = m \* a

For an external applied force, the change in velocity depends on the mass of the object. A force will cause a change in velocity; and likewise, a change in velocity will generate a force. The equation works both ways.

The third law states that for every action (force) in nature there is an equal and opposite reaction. In other words, if object A exerts a force on object B, then object B also exerts an equal force on object A. Notice that the forces are exerted on different objects. The third law can be used to explain the generation of lift by a wing and the production of thrust by **a jet engine.**

**https://www.grc.nasa.gov/www/k-12/airplane/newton.html**

* Motion affected by dissipative forces (e.g. friction, fluid resistance)

Kinetic friction is constant and acts in the opposite direction of motion F kinetic friction = miuk N

Other kinds of resistance are proportional to the velocity or velocity squared of the object and act in the opposing direction. The resultant motion is exponential decay for the former while the latter is similar in shape but has a sharper decrease

Forces

Energy and Power

* Elastic, friction, normal, gravity including Newton’s law of gravitation, electric and

Magnetic

Elastic force = -kx

Static Friction less than equal to miusN

Kinetic Friction = miukN

Normal force occurs between two surfaces and is perpendicular to the surface

Gravity near the surface of the Earth = mg towards the centre of the earth

Gravity = GMm/r^2 towards each other

Coloumb’s law = 1/4piepsilon0 \*q1q2/r^2

Force by an electric field =qE

Magnetic force F= q**v**cross**b**

* Conservation of energy, conversion of energy

Energy is always conserved in a closed system in an inertial frame. Energy can be converted to other forms by cannot be destroyed

* Work done, power

P= dW/dt

* Potential energy (PE), kinetic energy (KE)

W=Fd Work done by an object through a force is equal to the product of the magnitude of the force acting parallel to the direction of motion.

EPE = ½ kx^2

Work done against kinetic friction = f\*d

GPE = mgh (for small values of h at the surface of earth)

GPE = GMm/r ( in general)

Electric potential energy = q deltaV = qint(edr) from r0 to r1

EPE= 1/4piepsilonnought \*q1\*q2/r for two particles in free space

Kinetic energy =1/2mv^2

* Impulse and momentum Conservation of linear momentum

Momentum **p**=m**v** Momentum is conserved in any closed system due to newton’s third law

* Collisions/explosions,

There are two types of collisions : Inelastic and elastic. For elastic collisions, both energy and momentum is conserved. This leads to the condition that the velocity of approach must be equal and in opposite direction to the receding velocity.

* coefficient of restitution

Ratio of the final to initial relative velocity between two objects after they collide

e is usually a positive, real number between 0 and 1:

e = 0: This is a perfectly inelastic collision. The objects do not move apart after the collision, but instead they coalesce. Kinetic energy is converted to heat or work done in deforming the objects.

0 < e < 1: This is a real-world inelastic collision, in which some kinetic energy is dissipated.

e = 1: This is a perfectly elastic collision, in which no kinetic energy is dissipated, and the objects rebound from one another with the same relative speed with which they approached.

* External and internal forces for a system of particles, centre of mass

Internal forces cannot be detected from outside the system. They do not cause a change in total momentum or energy of a system. The resultant force of an internal force acts on another object in the system.

External forces causes a change in the total momentum and energy of a system and its resultant force acts on an object outside the system.

COM is the weighted average of the displacement of the masses

XCOM= 1/M sum(mr) where M= sum(m)

For continuous distribution XCOm =1/M int(rdm)

2. Mechanics of Rigid Bodies

* Statics – equilibrium, stability

Static equilibrium is attained when the net forces acting on an object is zero

Rotational equilibrium is attained when the net torque acting on an object is zero

Stable equilibrium is attained when a small disturbance from its position is met with a restoring force

Dynamic equilibrium is attained when a small disturbance from its position causes a net force acting in the same direction

Neutral equilibrium is attained when the system experiences not net force after a small disturbance.

* Equilibrium of a rigid body Conditions for static equilibrium, stability
* Kinematics – angular position, angular displacement, angular velocity, angular acceleration, vector products

Theta is angular displacement relative to an angle

Angular velocity **omega** = d**theta**/dt

Angular acceleration **alpla** = d**omega**/dt

* Rotation Rotation with constant angular acceleration

Akin to kinematic equations.

Moment of Inertia I **=**int(r^2dm)

Theta = omega t+1/2alphat^2

Omegaf ^2=omegai^2+2alphatheta

* Relationship between linear and angular quantities

**v=r**cross**omega**

* Dynamics – moment of inertia, torque
* Torque

**Tau**=I**alpha**

* Angular momentum

**L=r**cross**p**=mvrsintheta **nhat**

Angular motion is conserved in a closed system. It remains constant if no torque is acting upon the body

For circular motion, L=mvr

* Rotational KE

Rotational KE = 1/2Iomega^2

Effect of torque on motion

Conservation of angular momentum

Energy of rotational motion

3. Fluid Mechanics

* Fluid statics Density, pressure, buoyancy, surface tension

Rho=m/v

Pressure=f/a =rhpgh in a fluid

Buoyancy force is equal to the weight of fluid displaced caused due to difference of pressure between the top and body of an object

Surface tension =gamma l where gamma is a constant based on the property of the fluid and l is the length of surface exposed to the liquid. For a film, the total surface tension si double since there are two surfaces.

Pascal’s law, Archimedes’ principle

Pascal's law (also Pascal's principle or the principle of transmission of fluid-pressure) is a principle in fluid mechanics that states that a pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere. Ie the pressure of a fluid at a height is always equal

Fluid dynamics Continuity equation, mass, momentum, energy

Archimedes' principle states that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces and acts in the upward direction at the center of mass of the displaced fluid.

Bernoulli’s principle

{\displaystyle {\frac {v^{2}}{2}}+gz+{\frac {p}{\rho }}={\text{constant}}} {\displaystyle {\frac {v^{2}}{2}}+gz+{\frac {p}{\rho }}={\text{constant}}}

4. Oscillations and Waves

Simple harmonic oscillations:

* Solution of the SHM equation

a=-kx

Mechanical, Electrical

* Frequency, period, phase difference.

Frequency f is the number of oscillations that occur per second

Period is the time taken for an oscillation to occur, the inverse of frequency

Phase difference is the difference in the phase angle between two oscillating systems ie how much one system is leading another.

If they are in phase, the phase difference is equal to 2pi and the two systems reach their maxima and minima at the same time

If they are out of phase, the phase difference is pi and the maxima of one system occurs at the minima of another system

* Qualitative understanding of damping and resonance.

Damping occurs when a force opposes a system’s change, it is modelled as proportional to the system’s rate of change i.e drag force. There are three types of damping: Lightly damped. Still sinusoidal but the amplitude is contained in an exponential decay envelope. Overdamped, never passes the origin, tends towards equilibrium. Critically damped, may pass through the origin at most once. Reaches the origin in the fastest possible time.

Waves: Mechanical (Sound,

String, Fluid), Electromagnetic

* Solutions of the wave equation.
* Qualitative understanding of attenuation.

Attenuation is the lost of energy of a wave over a distance.

* Propagation of waves, wavelength, wave speed

Wavelength is the distance of space over which a wave repeats

Wave speed is the speed at which a wave propagates. v=flambda

* Transverse and longitudinal waves

Transverse waves oscillate in the plane perpendicular to the direction of propagation

Longitudinal waves oscillate along the direction of propagation

* Polarization, Malus’ law

Polarized light occurs when the vibrations only occur along a single plane

Malus law states that the intensity of a beam of plane-polarized light after passing through a rotatable polarizer varies as the square of the cosine of the angle through which the polarizer is rotated from the position that gives maximum intensity.

I=Inoughtcos^2theta

* Principle of superposition

The nett displacement of the sum of waves at a point is equal to the sum of the displacements caused by each wave separately. I.e. waves can be added on each other

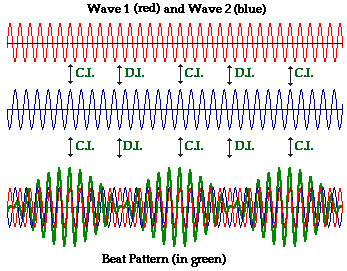
* Standing waves, interference, diffraction, beats

Standing waves occur when two waves travelling in opposite directions interfere and form a wave where the nodes and antinodes have fixed positions.

Interreference occurs when two waves in the same medium superpose. Constructive interference occurs when the waves are in phase and destructive interference occurs when the waves are exactly out of phase.

Diffraction occurs when waves bend around corners of an object or aperture into the geometrical shadow of the obstacle

Beats occur when two waves interfere. It results in a sinusoidal pattern where the amplitude is controlled by another sinusoidal pattern.



http://www.physicsclassroom.com/class/sound/Lesson-3/Interference-and-Beats

Geometric optics

* Reflection, refraction, dispersion

Incident angle equals reflected angle

* Refraction: optical density of medium: eta =c/vof light in the medium

Sin theta i/sin theta r = etai/etar

* Total internal reflection

From medium of greater optical density to a lower one when the incident angle is greater than the critical angle

1/sinc=etai/etar

5. Electric Charge and Electric Field

Electric charge and electric

field

**Coulomb’s Law** 𝐹=14𝜋𝜀0𝑞1𝑞2𝑟2

**Electric Field** E=14𝜋𝜀0Σ𝑄𝑖𝑖𝑟2=14𝜋𝜀0∫𝑑𝑞𝑟2

**Electric Potential** 𝑉=14𝜋𝜀0Σ𝑄𝑖𝑖𝑟=14𝜋𝜀0∫𝑑𝑞𝑟

**Electric Potential Energy** 𝑈=𝑞𝑉

**Electric Force on a Charged Particle in an Electric Field** 𝐹=𝑞𝐸

**Work done to assemble a system of charges** 𝑊=14𝜋𝜀0Σ𝑞𝑖𝑞𝑗𝑟2𝑖≠𝑗

**Work done to bring a positive charge in the direction of electric field lines is negative.**

**Work done to bring a positive charge against the direction of the electric field lines is positive.**

**Capacitance** 𝐶=𝑄𝑉

Capacitance is the ratio of charge stored between conductors to potential difference. Capacitance is only dependent on the geometrical factors of the capacitor. Doubling the magnitude of charge on each conductor will double the charge density, electric field and also the potential difference.

**Equivalence Capacitance of a system of capacitors** 𝐶𝑠𝑒𝑟𝑖𝑒𝑠=(Σ1𝐶𝑖𝑖)−1 𝐶𝑝𝑎𝑟𝑎𝑙𝑙𝑒𝑙=Σ𝐶𝑖𝑖

**Electric Potential Energy** stored in a capacitor is defined as the work done to charge a capacitor, which is to separate opposite charges and place them on different conductors. 𝑑𝑊=𝑉𝑑𝑞=𝑄𝐶𝑑𝑞 𝑊=1𝐶∫𝑞𝑑𝑞=𝑄22𝐶=12𝐶𝑉2=12𝑄𝑉

**Electric Energy Density** 𝑢=0.5𝐶𝑉2𝐴𝑑=12𝜀0𝐸2

**Gauss Law (for symmetrical continuous charge distributions)** ∯𝐸𝑑𝐴=𝑄𝜀0

* Conservation and quantization of charge

Charge is a conserved quantity. The minimum unit of charge is e=1.60\*10^-19, the charge of an electron or proton

* Coulomb’s law
* Electric field, Electric flux

Electric flux is the product of the electric field and area. Analogous to the number of field lines cutting through a surface per area

* Motion of charged particles in electric field

F=qE

Electric potential and

capacitance

Electric potential, electric potential energy, electric potential difference

Capacitors

6. Current and Magnetic Field

Current, impedance, and

potential difference in DC and

AC circuits

**Resistance** 𝑅=𝑉𝐼=𝜌𝐿𝐴

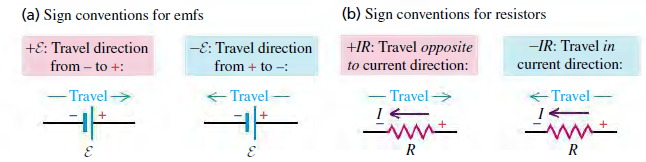
**Current** 𝐼=𝑛𝑒𝑡=𝑛𝑒𝑣𝐿

**Capacitance** 𝑉=𝑄𝐶

**Inductance** 𝑉=-𝐿𝑑𝐼𝑑𝑡

**Kirchoff’s Loop Rule** The sum of voltage drops across all circuital elements is zero.

**Kirchoff’s Junction Rule** At any point where there is a node formed by the junction of various current carrying branches, by current conservation, the sum of the currents into the mode must equal to the sum of the currents out of the node.



Ohm’s law, resistance, resistivity, (V-I relationship for common passive devices)

Impedance in an AC circuit

Internal impedance in a source of emf

Energy and power in electric circuits

P=VI=I^2R=V^2/R

Circuits containing non-ohmic devices with known V-I characteristics

**Semiconductors. The resistance at a point is equal to the Potential difference across divided by the current, NOT necessarily the slope at the point**

Magnetic field and magnetic

forces

Motion of charged particles in magnetic field

Current in a magnetic field

Magnetic field of a current in a long, straight conductor, in a current loop, and in

solenoids

Electromagnetic induction

and inductance

Magnetic flux

Faraday’s law, Lenz’s law

Inductors

**Magnetic Force (for wire)** 𝑭=𝐼(𝑳×𝑩)

**Lorentz Force (for moving point charge)** 𝑭=𝑞(𝑬+𝒗×𝑩)

**Biot Savart Law (for wire)** d𝐁=μ0𝐼4π𝒅𝒍×𝒓|𝑟|3

**Biot Savart Law (for moving point charge)** 𝑑𝑩=μ0𝑞4𝜋𝒗×𝒓|𝑟|3

**Magnetic Dipole Moment** μ=𝑁𝑰×𝑨

**Ampere’s Law** ∮𝑩∙𝒅𝒍=μ0𝐼

**Magnetic Flux** 𝜑=𝑩∙𝑨

**Faraday’s Law** 𝜀=−𝑁𝑑𝜑𝑑𝑡

**Lenz’s Law (accounts for the negative sign)**

**Self Inductance**

Consider a circuit consisting of a switch, power source and wires. Initially, current flows in the wire. When the switch is turned off, the current in the wire does not instantaneously drop to zero but slowly falls to zero. According to Faraday’s Law, his effect results in the induction of a magnetic field to oppose this change. This induced magnetic field is in the opposite direction of the magnetic field of the original current. This property of the loop in which its own magnetic field opposes any change in current is called self-inductance. 𝜀𝑏𝑎𝑐𝑘=−𝐿𝑑𝐼𝑑𝑡 𝐿=𝑁𝜑𝐼

**Mutual Inductance**

Consider two coils placed near to each other. Suddenly, a current flows in the first coil (with N turns and current I1) which gives rise to a magnetic field. Some of the magnetic field lines through coil 1 will also pass through coil 2. This results in an increase in magnetic flux linkage through coil 2. By Faraday’s Law, an induced emf occurs in coil B. 𝑁2𝑑𝜑2𝑑𝑡=𝑀𝑑𝐼1𝑑𝑡 𝑀=𝑁2𝜑𝐼1

7. Thermodynamics

* Zeroth law Thermal equilibrium and absolute temperature

The zeroth law of thermodynamics states that if two thermodynamic systems are each in thermal equilibrium with a third, then they are in thermal equilibrium with each other. Absolute temperature is defined with reference to absolute zero – particles have zero vibrational motion. It is defined in Kelvins

* Kinetic theory of an ideal gas

Vrms of a gas particle = 3kT/m for monatomic gasses

* Equation of state for an ideal gas

PV=nRT where P is pressure, V is volume, n is the number of moles of gas, R is the ideal gas constant and T is absolute temperature. Or NkT where N is the number of particles and k is the boltzmann’s constant

* Avogadro’s number

1 mol = 6.02 \*10\*23 particles

* Thermal properties of Materials Thermal conductivity, thermal expansion

Conductivity H=-kA{\frac {\mathrm {d} T}{\mathrm {d} x}}.

{\displaystyle H=kA{\frac {T\_{\text{H}}-T\_{\text{L}}}{L}}.}

Where H is heat flux

Heat capacity

Q=mcdeltaT

Latent heat for processes such as boiling and condensation, melting and freezing

L=mC

Thermodynamic processes

Thermal expansion <http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/thexp.html> first table

First Law <http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/firlaw.html> first table

Heat, internal energy, and work done by an expanding gas

W=pdeltaV

Work is done by the gas when expanding and work is done on the gas when contracting

Internal energy

Monatomic gas= 3/2nRT

Thermodynamic efficiency

{\displaystyle \eta \_{th}\equiv {\frac {W\_{out}}{Q\_{in}}}={\frac {{Q\_{in}}-Q\_{out}}{Q\_{in}}}=1-{\frac {Q\_{out}}{Q\_{in}}}}