# Physics AS - Unit 2 - Mechanics, Materials and Waves - Revision Notes
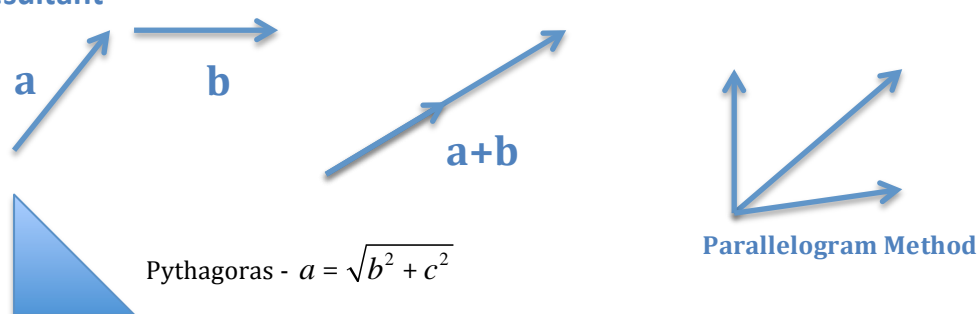
## Mechanics

### Scalar and Vector Quantities
- **Definition – A Vector Quantity has magnitude as well as direction while a scalar quantity only had magnitude**
- Scalar – Distance, Speed, Mass
- Vectors – Displacement, Velocity, Acceleration

### Resultant



Pythagoras - $a = \sqrt{b^2 + c^2}$

**Parallelogram Method**

Note: when you know the resultant and drawing the horizontal and vertical component draw both of the components from the same point that the resultant starts from (resultant should be in-between 2 components)

### Resolution Of Vectors
- Resolves vector into horizontal and vertical components.
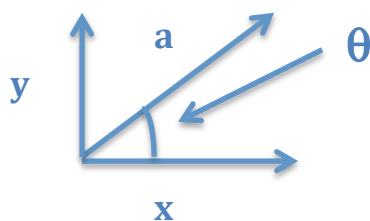


- $x = a\cos\theta$
- $y = a\sin\theta$

### Balanced Forces
- If an object is in equilibrium the two forces acting upon a point are equal and opposite to each other and the sum of the anticlockwise moments = the sum of the clockwise moments. No resultant force acting.
- Equilibrium – 3 forces – 2 of the forces (resultant) are equal and opposite to the third force, there is no resultant force acting. Can also be drawn in a closed triangle.

To calculate and unknown force or forces resolve each horizontally and vertically and solve, if object is in equilibrium there is no resultant force!

## Moments

- **Definition – The moment of a force about a point is equal to the force multiplied by the perpendicular distance between the line of action (of force) and the pivot (place taking moment about)**
- The principle of moments states that for an object to be in equilibrium the sum of the anticlockwise moments must equal the sum of the clockwise moments at any point.

## Two Support Problems

- If center of mass of beam is midway between both supports the force each support exerts is equal.
- If not:
  - Take moments about $S_1$ to calculate $S_2$ to work out $S_1$ or vice versa

## Couples

- **Definition – A couple is pair of equal and opposite parallel forces acting on a body but not at the same point.**
- The turning effect of a couple of equal and opposite forces is equal to One of the forces multiplied by the perpendicular distance between the two forces.

## Motion Along a Straight Line

### Displacement Time Graphs

- Gradient = Velocity

### Velocity Time Graphs

- Gradient = Acceleration
- Area Underneath = Displacement (if velocity is always +)

### Constant Acceleration Formulas

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

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

- $$v = u + at$$

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

Where V=final velocity, S=displacement, U=initial velocity, T=time
Remember Acceleration is ms$^{-2}$

- When calculating distance covered when something is accelerating and starting velocity is not 0 use formulas!!

**IF EVER ASKS FOR DECELERATION NEVER USE A MINUS SIGN IS IT IS SLOWING DOWN!**

### Projectile Motion

- Acceleration due to gravity = 9.81ms$^{-2}$
- Resolve horizontally and vertically
- Gravity only effects the vertical component of motion

## Newton's First Law Of Motion

- **Objects stay at rest or remain in uniform motion unless acted upon my an external force**
- So basically if an object is moving and nothing is acting upon it (e.g air resistance) the object will carry on going forever, this happens in space as no air resistance

## Newton's Second Law of Motion

- **The force applies to an object is proportional to the mass and the acceleration of the object as a result of the being applied**

$$F = ma$$

- If 2 forces are acting upon the object it is the resultant force that is used in this equation - $F_1 - F_2$ if $F_1$ is bigger than $F_2$
- With a rocket that is travelling directly upwards the object has to overcome its own weight ($mg$) in order to accelerate so $F - mg = ma$
- With a lift
  - o If moving at a constant speed upwards $F = mg$
  - o If moving upwards and accelerating $F = mg + ma > mg$
  - o If lift moving up and decelerating $F = mg + ma < mg$
  - o If moving downwards and accelerating (going faster in downwards direction) $F = mg + ma > mg$
  - o If moving downwards and decelerating $F = mg + ma < mg$

### Terminal Speed

- Drag force depends upon Velocity, viscosity of liquid moving through and shape of an object
- Drag operates in the opposite direction of travel so $F = mg - d$ therefor $ma = mg - d$

  so acceleration equals $a = g - \dfrac{d}{m}$

- Remember when an object is falling the force acting downwards towards earth is its weight! ($mg$)

## Stopping Distances

- Thinking distance
- Braking Distance – using $v^2 = u^2 + 2as$ gives us $a = \dfrac{v^2}{2s}$
  - o So if speed reduced from 20mph to 10 mph the braking distance is reduced by **more than half**
- Limiting friction is the largest frictional force an object can experience due to the road before skidding (measured in N)

## Impact Forces

- Impact force can be in g which is the declaration divides by g
- **Impact Time –** time from when 2 objects collide at 2 different velocities to the time there are both travelling with the same velocity
- **Contact Time –** Time 2 objects are in contact with each other

- As $F = ma$ the force an object experiences can be minimized by reducing the acceleration or declaration of an object this is done by increasing the time the object is changing speed as $a = \dfrac{\Delta v}{\Delta t}$ so increasing t decreases a which subsequently reduces F
- This is why things like crumple zones and seat belts are used – to increase time of declaration – to decrease average force applied to a person – safer!

## Work

$$Work = F \times d \times \cos\theta$$
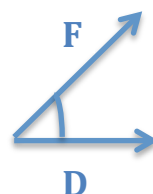
- Measured in Joules

## Kinetic Energy

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

## Gravitational Potential Energy

- $$\Delta E_g = mg\Delta h$$

As an object of mass m is released above the ground, it gravitational potential energy is converted into kinetic energy as the height above ground decreases as $\Delta E_g = mg\Delta h$, in reality this is not strictly true as some gravitational potential is converted into work against Air resistance and some lost as heat and sound.

### Pendulum Bob

- if released from height $h_i$ then at any point where the height is $h_v$ the speed of the bob is such that Kinetic energy at that point = loss in gravitational potential (ignoring all over external forces)

$$\frac{1}{2}mv^2 = mg(h_i - h_f)$$

## Power

- **Power –** Rate of transfer of energy measured in Watts

$$p = \frac{\Delta E}{\Delta t} \quad p = \frac{\Delta W}{\Delta t} \quad p = fv$$

- Where E = Energy, W= Work and t = time
- Power = force x velocity as it's the rate work is done per second as its force multiplied by distance moved each second

## Efficiency

$$efficiency\ of\ a\ machine = \frac{useful\ energy\ transfered\ by\ machine}{energy\ supplied\ to\ machine}$$

$$efficiency\ of\ a\ machine = \frac{Work\ Done\ by\ machine}{energy\ supplied\ to\ machine}$$

- So basically efficiency is output power over input power

# Materials

## Density

- **Density –** A materials mass per unit volume

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

- Mass of alloy, $m = p_a v_a + p_b v_b$ and the density of that alloy $p = \frac{m}{v} = \frac{p_a v_a + p_b v_b}{m}$

## Springs

### Hooke's Law

- **Hooke's Law –** The extension of a spring is proportional to the force applied to it as long as the limit of proportionality is not **exceeded**

$$F = k\Delta l$$

(where k is the spring constant)

- **Elastic Limit –** Maximum stress that can be applied to a material without plastic behavior occurring – deformation
  Note : Elastic limit may be different to Limit of Proportionality
- **Yield Point –** A point is reached at which noticeably larger change in length due to force
- **Breaking Stress/Ultimate Tensile Stress –** most stress a material can withhold without breaking
- **Brittleness –** Materials that cant extend without breaking are said to be brittle however brittle materials are strong in compression and used in building where compression is constant.
- **Springs in parallel -** $K = K_1 + K_2$ where k is the effective spring constant
- **Springs in series -** $\frac{1}{K} = \frac{1}{K_1} + \frac{1}{K_2}$

In order to compare 2 different materials' elastic properties use young's modulus

### Young's Modulus

- **Young's Modulus –** Stiffness constant of material
- **Tensile Stress =** force per unit area $\sigma = \frac{f}{a}$ measured in Nm$^{-2}$
- **Tensile Strain =** ratio of original length and extension $\varepsilon = \frac{\Delta L}{L}$ **NO UNITS**
- **This is delta L as in change in L so final - initial**
- $E = \frac{\sigma}{\varepsilon} = \frac{Stress}{Strain}$ Young's modulus has units Nm$^{-2}$ or Pascal (Pa)

$$E = \frac{FL}{A\Delta L}$$

## Experimental determination of Young's Modulus Of a Material

- Two identical wires are fixed in parallel
- Both wires initially loaded to remove kinks/strengthen knots
- Micrometer adjusted to make sprit level horizontal
- Initial micrometer reading taken
- Meter ruler measure original length of wire l (one under test)
- Second micrometer used to measure diameter of wire in several places to improve accuracy
- Calculate area by using $\pi r^2$ (half d to give r)
- Test wire loaded with mass and micrometer adjusted to level sprit level
- Micrometer reading taken and extension calculated by final micrometer – initial
- Further loads are added and repeated until range obtained
- Unload – second set
- Graph of force against extension
- Gradient calculated using big triangle $\dfrac{y_2 - y_1}{x_2 - x_1}$
- As gradient = $\dfrac{F}{\Delta L}$ and $Y = \dfrac{FL}{A\Delta L}$ Y can be calculated by gradient multiplied by

$$y = Gradient \times \frac{L}{A}$$
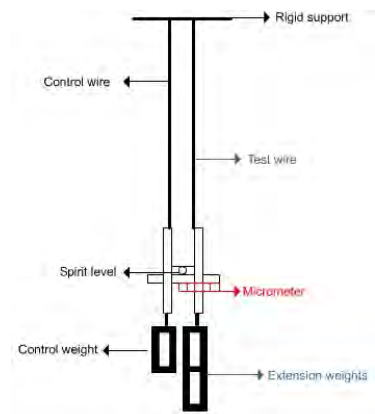
### *Accuracy Improved*

- Long thin wire – gives large extension per unit force therefor percentage uncertainty decreases
- Control wire used so temperature changes do not impact results
- Measure diameter in several places to give average
- Large triangle/range used to calculate gradient

### Loading and Unloading

- If elastic limit is reached the unloading curve will not have same value as loading curve at F=0 – it has been misshaped – metal extended
- *Loading area − Unloading area = Thermal Energy Losses into Material*
- As loading area = work done and unloading area = energy given back
- Remember when counting squares to calculate work done that each square is worth whatever the square represents vertically multiplied by whatever it represents horizontally

# Waves

- **Progressive Waves –** Waves whose oscillations travel and do not stay about a fixed point, this type of waves transfers energy
- **Frequency –** Number of wave cycles that occur in one second measured in Hz
- **Amplitude-** Maximum displacement of a vibrating particle from equilibrium
- **Wavelength –** Distance between 2 adjacent points/particles in phase in a wave
- **Period –** time for one complete wave to pass a fixed point in space

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

- **Transverse Waves –** Waves whose oscillations/vibrations are perpendicular to the direction of travel (light etc.)
- **Longitudinal Waves –** Waves whose oscillations/vibration are in the same direction of travel (sound)
  Note: Sound waves propagate as a a series of compressions and rarefactions
- **Wave Speed –** Speed of the waves is equal to distance traveled by wave in one cycle divided by time taken for one cycle

$$C = \frac{\lambda}{1/f} \text{ Therefor } c = f\lambda$$

## Path/Phase Difference

- 2 points are in phase if they are a whole wavelength apart (max displacement at same time)- there oscillations are in time with each other
- 2 Points are in Antiphase if they are half a wavelength apart (one max displacement while other experiences min displacement)
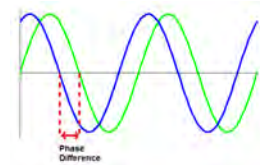
Phase Difference

$$\phi = 2\pi\left(\frac{x_1 - x_2}{\lambda}\right) \text{(in radians)} \textbf{ OR } \phi = 360\left(\frac{x_1 - x_2}{\lambda}\right) \text{ in degrees}$$
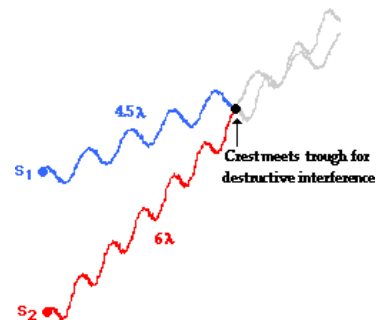
note: $x_1$-$x_2$ is the distance between the two points

Path Difference

- Between 2 different sources the phase difference between the 2 waves then they converge is:

$$\phi = 360\left(\frac{S_1 P - S_2 P}{\lambda}\right)$$

note: where $S_1 P$ is the distance from source 1 to the point where the 2 waves converge

## Polarization

- **Polarization –** When oscillations of the electric field of an E.M wave are restricted to only one plane/direction the wave is said to be polarized
- **Application –** Polaroid sunglasses reduce glare from water as the light is partially polarized when reflected off water thus the intensity of the light can be reduced – This reduces glare

## Reflection

- Angle of incidence is the same as angle of reflection

$$i = r$$

## Stationary Waves

### Superposition

- When 2 similar waves of similar frequency meet their resultant depends upon their amplitude and their relative phase difference
    - If no phase difference angle then constructive interference occurs
    - If 180 degrees difference angle then destructive interference occurs and waves cancel out at that point
- **Principle Of Superposition –** States that the resultant displacement caused by 2 waves arriving at a point is the vector sum of the 2 displacements caused by each waves at that instant

### Stationary Waves Formation

- Formed when 2 continuous waves travelling in opposite directions of same frequency superimpose to form no displacement (nodes - complete destructive) and points of max displacement (antinodes – complete constructive interference)
- **Stationary Wave –** Fixed pattern of vibration where no energy is transferred along the wave
- **Node –** particle/point with zero displacement no amplitude
- **Antinode –** Point/particle with max displacement/amplitude
- The phase difference between 2 particles/points on standing wave (that is the difference when one is at max displacement and other one also is, in degrees) is zero if the points/particles are between adjacent nodes or separated by even number of nodes or 180 degrees if they are separated by an odd number of nodes.
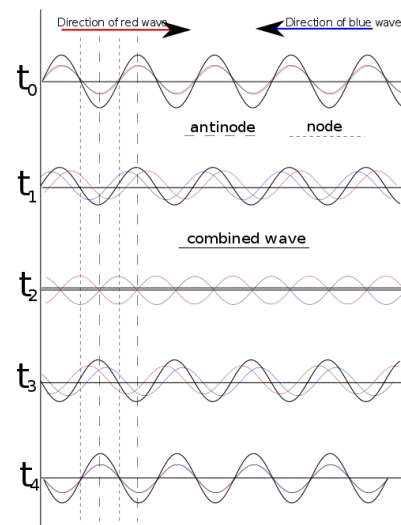
## Fundamental Frequencies

- **Distance between 2 Adjacent Nodes = $\dfrac{\lambda}{2}$** (as from node to node = half a wavelength of one of the continuous waves that formed stationary wave – seen in diagram)

- As seen in diagram the first fundamental that is when there is one standing wave (1 anti-node 1 node) the length is half of the wavelength
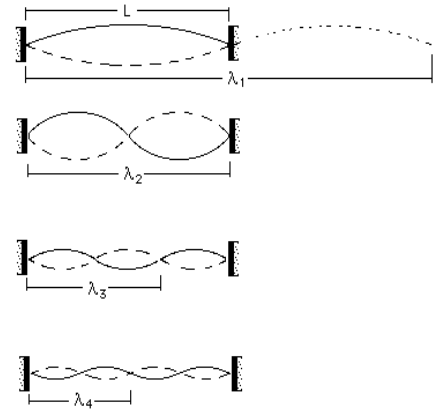
$$\lambda = 2L$$

Using $c = f\lambda$

We find: $f_0 = \dfrac{c}{2l}$

(where c is speed of propagation of waves)

- Hence at the **second harmonic or first overtone**: $\lambda = L$

  - Hence: $f_1 = \dfrac{c}{l}$

- Furthermore at the **third harmonic or second overtone**: $\lambda = \dfrac{2}{3}L$

  - Hence: $f_2 = \dfrac{c}{\frac{2}{3}l}$

# Refraction

- **Refraction –** Change of direction of a wave when it propagates through a different medium
- Speed of light in air is $3.00 \times 10^8$ however when it enters more optically dense medium it reduces speed
- So when light enters a more optically dense medium its speed decreases and its direction changes more towards the normal
- As $c = f\lambda$ and the speed of light is reduced in more optically dense medium the wavelength of light changes (makes sense really the frequency cant suddenly change!)

## Absolute Refractive index

$$n = \frac{Speed\ of\ light\ in\ Vacum}{Speed\ of\ Light\ in\ Medium}$$

note: as the speed of different frequency of light is not the same in a given medium (due to the fact the propagation direction changes to a different degree for each frequency) to give absolute refractive index Yellow light from a sodium bulb is used as a standard

Some typical R.Is
  Diamond – 2.4
  Perspex – 1.5
  Air – 1
  Ice – 1.31

## Refractive Index between 2 materials

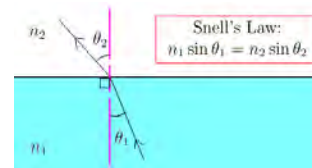$$n = \frac{Absolute\ of\ N_2}{Absolute\ of\ N_1}$$

- If light from one medium 1 to medium 2 is N then light from 2 to 1 is 1/N

## Snell's Law

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
**OR**
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

Note where n is the absolute refractive index of a certain medium
  and $\theta 1$ is the angle of incidence and $\theta 2$ is the angle of refraction



## Total Internal Reflection

- If angle of incidence is so large and the light is moving from a more dense to less dense medium (hence propagation direction changing away from normal) the angle of incidence will be larger than 90 and subsequently the light does not exit but is reflected back into medium
- The angle that this happens at – that is the angle at which light is reflected at 90 to the normal ($\theta_2$ = 90) is called the critical angle and usually denoted by $i$

$$\frac{\sin i}{\sin 90} = \frac{n_1}{n_2}$$

and as sin 90 = 1:
$$\sin i = \frac{n_2}{n_1}$$
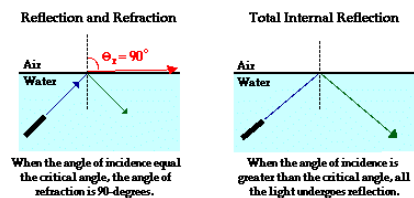


This is how fiber optic cables work:
- **Cladding In Fiber Optic Cables**
  - Improve tensile strength of the cable as the core has to be very thin.
  - Increase the critical angle needed for total internal reflection: hence reducing the multipath dispersion (merging of signals of light down a cable)

- o Stops core being scratched as scratches cause light to be dispersed if it hits the scratch
- o Improves security as without cladding light would be able to travel between fibers, as with cladding total internal reflection occurs and light cannot travel between fibers however without cladding light would be free to travel between medians of similar optical density (core to core)

Used in Internet broadband to deliver fast internet connection to households.

## Interference

- When 2  similar waves meet at a point, by the principle of superposition the combined displacement is found by the vector sum of the 2 displacements of each wave at that point, if they arrive exactly in phase the waves will constructively interfere to form a double height wave, if exactly out of phase (180 degrees) they will add together destructively and cancel
- In order to view a steady interference pattern the wave sources have to be **coherent**
- **Coherent –** Constant phase relationship and same frequency
- The pattern we see will depend upon the phase difference of the 2 sources when they hit that point
- **A bright fringe –** When the waves constructively interfere, occurs when path difference $= n\lambda$
- **A dark fringe –** When the waves destructively interfere, occurs when path difference $= (n + \frac{1}{2})\lambda$ as the waves have to be 180 degrees out of phase

### Two-Slit interference patterns (Young's Slits)

- Single slit diffraction spreads out one wave and causes it to act as 2 coherent sources for 2 further slits.
- Showed evidence for wave theory of light
- Light bands occur whenever the path difference between the light waves are a whole number of wavelengths (and dark when half number)
- The distance between two successive maxima w depends upon:
  - o The distance between the 2 slits; increasing S makes fringes closer together (or w smaller)
  - o The wavelength of light , W is smaller at smaller wavelengths
  - o Distance D between the slits and the screen, if D increase W increases.
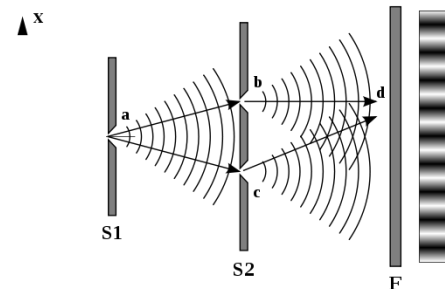
$$w = \frac{\lambda D}{s}$$

- Also can use laser
  - o Laser light monochromatic
  - o Laser light Is coherent (constant phase relationship same Hz)
  - o Highly directional – very little divergence
- **Pattern – Maxima Similar intensity and same width as central fringe**
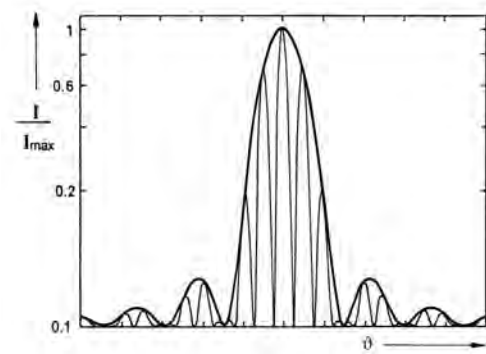
## Diffraction

- When waves pass through a gap or around an obstacle the waves spread out – this is called **Diffraction**
- When the slit width is the same as the wavelength – perfect diffraction occurs
- When slit is large than wavelength less diffraction occurs

### Single Slit Diffraction Pattern

- Central maximum is twice as wide as the others

- Rest of the fringes decrease slightly in intensity as way from the middle (same width)
- Maxima occurs with constructive interference and zero intensity with destructive interference
- If gap gets smaller of distance between screen and slit increases so does width of maxima
- Central maxima gets larger if wavelength is longer or the gap is smaller



### Diffraction Grating
- Series of uniform narrow slits in parallel

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

- Where d= the distance from center to center of adjacent slits (N=1/d to work out d if you only have number of slits in say a meter) $\theta$ is the angle of the order you are trying to calculate, n is the order number trying to calculate – 1 2 or 3 etc.
- Fractions of a degree usually expressed in minutes '
- To find max number of order substitute $\theta$ for 90 (therefor $\sin \theta$ = 1) and use equation
- **Application: Spectrometer**
    - Uses collimator to produce parallel light and then uses diffraction grating to produce spectrum pattern
    - Use sample light from exciting an atom to produce pattern and analysis can be done on this12
    - Always a white line at the Zero order as all wavelengths arrive in phase at this point
    - The shorter the wavelength the shorter the angle
    - Hence patterns can be complicated – first order red light line can be close to second order blue