Kinematics

Notation & units

quantity	time	displacement	velocity	acceleration	
symbol	t	d	u, v	a	
unit	s	m	ms^{-1}	ms^{-2}	

Useful formulae

1. for $X = \frac{AB^2}{\sqrt{C}}$, %X = %A + 2%B + ½%C where %X = ΔX/X
2. equation of motions: ①$v = u + at$ ②$s = ut + \frac{1}{2}at^2$ ③$v^2 - u^2 = 2as$
3. relative velocity: $\vec{v}_{AB} = \vec{v}_A - \vec{v}_B = \vec{v}_A + (-\vec{v}_B)$
4. projectile: trajectory $y = x\tan\theta - \frac{g}{2u^2\cos^2\theta}\cdot x^2$; max. height $H = \frac{u^2\sin^2\theta}{2g}$; range $R = \frac{u^2\sin 2\theta}{g}$

I. Significant figures:
   1. leftmost non-zero, rightmost (non-zero), # of s.f.
   2. multiplication or division: # of s.f. for the answer = smallest # of s.f. in previous one
   3. addition or subtraction: # of s.f. for the answer = smallest # of s.f. on the right side of dec. pt. of the smallest one

II. Measurements:
   1. length: metre rule, vernier caliper, micrometer gauge
   2. time interval: stop watch, ticker tape timer, stroboscope
   3. mass: triple beam balance, electronic balance
   4. data logger

III. Error treatment:
   1. personal error: personal bias or carelessness in reading an instrument.
   2. random error: poor sensitivity of the apparatus (Vs precision)
   3. system error: inaccurate apparatus or poor design (Vs calibration)
   4. accuracy Vs precision: the accuracy of a measurement signifies how close it comes to the true value. precision refers to the agreement among repeated measurements.

Reminders

1. symbols Vs units; fundamental units Vs derived units; units ⇒ equation
2. standard prefixes: T, G, M, k, $\boxed{\text{d}}$, m, μ, n, p
3. beware of the sign (direction)
4. the consistence of time (simultaneous)
5. full knowledge of motion graphs
6. attention to motion under acceleration (gravity)
7. parabolic motion: constant horizontal velocity, accelerating vertical velocity

Newton's Laws of motion

Useful formulae

1. Momentum: $p = mv$
2. Net force: $F = ma$ $(= \frac{d}{dt}mv)$
3. Weight: $W = mg$
4. Impulse: $J = Ft = \Delta mv$
5. Friction: limiting friction $f_L = \mu_s R$; kinetic friction $f_k = \mu_k R$
6. Conservation of momentum: $\Sigma m_i u_i = \Sigma m_i v_i$
7. Hooke's Law: $F = ke$; energy stored = $\frac{1}{2}ke^2$
8. Equivlanet spring constant: in series $k = \frac{k_1 k_2}{k_1 + k_2}$; in parallel $k = k_1 + k_2$
9. Energies: $W = Fs$; $E_k = \frac{1}{2}mv^2$; $E_p = mgh$, $E_e = \frac{1}{2}ke^2$
10. Power: $P = E/t = Fv$
11. Archimedes principal: upthrust = the weight of the fluid displaced

I. Types of collision

	perfectly elastic	elastic	inelastic (stick together)
energy	conserved	not conserved	not conserved
momentum	conserved	conserved	conserved

II. Form of energies

1. Kinetic energy: all moving object carry KE.
2. Potential energy: gravitational, elastic and electrostatic.
3. Work done: energy transfer to (+) / from (-) a body to another body.

III. Terminal velocity

1. Body falling onto a viscous media.
2. When terminal velocity attained, resistive force = weight.

IV. Resultant and components

1. Find the resultant force/velocity of a body when there are more than one force/velocity acting on.
2. Resolve the force/velocity into two mutually perpendicular components, usually horizontal and vertical (expect in an inclined plane).

V. In a lift

1. Apparent weight = $m(g - a)$, *a* is the acceleration of the lift. $(g - a)$ means the apparent gravitation **relative** to the lift.
2. Put a positive when the lift is just starts going up OR just before stop when going down.
3. Put a negative when the lift is just starts going down OR just before stop when going up.

VI. Equilibrium: The 2 conditions of equilibrium

1. 1st condition: the balance of forces $\Sigma F_i = 0$
2. 2nd condition: the balance of moment of force $\Sigma L_i = 0$

Reminders

1. By 1st Law, even there is no change in velocity, acceleration can be applied to a body.
2. Action & reaction force pair: when removing the action force, the reaction force will disappear.
3. Beware of the loss of momentum. Beware of the motion in vertical situation.
4. Before the limiting friction, frictional force is equal and opposes to the applied force.
5. Tension in a string may not be equal to the weight of a body when the body is in motion(acceleration).

Circular Motion

Definition: A particle performs uniform circular motion when it is moving in a circular path at a constant speed.

Notation & units

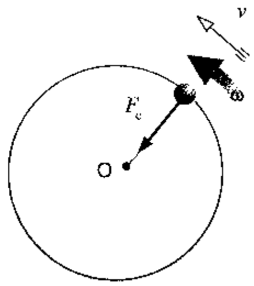
quantity	angular displacement	angular speed	linear speed/ tangential speed	centripetal acceleration	centripetal force	period
symbol	θ	ω	v	a	F	T
unit	rad	rad s^{-1}	ms^{-1}	ms^{-2}	N	s

Useful formulae

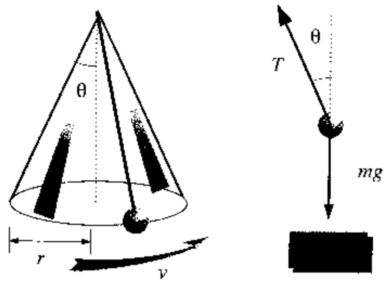
1. Angular speed $\omega = 2\pi N/t$, N – no. of revolution per mins. $\omega = 2\pi/T$, T – period.
2. Tangential speed $v = \omega r$. Acceleration $a = \omega^2 r = v^2/r$.
3. Centripetal force $F = m\omega^2 r = mv^2/r$.
4. General formula $\tan\theta = v^2/gr$

Typical cases

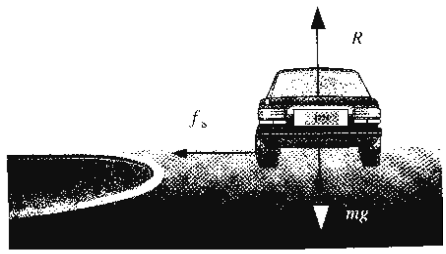
1. horizontal circle



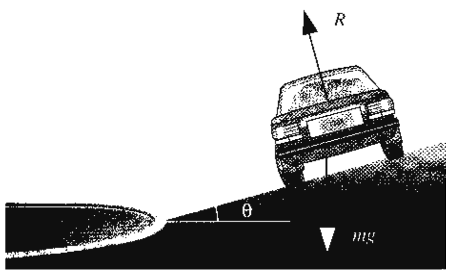
2. conical pendulum



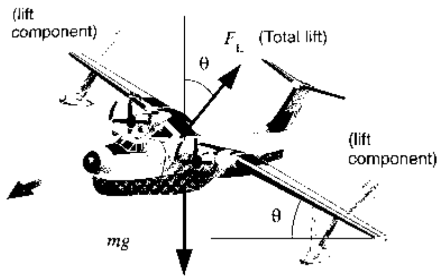
3. rounding a bend



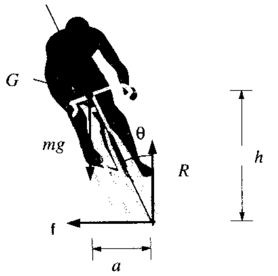
4. banked road



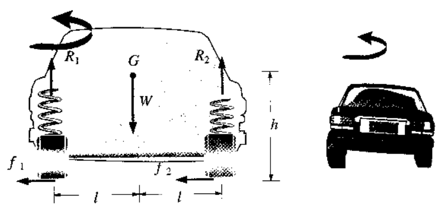
5. aircraft



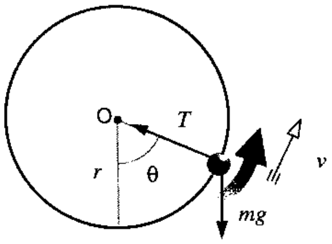
6. bicycle on a level road



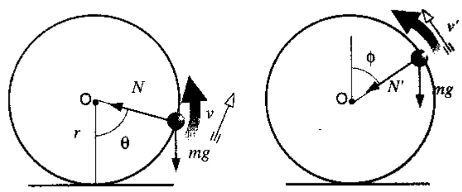
7. tilt of a car in circular motion



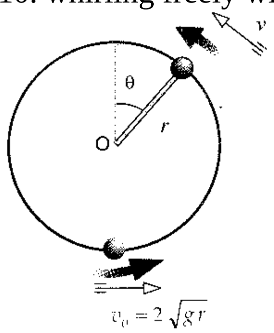
8. uniform motion in a vertical circle



9. non-uniform motion in a vertical plane



10. whirling freely with a rod



Reminders

1. The centripetal force do no work done on the object.
2. To perform circular motion, find out which force responsible to do so.
3. Normal reaction plays an important role in circular motion.
4. Be able to distinguish vertical circular motion in the cases with circular track, string and rod.
5. The angle θ is measuring from the vertical line when the object is in equilibrium.
6. Normal reaction will change in magnitude and direction in vertical circle.
7. Vertical circle is different from s.h.m.

Gravitation

I. Useful constant: G = 6.67×10^{-11} $Nkg^{-2}m^2$, $m_e \approx 6\times10^{24}$ kg, $r_e \approx 6400$ km

II. Gravitational force, $F = \frac{Gm_1m_2}{r^2}$ (the inverse square law); field strength, $g = \frac{F}{m} = \frac{GM}{r^2}$

III. Shell Theorem
1. Outside: all the shell's masses were concentrated at its center.
2. Inside: the net attraction by the shell is zero.

IV. Apparent weight
1. The density of the Earth crust is not uniform.
2. The Earth is not a perfect sphere.
3. The Earth is rotating.

V. Variation of *g* with height and depth
1. Outside the Earth: $g = g_o \frac{R_e^2}{r^2} = g_o\left(1 - \frac{2h}{R_e}\right) \propto \frac{1}{r^2}$
2. Below the Earth's surface: $g = \frac{g_o}{R_e} r = g_o\left(1 - \frac{d}{R_e}\right) \propto r$

VI. Gravitational Potential Energy
1. Zero PE is defined at infinity. WD is negative when moving an object from infinity to that point. $U_P = -\frac{GM_e m}{r}$. When there is more than one "reference mass", the total PE = the sum of all the PE
2. Escape speed, $v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2g_o R}$; where orbital speed, $v_o = \sqrt{\frac{GM}{R}} = \sqrt{g_o R}$
3. Gravitational potential, $V = \frac{U}{m}$
4. Potential V and field strength *g*, $g = -\frac{dV}{dr}$. Earth-Moon system, Fig.16

VII. Orbital Motion
1. Kepler's Laws:
   - (i) The Law of orbits: all planets move in elliptical orbits, with the Sun at one focus.
   - (ii) The Law of areas: the area swept out in a given time by the line joining any planet to the sun is always the same.
   - (iii) The Law of Periods: the square of the period T of any planet about the Sun is proportional to the cube of their mean distance r from the Sun. $T^2 \alpha r^3$.
2. Satellites: natural satellites Vs artificial satellite; geosynchronous satellite Vs polar satellite.
3. Energy and Satellite Motion
   - (i) KE: $U_k = \frac{1}{2}mv^2 = \frac{GM_e m}{2r}$
   - (ii) PE: $U_p = -\frac{GM_e m}{r}$
   - (iii) E_o: $U = U_k + U_p = -\frac{GM_e m}{2r}$

VIII. Reminders
1. The gravitational force is an action and reaction pair.
2. $T^2 = kR^3$, k is valid only for the same mass centre.
3. Density $\rho = m/V \ \alpha \ m/r^3$

Simple Harmonic Motion

Definition: Motion of a particle whose acceleration is always directed towards a fixed point and is directly proportional to the distance of the particle from that point. i.e. $a \propto -\omega^2 x$.

Notation & units

quantity	angular freq	velocity	acceleration	period	amplitude
symbol	ω	v	a	T	A
unit	rad s^{-1}	ms^{-1}	ms^{-2}	s	m

Description: displacement *x* changes sinusoidally with time *t*; $a = -\omega^2 x$ NB: $a = \frac{d^2x}{dt^2} = \ddot{x}$

General formulae: $x = A\sin\omega t$, $v = \omega A\cos\omega t$, $a = -\omega^2 A\sin\omega t$, $T = 2\pi/\omega$ or $\omega = 2\pi f$, $v = \pm\omega\sqrt{A^2 - x^2}$

Phase relationship: *v* leads *x* by $\pi/2$, *a* leads *v* by $\pi/2$, *a* & *x* are in anti-phase

Typical cases

1. Horizontal block-spring system

Fig. 12: $T = 2\pi\sqrt{\frac{m}{k}}$

2. Vertical block-spring system

Fig. 13: $T = 2\pi\sqrt{\frac{m}{k}}$

3. Simple pendulum

Fig. 14: $T = 2\pi\sqrt{\frac{l}{g}}$

4. A floating object

Fig. 15: $T = 2\pi\sqrt{\frac{m}{\rho g A}}$

5. Liquid in a U-tube

Fig. 16: $T = 2\pi\sqrt{\frac{l}{2g}}$

Energy in SHM

<u>maximum values</u>

$U_{po} = ½kA^2 = ½m\omega^2A^2$

$U_{ko} = ½mv_o^2 = ½m\omega^2A^2$

<u>energy versus displacement</u>

$U_p = ½kx^2 = ½m\omega^2x^2$

$U_k = ½mv^2 = ½m\omega^2(A^2 - x^2)$

<u>energy versus time</u>

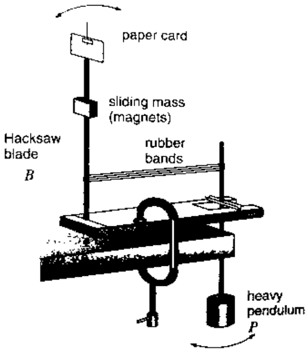
$U_p = ½m\omega^2A^2\sin^2\omega t$

$U_k = ½m\omega^2A^2\cos^2\omega t$

Damped Oscillation

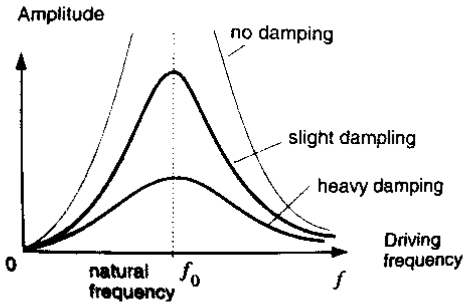
1. no damping
2. slight damping
3. critical damping
4. heavy damping

Forced oscillations



Natural freq Vs Driving freq

Resonance



Resonance, $\pi/2$ phase lag

Reminders

1. At equilibrium position, $x = 0$, $a = 0$, no net force.
2. Period *T* is independent of the amplitude ⇒ isochronous oscillation.
3. Maximum acceleration means maximum restoring force.
4. Remember to use radian for the angles. Define $x = A\sin\omega t$ or $A\cos\omega t$.
5. The crack SHM problems: ①proof $a \propto -x$, ②find out ω, ③work out for the *T*
6. When oscillating freely, the frequency is equal to its natural frequency.
7. In driving mode, the oscillating frequency follows the driving frequency.
8. Apply the conservation of energy.

Angular Momentum

Definition: A particle performs uniform circular motion when it is moving in a circular path at a constant speed.

Notation & units

quantity	angular displacement	angular velocity	angular acceleration	tangential acceleration	radial acceleration	
symbol	θ	ω or $\dot{\theta}$	α or $\ddot{\theta}$	a_t	a_r	
unit	rad	rad s^{-1}	rad s^{-2}	ms^{-2}	ms^{-2}	

Moment of inertia

1. Def$^{\underline{n}}$: The resistance of a rigid body to any change in rotational motion.
2. Dependence: 1. the mass of the body, 2. the way the mass is distributed (shape), 3. the axis of rotation.
3. Formula: $I = \sum_{i=1}^{N} m_i r_i^2$
4. Parallel Axes Theorem: $I = I_G + Mh^2$ Perpendicular Axes Theorem: $I_z = I_x + I_y$

Analogy between Translational and Rotational Motion

	displacement	velocity	accelerat-ion	inertia	force/ torque	momentum	Newton's 2nd Law	WD	power	KE
translational	s	$v = ds/dt$	$a = dv/dt$	m	F	$p = mv$	$F = ma$	$W = \int Fds$	$P = Fv$	$E_k = \frac{1}{2}mv^2$
rotational	θ	$\omega = d\theta/dt$	$\alpha = d\omega/dt$	I	Γ	$L = I\omega$	$\Gamma = I\alpha$	$W = \int \Gamma d\theta$	$P = \Gamma\omega$	$K_r = \frac{1}{2}I\omega^2$

For constant acceleration

Translational	Rotational
$v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$	$\omega = \omega_o + \alpha t$ $\theta = \omega_o t + \frac{1}{2}\alpha t^2$ $\omega^2 = \omega_o^2 + 2\alpha\theta$

Law of conservation of angular momentum and energies

Momentum: $I_1\omega_1 = I_2\omega_2$

Energies: $PE \rightarrow E_k + K_r$

Reminders

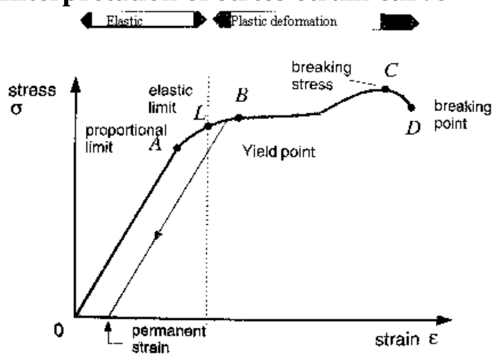
1. One turn (revolution) has 2π rad.
2. The direction of a rotational body or angular momentum is perpendicular to the plane of rotation.
3. Conditions for equilibrium: $\Sigma F = 0$ and $\Sigma\Gamma = 0$
4. Remember the relationship $v = \omega r$.
5. In rolling case, $v = r\omega$, $a = r\alpha$.
6. Rolling down an inclined plane, object will be rolling down without slipping due to frictional force, but do not WD.
7. In rolling down an inclined plane, a solid cylinder will be rolling down faster than that with a hollow cylinder with the same mass.
8. In pulley, we assume there is no friction in the axle but rough enough between the string and the rim.

Solids

Hooke's Law for springs
- $F = ke$
- $U_e = ½Fe = ½ke^2$

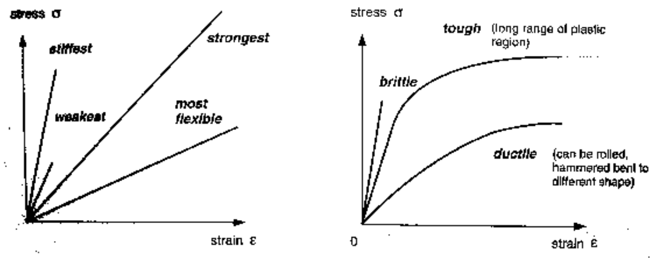
Young Modulus
- Stress $\sigma = F/A$, Strain $\varepsilon = e/l$
- Young Modulus $E = \sigma/\varepsilon = Fl/eA$
- $F = (EA/l)e \Rightarrow k = EA/l$

Interpretation of stress-strain curve



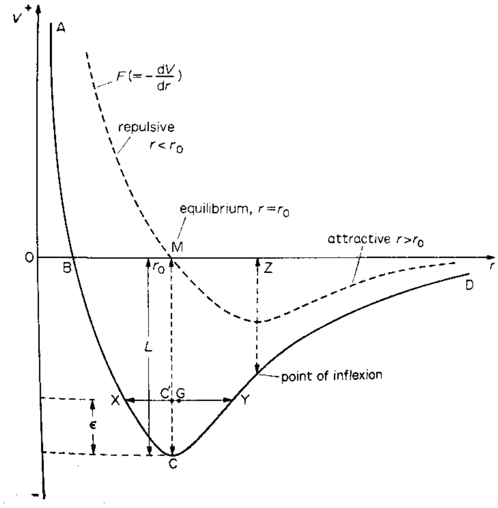
Energy of deformation
$W = ½\sigma\varepsilon$ = elastic PE/volume

Properties of materials
- Stiffness: larger E $\Rightarrow$ stiff (soft)
- Strength: larger breaking stress $\Rightarrow$ strong (weak)
- Ductility: easy to be reshaped $\Rightarrow$ ductile (rigid)
- Toughness: tough material does not crack readily



Plastic deformation of different materials
- Metals: Plastic deformation due to slip. Fatigue is due to fracture after repeated applications of stress. Creep is due to gradual elongation under high temperature.
- Glass: Plastic deformation is not possible due to crack.
- Rubber/Polythene: Molecules are twisted and tangled. Under stress, they become untangled.

Model of solid
- Intermolecular forces: Attractive force comes from the electrons of one molecule with the proton of adjacent molecule. Repulsive force comes from the electrons of both molecules.
- Intermolecular separation: Distance between the centers of two adjacent molecules. $Nr^3 = V$
- Force-separation curve

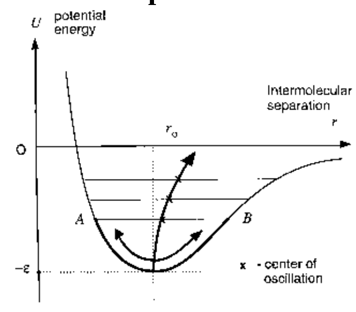


Intermolecular Potential energy
Refer to the above figure.

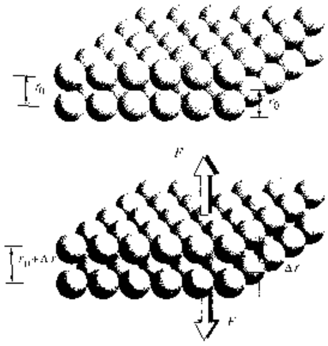
Vibration of molecules
$F = -kr$

Phase of matter
- Solids: Latent heat of fusion is required to melt the solid.
- Liquids: Latent heat of vaporization is required to overcome the intermolecular attraction between the molecules from equilibrium separation into infinity involving bond energy ε.
- Gases: Molecules are moving at high speed in random direction.

Thermal expansion



Young Modulus



$E = \sigma/\varepsilon = k/r_o$

Liquids

Newtonian Fluid (ideal Fluid)**:** *incompressible, non-viscous, streamlined flow*

Useful formulae

density	pressure	pressure difference	total pressure	equation of continuity
$\rho = \frac{m}{V}$	$p = \frac{F}{A}$	$\Delta p = \rho g h$	$p_t = p_o + \rho g h$	$A_1 v_1 = A_2 v_2$

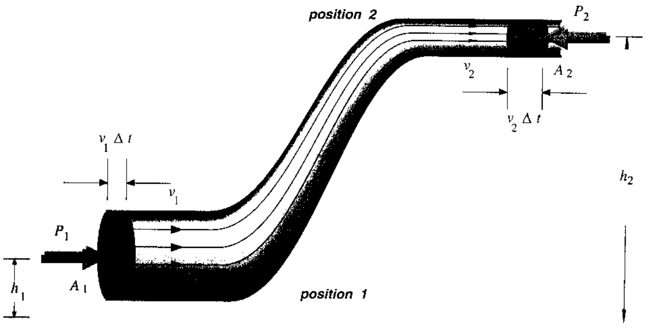
Measuring instruments

Bourdon Gauge, Mercury Barometer, Manometer

Archimedes' Principle

When an object is wholly or partially *immersed* in a fluid, the *upthrust* on the object is equal to the weight of the fluid *displaced*: $U = \rho V g$

Bernoulli's Principle

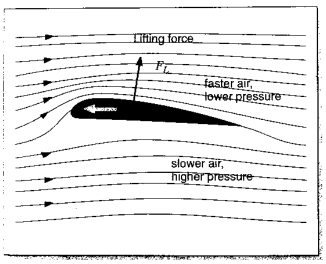


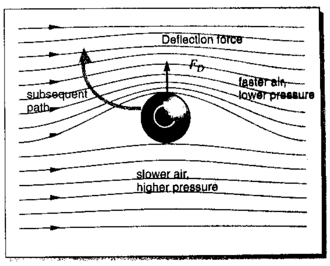
Bernoulli's Equation

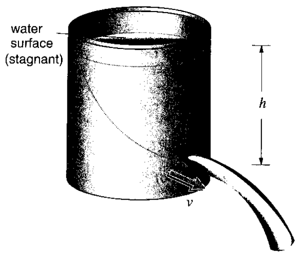
$\Delta W = \Delta E_k + \Delta E_p$

$\Rightarrow P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$

Examples of Bernoulli's Effect



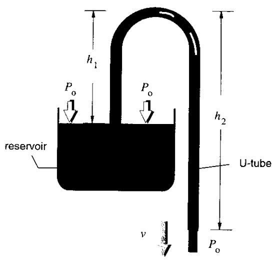




A hole in a water tank

$P_o + 0 + \rho g h = P_o + \frac{1}{2}\rho v^2 + 0$

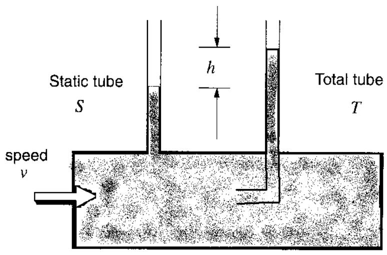
$\Rightarrow \quad v = \sqrt{2gh}$



Siphon

$P_o + \rho g(h_2 - h_1) = P_o + \frac{1}{2}\rho v^2 + 0$

$\Rightarrow$ v = $v = \sqrt{2g\Delta h}$



Pitot Tube

$P_s + \frac{1}{2}\rho v^2 = P_t + 0$

and

$P_t - P_s = \rho g h$

$\Rightarrow$ v = $v = \sqrt{2gh}$

Reminders

1. Be able to derive the Bernoulli's equation.
2. Useful wordings: turbulence, streamlined flow, streamline.
3. Pressure at two points at the same horizontal level in the same liquid is the same.
4. Pressure is equal to the atmospheric pressure when open to air.
5. When calculating the total pressure, remember to add P_o, the *atmospheric pressure*.
6. Density of water = 1000 kg m^{-3} = 1 g cm^{-3}; 1 cc = 1 $m\ell$ = 1 cm^3.

Heat and Gases

Table of constants

standard temperature and pressure	absolute zero	universal gas constant	Avogadro constant	Boltzmann constant
s.t.p.	0 K	R	N_A	k
1.03×10^5 Pa & 0°C	-273.15°C	8.31 J K^{-1} mol^{-1}	6.023×10^{23} mol^{-1}	1.38×10^{-23} J K^{-1}

Kinetic Theory Formulae

r.m.s. speed	energy	pressure & density	average translational KE	internal energy
$c_r = \sqrt{\overline{c^2}}$	$pV = \frac{1}{3}Nmc_r^2$	$p = \frac{1}{3}\rho c_r^2$	$E_k = \frac{1}{2}mc_r^2 = \frac{3}{2}\left(\frac{R}{N_A}\right)T = \frac{3}{2}kT$	$U = \frac{3}{2}nRT = \frac{3}{2}pV$

Ideal Gas

- *macroscopic scale*: obey Boyle's Law
- *microscopic scale*: no intermolecular force, volume of molecules are zero, collisions between molecules and container are perfectly elastic, molecules are in constant *random* motion
- *real gas* will behave like ideal gas at high temperature and low pressure

Gas Laws

Boyle's Law	Charle's Law
$pV = constant$	$\frac{V}{T} = constant$
Pressure Law	General Gas Law
$\frac{p}{T} = constant$	$\frac{pV}{T} = constant$

General Gas Law

for fixed mass of gas: $\boxed{pV = nRT}$

Conversions

- one mole of gas contains 6.023×10^{23} molecules
- one mole of gas has a mass of one molar mass in gram

Important Laws

- Avogadro's Law: Under the same conditions of volume, temperature and pressure, two ideal gases contain equal number of molecules.
- Dalton's Law of partial pressure: In a mixture of ideal gas, the total pressure equals the sum of the pressure which each gas would produce if it occupied the whole volume by itself at that temperature.

Real Gases

- *finite size*, have *intermolecular force*
- Van der Waals equation of state: (p + k)(V – nb) = nRT
- critical temperature: the temperature above which a gas cannot be *liquefied* by applying high pressure only.

Thermodynamics

- Heat: energy transfer
- Internal energy: KE + PE
- +WD: work done **BY** the gas (expansion)
- -WD: work done **ON** the gas (compression)
- $W = \Sigma\Delta W = \int dW = \int_{V_1}^{V_2} pdV$

The indicator diagrams

fig. 18 - 26

First Law of Thermodynamics

$\boxed{Q = \Delta U + W}$ Q – heat, ΔU – internal energy, W - work

Typical process

adiabatic	isovolumetric/isochoric
Q = 0, ΔU = -W	W = 0, ΔU = Q
isothermal	isobaric
ΔU = 0, Q = W	p const, ΔU>0, Q>W>0

Reminders

1. Able to derive pV = $\frac{1}{3}Nmc_r^2$ from kinetic theory.
2. Be clear that you are studying the "whole" gas or the gas "molecule".
3. Internal energy E = Kinetic energy KE (temperature) + Potential energy PE (state).
4. The first law of thermodynamics is a concept the conservation of energy.
5. Whatever there are changes in P, V and T, the total number of moles / molecules remain unchanged.
6. Apart from monatomic gas, polyatomic gas molecules have both translational and rotational KE.
7. Ideal gas has no PE, thus its internal energy is purely represented by its KE

Wave Phenomena

Terms: *progressive* Vs *stationary*, *mechanical* Vs *electromagnetic*, *transverse* Vs *longitudinal*, *crest* Vs *trough*, *compression* Vs *rarefaction*; sinusoidal, square, saw-toothed

Major properties: speed *c*, frequency *f*, period *T*, wavelength λ, amplitude *a*; $\boxed{c = f\lambda,\ f = 1/T}$

Graphical representations and phase relationship

General equation: $y = a \sin(\omega t + \phi)$, $\omega = 2\pi f$, $\phi = 2\pi x/\lambda$ or $2\pi t/T$

Phase: in phase, out of phase, π out of phase/antiphase

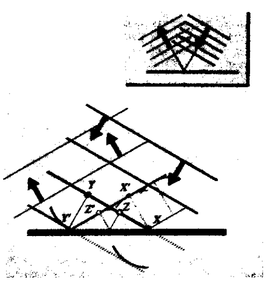
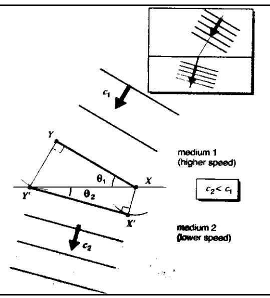
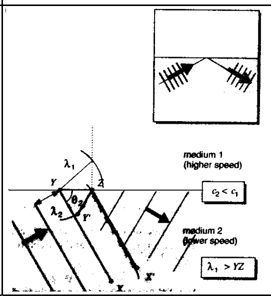
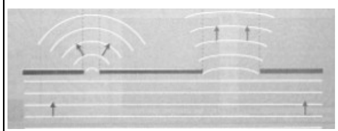
Leading wave: 2 points on a displacement-position graph, peak on the *left* one (near the source)
2 waves on displacement-position graph, peak on the *right* one (oscillate first)
2 waves on displacement-time graph, peak on the *left* one (crest first)

Wave speed

general equation	$c = \sqrt{\dfrac{elastic \cdot property \cdot of \cdot the \cdot medium}{inertial \cdot property \cdot of \cdot the \cdot medium}}$	longitudinal wave speed in a solid	$c = \sqrt{\dfrac{Young \cdot mod\ ulus}{density}} = \sqrt{\dfrac{E}{\rho}}$
speed of transverse wave in a string	$c = \sqrt{\dfrac{tension}{mass \cdot per \cdot unit \cdot length}} = \sqrt{\dfrac{T}{\mu}}$	speed of sound in air	$c = \sqrt{\dfrac{const \times pressure}{air \cdot density}} = \sqrt{\dfrac{\gamma p}{\rho}}$

General wave properties

Huygen's Principle: Every point on the wavefront may be regarded as a source of secondary wave. The new wavefront is the envelope of these secondary waves.

reflection	refraction	total internal reflection	Snell's Law	diffraction
			$\dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{c_1}{c_2} = \dfrac{\lambda_1}{\lambda_2}$	

Interference

Principle of superposition: *reinforcement* and *cancellation*.

Condition: coherent sources (const phase difference, same frequency, separation < several wavelength)

Constructive interference: $\Delta = m\lambda$, destructive interference: $\Delta = (m + ½)\lambda$; m = 0, 1, 2….

Power of mechanical waves: $P \propto f^2, a^2, c$; intensity $I \propto a^2$, for spherical wave $I = \dfrac{P_o}{4\pi r^2} \alpha \dfrac{1}{r^2}$

Refection and phase change: π phase change at fixed end, no phase change at free end

Stationary waves

Terms: *node* Vs *antinode*, *fundamental* (the number of "copies" of the fundamental) Vs *overtones* (the n[th] variation of the fundamental)

Frequency in a string: $f_n = \dfrac{c}{\lambda} = \dfrac{n}{2l}\sqrt{\dfrac{T}{\mu}}$, n = 1, 2, 3….; beats: $f_{beat} = 1/T_b = f_1 - f_2$

Polarization: *unpolarized* Vs *plane-polarized*; $a' = a\cos\theta$

Reminders

1. If $\phi > T/2$ or $\lambda/2 \Rightarrow$ **A** leads **B** will becomes **B** leads **A** with $\phi' < T/2$ or $\lambda/2$.
2. Speed of sound in air is independent of pressure, $c \ \alpha \sqrt{T}$.
3. Speed depends on medium, frequency depends on the vibrating source, λ depends on both.
4. When unpolarized wave passed through polarizer, the orientation of the polarized wave will follow the orientation of the "slit" of the polaroid.

Sound Waves

Useful information

Audible frequency	room temp speed	minimum detectable intensity / threshold of hearing	reference frequency
20 – 20 kHz	340 ms^{-1}	10^{-12} Wm^{-2}	1 kHz

Intensity

Intensity: $I = \frac{sound \cdot power}{area} = \frac{P}{A} = \frac{P}{4\pi r^2}$ (for spherical)

Intensity level: $IL = 10\, log_{10} \frac{I}{I_o}$; unit: decibel (dB) where d = 10^{-1}

Loudness: Physiological perception of sound intensity.

Speed of sound

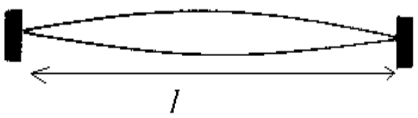
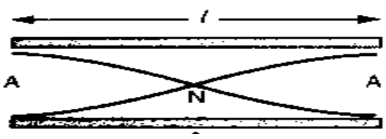
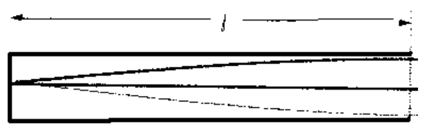
In gas (air): $c = \sqrt{\frac{\gamma RT}{M_m}}$; in solid: $c = \sqrt{\frac{E}{\rho}}$

Doppler effect

Doppler effect: Relative motion between the source and the receiver/observer would result in an apparent change in the observer frequency of a wave.

general formula	source approaching observer or observer approaching source	source moving away from observer or observer moving away from source	Approximate relationship
$f' = \left(\frac{c \pm v_o}{c \mp v_s}\right) f$	apparent frequency becomes higher	apparent frequency becomes lower	$\frac{\Delta f}{f} = \frac{v}{c}$

Musical instruments

Stringed	Open pipe	Closed pipe
		
$f_o = \frac{c}{2l}$	$f_o = \frac{c}{2l}$	$f_o = \frac{c}{4l}$

Reminders

1. Be able how to derive the "Doppler formulae" from first principle: change of wavelength and change of velocity.
2. For moving reflector, remember to put "2v_s".
3. In calculating the intensity level, put the Power into the equation is also applicable.
4. Remember to check whether there is an "end-correction" in the Pipe instruments.
5. Be sure that where are the positions of the Node and Anti-node in musical instruments.

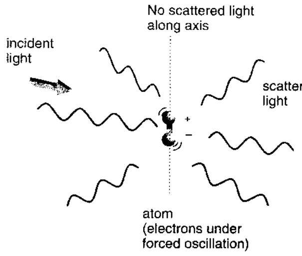
Electromagnetic Waves

The EM waves

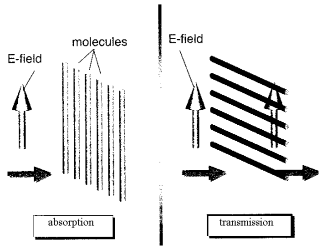
radio waves	microwaves	infrared	visible	ultraviolet	X-rays	γ-rays
0.1m – 10 km	1mm – 0.1m	0.7μm – 1mm	0.4μm – 0.7μm	1nm – 0.4μm	10^{-11}m – 10^{-9} m	10^{-14}m – 10^{-11}m

Light

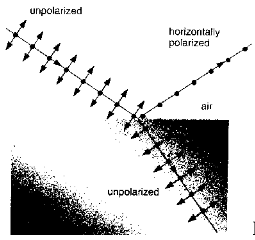
Scattering of light



Polarization of light



Brewster's angle



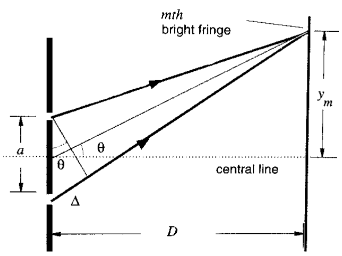
$n = \tan\theta_p$

Interference

Conditions: *coherent* sources (same frequency, constant phase difference), approximately equal amplitude), not too great path difference, sources separation ~nλ.

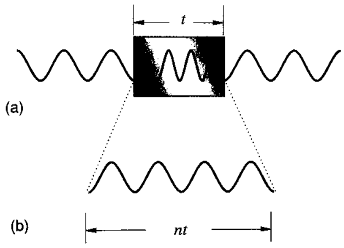
Coherent length: the average length of section of wave train without jumps of phase change.

Young's double slit experiment (division of wavefront)



CI: $a\sin\theta = m\lambda$
DI: $a\sin\theta = (m + ½)\lambda$
$S = \lambda D/a$

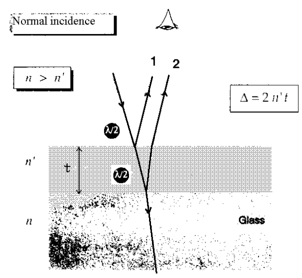
Optical path



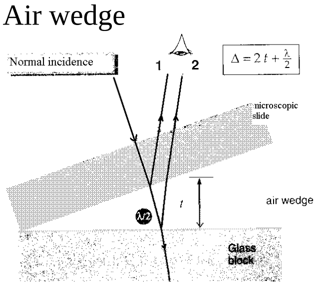
optical path
= $n \times$ physical path
= nt

Other example illustrating path difference and phase change (division of amplitude)

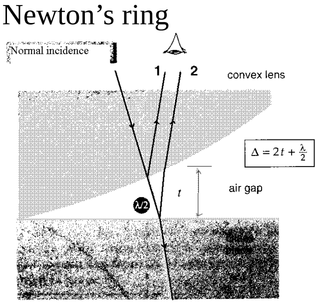
Blooming of lenses



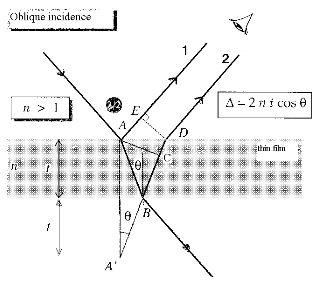
Air wedge



Newton's ring



Thin films



Diffraction grating (interference)

$d\sin\theta_n = n\lambda$ (for bright fringes), $n_{max} \leq a/\lambda$

Diffraction

$d\sin\theta_n = n\lambda$ (for dark fringes)

Reminders

1. The higher the frequency, the higher the energy of the EM wave.
2. Each colour of light has a different refractive index in glass ⇒ dispersion.
3. Both scattering and polarization are due to E-field (resonance).
4. Red light refracted less but diffracted more; blue light refracted more but diffracted less.
5. In white light diffraction spectrum, there may be a overlapping of colour of m^{th} and $(m+1)^{th}$ spectra. Maximum number of order of diffraction depends on the slit width and wavelength.
6. "Horizontally polarized" means there is only the horizontal wave can be propagate.
7. Optical path means the "equivalent path length" of a light wave in vacuum.
8. Remember to put a λ/2 to the path when light is reflected at denser medium.

Optical Instrument

Terms

regular reflection	real image	lateral displacement	spherical aberration	
diffuse reflection	virtual image	angle of deviation	chromatic aberration	

Mirror and Lens Formula

$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$$

$$m=\frac{h_i}{h_o}=\frac{v}{u}$$

	concave mirror	convex mirror	convex lens	concave lens
focus & focal length	+f on objective side	-f on image side	+f on image side	-f on object side
object & distance	+u	+u	+u	+u
image &distance	+v in front of mirror, -v behind the mirror	-v behind the mirror	+v on opposite side, -v on the same side	-v on the same side

Real is positive convention

Useful Formulae

Prism

$$n_g=\frac{\sin\frac{1}{2}\left(A+D_{min}\right)}{\sin\frac{1}{2}A}$$

Lenses in contact

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$

Converging power of a lens

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

Optical Instruments

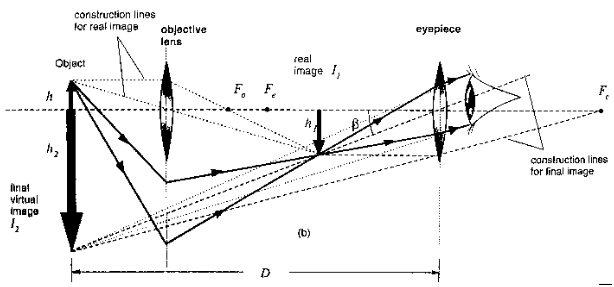
Angular magnification, $M=\frac{\beta}{\alpha}=\frac{visual\cdot angle\cdot of\cdot the\cdot final\cdot image}{visual\cdot angle\cdot of\cdot the\cdot object}$

Least distance of distinct vision: D = 25 cm

Normal adjustment

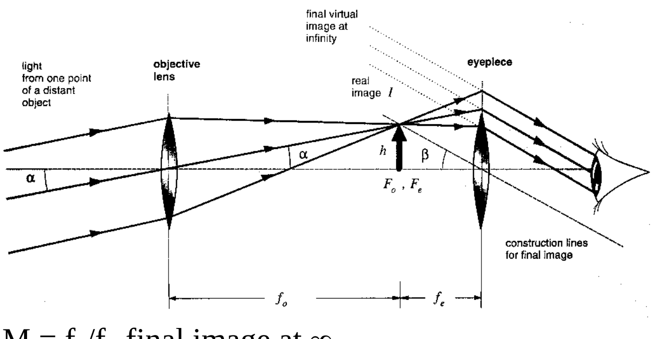
Telescope: at infinity; magnifying glass & microscope: near point of the observer

Compound Microscope



M = $m_e \cdot m_o$, final image at D

Refracting Telescope



M = f_o/f_e, final image at ∞

Magnifying glass

M = D/f +1

Eye ring

$$\frac{1}{f_e}=\frac{1}{L}+\frac{1}{d}$$

Reminders

1. Know the methods of measuring focal lengths of mirror and lens.
2. Remember the construction rules.
3. A spectrometer contains: collimator, turntable and telescope.
4. Remember the general form of Snell's Law, $n_1\sin\theta_1 = n_2\sin\theta_2$
5. Normal adjustment: final image at a position which the user expects to see.

Electrostatics

Useful equations

1. surface charge density, $\sigma = \frac{Q}{A}$
2. electric field strength, $E = \frac{F}{q}$ or $F = qE$
3. Coulomb's law, $F = \frac{1}{4\pi\varepsilon} \cdot \frac{Q_1 Q_2}{r^2}$
4. relative permittivity, $\varepsilon = \varepsilon_r \varepsilon_o$
5. current, $I = \frac{Q}{t}$
6. work done, $W = F \cdot r$
7. potential energy, $W = QV$
8. 1 eV = 1.6×10^{-19} J
9. field Vs potential, $E = -\frac{dV}{dr}$
10.

	point charge	charged spherical conductor	parallel plates
electric field	$E_r = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Q}{r^2}$ (radial field)	inside, $E_r = 0$ outside, $E_r = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Q}{r^2}$ surface, $E_a = \frac{\sigma}{\varepsilon_o}$	$E = \frac{\sigma}{\varepsilon_o}$ (uniform field)
electric potential	$V = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Q}{r}$	inside, $V = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Q}{a}$ outside, $V = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Q}{r}$	$V = Ed = \frac{\sigma d}{\varepsilon_o}$
potential energy	$V = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Qq}{r}$		$V = qEd$

Reminders

1. Edge effect on plates.
2. Definitions of field, force, potential are based on a positive testing charge.
3. Electric is defined at infinite (the earth).
4. Equipotential lines are drawn perpendicular to field lines.
5. In vacuum (free space), $\varepsilon_r = 1$
6. Electric field strengths can be added together when more than one charge exist.
7. Electric potential can be added together when more than one charge exist.
8. *Joule* energy is too large for charges, *eV* is used instead of.
9. Electric potential V at a point is the WD per coulomb required to bring a +ve charge from infinity to the point.
10. p.d. between any 2 points is the WD per coulomb on a +ve charge in moving between them.
11. Earthed conductor, *zero* potential.
12. Know the working mechanism of flame probe.

Comparison of electric field with gravitational field

	Electric	Gravitational
Force	$F = \frac{1}{4\pi\varepsilon} \cdot \frac{Q_1 Q_2}{r^2}$	$F = G\frac{m_1 m_2}{r^2}$
Field	$E_r = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Q}{r^2}$	$g = G\frac{M}{r^2}$
Field & force	F = qE	W = mg
Potential	$V = \frac{1}{4\pi\varepsilon_o} \cdot \frac{Q}{r}$	$V = -\frac{GM}{r}$

Capacitance

Useful formulae

1. capacitance, $C = \frac{Q}{V}$ or $CV = Q$

2. capacitance for 2 parallel plates, $C = \frac{\varepsilon A}{d} = \frac{\varepsilon_r \varepsilon_o A}{d}$

3. capacitance for an isolated sphere, $C = 4\pi\varepsilon_o a$

4. capacitors combinations

parallel	$C = C_1 + C_2 + C_3$
series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

5. energy stored in capacitor, $U = \frac{1}{2}\frac{Q_o^2}{C} = \frac{1}{2}CV_o^2 = \frac{1}{2}Q_o V_o$

6. charging and discharging a capacitor via a resistor

	charging	*discharging*
charge	$Q = Q_o(1 - e^{-t/RC})$	$Q = Q_o e^{-t/RC}$
current	$I = I_o e^{-t/RC}$	$I = I_o e^{-t/RC}$
voltage	$V_c = V_o(1 - e^{-t/RC})$	$V_c = V_o e^{-t/RC}$

Reminders:

1. CV = Q, $\uparrow$C or $\uparrow$V $\Rightarrow$ $\uparrow$Q; C is the intrinsic property, V is the dominant property, Q depends on both.
2. Equal quantity of charges on both plates of a capacitor.
3. Dielectic (relative permittivity ε_r).
4. While dielectric is putting into the capacitor, work is done on the capacitor and vice versa.
5. Stray capacitance C_s, $C = C_o + C_s$
6. For capacitors combinations: same potential (in parallel); same charge quantity (in series).
7. When there is more than one capacitor in the circuit, find out the equivalent capacitance first
8. Time constant RC:
9. Initial charging or discharging current = V_o/R
10. Charging and discharging, useful equations: $V_o = I_oR$, $C_oV_o = Q_o$, $Q_o = I_ot$, $I = -\frac{dQ}{dt}$
11. Sometimes, capacitor will be charging or discharging with constant current, apply $I = -\frac{dQ}{dt}$ to calculate the time or charge.
12. We are hardly to measure the charge storage in a capacitor, we measure the voltage instead of.
13. Remember the charging and discharging curves. Small CR, easier to be discharged, vice versa.
14. When charging, currents in both capacitor and resistor are the same. When discharging, currents are opposite, V_C is keep positive, but V_R is reversed.
15. Always ask yourself a question: where are the charges?

Electric Circuits

Notation & units

quantity	current	charge	charge density	drift velocity	EMF	E-field	resistance	resistivity	electric power
notation	I	Q	n	V_D	ε	E	R	ρ	P
unit	A	C	$C\ m^{-3}$	$m\ s^{-1}$	$J\ C^{-1}$ or V	$V\ m^{-1}$	$V\ A^{-1}$ or Ω	Ω m	W

Common electric circuits

Combination of cells, circuits with diode, bridge circuits, potentiometer, voltmeter-ammeter method, electrical meters (V & A), ohm-meter, multi-meter

Useful formulae

1. Drift velocity: $V_D = \frac{I}{nAq}$ or (I = vane)
2. Electrical energy: U = Qε or (W = QV)
3. Combination of cells: $\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$ (in series); $\varepsilon = \varepsilon_1$ (in parallel and $\varepsilon_1 \geq \varepsilon_2$ & ε_3)
4. Resistance: $R = \frac{V}{I}$ or V = IR; $R = \frac{\rho l}{A}$
5. Internal resistance of battery: ε = V + Ir; for open circuit, V = ε
6. Combination of resistors: $R = R_1 + R_2 + R_3$ (in series); $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ (in parallel)
7. Power and heating effect: P = VI = IR = $\frac{V^2}{R}$; $P_o = \varepsilon I = IR = \frac{\varepsilon^2}{R}$
8. Power loss in transmission: $P_{loss} = I_L^2 R$

Reminders

1. **Shunt** is used to convert milliammeter into ammeter according that the p.d. of both is the same. M**ultiplier** is used to convert galvanometer into voltmeter according that the current flow through them is the same.
2. Earth point in circuit is zero potential.
3. In Wheatstone Bridge, potentials at mid-point are the same.
4. In Potentiometer, balancing point implies same p.d.
5. Know the full scale deflection (f. s. d.); protective resistor.
6. *Zero* current, *zero* p.d.
7. Redraw (circuit) diagram.
8. Put arbitrary values into the components.
9. Find out the resistance of the component (light bulb) first.
10. Identify which is the intrinsic factor in electric components; find out the resistance of light bulb or heater.
11. Keys to success: note where will be same in current or same in p.d.
12. Always ask a question: where does to current come and go.

Electromagnetism

Notation & units

quantity	magnetic flux density	Permeability	Magnetic flux	inductance	
notation	B	μ_o	ϕ	L	
unit	T	TmA^{-1}	Tm^2 / Wb	H	

Useful formulae

1. Magnetic flux density, $B = \frac{F}{Il}$ or F=BIl; magnetic flux, $\phi =$ BA
2. Torque in coil, Γ = NBAI
3. Magnetic force, F = qvB; electric force, F = qE
4. Hall voltage, $V_H = \frac{BI}{nqd}$
5. Magnetic field density

solenoid	coil	straight line
$B = \mu_o nI$	$B = \frac{\mu_o NI}{2r}$	$B = \frac{\mu_o I}{2\pi r}$

6. Definition in induced e.m.f., $\varepsilon = -\frac{d\phi}{dt}$ (golden formula) = $-\frac{d(NBA)}{dt}$
7. Induced e.m.f. in generator, ε = NBAωsinωt; in rod, ε = Blv
8. Inductance, $L = \frac{N\phi}{I}$
9. Self-induced e.m.f. in inductor, $\varepsilon = -L\frac{dI}{dt}$
10. Current in a resistive circuit with inductor, $I = I_o(1 - e^{-\frac{R}{L}t})$
11. Magnetic energy stored in an inductor, $U_B = \frac{1}{2}LI^2$
12. In transformer, $N_p \frac{d\phi}{dt} = N_S \frac{d\phi}{dt}$

Reminders

1. Put "sinθ" or "cosθ" into the formula while the conductor is not perpendicular to the magnetic field.
2. Definition of sensitivity of moving coil meter: S = θ/I. Know the construction of a meter.
3. Know DC / AC motor and their practical restrictions.
4. Electric force and magnetic force will both applied on a moving charge. Know the correlation between centripetal force and magnetic force.
5. Hall probe cannot only to find out the B-field strength, but also the kind of the charge carrier.
6. Use Lenz's law to explain electromagnetic phenomenon.
7. Incomplete circuit→no current; complete circuit without resistance→no p.d.
8. Understand back e.m.f.
9. Capacitor stores electric energy (energy stores in electric field), inductor stores magnetic energy (energy stores in magnetic field).

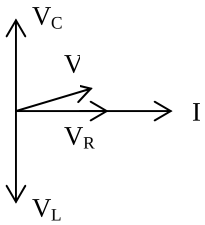
Alternating Currents

Notation & units

quantity	r.m.s I & V	resistance	capacitive reactance	inductive reactance	impedance
notation	I_{rms}, V_{rms}	R	X_c	X_L	Z
unit	A, V	Ω	Ω	Ω	Ω

Useful formulae

1. Alternating current, $I = I_o \sin\omega t$, alternating voltage, $V = V_o \sin\omega t$; where $\omega = 2\pi f$
2. Definition of power: $P = VI$
3. Average power dissipation by R, $\overline{P} = I_{rms}^2 R$, $I_{rms} = \dfrac{I_o}{\sqrt{2}}$, $V_{rms} = \dfrac{V_o}{\sqrt{2}}$
4. Average power, $\overline{P} = V_{rms} I_{rms} \cos\phi$, where $\cos\phi$ is the power factor.
5. Reactance, capacitive: $X_c = \dfrac{1}{\omega C}$, inductive: $X_L = \omega L$
6. Impedance, RC: $Z = \sqrt{R^2 + X_C^2}$; RL: $Z = \sqrt{R^2 + X_L^2}$; LRC: $Z = \sqrt{R^2 + (X_L - X_C)^2}$
7. Natural (resonant) frequency, $f_o = \dfrac{1}{2\pi\sqrt{LC}}$



8. Summarizing chart

For $I = I_o \sin\omega t$; V leads I: $V = V_o \sin(\omega t + \phi)$; V lags I: $V = V_o \sin(\omega t - \phi)$

	Pure R	Pure C	Pure L	RC	RL	LRC	
Phase	V & I are in phase	I leads V by 90°	I lags V by 90°	I leads V by ϕ, $\tan\phi = X_C/R$	I lags V by ϕ, $\tan\phi = X_L/R$	$\omega > \omega_o$: V leads I $\omega < \omega_o$: I leads V $\omega = \omega_o$: in phase	$\tan\phi = (X_L - X_C)/R$
I_o	$I_o = \dfrac{V_o}{R}$	$I_o = \dfrac{V_o}{X_C}$	$I_o = \dfrac{V_o}{X_L}$	$I_o = \dfrac{V_o}{Z} = \dfrac{V_o}{\sqrt{R^2 + X_C^2}}$	$I_o = \dfrac{V_o}{Z} = \dfrac{V_o}{\sqrt{R^2 + X_L^2}}$	$I_o = \dfrac{V_o}{Z} = \dfrac{V_o}{\sqrt{R^2 + (X_L - X_C)^2}}$	

Reminders

1. Both mean current and voltage in an a.c. are zero.
2. In HK, 220V indicates the r.m.s. voltage, thus the peak voltage = 311V
3. Know how to draw a full-wave rectifier circuit.
4. In phase diagram, I is always drawn on the right side on the horizontal line. Applied voltage follows the current; V_R is in phase with both current and applied voltage.
5. Use $CV = Q$, $I = \dfrac{dQ}{dt}$, $V_L = L\dfrac{dI}{dt}$ to solve problems.
6. Beware of the connection of CRO in a circuit.
7. The peak on the left hand side in wave form leads the other.
8. The average power consumed in pure C or L circuit is zero where $P = V_{rms} I_{rms} \cos\phi$

Electronics

Diodes
1. Forward bias, reverse bias, forward voltage, breakdown (voltage),
2. Rectification of a.c.

Transistors
1. $I_e = I_b + I_c$ (when conducting)
2. Input characteristics ($I_b - V_{BE}$)
   (a) Cut off: $V_{BE} < 0.5V$
   (b) Conducting: $V_{BE} > 0.7V$
3. Current transfer characteristics ($I_c - I_b$)
   (a) Current gain, $\beta = \frac{\Delta I_c}{\Delta I_b}$ ($\beta \sim 100$)
   (b) $I_{c\,max} = V/R_L$
4. Collector characteristics ($I_c - V_{CE}$)
   (a) I_c is independent of V_{CE}; I_c depends on I_b only
5. Input-Output voltage characteristics ($V_{out} - V_{in}$)
   (a) Cut off: no current flows ($V_{in} < 0.7V$)
   (b) Linear and saturation: $I_b = (V_{in} - V_{BE})/R_B$
   (c) Linear: $I_c = \beta I_b$; $V_{out} = 6 - I_cR_L = 6 - \beta I_bR_L = 6 - \beta(V_{in} - V_{BE})R_L/R_B$
   (d) Saturation: $I_c = (6 - V_{CE})/R_L$
   (e) Voltage gain: $G = -\beta\frac{R_L}{R_B}$ ($G \sim -15$); V_{in} and V_{out} are anti-phase (inverting amplifier)
   (f) To avoid distortion, $V_{out} < \pm 3.0$ V, $V_{in} < \pm 0.2V$
   (g) Know biasing current

Operational amplifier
1. Intrinsic properties: very high voltage gain; high input resistance; low output resistance; draw negligible current.
2. Rules: ❶$V_+ \approx V_-$ ❷very large input impedance ❸no current flow into the op-amp
3. Open-loop configuration
   (a) Open-loop gain: $V_o = A_o(V_+ - V_-)$; $A_o = 10^5$
   (b) Voltage comparator: V_o is either 'High' or 'Low'
4. Feedback configurations: Negative feedback
   (a) Inverting amplifier: $V_{out} = -\frac{R_f}{R_{in}}V_{in}$
   (b) Inverter: $R_f = R_{in} = R$, $V_{out} = -V_{in}$
   (c) Summing amplifier: $V_{out} = -(V_1 + V_2 + V_3)$
5. Non-inverting amplifier
   (a) $V_{out} = (1 + \frac{R_f}{R_{in}})V_{in}$
   (b) Voltage follower: $R_f = 0$, $R_{in} = \infty$, voltage gain = 1

Golden rule: Where do the Voltage & Current come and go?

Extra-nuclear Physics

Cathode Ray

1. Gas discharged tube, electrodes, charge-to-mass ratio, ionization, ground state.
2. Production of cathode ray: heated cathode, evacuated glass tube, anode, electron cloud, thermionic emission, $\frac{1}{2}m_e v^2 = eV_A$
3. Determination of e/m_e
   甲、*Thomson's method*: electric force = magnetic force
   乙、Fine beam tube method: magnetic force provides the centripetal force
4. Deflection in a uniform electric field
   丙、Trajectory: knowing both the horizontal and vertical movements linked by time t, the track of the electron is moving in parabolic motion.
   丁、$tan\,\theta = \dfrac{D}{\frac{1}{2}L}$

Oscilloscope

1. Electron gun: cathode, grid, focusing anode, accelerating anode, graphite coating tube
2. Deflecting system: X-plates, Y-plates
3. Time base circuit
4. Display screen: fluorescent screen
5. Application: voltmeter, displaying waveform, measuring frequency, measuring phase difference

Photoelectric effect (wave-particle duality)

Three types of energies:

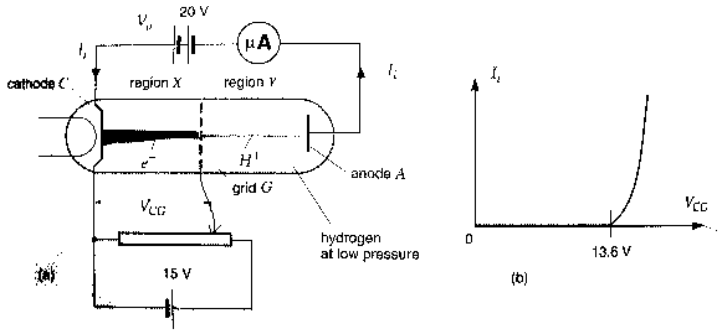
Photons	KE	WD
hf	$\frac{1}{2}m_e v^2$	eV

NB: 1eV = 1.6×10^{-19} J

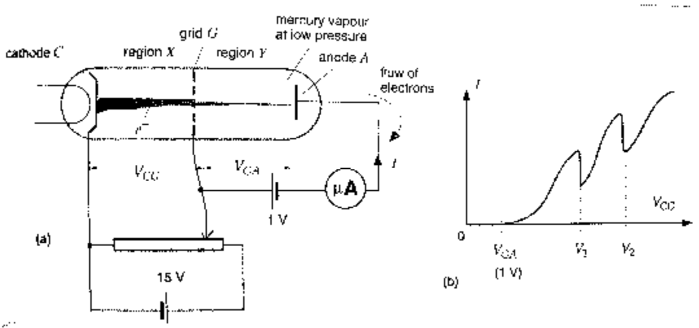
1. Threshold frequency: Minimum frequency cause photoelectric emission occurs. (emission occurs on the metal surface only)
2. Intensity of radiation: The amount of light. (Intensity is proportional to both frequency and number of photons)
3. Kinetic energy of photelectrons:
   $U_k = \frac{1}{2}m_e v_{max}^2 = eV_s$ (V_s – stopping potential)
4. Einstein's photoelectric equation
   (a) A photon possess energy, E = hf
   (Planck's constant, h = 6.63×10^{-34} Js)
   (b) Maximum KE: $\frac{1}{2}m_e v_{max}^2 = hf - \phi$
   ($\phi = hf_o$)
   (c) Stopping potential: $V_s = \frac{h}{e}(f - f_o)$
5. Photon is absorbed as a quanta, but electron can loss whole of its energy of part.

Electrons inside atoms

1. Ionization by collision (elastic collision): determination of ionization potential of hydrogen



2. Excitation by collision (inelastic collision): Franck and Hertz experiment



The shorter the wavelength, the higher the frequency/energy

3. Emission and absorption spectra
   (a) Line emission spectrum (monatomic gas): $|E_m - E_n| = hf$
      (i) in hydrogen: $13.6\text{eV}(\frac{1}{n^2} - \frac{1}{m^2}) = hf$

      where $E_n = -\frac{13.6\text{eV}}{n^2}$ and n & m are the energy levels.
      (ii) ground state energy: E_1 = -13.6eV
      (iii) ionization level energy: $E_\infty = 0$
   (b) Absorption spectrum: Sun's spectrum, Fraunhofer lines

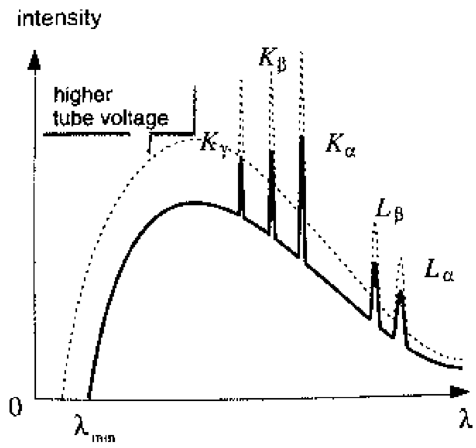
The Laser

1. Principle
   (a) Population inversion: pumping, *spontaneous emission* to metastable state
   (b) *Stimulated emission*: incident photon→emitted photon⇒chain reaction
   (c) Properties: powerful, coherent, monochromatic, parallel / uni-directional

X-rays

1. Production: heated cathode, evacuated glass tube, tungsten target, cooling fins, EHT
2. Properties of X-ray: high penetration power, minimum wavelength, continusous spectrum, line sepectrum
3. Detection of X-rays
4. Energy of X-rays: combine $\frac{1}{2}m_e v^2 = eV_A$

   and $hf_{max} = eV_A$, we have minimum wavelength, $\lambda_{min} = \frac{hc}{eV_A}$
5. X-ray spectrum



   (a) Continuous spectrum
   (b) Line spectrum
6. Applications of X-rays
   (a) Medicine
   (b) Industry
   (c) X-ray crystallography

Radioactivity and Nucleus

Radioactivity

- 3 Radiations: α-particle (He nucleus), β-particle (e), γ-ray (EM wave)
- Properties: nature, charge, mass, speed, energy, range in air, penetrating power, ionizing power, effect of magnetic and electric fields
- High ionization power of α are due to its massive and charge
- Detectors: ionization chamber, diffusion cloud chamber, Geiger Muller Tube (G-M tube)
- Radiation detections is mainly due to ionization effect
- 1 atomic mass unit (a.m.u or u): 1/12 of the mass of an atom of the isotope C-12
- Estimation on the *upper limit* of nucleus size: KE of $\alpha \rightarrow$ PE
- Nuclear transformation:

α-decay	β-decay	γ-decay
${}^{A}_{Z}P \rightarrow {}^{A-4}_{Z-2}D + {}^{4}_{2}\alpha$	${}^{A}_{Z}P \rightarrow {}^{A}_{Z+1}D + {}^{0}_{-1}\beta$	${}^{A}_{Z}P^{*} \rightarrow {}^{A}_{Z}P + \gamma$

- Different Z$\rightarrow$different element
- α sources are radioisotopes of large nuclei; β sources are radioisotopes of too many neutrons
- Artificial radioisotopes are produced by bombarding stable elements with neutrons

Rate of decay

- Activity A: number of decays per unit time, $A = -\frac{dN}{dt}$
- Half-life $T_{1/2}$: time taken for the number of atoms to decrease to half the initial number
- Decay constant λ: probability of decay per unit time
- Decay equation: $N = N_o e^{-\lambda t}$, $A = A_o e^{-\lambda t}$, $T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$ or $\lambda = \frac{\ln 2}{T_{1/2}}$, $A=\lambda N$

Nuclear Energy

- Mass-energy relation: $E = mc^2$ (1u = 934 MeV)
- Mass defect: difference between the mass of separated nucleons and the combined mass of the nucleus
- Binding energy: work done on the nucleus to separate it into its constituent neutrons and protons
- Binding energy per nucleon: E_b/A; $E_b/A\uparrow \rightarrow$ nuclear PE of the nucleus$\downarrow$ (need more energy to separate all the nucleons); E_b/A for Fe is the highest
- Fission: nucleus splits into 2 approximately equal halves
- Fusion: light nuclei are joined together
- Nuclear fission: thermal neutron, chain reaction, moderator
- Nuclear reactor: control rods, moderator, coolant, nuclear waste