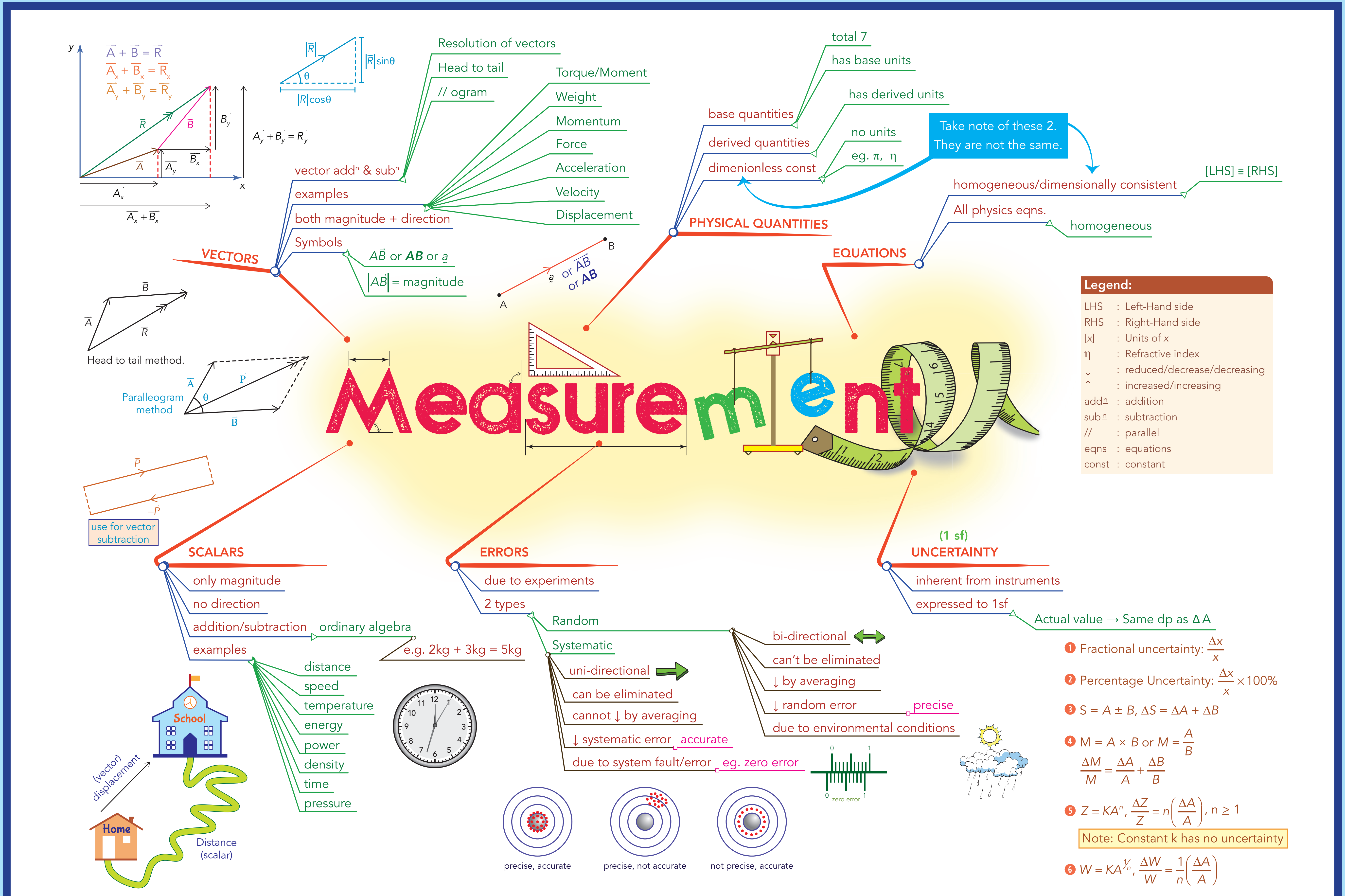
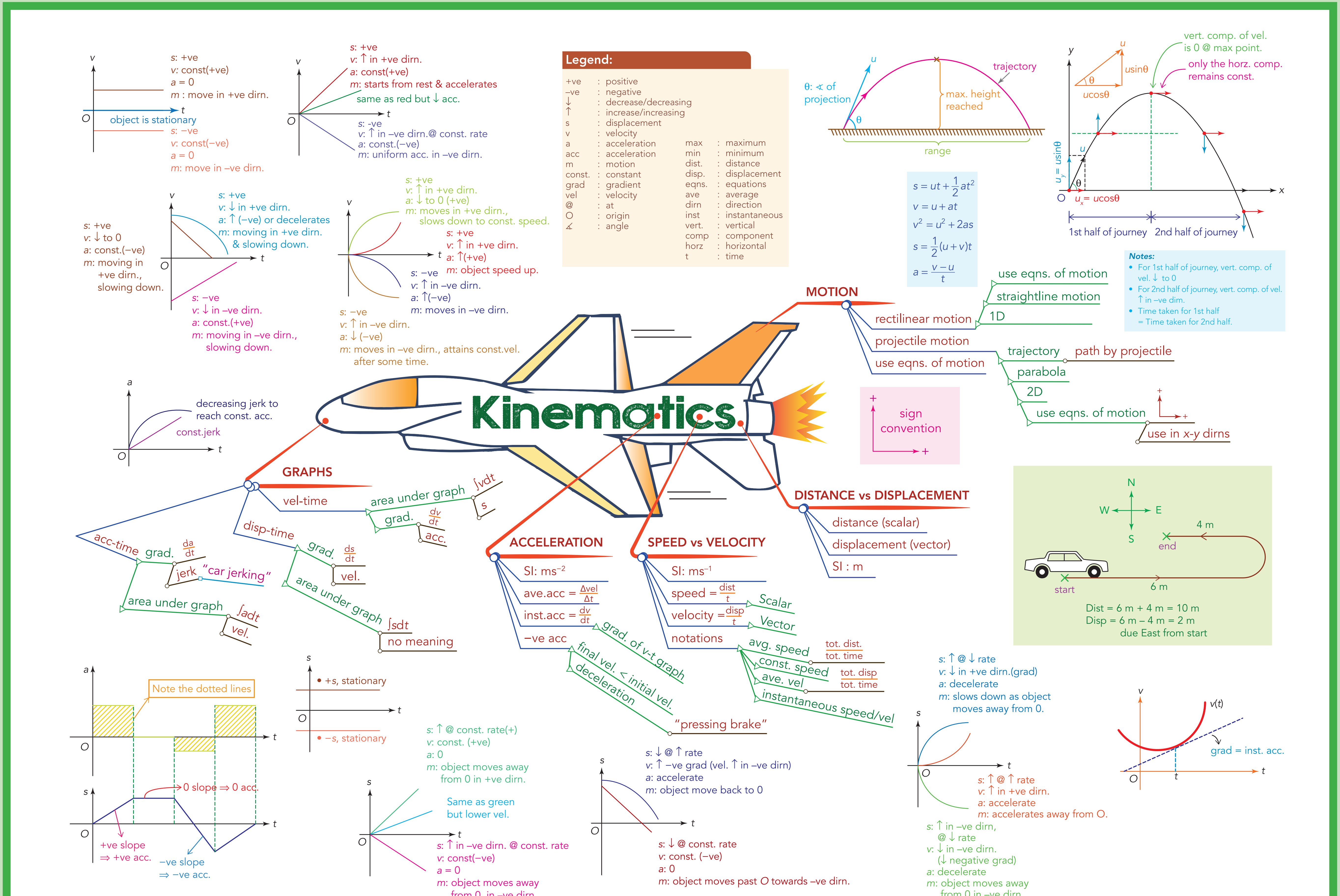
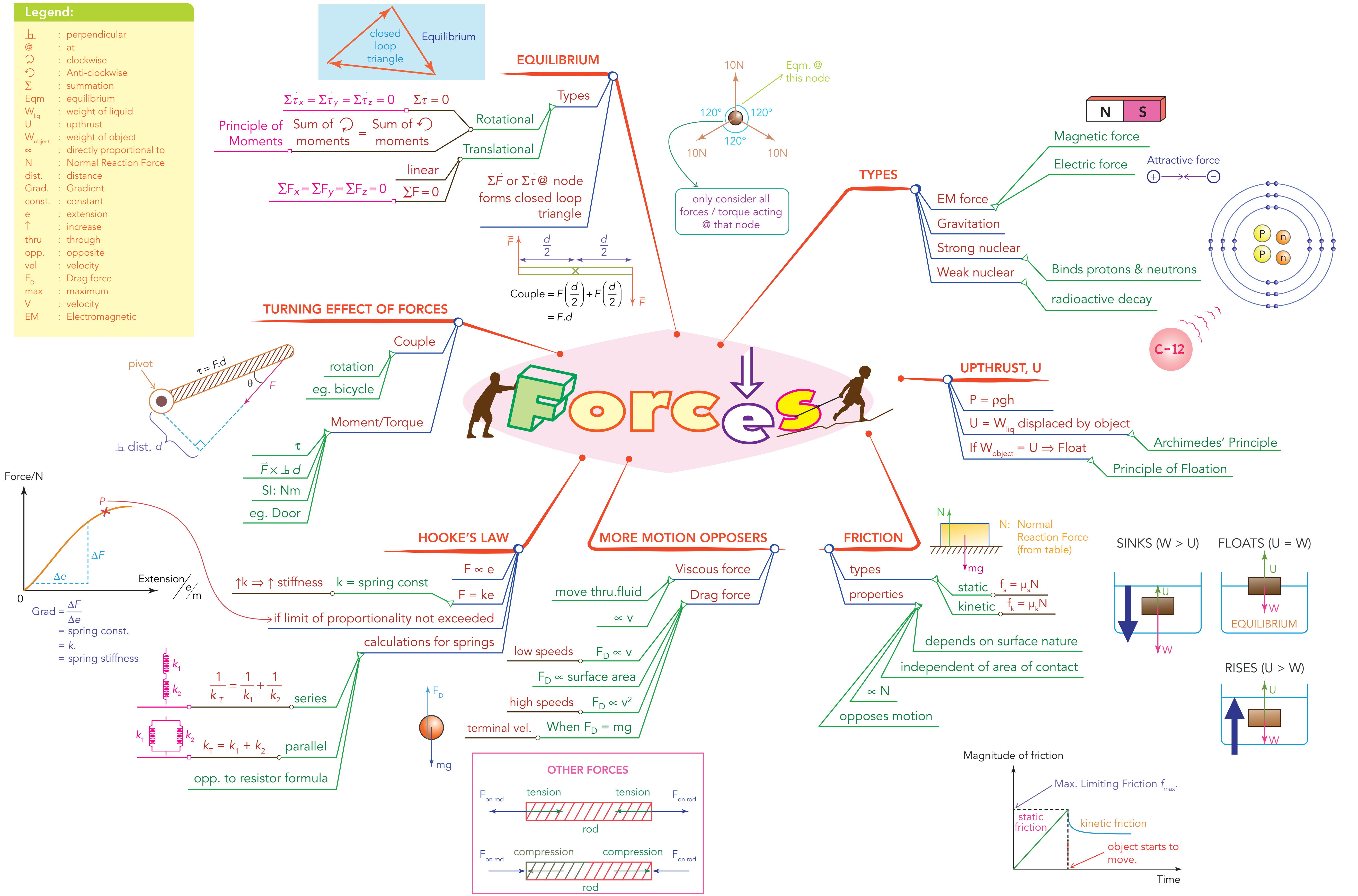
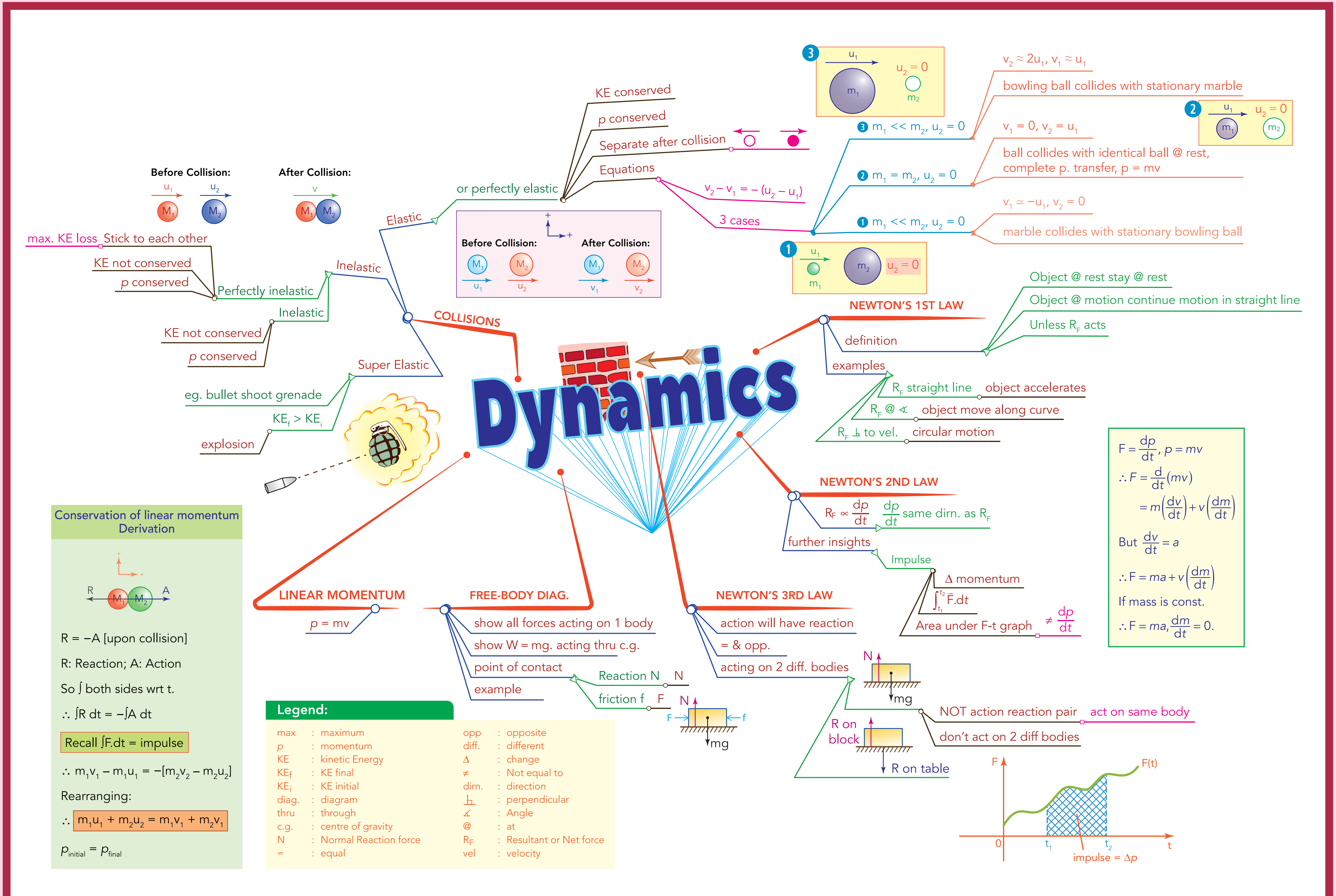


Measurement
VECTORS
vector addⁿ & subⁿ
Resolution of vectors
Head to tail
// ogram
examples
Torque/Moment
Weight
Momentum
Force
Acceleration
Velocity
Displacement
both magnitude + direction
Symbols
AB or AB or a
|AB| = magnitude
Head to tail method.
Paralleogram method
use for vector subtraction
PHYSICAL QUANTITIES
base quantities
total 7
has base units
derived quantities
has derived units
dimenionless const
no units
eg. π, η
Take note of these 2. They are not the same.
EQUATIONS
homogeneous/dimensionally consistent
[LHS] ≡ [RHS]
All physics eqns.
homogeneous
Legend:
LHS : Left-Hand side
RHS : Right-Hand side
[x] : Units of x
η : Refractive index
↓ : reduced/decrease/decreasing
↑ : increased/increasing
addⁿ : addition
subⁿ : subtraction
// : parallel
eqns : equations
const : constant
SCALARS
only magnitude
no direction
addition/subtraction
ordinary algebra
e.g. 2kg + 3kg = 5kg
examples
distance
speed
temperature
energy
power
density
time
pressure
School
Home
(vector) displacement
Distance (scalar)
ERRORS
due to experiments
2 types
Random
bi-directional
can't be eliminated
↓ by averaging
↓ random error
precise
due to environmental conditions
Systematic
uni-directional
can be eliminated
cannot ↓ by averaging
↓ systematic error
accurate
due to system fault/error
eg. zero error
zero error
precise, accurate
precise, not accurate
not precise, accurate
UNCERTAINTY
(1 sf)
inherent from instruments
expressed to 1sf
Actual value → Same dp as ΔA
1 Fractional uncertainty: Δx/x
2 Percentage Uncertainty: Δx/x × 100%
3 S = A ± B, ΔS = ΔA + ΔB
4 M = A × B or M = A/B
ΔM/M = ΔA/A + ΔB/B
5 Z = KAⁿ, ΔZ/Z = n(ΔA/A), n ≥ 1
Note: Constant k has no uncertainty
6 W = KA^(1/n), ΔW/W = 1/n (ΔA/A)

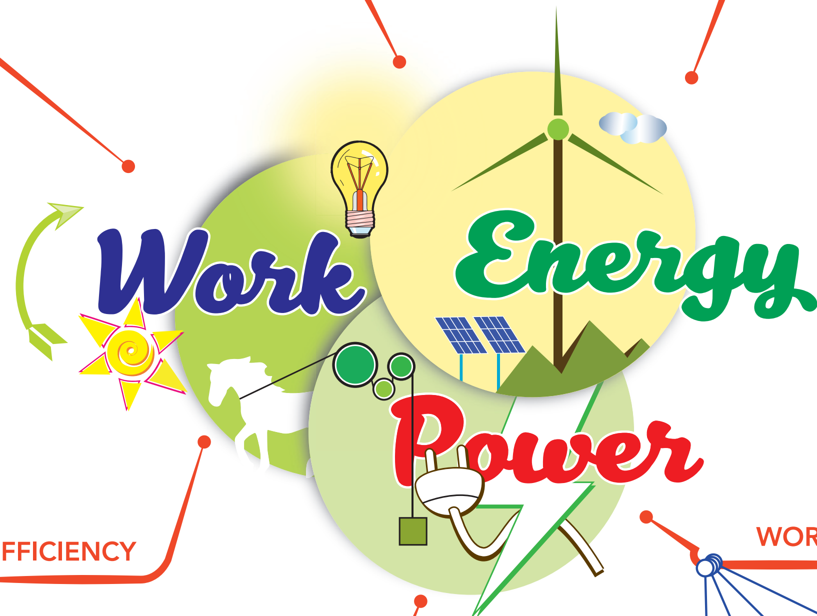

Kinematics
Legend:
+ve : positive
–ve : negative
↓ : decrease/decreasing
↑ : increase/increasing
s : displacement
v : velocity
a : acceleration
acc : acceleration
m : motion
const. : constant
grad : gradient
vel : velocity
@ : at
O : origin
∡ : angle
max : maximum
min : minimum
dist. : distance
disp. : displacement
eqns. : equations
ave : average
dirn : direction
inst : instantaneous
vert. : vertical
comp : component
horz : horizontal
t : time
s: +ve
v: const(+ve)
a = 0
m : move in +ve dirn.
object is stationary
s: –ve
v: const(–ve)
a = 0
m: move in –ve dirn.
s: +ve
v: ↑ in +ve dirn.
a: const(+ve)
m: starts from rest & accelerates
same as red but ↓ acc.
s: -ve
v: ↑ in –ve dirn.@ const. rate
a: const.(–ve)
m: uniform acc. in –ve dirn.
s: +ve
v: ↓ to 0
a: const.(–ve)
m: moving in +ve dirn., slowing down.
s: +ve
v: ↓ in +ve dirn.
a: ↑ (–ve) or decelerates
m: moving in +ve dirn. & slowing down.
s: –ve
v: ↓ in –ve dirn.
a: const.(+ve)
m: moving in –ve dirn., slowing down.
s: +ve
v: ↑ in +ve dirn.
a: ↓ to 0 (+ve)
m: moves in +ve dirn., slows down to const. speed.
s: +ve
v: ↑ in +ve dirn.
a: ↑(+ve)
m: object speed up.
s: –ve
v: ↑ in –ve dirn.
a: ↑(–ve)
m: moves in –ve dirn.
s: –ve
v: ↑ in –ve dirn.
a: ↓ (–ve)
m: moves in –ve dirn., attains const.vel. after some time.
θ: ∡ of projection
trajectory
max. height reached
range
y
vert. comp. of vel. is 0 @ max point.
only the horz. comp. remains const.
usinθ
ucosθ
$u_y = u\sin\theta$
$u_x = u\cos\theta$
1st half of journey
2nd half of journey
$s = ut + \frac{1}{2}at^2$
$v = u + at$
$v^2 = u^2 + 2as$
$s = \frac{1}{2}(u+v)t$
$a = \frac{v-u}{t}$
Notes:
For 1st half of journey, vert. comp. of vel. ↓ to 0
For 2nd half of journey, vert. comp. of vel. ↑ in –ve dirn.
Time taken for 1st half = Time taken for 2nd half.
MOTION
rectilinear motion
use eqns. of motion
straightline motion
1D
projectile motion
use eqns. of motion
trajectory
path by projectile
parabola
2D
use eqns. of motion
use in x-y dirns
sign convention
decreasing jerk to reach const. acc.
const.jerk
GRAPHS
vel-time
area under graph
∫vdt
s
grad.
dv/dt
acc.
disp-time
grad.
ds/dt
vel.
area under graph
∫sdt
no meaning
acc-time
grad.
da/dt
jerk
"car jerking"
area under graph
∫adt
vel.
ACCELERATION
SI: ms⁻²
ave.acc = Δvel/Δt
inst.acc = dv/dt
–ve acc
grad. of v-t graph
final vel. < initial vel.
deceleration
"pressing brake"
SPEED vs VELOCITY
SI: ms⁻¹
speed = dist/t
Scalar
velocity = disp/t
Vector
notations
avg. speed
tot. dist. / tot. time
const. speed
ave. vel
tot. disp / tot. time
instantaneous speed/vel
DISTANCE vs DISPLACEMENT
distance (scalar)
displacement (vector)
SI : m
N
W
E
S
4 m
end
start
6 m
Dist = 6 m + 4 m = 10 m
Disp = 6 m – 4 m = 2 m due East from start
Note the dotted lines
0 slope ⇒ 0 acc.
+ve slope ⇒ +ve acc.
–ve slope ⇒ –ve acc.
+s, stationary
–s, stationary
s: ↑ @ const. rate(+)
v: const. (+ve)
a: 0
m: object moves away from 0 in +ve dirn.
Same as green but lower vel.
s: ↑ in –ve dirn. @ const. rate
v: const(–ve)
a = 0
m: object moves away from 0, in –ve dirn.
s: ↓ @ ↑ rate
v: ↑ –ve grad (vel. ↑ in –ve dirn)
a: accelerate
m: object move back to 0
s: ↓ @ const. rate
v: const. (–ve)
a: 0
m: object moves past O towards –ve dirn.
s: ↑ @ ↓ rate
v: ↓ in +ve dirn.(grad)
a: decelerate
m: slows down as object moves away from 0.
s: ↑ @ ↑ rate
v: ↑ in +ve dirn.
a: accelerate
m: accelerates away from O.
s: ↑ in –ve dirn, @ ↓ rate
v: ↓ in –ve dirn. (↓ negative grad)
a: decelerate
m: object moves away from 0 in –ve dirn.
v(t)
grad = inst. acc.


Legend:
⊥ : perpendicular
@ : at
clockwise
Anti-clockwise
Σ : summation
Eqm : equilibrium
W liq : weight of liquid
U : upthrust
W object : weight of object
∝ : directly proportional to
N : Normal Reaction Force
dist. : distance
Grad. : Gradient
const. : constant
e : extension
↑ : increase
thru : through
opp. : opposite
vel : velocity
F D : Drag force
max : maximum
V : velocity
EM : Electromagnetic
Forces
closed loop triangle
Equilibrium
EQUILIBRIUM
Types
Rotational
Translational
Στx = Στy = Στz = 0
Στ = 0
Principle of Moments
Sum of clockwise moments = Sum of anti-clockwise moments
linear
ΣFx = ΣFy = ΣFz = 0
ΣF = 0
ΣF or Στ @ node forms closed loop triangle
10N
Eqm. @ this node
120°
120°
120°
10N
10N
only consider all forces / torque acting @ that node
Couple = F(d/2) + F(d/2) = F.d
d/2
d/2
TURNING EFFECT OF FORCES
Couple
rotation
eg. bicycle
Moment/Torque
τ
F × ⊥ d
SI: Nm
eg. Door
pivot
τ = F.d
θ
F
⊥ dist. d
TYPES
EM force
Gravitation
Strong nuclear
Weak nuclear
Magnetic force
Electric force
Attractive force
N
S
Binds protons & neutrons
radioactive decay
P
n
C-12
UPTHRUST, U
P = ρgh
U = W liq displaced by object
If W object = U ⇒ Float
Archimedes' Principle
Principle of Floation
Force/N
P
ΔF
Δe
Extension/ e/m
0
Grad = ΔF/Δe
= spring const.
= k.
= spring stiffness
HOOKE'S LAW
F ∝ e
F = ke
↑k ⇒ ↑ stiffness
k = spring const
if limit of proportionality not exceeded
calculations for springs
k1
k2
1/kT = 1/k1 + 1/k2
series
kT = k1 + k2
parallel
opp. to resistor formula
MORE MOTION OPPOSERS
Viscous force
move thru.fluid
Drag force
∝ v
low speeds
FD ∝ v
FD ∝ surface area
high speeds
FD ∝ v²
terminal vel.
When FD = mg
FD
mg
OTHER FORCES
F on rod
tension
tension
F on rod
rod
F on rod
compression
compression
F on rod
rod
FRICTION
types
properties
static
fs = μsN
kinetic
fk = μkN
depends on surface nature
independent of area of contact
∝ N
opposes motion
N
mg
N: Normal Reaction Force (from table)
SINKS (W > U)
FLOATS (U = W)
U
W
EQUILIBRIUM
RISES (U > W)
Magnitude of friction
Max. Limiting Friction f max.
static friction
kinetic friction
object starts to move.
Time

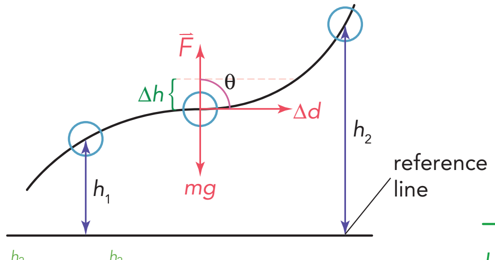


Dynamics
COLLISIONS
Elastic
or perfectly elastic
KE conserved
p conserved
Separate after collision
Equations
$v_2 - v_1 = -(u_2 - u_1)$
3 cases
3 $m_1 << m_2$, $u_2 = 0$
2 $m_1 = m_2$, $u_2 = 0$
1 $m_1 << m_2$, $u_2 = 0$
$v_2 \approx 2u_1$, $v_1 \approx u_1$
bowling ball collides with stationary marble
$v_1 = 0$, $v_2 = u_1$
ball collides with identical ball @ rest, complete p. transfer, p = mv
$v_1 \approx -u_1$, $v_2 = 0$
marble collides with stationary bowling ball
u_1 $u_2 = 0$ m_1 m_2
Before Collision:
After Collision:
M_1 M_2 u_1 u_2 v_1 v_2 v
Inelastic
Perfectly inelastic
max. KE loss
Stick to each other
KE not conserved
p conserved
Inelastic
KE not conserved
p conserved
Super Elastic
eg. bullet shoot grenade
$KE_f > KE_i$
explosion
NEWTON'S 1ST LAW
definition
Object @ rest stay @ rest
Object @ motion continue motion in straight line
Unless R_F acts
examples
R_F straight line — object accelerates
R_F @ ∡ — object move along curve
R_F ⊥ to vel. — circular motion
NEWTON'S 2ND LAW
$R_F \propto \frac{dp}{dt}$
$\frac{dp}{dt}$ same dirn. as R_F
further insights
Impulse
Δ momentum
$\int_{t_1}^{t_2} F.dt$
Area under F-t graph
$\neq \frac{dp}{dt}$
$F = \frac{dp}{dt}$, $p = mv$
$\therefore F = \frac{d}{dt}(mv)$
$= m\left(\frac{dv}{dt}\right) + v\left(\frac{dm}{dt}\right)$
But $\frac{dv}{dt} = a$
$\therefore F = ma + v\left(\frac{dm}{dt}\right)$
If mass is const.
$\therefore F = ma$, $\frac{dm}{dt} = 0$.
NEWTON'S 3RD LAW
action will have reaction
= & opp.
acting on 2 diff. bodies
N mg
NOT action reaction pair — act on same body
don't act on 2 diff bodies
R on block
R on table
F F(t) 0 t_1 t_2 t
impulse = Δp
LINEAR MOMENTUM
p = mv
FREE-BODY DIAG.
show all forces acting on 1 body
show W = mg. acting thru c.g.
point of contact
Reaction N — N
friction f — F
example
N F f mg
Conservation of linear momentum Derivation
R A M_1 M_2
R = −A [upon collision]
R: Reaction; A: Action
So ∫ both sides wrt t.
∴ ∫R dt = −∫A dt
Recall ∫F.dt = impulse
$\therefore m_1v_1 - m_1u_1 = -[m_2v_2 - m_2u_2]$
Rearranging:
$\therefore m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$
$p_{initial} = p_{final}$
Legend:
max : maximum
p : momentum
KE : kinetic Energy
KE_f : KE final
KE_i : KE initial
diag. : diagram
thru : through
c.g. : centre of gravity
N : Normal Reaction force
= : equal
opp : opposite
diff. : different
Δ : change
≠ : Not equal to
dirn. : direction
⊥ : perpendicular
∡ : Angle
@ : at
R_F : Resultant or Net force
vel : velocity

Work Energy Power

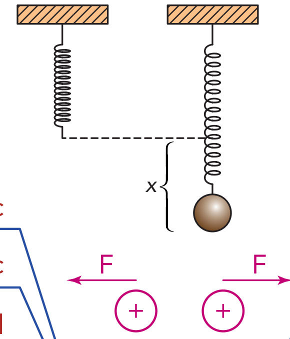


POTENTIAL ENERGY



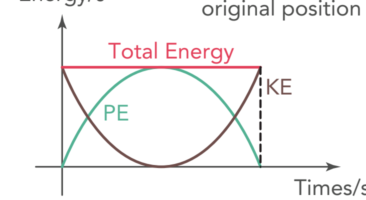
$$W = \int_{h_1}^{h_2} \vec{F}.dh = \int_{h_1}^{h_2} mgdh = mgh_2 - mgh_1 = \Delta U$$

- Elastic: $W = \frac{1}{2}kx^2$
- Electric: $U_E = \frac{Q_1Q_2}{4\pi\varepsilon_0 r}$
- Gravitational
  - reference line impt.
  - $WD = \Delta U$



ENERGY

- capacity do work
- diff. forms
- converted 1 form to another



ENERGY CONSERVATION

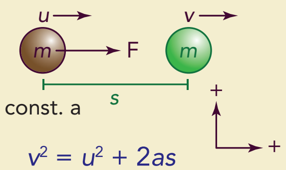
- Tot. Energy of system is Const.
- cannot be created
- cannot be destroyed
- only transformed

POWER

- $P = WD/t$
- $P = Fv$ where F is const. force

$$P = \frac{WD}{t} = \frac{Fs}{t} = F\left(\frac{s}{t}\right) = Fv$$

Work Energy Theorem



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

$\therefore mv^2 = mu^2 + 2mas$

$2mas = mv^2 - mu^2$

$mas = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

$WD = \vec{F}\cdot\vec{s} = mas$

Hence $WD = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \Delta KE$

KINETIC ENERGY

- KE & WET
- $KE = \frac{1}{2}mv^2$

EFFICIENCY

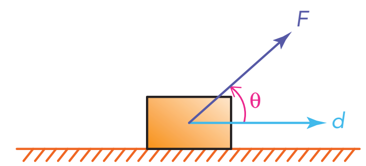
$$\frac{\text{Useful Energy Output}}{\text{Total Energy Input}} \times 100\%$$

FORCE & PE (U)

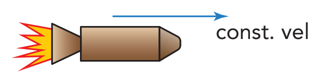
$$F = -\frac{dU}{dx}$$

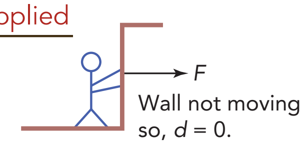
WORK DONE

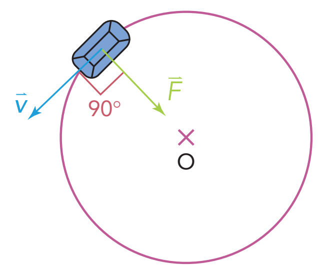
- $WD = Fd\cos\theta$
  - const. force
  - −ve WD: remove energy from object
  - +ve WD: transfer energy to object



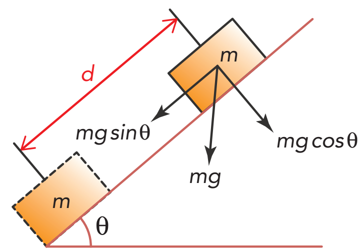
- Zero WD
  1. F = 0: no force applied
  2. d = 0
  3. θ = 90°: centripetal motion







- WD by gravity

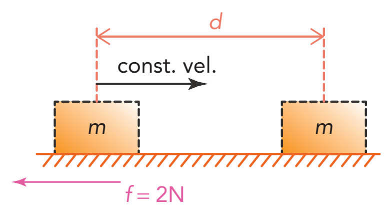


$W_{gravity} = Fd\cos\theta$

$= (mg\sin\theta)(d)(\cos 0°)$ [cos 0° = 1]

$= mgd\sin\theta$ J

- WD by friction



$W_{friction} = (F)(d)(\cos\theta)$

$= (2N)(d)(\cos 180°)$ [cos 180° = −1]

$= -2d$ J

1-D System:

$K_2 + U_2 = K_1 + U_1$

$\Delta U = U_2 - U_1 = K_1 - K_2$

$= -(K_2 - K_1)$

$= -\Delta K$

$\Delta K = W$ [Work-Energy Theorem]

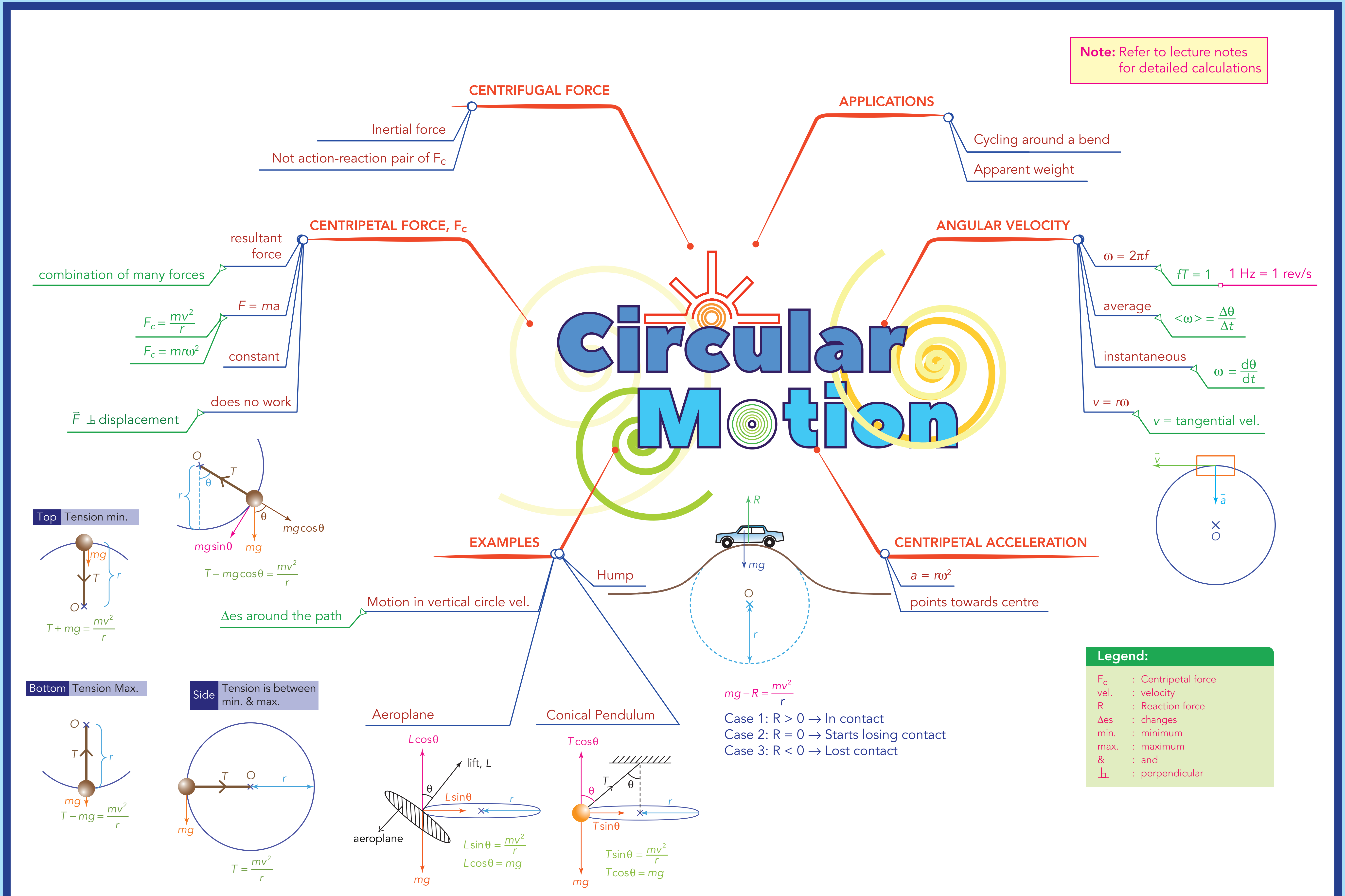
$\therefore \Delta U = -W = -F.\Delta d$

and $F = -\frac{\Delta U}{\Delta d}$

$F = \lim_{\Delta d \to 0}\left(-\frac{\Delta U}{\Delta d}\right) = -\frac{dU}{dd}$ or $-\frac{dU}{dx}$

Legend:

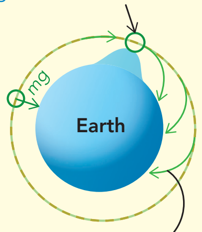
KE or K	Kinetic Energy
W, WD	Work done
Δ	change
U or PE	Gravitational potential energy
U_E	Electric potential energy
impt.	important
diff.	different
Tot.	Total
const.	constant
vel	velocity
s, d, x	displacment/distance
a	acceleration
t	time


Note: Refer to lecture notes for detailed calculations
Circular Motion
CENTRIFUGAL FORCE
Inertial force
Not action-reaction pair of F_c
APPLICATIONS
Cycling around a bend
Apparent weight
CENTRIPETAL FORCE, F_c
resultant force
combination of many forces
$F = ma$
$F_c = \frac{mv^2}{r}$
$F_c = mr\omega^2$
constant
does no work
$\vec{F}$ ⊥ displacement
ANGULAR VELOCITY
$\omega = 2\pi f$
$fT = 1$
1 Hz = 1 rev/s
average
$\langle\omega\rangle = \frac{\Delta\theta}{\Delta t}$
instantaneous
$\omega = \frac{d\theta}{dt}$
$v = r\omega$
v = tangential vel.
$\vec{v}$
$\vec{a}$
O
EXAMPLES
Hump
R
mg
O
r
$mg - R = \frac{mv^2}{r}$
Case 1: R > 0 → In contact
Case 2: R = 0 → Starts losing contact
Case 3: R < 0 → Lost contact
CENTRIPETAL ACCELERATION
$a = r\omega^2$
points towards centre
Motion in vertical circle vel.
Δes around the path
Top Tension min.
mg
T
r
O
$T + mg = \frac{mv^2}{r}$
O
T
θ
r
θ
mg cosθ
mg sinθ
mg
$T - mg\cos\theta = \frac{mv^2}{r}$
Bottom Tension Max.
O
T
r
mg
$T - mg = \frac{mv^2}{r}$
Side Tension is between min. & max.
T
O
r
mg
$T = \frac{mv^2}{r}$
Aeroplane
L cosθ
lift, L
θ
L sinθ
r
aeroplane
mg
$L\sin\theta = \frac{mv^2}{r}$
$L\cos\theta = mg$
Conical Pendulum
T cosθ
T
θ
θ
r
T sinθ
mg
$T\sin\theta = \frac{mv^2}{r}$
$T\cos\theta = mg$
Legend:
F_c : Centripetal force
vel. : velocity
R : Reaction force
Δes : changes
min. : minimum
max. : maximum
& : and
⊥ : perpendicular

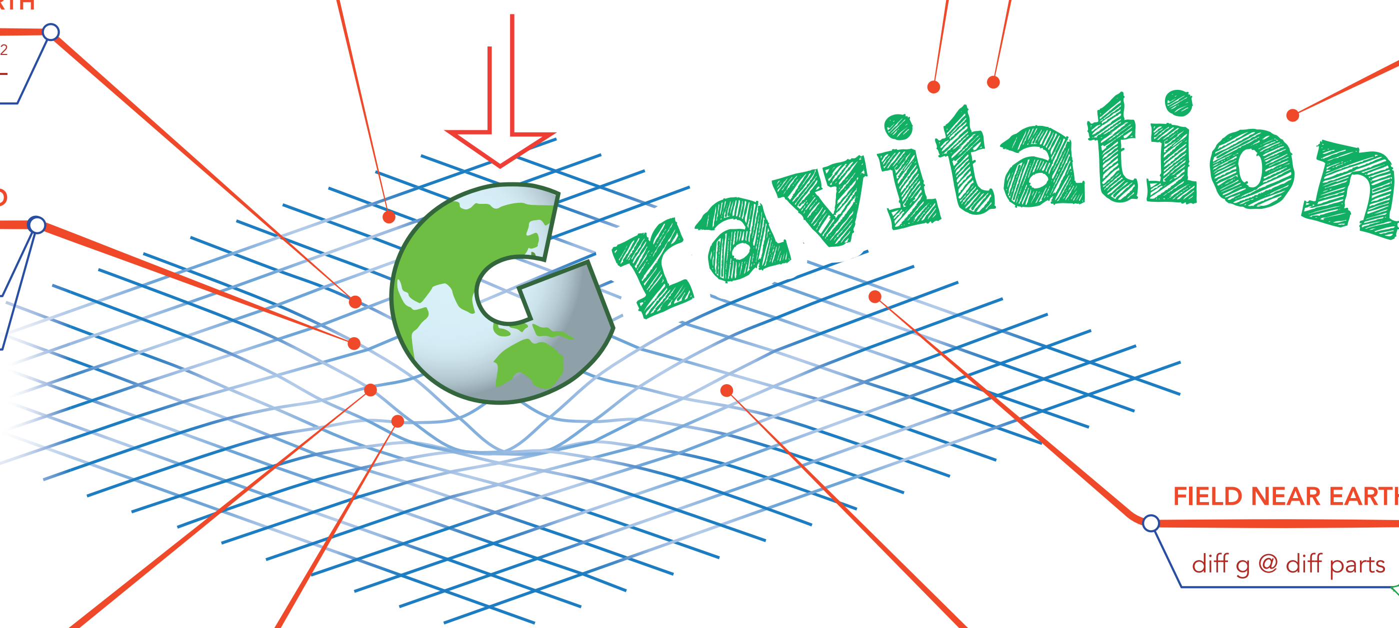
Legend:

dirn : direction
F_c : Centripetal force
F_g : Gravitational force
opp. : opposite
diff. : different
@ : at
WD : Work done
∴ : Therefore
–ve : negative
↓ : decrease
↑ : increase
M_E : mass of Earth
M_S : mass of Sun
rev. : revolution
∝ : directly proportional to
⊥ : perpendicular

If velocity of projection is large enough, it will go around the Earth.



Small velocity of projection causes object to fall back to Earth



GEOSTATIONERY ORBIT

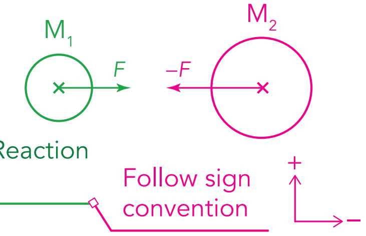
- directly above equator
- same period as Earth
- rotates in same dirn. as Earth
  - West to East

TOTAL ENERGY OF SATELLITE

- KE: $\mathrm{KE} = \frac{1}{2}mv^2$
  - $\frac{mv^2}{r} = \frac{GMm}{r^2}$, $v^2 = \frac{GM}{r}$, $\mathrm{KE} = \frac{GMm}{2r}$
- PE: $U = -\frac{GMm}{r}$
- Total = KE + PE
  - $TE = \frac{-GMm}{2r}$

NEWTON'S LAW OF GRAVITATION

- $F = \frac{GM_1M_2}{r^2}$
- point masses
- equal & opp.
  - Action Reaction Pair
    - Follow sign convention

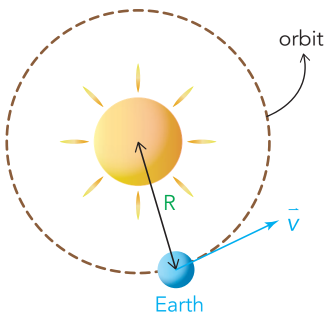


ORBIT AROUND EARTH

- $mg = \frac{mv^2}{r}$
  - $mg = F_c$

EARTH'S PERIOD

- $T^2 \propto R^3$
  - Kepler's 3rd Law
- $F_g = F_c$
  - $G\frac{M_EM_S}{R^2} = M_ER\omega^2$
    - $\omega = \frac{2\pi}{T}$
      - T = period of Earth rev.



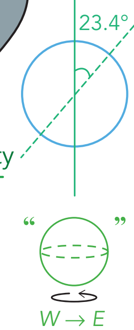
GRAVITATIONAL FIELD OF POINT MASS

- $g = \frac{-d\phi}{dr}$
- vector
- $g = \frac{GM}{r^2}$
- $[g] = \mathrm{ms^{-2}}$ or $\mathrm{Nkg^{-1}}$

$F = ma$
$= mg$
$\therefore \frac{GMm}{r^2} = mg$ (m cancelled)
and $g = \frac{GM}{r^2}$

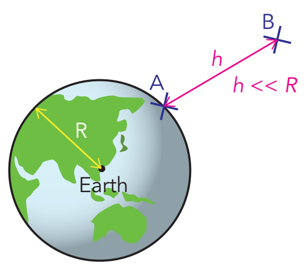
FIELD NEAR EARTH SURFACE

- diff g @ diff parts
  - 23.4° tilted
  - non-uniform Earth's density
  - not a perfect sphere
  - Rotating Earth



PROOF OF PE = mgh

- near Earth



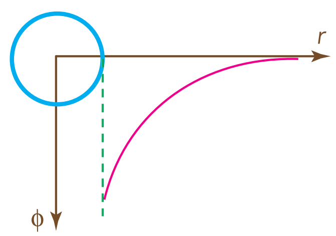
Note: Figure not drawn to scale

A → B:
$\Delta\phi = \phi_B - \phi_A$
$= -\frac{GM}{R+h} - \left(-\frac{GM}{R}\right)$
$= \frac{GM}{R} - \frac{GM}{R+h}$
$= \frac{GMh}{R(R+h)}$
$= \frac{GMh}{R^2\left(1+\frac{h}{R}\right)}$

Since $h << R$
$\therefore R^2\left(1+\frac{h}{R}\right) \approx R^2$
$\therefore \Delta\phi = \frac{GMh}{R^2}$
RECALL $g = \frac{GM}{R^2}$
$\therefore \Delta\phi = gh$
$\therefore U_B - U_A = mgh,\ \phi = \frac{U}{m}$

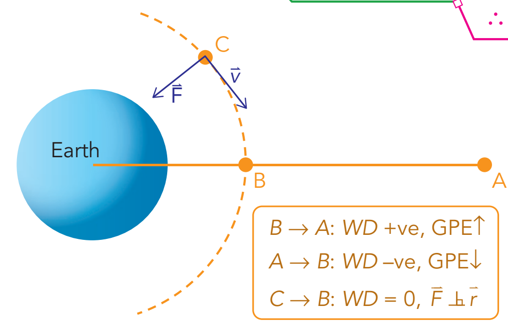
GRAVITATIONAL POTENTIAL

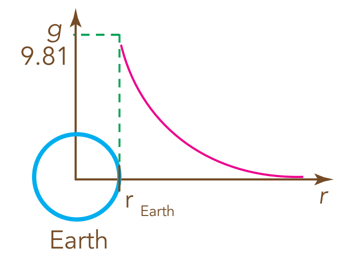
- $\phi = \frac{W}{m}$
  - $\phi = \frac{U}{m}$
    - $g = -\frac{d\phi}{dr}$
      - g points in direction of ↓ ϕ
        - g↑ closer to mass
- $\phi = -\frac{GM}{r}$
- SI unit = $\mathrm{Jkg^{-1}}$

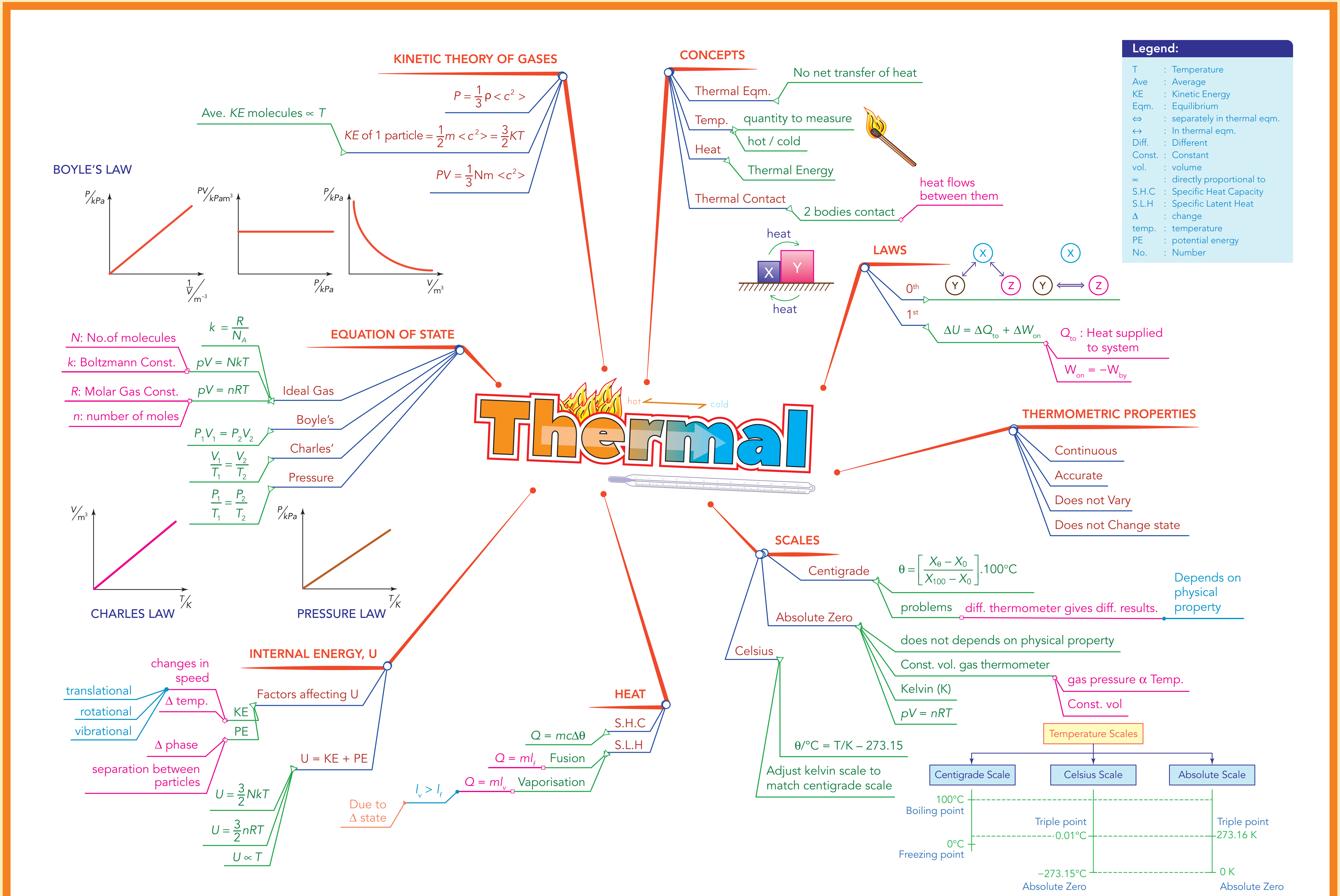


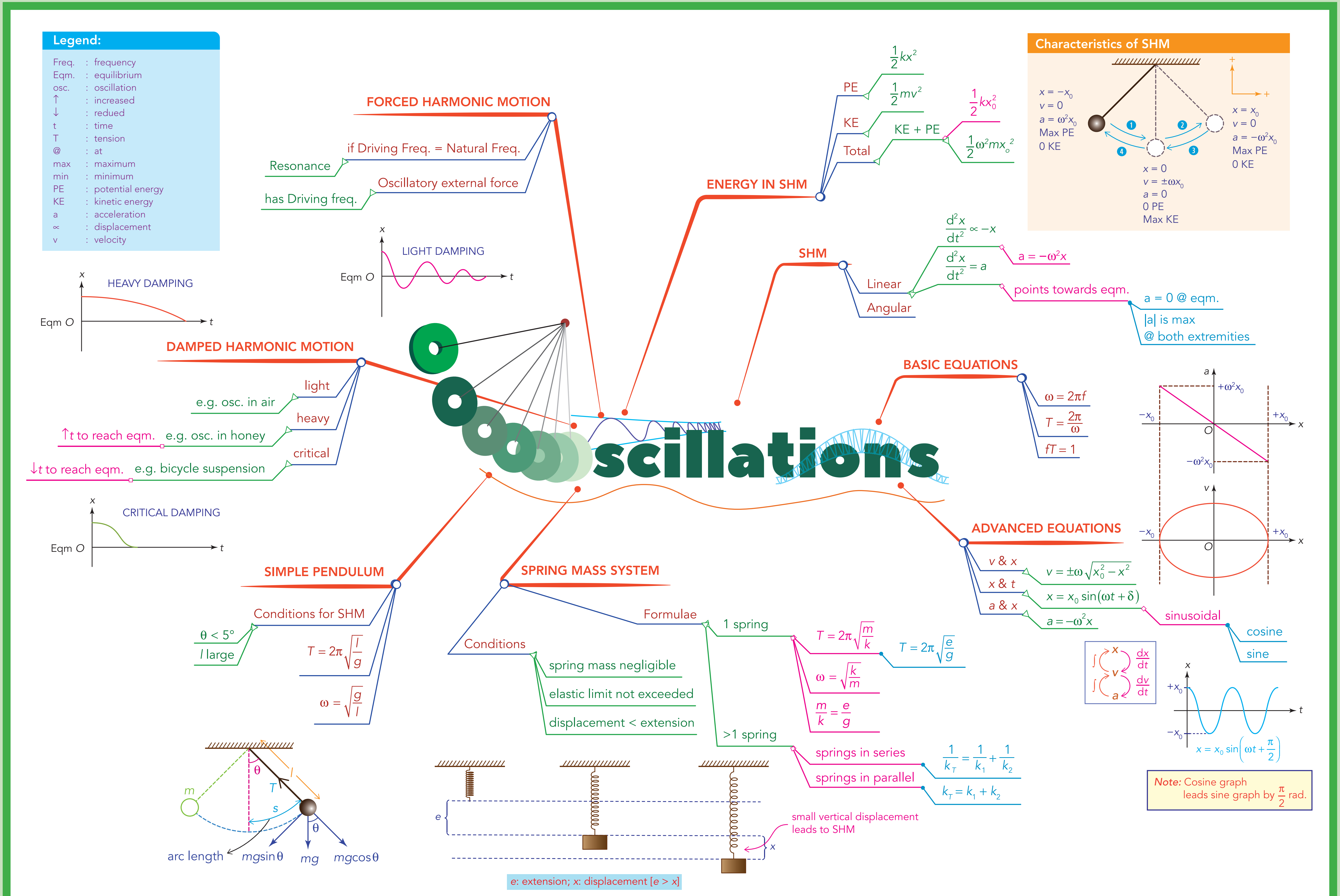
GPE

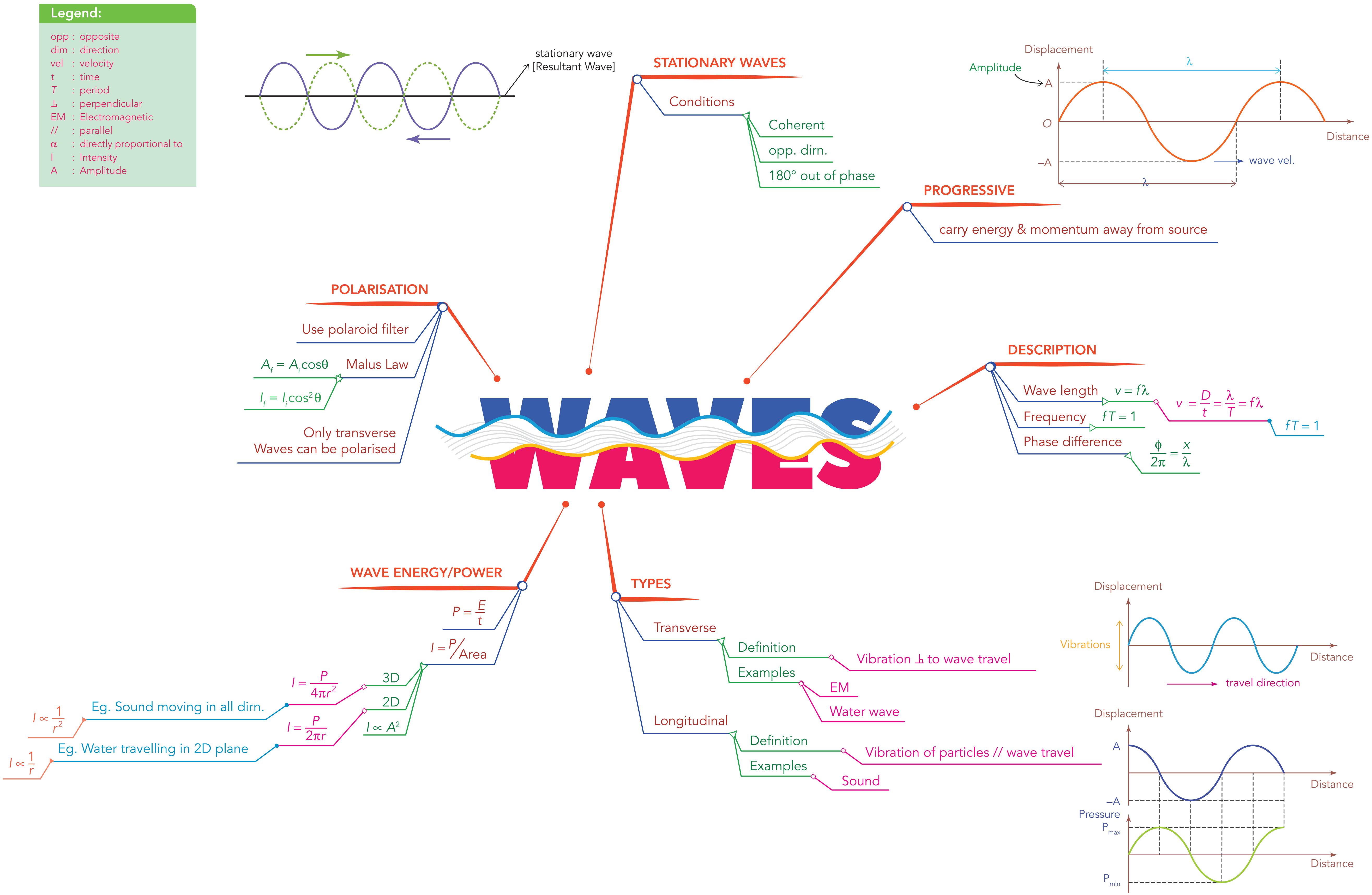
- $WD = \int \vec{F}.d\vec{r}$
  - $F = -\frac{dU}{dr}$
- $U = -\frac{GMm}{r}$
  - $U = 0$ @ $r = \infty$
    - ∴ –ve

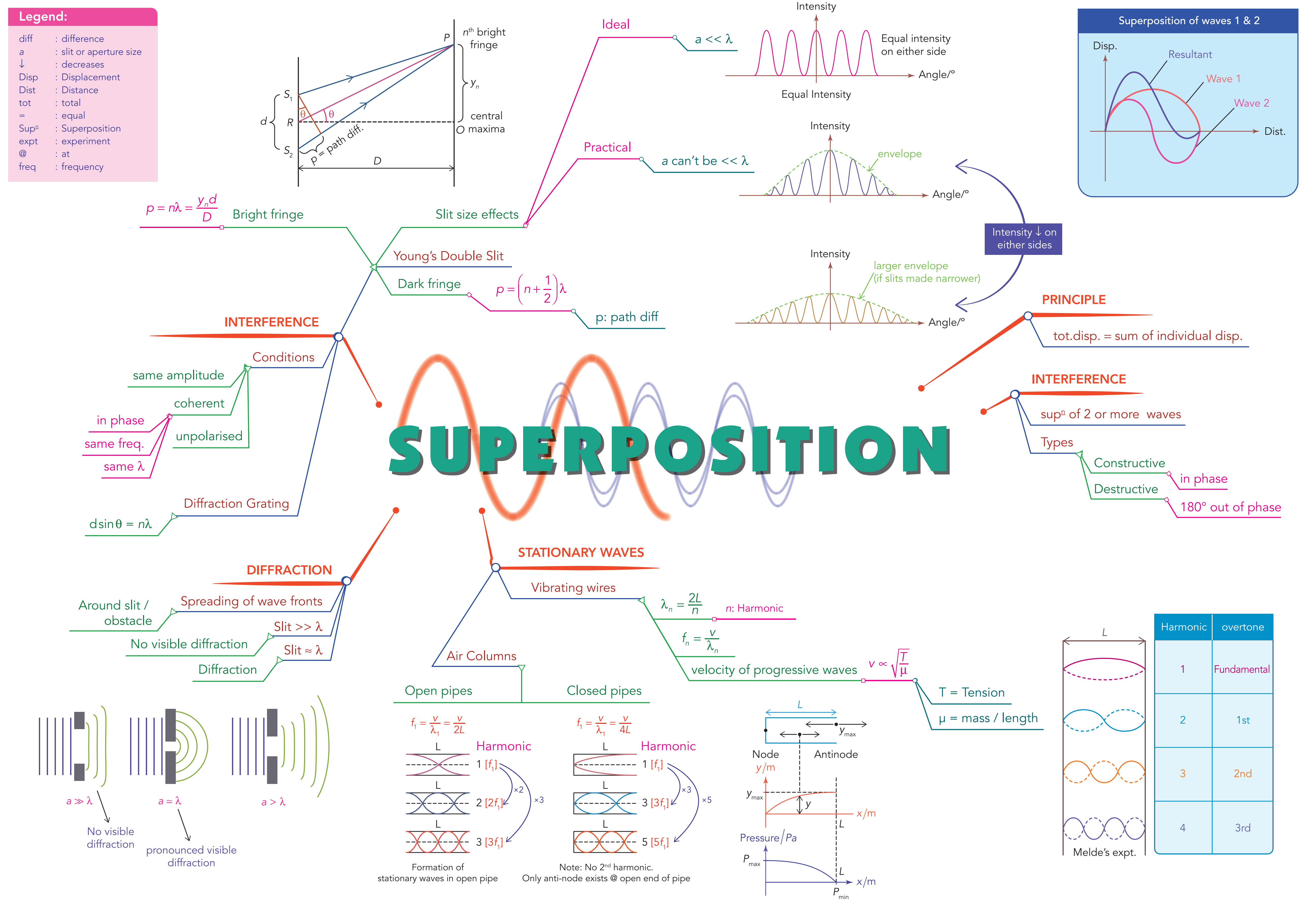




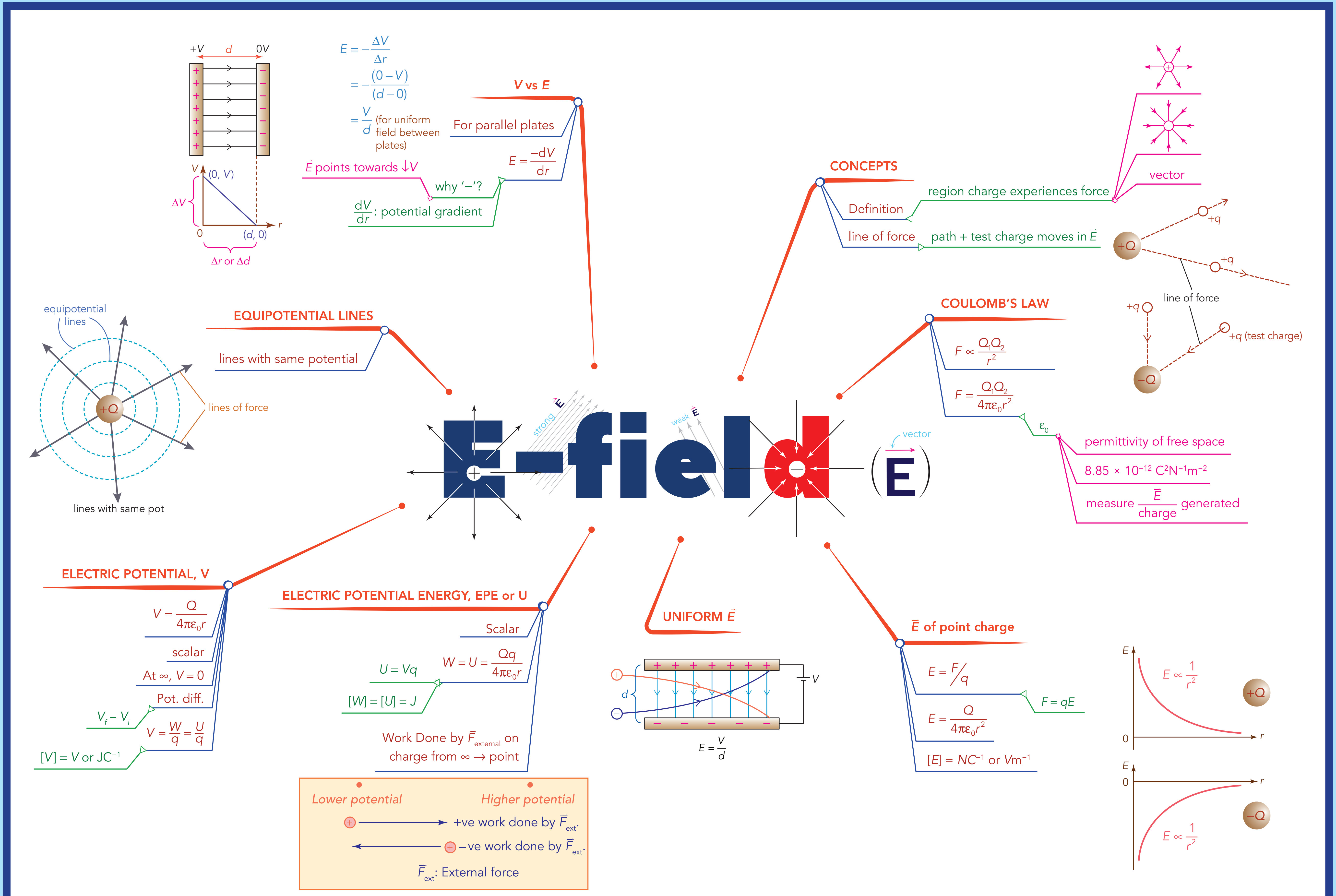

Thermal
hot
cold
KINETIC THEORY OF GASES
$P = \frac{1}{3}\rho < c^2 >$
Ave. KE molecules ∝ T
KE of 1 particle $= \frac{1}{2}m < c^2 > = \frac{3}{2}KT$
$PV = \frac{1}{3}Nm < c^2 >$
BOYLE'S LAW
P/kPa
1/V /m⁻³
PV/kPam³
P/kPa
P/kPa
V/m³
EQUATION OF STATE
N: No.of molecules
k: Boltzmann Const.
R: Molar Gas Const.
n: number of moles
$k = \frac{R}{N_A}$
$pV = NkT$
$pV = nRT$
Ideal Gas
Boyle's
$P_1V_1 = P_2V_2$
Charles'
$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Pressure
$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
V/m³
T/K
CHARLES LAW
P/kPa
T/K
PRESSURE LAW
INTERNAL ENERGY, U
changes in speed
translational
rotational
vibrational
Δ temp.
Δ phase
separation between particles
KE
PE
Factors affecting U
U = KE + PE
$U = \frac{3}{2}NkT$
$U = \frac{3}{2}nRT$
$U \propto T$
HEAT
S.H.C
$Q = mc\Delta\theta$
S.L.H
$Q = ml_f$
Fusion
$Q = ml_v$
Vaporisation
$l_v > l_f$
Due to Δ state
CONCEPTS
No net transfer of heat
Thermal Eqm.
Temp.
quantity to measure
hot / cold
Heat
Thermal Energy
Thermal Contact
2 bodies contact
heat flows between them
heat
X
Y
heat
LAWS
X
Y
Z
X
Y
Z
0th
1st
$\Delta U = \Delta Q_{to} + \Delta W_{on}$
Q_{to} : Heat supplied to system
$W_{on} = -W_{by}$
THERMOMETRIC PROPERTIES
Continuous
Accurate
Does not Vary
Does not Change state
SCALES
Centigrade
$\theta = \left[\frac{X_\theta - X_0}{X_{100} - X_0}\right].100°C$
problems
diff. thermometer gives diff. results.
Depends on physical property
Absolute Zero
does not depends on physical property
Const. vol. gas thermometer
gas pressure α Temp.
Const. vol
Kelvin (K)
$pV = nRT$
Celsius
θ/°C = T/K – 273.15
Adjust kelvin scale to match centigrade scale
Temperature Scales
Centigrade Scale
Celsius Scale
Absolute Scale
100°C
Boiling point
0°C
Freezing point
Triple point
0.01°C
–273.15°C
Absolute Zero
Triple point
273.16 K
0 K
Absolute Zero
Legend:
T : Temperature
Ave : Average
KE : Kinetic Energy
Eqm. : Equilibrium
⇔ : separately in thermal eqm.
↔ : In thermal eqm.
Diff. : Different
Const. : Constant
vol. : volume
∝ : directly proportional to
S.H.C : Specific Heat Capacity
S.L.H : Specific Latent Heat
Δ : change
temp. : temperature
PE : potential energy
No. : Number

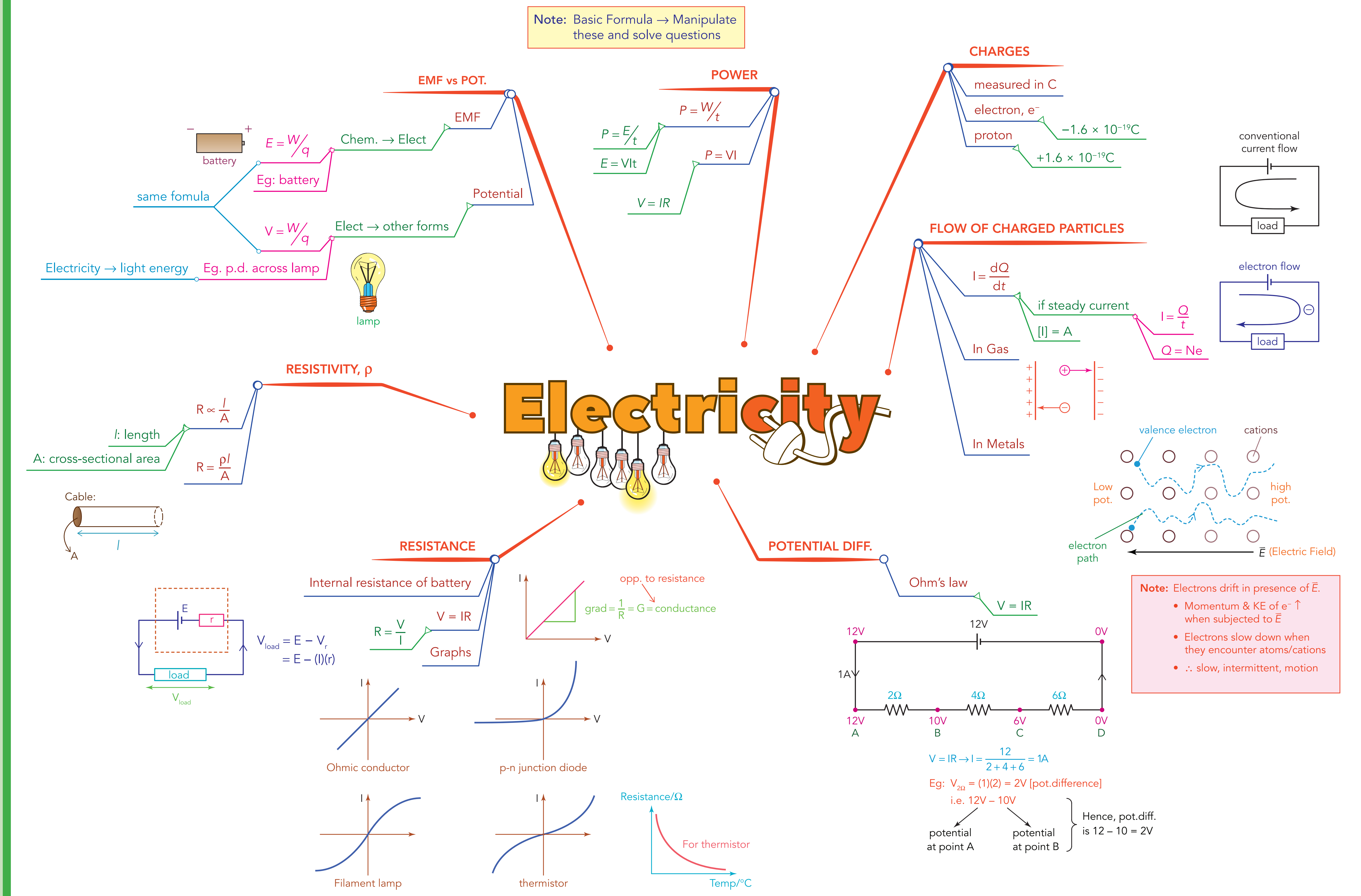

Legend:
Freq. : frequency
Eqm. : equilibrium
osc. : oscillation
↑ : increased
↓ : redued
t : time
T : tension
@ : at
max : maximum
min : minimum
PE : potential energy
KE : kinetic energy
a : acceleration
∝ : displacement
v : velocity
Oscillations
FORCED HARMONIC MOTION
Resonance
if Driving Freq. = Natural Freq.
Oscillatory external force
has Driving freq.
LIGHT DAMPING
HEAVY DAMPING
CRITICAL DAMPING
Eqm O
DAMPED HARMONIC MOTION
light
e.g. osc. in air
heavy
e.g. osc. in honey
↑t to reach eqm.
critical
e.g. bicycle suspension
↓t to reach eqm.
ENERGY IN SHM
PE
$\frac{1}{2}kx^2$
KE
$\frac{1}{2}mv^2$
Total
KE + PE
$\frac{1}{2}kx_0^2$
$\frac{1}{2}\omega^2 m x_0^2$
Characteristics of SHM
$x = -x_0$, $v = 0$, $a = \omega^2 x_0$, Max PE, 0 KE
$x = x_0$, $v = 0$, $a = -\omega^2 x_0$, Max PE, 0 KE
$x = 0$, $v = \pm\omega x_0$, $a = 0$, 0 PE, Max KE
SHM
Linear
Angular
$\frac{d^2x}{dt^2} \propto -x$
$\frac{d^2x}{dt^2} = a$
$a = -\omega^2 x$
points towards eqm.
a = 0 @ eqm.
|a| is max @ both extremities
BASIC EQUATIONS
$\omega = 2\pi f$
$T = \frac{2\pi}{\omega}$
$fT = 1$
ADVANCED EQUATIONS
v & x
$v = \pm\omega\sqrt{x_0^2 - x^2}$
x & t
$x = x_0 \sin(\omega t + \delta)$
a & x
$a = -\omega^2 x$
sinusoidal
cosine
sine
$+\omega^2 x_0$
$-\omega^2 x_0$
$-x_0$
$+x_0$
$x = x_0 \sin\left(\omega t + \frac{\pi}{2}\right)$
Note: Cosine graph leads sine graph by $\frac{\pi}{2}$ rad.
SIMPLE PENDULUM
Conditions for SHM
θ < 5°
l large
$T = 2\pi\sqrt{\frac{l}{g}}$
$\omega = \sqrt{\frac{g}{l}}$
arc length
mgsinθ
mg
mgcosθ
SPRING MASS SYSTEM
Conditions
spring mass negligible
elastic limit not exceeded
displacement < extension
Formulae
1 spring
$T = 2\pi\sqrt{\frac{m}{k}}$
$T = 2\pi\sqrt{\frac{e}{g}}$
$\omega = \sqrt{\frac{k}{m}}$
$\frac{m}{k} = \frac{e}{g}$
>1 spring
springs in series
$\frac{1}{k_T} = \frac{1}{k_1} + \frac{1}{k_2}$
springs in parallel
$k_T = k_1 + k_2$
small vertical displacement leads to SHM
e: extension; x: displacement [e > x]


Legend:
opp : opposite
dim : direction
vel : velocity
t : time
T : period
⊥ : perpendicular
EM : Electromagnetic
// : parallel
α : directly proportional to
I : Intensity
A : Amplitude
stationary wave
[Resultant Wave]
WAVES
STATIONARY WAVES
Conditions
Coherent
opp. dirn.
180° out of phase
PROGRESSIVE
carry energy & momentum away from source
Displacement
Amplitude
A
O
–A
λ
Distance
wave vel.
POLARISATION
Use polaroid filter
$A_f = A_i \cos\theta$
Malus Law
$I_f = I_i \cos^2\theta$
Only transverse
Waves can be polarised
DESCRIPTION
Wave length
$v = f\lambda$
$v = \frac{D}{t} = \frac{\lambda}{T} = f\lambda$
Frequency
$fT = 1$
$fT = 1$
Phase difference
$\frac{\phi}{2\pi} = \frac{x}{\lambda}$
WAVE ENERGY/POWER
$P = \frac{E}{t}$
$I = P/\text{Area}$
3D
$I = \frac{P}{4\pi r^2}$
2D
$I = \frac{P}{2\pi r}$
$I \propto A^2$
Eg. Sound moving in all dirn.
$I \propto \frac{1}{r^2}$
Eg. Water travelling in 2D plane
$I \propto \frac{1}{r}$
TYPES
Transverse
Definition
Vibration ⊥ to wave travel
Examples
EM
Water wave
Longitudinal
Definition
Vibration of particles // wave travel
Examples
Sound
Displacement
Vibrations
Distance
travel direction
Displacement
A
–A
Distance
Pressure
P_{max}
P_{min}
Distance

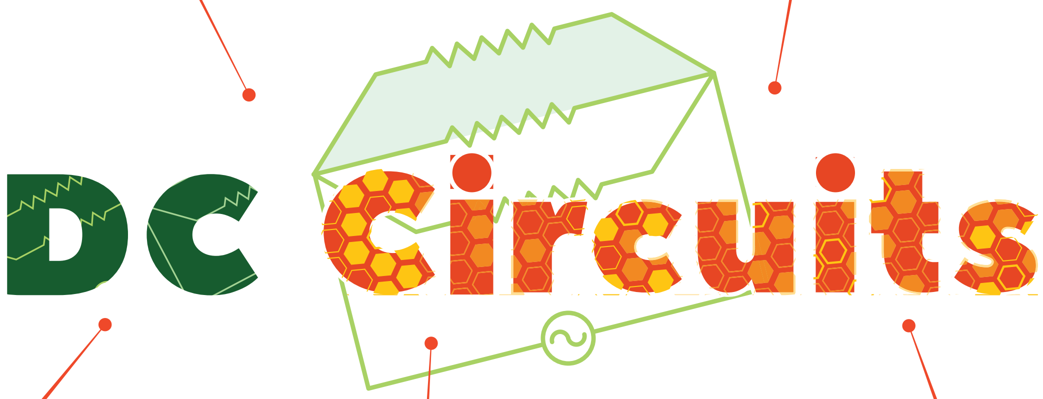


Harmonic	overtone
1	Fundamental
2	1st
3	2nd
4	3rd


E-field
$\vec{E}$ vector
strong $\vec{E}$
weak $\vec{E}$
V vs E
For parallel plates
$E = -\frac{\Delta V}{\Delta r} = -\frac{(0 - V)}{(d - 0)} = \frac{V}{d}$ (for uniform field between plates)
$E = \frac{-dV}{dr}$
why '−'?
$\vec{E}$ points towards ↓V
$\frac{dV}{dr}$: potential gradient
+V d 0V
V (0, V) ΔV 0 (d, 0) r
Δr or Δd
EQUIPOTENTIAL LINES
lines with same potential
equipotential lines
lines of force
lines with same pot
+Q
CONCEPTS
Definition
region charge experiences force
vector
line of force
path + test charge moves in $\vec{E}$
+q
line of force
+q (test charge)
−Q
COULOMB'S LAW
$F \propto \frac{Q_1Q_2}{r^2}$
$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$
ε_0
permittivity of free space
$8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$
measure $\frac{\vec{E}}{\text{charge}}$ generated
ELECTRIC POTENTIAL, V
$V = \frac{Q}{4\pi\varepsilon_0 r}$
scalar
At ∞, V = 0
Pot. diff.
$V_f - V_i$
$V = \frac{W}{q} = \frac{U}{q}$
[V] = V or JC^{-1}
ELECTRIC POTENTIAL ENERGY, EPE or U
Scalar
$W = U = \frac{Qq}{4\pi\varepsilon_0 r}$
U = Vq
[W] = [U] = J
Work Done by $\vec{F}_{external}$ on charge from ∞ → point
Lower potential
Higher potential
+ve work done by $\vec{F}_{ext}$.
−ve work done by $\vec{F}_{ext}$.
$\vec{F}_{ext}$: External force
UNIFORM $\vec{E}$
d
V
$E = \frac{V}{d}$
$\vec{E}$ of point charge
$E = F/q$
F = qE
$E = \frac{Q}{4\pi\varepsilon_0 r^2}$
[E] = NC^{-1} or Vm^{-1}
E
$E \propto \frac{1}{r^2}$
+Q
0 r
E
0 r
−Q
$E \propto \frac{1}{r^2}$


Note: Basic Formula → Manipulate these and solve questions
Electricity
EMF vs POT.
EMF
Chem. → Elect
E = W/q
Eg: battery
battery
same fomula
Potential
Elect → other forms
V = W/q
Eg. p.d. across lamp
Electricity → light energy
lamp
POWER
P = W/t
P = E/t
E = VIt
P = VI
V = IR
CHARGES
measured in C
electron, e⁻
−1.6 × 10⁻¹⁹C
proton
+1.6 × 10⁻¹⁹C
conventional current flow
load
electron flow
load
FLOW OF CHARGED PARTICLES
I = dQ/dt
if steady current
I = Q/t
[I] = A
Q = Ne
In Gas
In Metals
valence electron
cations
Low pot.
high pot.
electron path
E (Electric Field)
Note: Electrons drift in presence of E.
• Momentum & KE of e⁻ ↑ when subjected to E
• Electrons slow down when they encounter atoms/cations
• ∴ slow, intermittent, motion
RESISTIVITY, ρ
R ∝ l/A
l: length
A: cross-sectional area
R = ρl/A
Cable:
A
l
RESISTANCE
Internal resistance of battery
E
r
load
V_load
V_load = E − V_r
= E − (I)(r)
V = IR
R = V/I
Graphs
opp. to resistance
grad = 1/R = G = conductance
I
V
Ohmic conductor
p-n junction diode
Filament lamp
thermistor
Resistance/Ω
For thermistor
Temp/°C
POTENTIAL DIFF.
Ohm's law
V = IR
12V
12V
0V
1A
2Ω
4Ω
6Ω
12V A
10V B
6V C
0V D
V = IR → I = 12/(2+4+6) = 1A
Eg: V_2Ω = (1)(2) = 2V [pot.difference]
i.e. 12V − 10V
potential at point A
potential at point B
Hence, pot.diff. is 12 − 10 = 2V

DC Circuits



Legend: resistor symbol : Resistor

SERIES

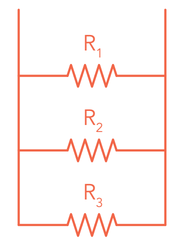
$R_T = R_1 + R_2 + R_3$

$R_T = R_1 + R_2 + R_3 + \ldots$

PARALLEL

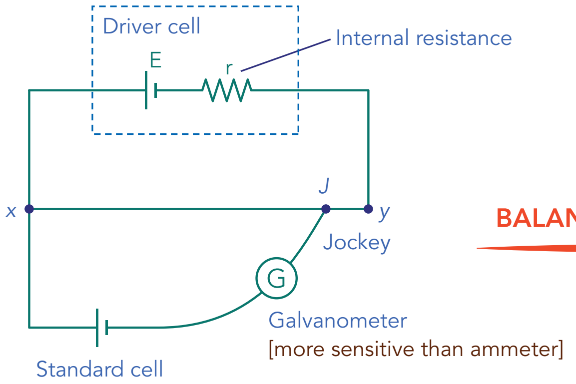
$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

if 2 resistors //: $R_T = \frac{(R_1)(R_2)}{R_1 + R_2}$



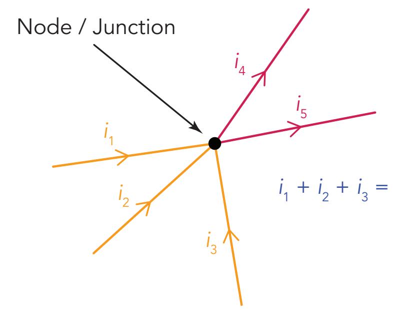
$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

BALANCED POTENTIALS



- If $V_{xJ} = V_{standard\ cell}$, no current flows through standard cell.

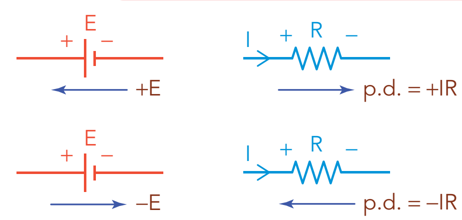
KIRCHOFF'S LAWS



$i_1 + i_2 + i_3 = i_4 + i_5$

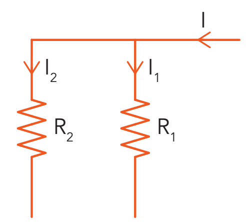
- KCL: $\Sigma I_{in} = \Sigma I_{out}$
- (optional) KVL:
  - Σemf = Σ p.d. drop across each load.
  - Conventions

→ / ← : traverse direction



(optional) CURRENT DIVIDER LAW

2 branches only

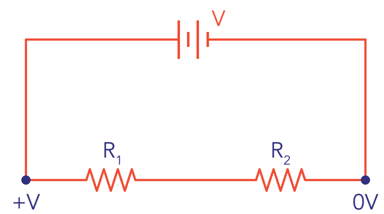


$I_1 = \left[\frac{R_2}{R_1 + R_2}\right][I]$

$I_2 = \left[\frac{R_1}{R_1 + R_2}\right][I]$

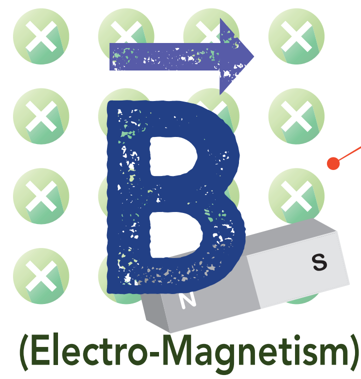
Note: Remember these formulae - Useful for simple circuits.

POTENTIAL DIVIDER



$V_{R1} = \left[\frac{R_1}{R_1 + R_2}\right][V]$

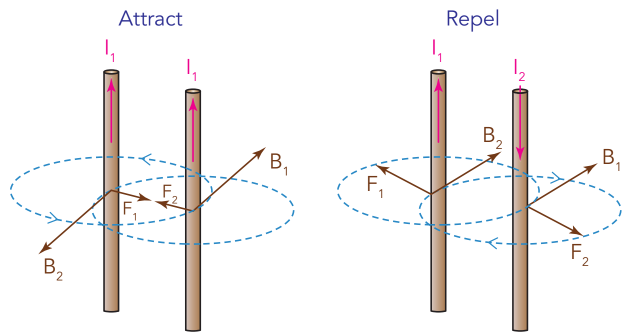
$V_{R2} = \left[\frac{R_2}{R_1 + R_2}\right][V]$



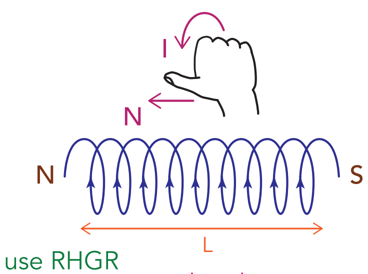
B (Electro-Magnetism)

$\vec{B}$ due to I

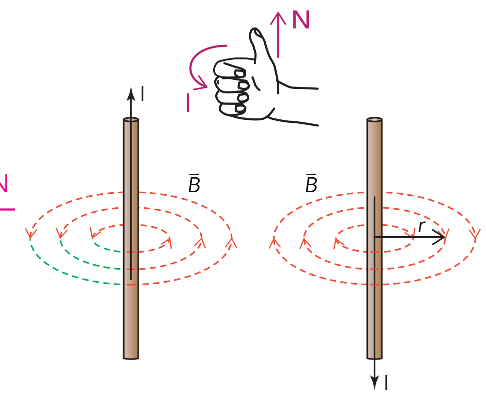
Parallel conductors
- I same direction — attract
- I diff. direction — repel



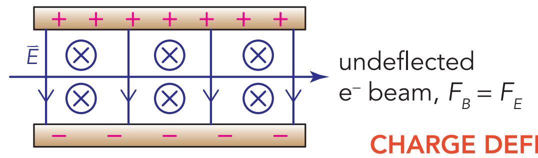
Solenoid
- use RHGR — thumb points to North, N
- $B = \mu_0 \frac{N}{L} I$
  - N: No.of turns
  - L: Length of solenoid



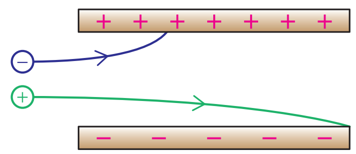
Straight conductor
- use Right Hand Grip Rule (RHGR)
- $B = \frac{\mu_0 I}{2\pi r}$



CHARGE DEFLECTION

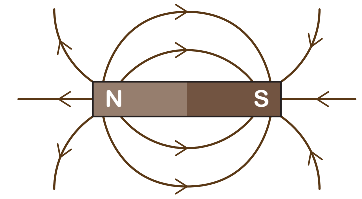


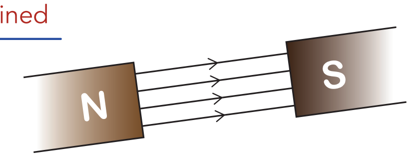
- $\vec{E}$ & $\vec{B}$ — $F_B = F_E$ — $Bev = eE$ — velocity selector
- $\vec{E}$ — if $\vec{E}$ accelerate Q — $\frac{1}{2}mv^2 = eV$

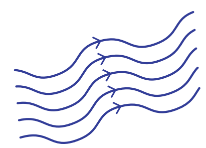


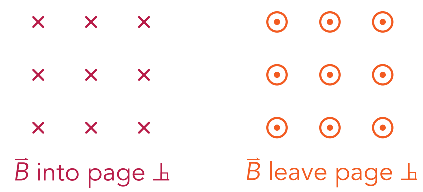
Note: proton heavier than electron

CONCEPT OF $\vec{B}$
- do not intersect
- when superimposed resultant obtained
- strength
  - strong
  - weak
- can be deformed

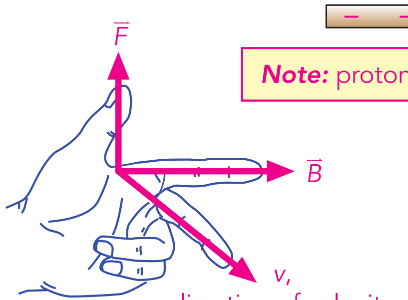








FORCE ON CHARGE
- $F_B = BQv\sin\theta$
  - θ: ∢ bet. v & B
  - still use Fleming's LHR
- Only acts on moving charges
  - $F_B = 0$ If charge stationary
  - **Recall:** Moving charge is current
- Circular motion
  - $F_C = F_B$
    - $\frac{mv^2}{r} = BQv$
    - $v = r\omega$



Note: If Q is electron,
then opposite direction.

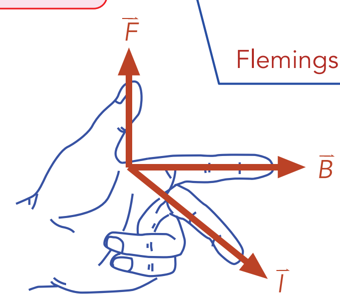
From $F = BIL\sin\theta$,

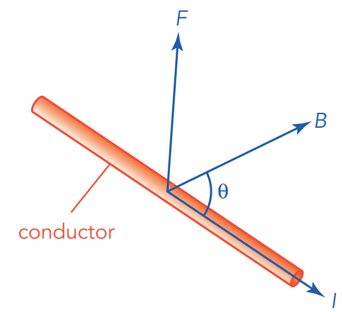
Recall: $I = \frac{Q}{t}$ and $v = \frac{L}{t}$

$\therefore F = B\left(\frac{Q}{t}\right)(vt)(\sin\theta)$

$= BQv\sin\theta$

CONDUCTOR WITH I
- $F_B = BIL\sin\theta$
  - B: Magnetic Flux Density — SI unit: Tesla, T
  - θ: ∢ bet. I and B
- Flemings LHR

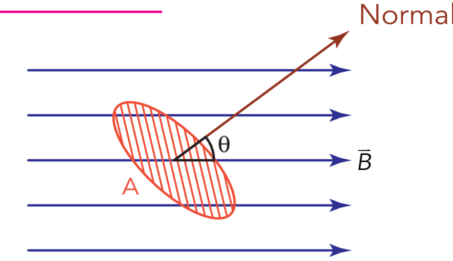




EMI

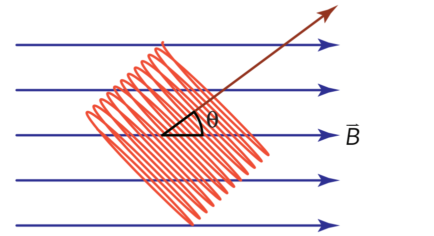
FLUX / FIELD

- $\phi = BA\cos\theta$
  - B: Magnetic Field strength/Magnetic Flux Density
  - ϕ: Magnetic Flux, SI unit: Wb
    - 1Wb = 1Tm^2
  - θ: ∢ bet. normal of plane & B
- $\vec{B}$ field produced by
  - moving charges
  - Current



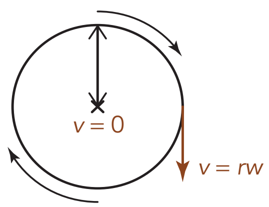
FLUX LINKAGE

- $\Phi = N\phi$
- SI unit: Wbturns



APPLICATIONS

- Faraday's Disc



$\therefore V_{av} = \frac{rw + 0}{2} = \frac{rw}{2}$

$E = BLv$

$= BL\left(\frac{r\omega}{2}\right), L = r$

$\therefore E = \frac{Br^2\omega}{2}$

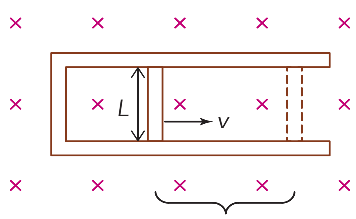
Recall: $\omega = 2\pi f$

$\therefore E = \frac{Br^2}{\not{2}} \cdot \not{2}\pi f$

$= B\pi r^2 f$

EMF in straight conductor

- Factors to ↑ E
  - ↑B
  - ↑v
  - ↑L



$A = L\Delta s = Lv\Delta t$

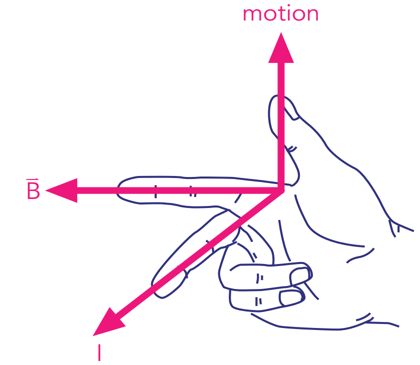
$\Delta\Phi = BA\cos\theta = BLv\Delta t, \cos\theta = 1 \text{ as } \theta = 0°$

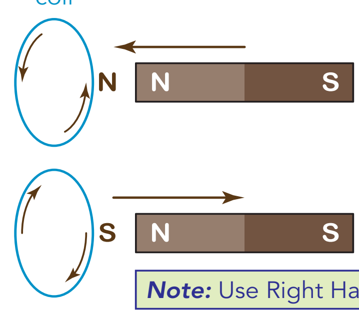
$\therefore E = \frac{\Delta\Phi}{\Delta t} = BLv$

LAWS

- Faraday's Law
  - $E = -\frac{d\Phi}{dt}$
  - magnitude only: $|E| = \left|-\frac{\Delta\Phi}{\Delta t}\right|$
- Lenz Law
  - polarity of induced emf opposes Δ producing it
  - COE
  - WD to overcome force provides electrical energy
- Fleming's Right-Hand rule
  - Don't confuse with Fleming's LHR

Note: • It is always induced Emf, E, that is produced, when there is a Δ in Φ.
• Induced current flows only when there is a complete circuit.





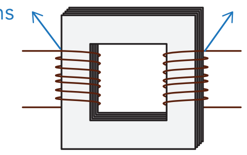
Lenz law: Induced current flows in a direction to produce a field that opposes the Δ producing it.

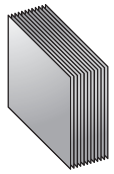
Note: Use Right Hand Grip Rule

AC

TRANSFORMER

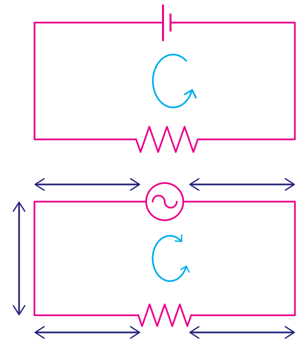
- Ideal
  - 100% power transfer
    - $\eta = 100\%$
  - Resistance = 0
  - $\frac{V_s}{V_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p}$
- Power losses
  - Eddy Currents
    - Use laminated sheets
  - Hysteresis loss
    - Use soft iron-core
      - Easily magnetise/demagnetize



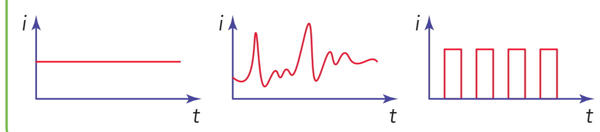


INTRODUCTION

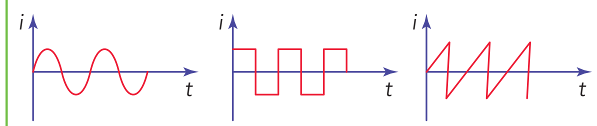
- Uses
  - industries
- DC
  - uni-directional
- AC
  - Δ-ing $\vec{B}$



DC examples



AC examples:



POWER FORMULAE

$$\langle P\rangle = \frac{P_{max}}{2}$$

$$P_{max} = I_0 V_0$$

$$\langle P\rangle = P_{ave} = I_{rms}V_{rms} = (I_{rms})^2 R = \frac{(V_{rms})^2}{R}$$

RMS

- steady DC value that gives same rate of power as AC
- Steps to obtain
  1. Square graph
  2. Find area within T
  3. $\frac{\text{Area}}{T}$ to find mean
  4. $\sqrt{\text{ans. from ③}}$

Recall:

$$\langle \sin^2\omega t\rangle = \frac{1}{2}$$

i.e. $\frac{\int_0^T \sin^2\omega t\,dt}{T} = \frac{1}{2}$

$$I = I_0 \sin\omega t$$

$$I_{rms} = \sqrt{\langle I^2\rangle} = \sqrt{\langle I_0^2 \sin^2\omega t\rangle} = I_0\sqrt{\langle \sin^2\omega t\rangle} = I_0\sqrt{1/2} = I_0/\sqrt{2}$$

[Likewise for V_{rms} : $V_{rms} = \frac{V_0}{\sqrt{2}}$]

Ave power $= P_{dc} = I^2_{dc}R$

$$\langle P_{ac}\rangle = \langle I^2_{ac}\rangle R$$

$$P_{dc} = \langle P_{ac}\rangle$$

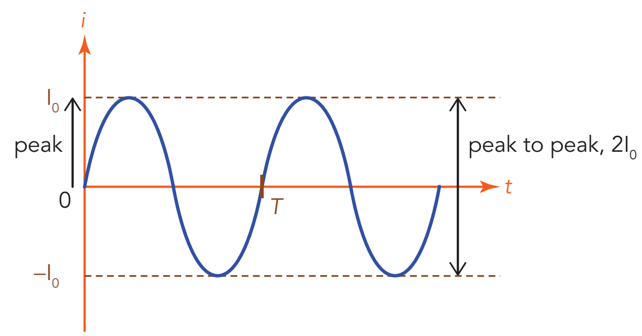
$$I_{dc}^2 \cancel{R} = \langle I_{ac}^2\rangle \cancel{R}$$

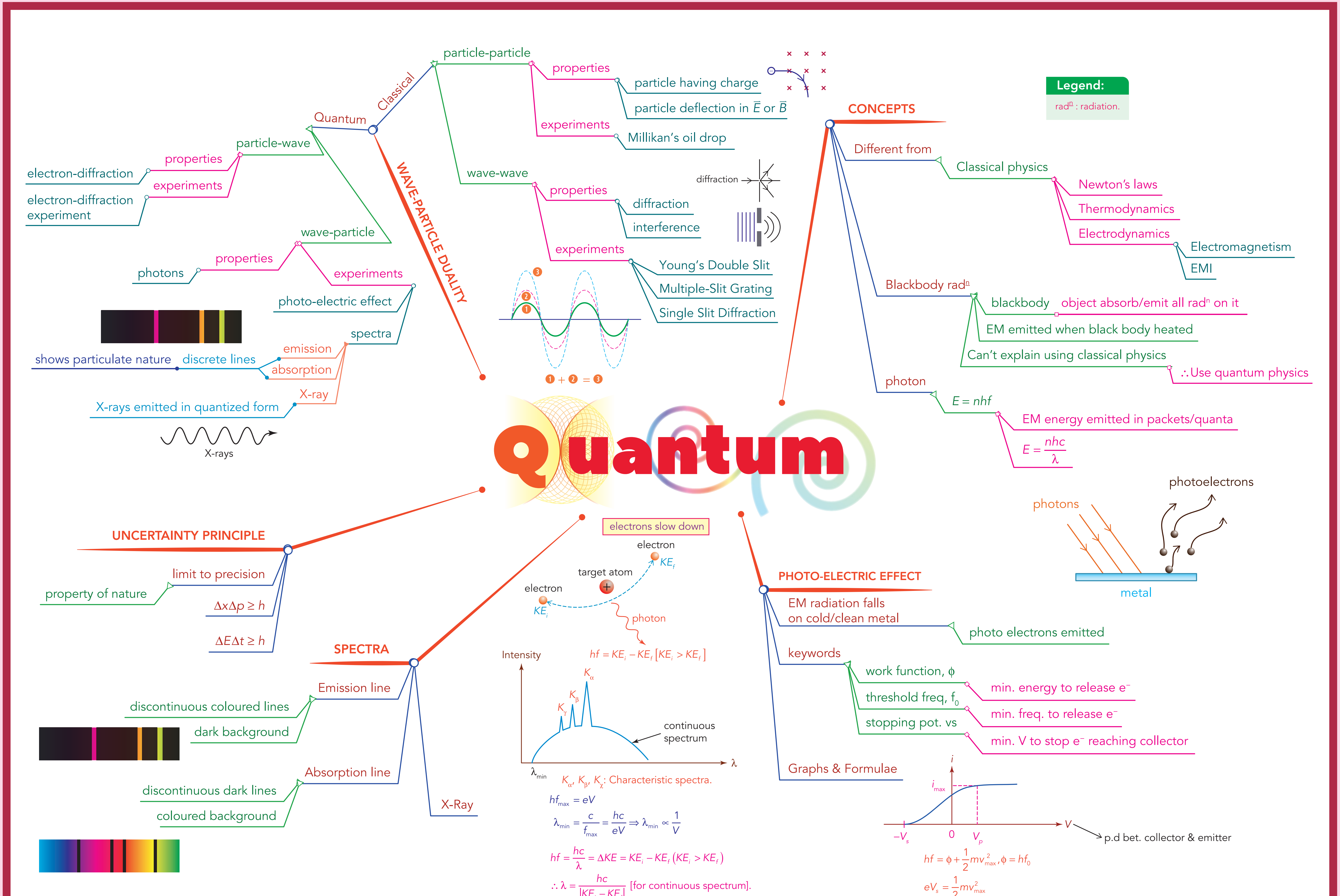
$$\therefore I_{dc} = \sqrt{\langle I_{ac}\rangle} = I_{rms}$$

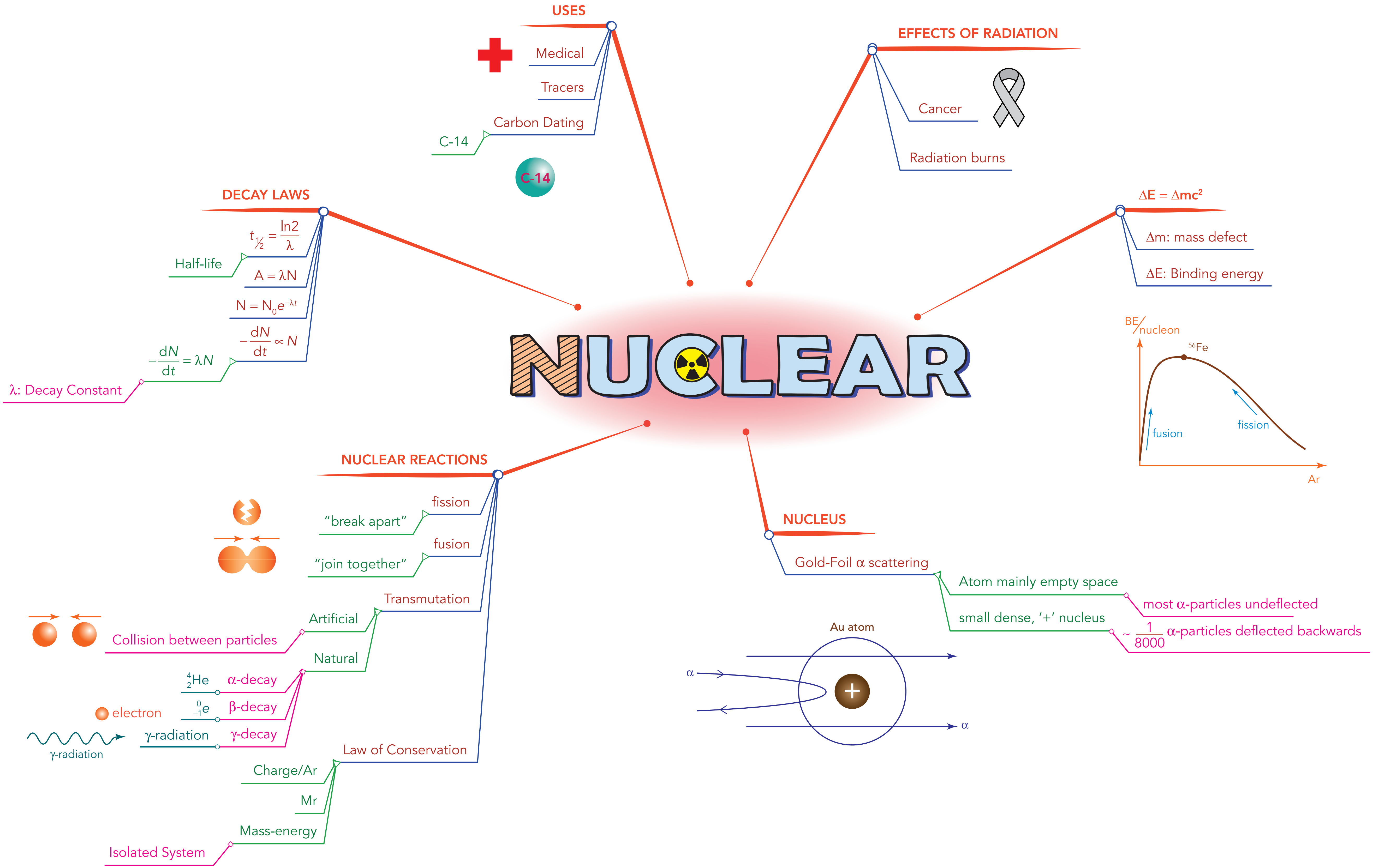
[Likewise for V_{rms} : $V_{rms} = \sqrt{\langle V_{ac}^2\rangle}$]

TERMS

- $I = I_0 \sin\omega t$
- $V = V_0 \sin\omega t$
  - $\omega = 2\pi f$
    - $fT = 1$




Quantum
WAVE-PARTICLE DUALITY
Classical
Quantum
particle-particle
properties
particle having charge
particle deflection in $\bar{E}$ or $\bar{B}$
experiments
Millikan's oil drop
wave-wave
properties
diffraction
interference
diffraction
experiments
Young's Double Slit
Multiple-Slit Grating
Single Slit Diffraction
①+②=③
particle-wave
properties
electron-diffraction
experiments
electron-diffraction experiment
wave-particle
properties
photons
experiments
photo-electric effect
spectra
emission
absorption
shows particulate nature
discrete lines
X-ray
X-rays emitted in quantized form
X-rays
Legend:
radⁿ : radiation.
CONCEPTS
Different from
Classical physics
Newton's laws
Thermodynamics
Electrodynamics
Electromagnetism
EMI
Blackbody radⁿ
blackbody
object absorb/emit all radⁿ on it
EM emitted when black body heated
Can't explain using classical physics
∴Use quantum physics
photon
$E = nhf$
EM energy emitted in packets/quanta
$E = \frac{nhc}{\lambda}$
photoelectrons
photons
metal
UNCERTAINTY PRINCIPLE
limit to precision
property of nature
$\Delta x \Delta p \geq h$
$\Delta E \Delta t \geq h$
SPECTRA
Emission line
discontinuous coloured lines
dark background
Absorption line
discontinuous dark lines
coloured background
X-Ray
electrons slow down
electron
KE_f
target atom
electron
KE_i
photon
$hf = KE_i - KE_f\ [KE_i > KE_f]$
Intensity
K_α
K_β
K_γ
continuous spectrum
λ_{min}
λ
$K_\alpha, K_\beta, K_\gamma$: Characteristic spectra.
$hf_{max} = eV$
$\lambda_{min} = \frac{c}{f_{max}} = \frac{hc}{eV} \Rightarrow \lambda_{min} \propto \frac{1}{V}$
$hf = \frac{hc}{\lambda} = \Delta KE = KE_i - KE_f\ (KE_i > KE_f)$
$\therefore \lambda = \frac{hc}{|KE_i - KE_f|}$ [for continuous spectrum].
PHOTO-ELECTRIC EFFECT
EM radiation falls on cold/clean metal
photo electrons emitted
keywords
work function, ϕ
min. energy to release e⁻
threshold freq, f_0
min. freq. to release e⁻
stopping pot. vs
min. V to stop e⁻ reaching collector
Graphs & Formulae
i
i_{max}
$-V_s$
0
V_p
V
p.d bet. collector & emitter
$hf = \phi + \frac{1}{2}mv^2_{max}, \phi = hf_0$
$eV_s = \frac{1}{2}mv^2_{max}$


NUCLEAR
USES
Medical
Tracers
Carbon Dating
C-14
C-14
EFFECTS OF RADIATION
Cancer
Radiation burns
DECAY LAWS
$t_{1/2} = \frac{\ln 2}{\lambda}$
Half-life
$A = \lambda N$
$N = N_0 e^{-\lambda t}$
$-\frac{dN}{dt} \propto N$
$-\frac{dN}{dt} = \lambda N$
λ: Decay Constant
$\Delta E = \Delta mc^2$
Δm: mass defect
ΔE: Binding energy
BE/nucleon
^{56}Fe
fusion
fission
Ar
NUCLEAR REACTIONS
fission
"break apart"
fusion
"join together"
Transmutation
Artificial
Collision between particles
Natural
$^4_2$He
α-decay
$^0_{-1}$e
β-decay
electron
γ-radiation
γ-decay
γ-radiation
Law of Conservation
Charge/Ar
Mr
Mass-energy
Isolated System
NUCLEUS
Gold-Foil α scattering
Atom mainly empty space
most α-particles undeflected
small dense, '+' nucleus
$\sim \frac{1}{8000}$ α-particles deflected backwards
Au atom
α
α