PHYSICS

Mechanics	Harmonics	Electromagnetism
Kinematics How Things Move Dynamics Why Things Move Energy Capacity to do Work Systems of Particles Center of Mass Momentum Collisions	Circular Orbits Kepler Rotational Analogues Linkages Relationships Oscillatory Period Energy	Statics Fields Conductors Dynamics Current Circuits Capacitors Magnetism Fields Induction Maxwell

Thermodynamics	Optics	Modern
Fluids Statics Dynamics Thermodynamics Temperature Processes Inefficiency	Geometric Refraction Images Physical Coherence Interference	Relativity Special General Quantum Orbitals Duality

KINEMATICS

kinematics		
kinematics	how things move	constant acceleration
	total displacement	area under velocity time
	$\overline{v} = \frac{x - x_0}{t}$	average velocity
	$\overline{a} = \frac{v - v_0}{t}$	average acceleration
	$\overline{v} = \frac{v + v_0}{2}$	constant acceleration
	$x = \frac{1}{2}at^2 + v_0 t + x_0$	substitution
	$2ax = v^2 - v_0^2$	replace time

problems		
frame of reference	choose simplifying	reference frame
	falling monkey	sliding pea shooter
rates	Barkimedes	use total distance
	$\frac{2ab}{a + b}$	harmonic same distance
dimensional analysis	conceptual solving	selection and scaling
	MLT	mass length time
extreme cases	test solution	with extreme values
	clear height	zero range

DYNAMICS

dynamics		
dynamics	why things move	force changes motion
	inertia	constant unless force
	$\mathbf{F} = m\mathbf{a}$	force changes motion
	$\mathbf{F}_{1_2} = \mathbf{F}_{2_1}$	equal opposite pairs
forces	contact forces	between objects
	friction parallel	normal perpendicular

problems		
inclines	choose simplifying	reference frame
	inclined plane as	horizontal axis
pulleys	propagates same force	changes direction
	system of pulleys	net force on area zero
friction	resistance to motion	anti parallel
	wheels static friction	terminal velocity
normal	system of boxes	ladder against wall
	not perpendicular	if need component
third law	person standing on bench	normal forces are pair
	jump on bench	gravity not equal normal
	giant astronaut	gravity cancel normal

ENERGY

energy		
energy	capacity to do work	conserved in universe
	$W = \mathbf{F} \cdot \mathbf{x}$	force over distance
	$W = \int m\mathbf{v}\, dv$	work energy
	$K = \frac{1}{2}mv^2$	kinetic energy
conservative	force performs work	stored as potential energy
	$W = \oint \mathbf{F} \cdot d\mathbf{r} = 0$	path independent state variable
potential	energy of configuration	by conservative force
	$U = -\int \mathbf{F} \cdot d\mathbf{r}$	negative work stored
	$F = -\frac{dU}{dx}$	restores to equilibrium
power	$\overline{P} = \frac{\Delta W}{\Delta t}$	rate of energy over time
	$P = \mathbf{F} \cdot \mathbf{v}$	substitution

problems		
shortcut	end points simpler	via energy conservation
	three balls thrown	same speed at bottom

SYSTEM OF PARTICLES

center of mass		
system of particles	real world	has solid bodies
	center of mass	obeys Newton's laws
center of mass	no external force	no change center of mass
	$\mathbf{F}_{total} = M \frac{d^2}{dt^2} \left(\frac{\sum m_i x_i}{M} \right)$	second law
	$x_{cm} = \frac{\sum m_i x_i}{M}$	center of mass
	$F_{int} = 0$	third law
	$F_{ext} = Ma_{cm}$	substitution

momentum		
momentum	$\mathbf{p} = m\mathbf{v}$	quantity of inertia
	$\mathbf{F} = \frac{d\mathbf{p}}{dt}$	second law
	$P = \sum m_i v_i = \frac{d}{dt} \sum m_i x_i$	system of particles
	$P = Mv_{cm}$	center of mass
	$F_{ext} = \frac{dP}{dt} = 0$	conservation

collisions		
collisions	brief intense	no time external force
	system momentum	always conserved
	$v_{1i} - v_{2i} = v_{2f} - v_{1f}$	elastic kinetic conserved
	$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$	inelastic together max loss

CIRCULAR

circular		
circular	changing velocity	from changing direction
	$\mathbf{a}_c = \frac{v^2}{\mathbf{r}}$	via geometric limit
	$\mathbf{F}_c = m\,\mathbf{a}_c$	tension normal friction
	$\mathbf{F}_g = \frac{G m_1 m_2}{\mathbf{r}^2}$	gravity
orbit	$v^2 = \frac{GM}{r}$	independent of mass
	$\frac{P^2}{r^3} = \frac{4\pi^2}{GM}$	lower faster shorter
energy	$U = -\frac{GMm}{r}$	potential zero at infinity
	$v^2 = \frac{2GM}{r}$	escape velocity
	$E = -K$	virial lower more K less total

Kepler		
first law	gravity orbits	are ellipses
	$e = \frac{c}{a}$	eccentricity
second law	orbits sweep out	same area in same time
	$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right)$	vis viva
third law	orbital periods	proportional semimajor axis
	$\frac{P^2}{a^3} = \frac{4\pi^2}{GM}$	mechanical energy

ROTATIONAL

rotational		
rotational	rotation motion	system of particles
	analogues	linkages
mechanics	$\theta = \frac{1}{2}\alpha t^2 + \omega_0 t + \theta_0$	$\theta = \frac{s}{r} \quad v = \omega r$
	$\tau = I\alpha$	$\tau = r \times F$
momentum	$L = I\omega$	$L = r \times p$
	$\tau_{ext} = \frac{dL}{dt} = 0$	conservation
inertia	$I = mr^2$	second law
	$I_d = I_{cm} + md^2$	parallel axis
energy	$K_{rot} = \frac{1}{2}I\omega^2$	integration
	$W = \tau \cdot \theta$	substitution

relationships		
rolling motion	rolling without slipping	due to static friction
	center of mass translation	edges rotation
	$v_{cm} = \omega R$	total wheel radius
	double velocity top	zero velocity bottom
	friction does no work	mechanical energy conserved
gyroscope	maintains orientation	fast spin large momentum
	requires large torque	to change axis
precession	no spin falls gravity torque	has spin does not fall
	perpendicular torque	changes rotation axis

OSCILLATORY

oscillatory		
oscillatory	restorative force	proportional displacement
	back and forth	around equilibrium
	$\frac{d^2x}{dt^2} = -\left(\frac{k}{m}\right)x$	substitution
	$x(t) = A\cos\omega t$	projected circular motion
	$P = 2\pi\sqrt{\frac{m}{k}}$	independent of amplitude
effective constant	$k_{eff} = k_1 + k_2$	parallel sum forces
	$k_{eff} = \frac{k_1 k_2}{k_1 + k_2}$	series sum distances
pendulum	$\tau = -mgl\sin\theta$	angle displacement
	$P = 2\pi\sqrt{\frac{l}{g}}$	small angle approximation

energy		
potential energy	$U = \frac{1}{2}kx^2$	integration
	$U = \frac{1}{2}kA^2\cos^2\omega t$	expansion
kinetic energy	$v(t) = -A\omega\sin\omega t$	differentiation
	$K = \frac{1}{2}kA^2\sin^2\omega t$	substitution
mechanical energy	$E = U + K$	definition
	$E = \frac{1}{2}kA^2$	trigonometry
velocity	$v^2 = \frac{k}{m}\left(A^2 - x^2\right)$	rearrangement

STATICS

statics		
statics	fundamental force	of the universe
	$\mathbf{F} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{\mathbf{r}^2}$	Coulomb
	charge creates field	other charges react
	$\mathbf{E} = \frac{\mathbf{F}}{q}$	force per unit charge
flux	field lines	per area
	$\Phi = E \cdot A$	field area orientation
	closed surface flux	proportional enclosed charge
	$\Phi = \oint E \cdot dA = \frac{q}{\epsilon_0}$	Gauss
potential	$\Delta W = F \cdot \Delta x$	by definition
	$\Delta V = -E \cdot \Delta r$	potential energy per unit charge
	$V = \frac{kq}{r}$	potential zero at infinity
	equipotential contour map	field directional derivative

conductor		
conductor	mobile electric charge	move in response to field
	charge separation	counters external field
	result interior field zero	excess charges on surface
	$E = \frac{\sigma}{\epsilon_0}$	Gauss
	is equipotential surface	no work move inside or on
	smaller sphere	denser stronger field

DYNAMICS

current		
current	charges in motion	net force exists
	inside conductors	where charges mobile
	charge per time	drift velocity on random
	$I = nqAv_d$ microscopic	$J = \frac{I}{A}$ flux
resistance	charges accelerate in field	collisions stop motion
	$J = \frac{E}{\rho}$ microscopic	$I = \frac{V}{R}$ macroscopic
	$R = \rho \frac{L}{A}$	by geometry

circuits		
circuits	components connected	with idealized conductors
	wires of no resistance	all points equipotential
	fixed potential difference	maintains electric field
	electromotive force source	lift charge fall through circuit
power	energy per time	for each component
	$P = IV$	substitution
resistors	conductor with resistance	dissipate energy as heat
	$R = R_1 + R_2$	series same current
	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$	parallel same voltage
Kirchhoff	loop law	conservation of energy
	sum voltage	around loop is zero
	node law	conservation of charge
	sum current	any node is zero

CAPACITOR

capacitor		
capacitor	store potential energy	of charge separation
	$C = \frac{Q}{V}$	charge per potential difference
parallel plate	archetype capacitor	equal opposite charges
	dielectric insulator	lower field higher capacity
	$E = \frac{\sigma}{\epsilon_0}$	$C = \kappa\, \epsilon_0 \frac{A}{d}$
	$C = C_1 + C_2$	parallel
	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$	series
energy	energy stored	work to create configuration
	$U = \frac{1}{2} C V^2$	stored energy
	$u_E = \frac{1}{2} \epsilon_0 E^2$	energy density

behaviour		
behaviour	voltage changes slowly	requires change in charge
	simplify analysis	with steady state
steady state	empty capacitor	ideal wire no resistance
	no charge no voltage	resistor voltage current
	full capacitor	open circuit infinite resistance
	full charge full voltage	no current opposes emf
intermediate	circuit voltage loop law	current charge differentials
	charging emf source	discharging into resistor
	$V_C = \varepsilon(1 - e^{-t/RC})$	RC time constant

MAGNETISM

magnetism		
magnetism	electric charges	interact with electric fields
	moving electric charges	interact with magnetic fields
charge	$F_B = qv \times B$	change direction does no work
	charges spiral	between field lines
current	microscopic	drift velocity
	$F = Il \times B$	substitution

field		
field	electric charges	produce electric fields
	moving electric charges	produce magnetic fields
	$dB = \frac{\mu_0}{4\pi} \frac{Idl}{r^2} \times \hat{r}$	Bio-Savart
	closed loop field lengths	proportional enclosed current
	$\oint B \cdot dl = \mu_0 I$	Ampere

usage		
Bio-Savart	single axis geometry	simple shape integral
	$B = \frac{\mu_0 I}{2\pi r}$ infinite line	$B = \frac{\mu_0 I}{2r}$ single loop
Ampere	constant distance strip	constant field strength
	radial length strip	zero field strength
	closed circle	simple shape integral
	given magnetic fields	sum integral segments

INDUCTOR

induction		
induction	changing magnetic field	induces electric current
	$\Phi_B = \int B \cdot dA$	field area orientation
	induced emf	proportional circuit area
	$\varepsilon = -\frac{d\Phi_B}{dt}$	Lenz opposes change
	$\varepsilon = Blv$	sliding edge changing area
inductor	changing current	changes magnetic field
	self inductance	field opposes own change
	store potential energy	of magnetic field
	$L = \frac{\Phi_B}{I}$	flux per current
	$\varepsilon_L = -L\frac{dI}{dt}$	proportional rate lethal voltage
	$L = \mu_0 n^2 A l$	solenoid archetype inductor
energy	energy stored	work to create field
	$U = \frac{1}{2}LI^2$	stored energy
	$u_B = \frac{B^2}{2\mu_0}$	energy density

behaviour		
behaviour	current changes slowly	requires change in flux
	empty steady state	full back emf open circuit
	full steady state	no back emf full current
	$I = I_0\left(1 - e^{-tR/L}\right)$	intermediate emf growth

MAXWELL

fields		
electric	induced emf	moves charges via electric field
	$\varepsilon = \oint E \cdot dl$	around magnetic flux circuit
	new source electric field	closed loops not conservative
	$\oint E \cdot dl = -\frac{d\Phi_B}{dt}$	Faraday
magnetic	new source magnetic field	changing electric field
	$\oint B \cdot dl = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$	Ampere

Maxwell		
Gauss	$\oint E \cdot dA = \frac{q}{\epsilon_0}$	charge makes electric field
Ampere	$\oint B \cdot dl = \mu_0 I$	current makes magnetic field
	$\oint B \cdot dl = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$	changing magnetic → electric
Faraday	$\oint E \cdot dl = -\frac{d\Phi_B}{dt}$	changing electric → magnetic

waves		
waves	electric magnetic fields	induce each other
	electromagnetic disturbance	propagate through space
	changing fields	regenerate and propagate
source	changing motion of	accelerated charges
	wavelength equals	size of accelerating system

FLUIDS

statics		
fluids	liquids or gases	fill given container
	$\rho = \frac{M}{V}$	density gas compressible
	$p = \frac{F}{A}$	pressure force per area
equilibrium	no motion inside fluid	no net force anywhere
	$p = \rho g h + p_0$	gravity differential pressure
Pascal	surface pressure	felt throughout liquid
	$\frac{F_1}{A_1} = \frac{F_2}{A_2}$	work constant distances vary
Archimedes	buoyancy force	displaced fluid weight
	$V_w \rho_w = V_o \rho_o$	equilibrium

dynamics		
dynamics	fluid motion	net force exists
	flowtube of streamlines	boundary never crossed
mass conservation	steady flow	constant mass per time
	$v_1 A_1 = v_2 A_2$	rearrangement
	steady flow	constant energy per time
energy conservation	$\Delta K = \frac{1}{2} m (\Delta v)^2$	kinetic energy
	$\Delta U = m g \Delta h$	potential energy
	$\Delta W = \Delta p A x$	pressure entry exit
	$p + \frac{1}{2} \rho v^2 + \rho g h$	Bernoulli

ZEROTH LAW

thermodynamics		
thermodynamics	temperature is intensity	match is hot ocean is cool
	heat is energy transfer	due to temperature difference
transfer	possible heat transfer	conduction physical contact
	convection fluid motion	radiation electromagnetic waves
zeroth law	thermal equilibrium	equal temperature
	two object equilibrium	if equilibrium with third
heat capacity	amount of heat transfer	per temperature change
	$Q = mc\Delta T$	specific and molar

temperature		
experiment	temperature via relation	of experiemnt and theory
	ideal gas law	observations about gases
	$pV = nRT$	macroscopic experiments
theory	kinetic molecular theory	theoretical derivation
	particle energy distribution	Maxwell-Boltzmann
	$pV = \frac{2}{3}N\left(\frac{1}{2}m\overline{v^2}\right)$	microscopic particles
temperature	is proportional to	system internal energy
	$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$	measure of internal energy

FIRST LAW

first law		
first law	internal energy	is heat and work
	$\Delta E = Q + W$	state variable
	$E \propto T$	temperature is measure
states	ideal gas law	macroscopic experiments
	$p\ V\ T$	two states determine third
	pV diagram	each point a complete state
processes	reversible process	equilibrium continuous path
	irreversible process	non-equlibrium shock jump
	gas cylinder	idealized reversible system
	heat transfer	thermal contact with reservoir
	$\Delta W = -p\Delta V$	work transfer with piston

isothermal		
isothermal	constant temperature	thermal contact reservoir
	$\Delta E = 0 \quad Q = -W$	heat transfer is work done
	$p = nRT\left(\frac{1}{V}\right)$	isotherm curves
	$\int p\,dV = nRT \ln\left(\frac{V_2}{V_1}\right)$	by integration
	bubble rising	gains heat does work

isometric		
isometric	constant volume	rigid container piston still
	$\Delta E = Q$	no work done only heat transfer
heat capacity	$Q = nC_V\Delta T$	constant volume
	$\Delta E = nC_V\Delta T$	all processes

isobaric		
isobaric	constant pressure	exposed to atmosphere
	$Q = \Delta E + p\Delta V$	substitution
heat capacity	$nC_p\Delta T = nC_V\Delta T + p\Delta V$	at constant pressure
	$C_p = C_V + R$	does expansion work

adiabatic		
adiabatic	no heat flow	insulated quick processes
	$\Delta E = W$	work done only
	$W = \int p\, dV$	integration
	transition between isotherms	loses temperature and energy
equipartition	$pV^\gamma = \text{constant}$	substitution
	$\gamma = \frac{C_p}{C_V}$	by definition
	particles store energy	for each degree of freedom
	increase degrees	exponent closer to one

SECOND LAW

second law		
second law	heat and work	not equivalent
	conversion inefficient	due to entropy
efficiency	random thermal motion	to ordered work
	always wastes heat	when done in cycle
	isothermal and adiabatic	expansion and compression
	$W = Q_h - Q_c$	work done
	$e_{Carnot} = 1 - \frac{T_c}{T_h}$	Carnot efficiency

entropy		
energy quality	work fully convertible heat	heat not fully convertible back
	mix hot and cold water	no energy loss
	but lost something	ability to do work
entropy	measure of energy quality	loss through transformations
	$\Delta S_{12} = \int_1^2 \frac{dQ}{T}$	state variable

measurement		
measurement	emulate irreversible process	by reversible process
	hot cold water irreversible	slow heat cold water reversible
adiabatic free expansion	gas expansion in vacuum	can do work
	$W = nRT \ln\left(\frac{V_2}{V_1}\right)$	reversible simulation
	$E = T_c \Delta S$	loss in avaiable energy

GEOMETRIC

refraction		
geometric	light as particles in rays	large scale vs wavelengths
	reflection equals incidence	parallel at corner
refraction	vacuum to media	change direction
	frequency constant	speed wavelength decrease
	$n = \frac{c}{v}$ index	$n_1 \sin\theta_1 = n_2 \sin\theta_2$ Snell
total internal reflection	slower to faster media	bend away from normal
	$\sin\theta_c = \frac{n_2}{n_1}$	underwater view cone

images		
mirrors	ideal parabola	sphere approximate
	concentrate parallels to focus	point source to parallel beam
	images by ray tracing	two rays determine
images	paraxial ray reflect focus	through focus reflects paraxial
	mirror center reflects axis	curvature center reflects back
	focus is half curvature center	relations by similar triangles
	$\frac{h'}{h} = -\frac{s'}{s}$	$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$
concavity	concave mirror	converge on real focus
	convex mirror	diverge on virtual focus
lenses	double refraction	thin lens approximation
	two focus on either side	concavity reverse of mirrors
	real image light from image	can see image without lens
	virtual image light not from	can see image only through lens

PHYSICAL

physical		
physical	light as waves interference	small scale at wavelengths
	coherent steady interference	same frequency and phase
coherence	recombine different paths	slits coherent light
	interferometry single light	diffraction circular wavefronts
interference	superposition of waves	path difference determines
	constructive whole wavelengths	destructive half wavelengths

interference		
slits	coherent sunlight through hole	two slits circular wavefronts
	produce interference	bright dark bands
	approximate parallel	$d \sin\theta$ path difference
	$d \sin\theta = m\lambda$	bright bands
	$y = m\frac{\lambda L}{d}$	small angle
interferometry	same light split recombine	sensitive small lengths
	string wave inversion	upon greater density
	phase shift	upon slower medium
	constructive interference	requires another phase shift
	$2nd = \left(m + \frac{1}{2}\right)\lambda$	Snell
diffraction	wavefront points	new spherical wavelets
	waves bend around objects	Huygen simplication
	single wide slit	as if multiple slit diffraction
	$a \sin\theta = m\lambda$	destructive interference

MODERN

relativity		
relativity	wave propagation	at speed of light
	relative to what ?	nothing, its always constant
special	$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$	Lorentz
	$E = mc^2$	mass rest energy invariant
general	gravity and inertia	mass equivalence
	mass curves spacetime	non Euclidean shortest path

quantum		
quantum	atomic realm	not infinitely divisible
	electron orbitals	do not collapse
	wave particle duality	aspects of same reality
	$R(\lambda, T) = \frac{2\pi hc^2}{\lambda^5(e^{hc/\lambda kT} - 1)}$	Planck
	$E = hf$	photon energy
	$\frac{1}{\lambda} = R_H\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)$	Bohr
	$\Delta x \Delta p \geq \hbar$	Heisenberg
	$\lambda = \frac{h}{p}$	de Broglie
	$P(x) = \Psi^2(x)dx$	Schrodinger