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Physics 1 CRAMSheet

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KINEMATICS IN ONE DIMENSION

DISPLACEMENT VELOCITY AND ACCELERATION

Equations you will need

Description	Equation	Description	Equation
Average velocity	$\overline{v_x} = \frac{\Delta x}{\Delta t}$	Instantaneous velocity	$v_x = \frac{dx}{dt}$
Average acceleration	$\overline{a_x} = \frac{\Delta v_x}{\Delta t}$	Equations of motion	$v = v_0 + at$ $s_f = s_i + v_0 t + \frac{1}{2}at^2$ $v^2 = v_0^2 + 2a(s_f - s_i)$
Instantaneous acceleration	$a_x = \frac{dv_x}{dt}$		

KINEMATICS IN TWO DIMENSIONS

VECTORS

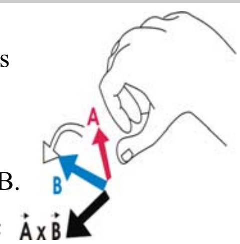
Good to know

Right hand rule: The direction of the vector product can be visualized with the right hand rule. If you curl the fingers of your right hand so that they follow a rotation from vector A to vector B, then the thumb will point in the direction of the vector product.

Diagram
Note that the direction of rotation is significant and that

$\vec{B}\times\vec{A} = -\vec{A}\times\vec{B}$

Curl fingers in direction from A to B.
Thumb points in direction of $\vec{A}\times\vec{B}$



Equations you will need

Description	Equation	Description	Equation
Dot product of vectors	$\vec{A}.\vec{B} = \|A\|\|B\|\cos\theta$	Cross products of vectors	$\vec{A}\times\vec{B} = \|A\|\|B\|\sin\theta$ $\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$ $\vec{A}\times\vec{B} = (A_yB_z - A_zB_y)\hat{i}$ $-(A_xB_z - A_zB_x)\hat{j} + (A_xB_y - A_yB_x)\hat{k}$
Unit vectors and their dot and cross products	$\hat{i}.\hat{i} = \hat{j}.\hat{j} = \hat{k}.\hat{k} = 1$ $\hat{i}.\hat{j} = \hat{i}.\hat{k} = \hat{j}.\hat{k} = 0$ $\hat{i}\times\hat{i} = \hat{j}\times\hat{j} = \hat{k}\times\hat{k} = 0$ $\hat{i}\times\hat{j} = \hat{k}, \hat{j}\times\hat{k} = \hat{i}, \hat{k}\times\hat{i} = \hat{j}$	Magnitude of resultant vector	$R = \sqrt{(A^2 + B^2 + 2AB\cos\theta)}$

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KINEMATICS IN TWO DIMENSIONS

TWO DIMENSIONAL MOTION

Equations you will need

Description	Equation	Description	Equation
Maximum height attained by a projectile	$h_{\max} = \frac{(v_0 \sin\theta)^2}{2g}$	Horizontal range of a projectile	$R = \frac{{v_0}^2 \sin 2\theta}{g}$
Time of flight	$t = \frac{2v_0 \sin\theta}{g}$ $t = (2v_0 \sin\theta)/g$	Equation of trajectory of a projectile	$y = (\tan\theta)x - (\frac{g}{2v_0^2 \cos^2\theta})x^2$ $y = (\tan\theta)x - (\frac{gx^2}{2v_0^2 \cos^2\theta})$
Velocity of a particle in the S' frame	$\vec{v}' = \vec{v} - \vec{v}_0$ $\sum \vec{F} = m\vec{a}$	Velocity of a particle in the S' frame	$\vec{v}' = \vec{v} - \vec{v}_0$

CIRCULAR MOTION

Equations you will need

Description	Equation	Description	Equation
Centripetal acceleration	$a_c = \frac{v^2}{r}$	Tangential acceleration	$a_T = \frac{d\lvert\vec{v}\rvert}{dt}$
Centripetal force	$\sum F = ma_c = m\frac{v^2}{r}$	Maximum speed of a body around a curve	$V_{\max} = \sqrt{\mu_s rg}$
Non-uniform circular motion	$\vec{a} = \vec{a}_T + \vec{a}_R$	Resistive force due to air	$R = \frac{1}{2}D\rho Av^2$

FORCES AND NEWTON'S LOWS OF MOTION

NEWTON'S LAW OF GRAVITATION

Good to know

NEWTON'S LAW OF UNIVERSAL GRAVITATION
Newton's law of universal gravitation states that the force of attraction between 2 bodies is directly proportional to the product of the masses of the 2 bodies and inversely proportional to the square of the distance between them.

$$F_g = \frac{Gm_1m_2}{r^2}$$

Equations you will need

Description	Equation	Description	Equation
Acceleration due to gravity at an altitude h above the earth's surface	$g_h = \frac{gR_E^2}{(R_E + h)^2}$	Acceleration due to gravity at a depth h below the earth's surface	$g_h = g(1 - \frac{h}{R})$
Acceleration due to gravity at a latitude φ	$g_L = g - R\omega^2 \cos^2\phi$		

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FORCES AND NEWTON'S LAWS OF MOTION

FORCES ON A SYSTEM

Good to know

Newton's 1st law of motion states that an object at rest tends to stay at rest and an object in motion tends to stay in motion at the same speed and direction unless acted upon by an unbalanced force.

Newton's 2nd law of motion states that the external force applied is directly proportional to the rate of change of linear momentum of the body.

Newton's 3rd law of motion states that every action has an equal and opposite reaction.

Equations you will need

Description	Equation	Description	Equation
Newton's first law	$\sum F \neq 0$	Apparent weight of a person traveling in an elevator accelerating downwards	$R = m(g - a)$
Newton's second law of motion	$\sum \vec{F} = m\vec{a}$	Co-efficient of static friction on an inclined plane	$\mu_s = \tan\theta$
Newton's third law of motion	$F_{12} = -F_{21}$	Apparent weight of a person traveling in an elevator accelerating upwards	$R = m(a + g)$
Principle of conservation of energy	$K_f + U_f = K_i + U_i$		

KEPLER'S LAWS OF PLANETARY MOTION

Good to know

Kepler's 1st law states that every planet moves in an elliptical orbit with the Sun at one of its foci.

Kepler's 2nd law states that a planet sweeps equal areas in equal intervals of time.

$$\frac{dA}{dt} = \frac{L}{2M_P} = const$$

Kepler's 3rd law states that square of the period of revolution of a planet is proportional to cube of the semi major axis of the elliptical orbit.

$$T^2 = \left(\frac{4\pi^2}{GM_S}\right)a^3 \qquad \vec{g} = \frac{\vec{F}_g}{m}$$

Equations you will need

Description	Equation	Description	Equation	Description	Equation
Gravitational potential	$U = -\int_{\infty}^{r} \vec{F}.d\vec{r}$	Escape velocity from the earth	$v_{esc} = \sqrt{\frac{2GM_E}{R_E}}$	Total energy of a satellite	
		For the earth $v_{esc} = 11.2$ km/s		For a circular orbit	$E = -\frac{GMm}{2r}$
Gravitational potential energy	$\Delta U = -\int_{r_i}^{r_f} \vec{F}.d\vec{r}$			For an elliptical orbit	$E = -\frac{GMm}{2a}$

WORK AND ENERGY

ENERGY AND CONSERVATION LAWS

Good to know

Hooke's law states that within elastic limits, stress is proportional to strain.	$F_S = -kx$
The kinetic energy is the amount of work done in bringing a body to rest from an initial velocity v.	$\sum W = \frac{1}{2}m(v_f^2 - v_i^2)$
Principle of conservation of energy: The principle of conservation of energy states that energy can neither be created nor destroyed but can be converted from one form to another.	$K_f + U_f = K_i + U_i$

Equations you will need

Description	Equation	Description	Equation
Work done by a force	$W = \|F\|\|r\| \cos\theta$	Kinetic energy of a body	$K = \frac{1}{2}mv^2$
Work-kinetic energy theorem for linear motion	$\Delta K = -f_K d + \sum W_{otherForces}$	Instantaneous power	$P = \frac{dW}{dt} = \vec{F}.\vec{v}$
Gravitational potential energy	$U_g = mgh$	Expression for mechanical energy	$E_{mech} = K + U$
Elastic potential energy stored in a spring	$U_S = \frac{1}{2}kx^2$	The external conservative force is defined as the negative potential gradient of the system	$\vec{F} = -\vec{\nabla}U$
Expression for mechanical energy when friction is present	$\Delta E_{mech} = \Delta K + \Delta U - f_K d$		

IMPULSE AND MOMENTUM

CONSERVATION OF LINEAR MOMENTUM

Perfectly inelastic collision: In a perfectly inelastic collision the kinetic energy of the system is not conserved.	Perfectly elastic collision: In a perfectly elastic collision the kinetic energy of the system is conserved.

Equations you will need

Description	Equation	Description	Equation
Perfectly inelastic collision	$\vec{v}_f = \frac{m_1\vec{v}_{1i} + m_2\vec{v}_{2i}}{m_1 + m_2}$	Perfectly elastic collision	$v_{1f} = (\frac{m_1 - m_2}{m_1 + m_2})v_{1i} + (\frac{2m_2}{m_1 + m_2})v_{2i}$ $v_{2f} = (\frac{2m_1}{m_1 + m_2})v_{1i} + (\frac{m_2 - m_1}{m_1 + m_2})v_{2i}$
Location of center of mass for a system of particles	$\vec{r}_{CM} = \frac{\sum_i m_i\vec{r}_i}{M}$	Location of center of mass for an extended object	$r_{CM} = \frac{1}{M}\int r dm$
Velocity of center of mass for a system of particles	$\vec{v}_{CM} = \frac{\sum_i m_i\vec{v}_i}{M}$	Expression for velocity of a rocket	$V_f - V_i = V_e \ln\left(\frac{M_i}{M_f}\right)$

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ROTATIONAL KINEMATICS

ROTATIONAL MOTION

Equations you will need

Moment of Inertia = I_{CM}

Description	Equation	Description	Equation
Circular ring about its axis	$I_{CM} = MR^2$	Circular ring about its radii	$I_{CM} = ½(MR^2)$
Circular disc about its axis	$I_{CM} = ½(MR^2)$	Circular disc about its radii	$I_{CM} = 1/4(MR^2)$
Long thin rod about one end	$I_{CM} = 1/3(ML^2)$	Long thin rod about its center	$I_{CM} = 1/12(ML^2)$
Rectangular lamina passing through the center and perpendicular to the plane	$I_{CM} = 1/12M(l^2 + b^2)$	Hollow cylinder about its axis	$I_{CM} = ½M(R_1^2 + R_2^2)$
Thin spherical shell about its diameter	$I_{CM} = 2/3MR^2$	Solid sphere about its diameter	$I_{CM} = 2/5MR^2$

TORQUE

Good to know

The torque is the measure of the tendency of a force to rotate a body. The change in the body's rotational energy is the amount of work done in rotating it.

$$\vec{\tau} = \vec{r} \times \vec{F}$$

Angular momentum
The angular momentum is defined as the cross product of the particle's position vector and its linear momentum.

$$L = r \times p$$

Principle of conservation of angular momentum
The principle of conservation of angular momentum states that if there is no external torque on the system then the total angular momentum of the system is conserved. $I_i \omega_i = I_f \omega_f$

Equations you will need

Description	Equation	Description	Equation
Relationship between torque and angular acceleration	$\sum \tau_{ext} = I\alpha$	Power delivered to the rotating body	$P = \tau\omega$
Work-kinetic energy theorem for rotational motion	$\sum W = \frac{1}{2} I(\omega_f^2 - \omega_i^2)$	Kinetic energy for a rolling sphere or cylinder	$K = \frac{1}{2} I_{CM} \omega^2 + \frac{1}{2} M v_{CM}^2$
Angular momentum for rigid body rotation	$L_z = IW_z$	Relationship between angular momentum and torque	$\vec{\tau} = \frac{d\vec{L}}{dt}$

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TEMPERATURE AND HEAT

CONCEPT OF TEMPERATURE

Definition to know

Temperature is defined as the property of a body that determines if it is in thermal equilibrium with its surrounding.

Equations you will need

Name	Description
Ideal gas equation	PV = nRT

Conversion of temperature in Celsius to	
Kelvin	$T = T_C + 273.15$
Fahrenheit	$\frac{F-32}{9} = \frac{C}{5}$

Co-efficient of expansion	
Linear	$L_f = L_i(1+\alpha\Delta T)$
Volume	$V_f = V_i(1+\beta\Delta T)$

THERMODYNAMICS

FIRST LAW OF THERMODYNMICS

Equations you will need

Description	Equation
External work done on the gas	$W = -\int_{V_i}^{V_f} PdV$
Adiabatic process	$Q = 0$; $\Delta E_{INT} = W$ PV^{γ} = constant
Work done in an adiabatic process	$W = (\frac{1}{1-\gamma})(P_2V_2 - P_1V_1)$
Work done in an isovolumetric (constant volume) process	W = 0
Relation between latent heat and heat transferred	Q = mL

Description	Equation
Isothermal process	$\Delta E_{INT} = 0$; $Q = -W$; PV = constant
Work done in an isothermal process	$W = nRT\ln(\frac{V_i}{V_f})$
Work done in an isobaric (constant pressure) process	$W = -P(V_f - V_i)$
Relation between specific heat capacity and heat transferred	$Q = mc\Delta\theta$
Equilibrium temperature for 2 bodies in contact $\theta_2 > \theta_1$	$\theta = \frac{m_2c_2\theta_2 + m_1c_1\theta_1}{m_1c_1 + m_2c_2}$

SECOND LAW OF THERMODYNAMICS, ENTROPY

Good to know

Features of entropy

It is a point function and is independent of the path between the initial and final points.	The change in entropy of a system and its surrounding must always be positive.	The change in entropy for a reversible process is zero.	The change in entropy for an irreversible process is always positive.

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THERMODYNAMICS

SECOND LAW OF THERMODYNAMICS, ENTROPY

Equations you will need

Description	Equation
Efficiency of an engine	$e = 1 - \dfrac{\lvert Q_C \rvert}{\lvert Q_H \rvert}$
Efficiency of a carnot engine: Even the carnot engine which is assumed to be an ideal engine does not have an efficiency of 100%.	$e = 1 - \dfrac{\lvert T_C \rvert}{\lvert T_H \rvert}$
Efficiency of the Otto cycle: V_1/V_2 is called the compression ratio, where V_1 and V_2 are the initial and final volumes.	$e = 1 - \dfrac{1}{(V_1/V_2)^{\gamma-1}}$
Change in entropy is given as	$dS = \dfrac{dQ}{T}$
Change in entropy for a reversible process	$\oint \dfrac{dQ}{T} = 0$
Entropy of a system and the environment	$\Delta S = nR\ln\dfrac{V_f}{V_i} + nC_V \ln\dfrac{T_f}{T_i}$

Description	Equation
Co-efficient of performance (a). Cooling mode	$COP = \dfrac{\lvert Q_C \rvert}{W}$
(b). Heating mode	$COP = \dfrac{\lvert Q_H \rvert}{W}$
The carnot COP in (a). Cooling mode	$COP_C = \dfrac{T_C}{T_H - T_C}$
(b). Heating mode	$COP_C = \dfrac{T_H}{T_H - T_C}$
Entropy is the measure of chaos and disorder of a system.	$\Delta S = \dfrac{Q}{T_H} + \dfrac{-Q}{T_C} > 0$
Change in entropy is an irreversible process	$\Delta S = m_1 c_1 \ln\dfrac{\theta}{\theta_1} + m_2 c_2 \ln\dfrac{\theta_2}{\theta}$
Relationship between entropy and the number of microstates of the system	$S = k_B \ln W$

THE TRANSFER OF HEAT

STEFAN'S LAW

Definition to know

Stefan's Law states that the rate at which a body radiates energy is proportional to the fourth power of its absolute temperature.
σ Stefan constant = 5.6696 x 10^{-8} W / m^2 □ = $\sigma A e T^4$

THE IDEAL GAS LAW AND KINETIC THEORY

KINETIC THEORY OF GASES

Definition to know

Boyle's Law	Charles' Law	Gay-Lussac's Law
Boyle's Law states that temperature remaining a constant, Pressure of a gas is inversely proportional to its volume. PV = constant	**Charles' Law** states that pressure remaining a constant, volume of a gas is directly proportional to its temperature. V/T = constant	**Gay-Lussac's Law** states that volume remaining a constant, pressure of a gas is directly proportional to its temperature. P/T = constant

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THE IDEAL GAS LAW AND KINETIC THEORY

KINETIC THEORY OF GASES

Equations you will need

Description	Equation
Relation between pressure of a gas and the mean square speed of the molecules	$P=\frac{2}{3}(\frac{N}{V})(\frac{1}{2}m\overline{v^2})$
The total translational kinetic energy	$K_{\text{TOT TRANS}}=N(\frac{1}{2}m\overline{v^2})=\frac{3}{2}Nk_BT=\frac{3}{2}nRT$
Relation between C_V and E_{INT}	$C_V=\frac{1}{n}\frac{dE_{INT}}{dT}$
Relation between energy transferred and specific heat capacity of a gas at (a). Constant volume (C_V): (b). Constant pressure (C_P):	 $Q = nC_V\Delta T$ $Q = nC_P\Delta T$
Root mean square speed	$v_{RMS}=\sqrt{\frac{3k_BT}{m}}=\sqrt{\frac{3RT}{M}}$
Mean speed	$\bar{v}=\sqrt{\frac{8k_BT}{\pi m}}$
Most probable speed	$v_{mp}=\sqrt{\frac{2k_BT}{m}}$
Mean free time	$t = 1/f$
Corrected values for the mean free path	$l=\frac{1}{\sqrt{2}\pi d^2 n_V}$

Description	Equation
Relation between the average kinetic energy and temperature	$\frac{1}{2}m\overline{v^2}=\frac{3}{2}k_BT$
Relation between Boltzmann constant and universal gas constant $R=8.31$ J/mol. K, $k_B=1.38 \times 10^{-23}$ J/K, $N_A=6.023 \times 10^{23}$	$R=k_BN_A$
Energy associated with each degree of freedom	$E_{INT}=\frac{1}{2}(k_BT)$
Relation between C_P and C_V	$C_P-C_V=R$
Ratio of specific heat capacities	$\gamma=\frac{C_P}{C_V}$
Maxwell-Boltzmann distribution	$n_V(E)=n_0e^{-E/k_BT}$
Maxwell-Boltzmann speed distribution function: $N_V=4\pi N(\frac{m}{2\pi k_BT})v^2\exp[-mv^2/2k_BT]$	
The mean free path	$l=\frac{\bar{v}\Delta t}{(\pi d^2\bar{v}\Delta t)n_V}=\frac{1}{\pi d^2 n_V}$
Collision frequency	$f=\sqrt{2}\pi d^2\bar{v}n_V$

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ELASTICITY AND SIMPLE HARMONIC MOTION

SIMPLE HARMONIC MOTION

Equations you will need

Description	Equation	Description	Equation
Equation of motion for simple harmonic motion	$\frac{d^2x}{dt^2} = -\frac{k}{m}x$	Displacement of the particle	$x(t) = A\cos(\omega t + \phi)$
Angular frequency	$\omega = \sqrt{\frac{k}{m}}$	Period of oscillation	$T = 2\pi\sqrt{\frac{m}{k}}$
Velocity of the particle	$v = \frac{dx}{dt} = -\omega A\sin(\omega t + \phi)$	Acceleration of the particle	$a = \frac{d^2x}{dt^2} = -\omega^2 A\cos(\omega t + \phi)$
Maximum velocity and acceleration of a particle executing simple harmonic motion (SHM)	$v_{MAX} = \omega A$ $a_{MAX} = \omega^2 A$	Total mechanical energy of the simple harmonic oscillator	$E = \frac{1}{2}kA^2$
Period of a simple pendulum	$T = 2\pi\sqrt{\frac{L}{g}}$	Period of the torsional pendulum	$T = 2\pi\sqrt{\frac{I}{\kappa}}$
Damped oscillation frequency When $(b/2m) > \omega_0$ the oscillator is said to be over damped When $(b/2m) = \omega_0$ the oscillator is said to be critically damped	$\omega = \sqrt{(\frac{k}{2m} - (\frac{b}{2m})^2)}$ $\omega = \sqrt{(\omega_0^2 - (\frac{b}{2m})^2)}$	Period of the physical pendulum	$T = 2\pi\sqrt{\frac{I}{mgd}}$
		Displacement of a damped oscillator	$x = Ae^{-\frac{b}{2m}t}\cos(\omega t + \phi)$
		Amplitude of the forced oscillator	$A = \frac{F_0 / m}{\sqrt{(\omega^2 - \omega_0^2)^2 + (\frac{b\omega}{m})^2}}$