Matthew Ning Honor Physics I 174009552

THERMODYNAMICS THERMAL Expansion $\Delta L = L\alpha\Delta T$, $\Delta V = V\beta\Delta T$ Heat $Q = C(T_f - T_i) = mc(T_f - T_i)$ Heat of Fusion/Vaporization $Q = Lm$ 1st Law of Thermodynamics $W = \int dW = \int p\,dV \Rightarrow \Delta E_{int} = Q - W$, $Q>0$ Heat enter the system. $W>0$. System does work. Adiabatic process $Q=0$, $\Delta E_{int} = -W$ Constant Volume $W=0$, $\Delta E_{int} = Q$ Cyclical $\Delta E_{int} = 0$, $Q = W$ Free Expansion $Q = W$, $\Delta E_{int} = 0$ PV Graph, $\Delta P \Delta V$ = Work, $M = mN_A$ Ideal Gas $PV = nRT = NkT$, $R = 8.31 \frac{J}{mol \cdot K}$ Isothermal (constant-T) process $W = nRT\ln(V_f/V_i)$ RMS speed $V_{rms} = \sqrt{\frac{3RT}{M}}$, $p = \frac{nMv_{rms}^2}{3V}$ Molar Specific Heat @ constant V $C_V = \frac{Q}{n\Delta T} = \frac{\Delta E_{int}}{n\Delta T}$ For ideal monatomic gas $C_V = \frac{3}{2}R$. Molar Specific Heat @ constant P $C_p = \frac{Q}{n\Delta T}$ $C_p = C_V + R$ Translational KE $K_{AVG} = \frac{3}{2}\frac{R}{N_A}T$ (is ind. of molar mass) Internal Energy of Ideal Gas $E_{INT} = \frac{3}{2}nRT = nC_VT$ For any process, $\Delta E_{INT} = nC_V\Delta T$. Degrees of Freedom $E_{INT} = \left(\frac{f}{2}\right)nRT$, $C_V = \left(\frac{f}{2}\right)R$ $f = 3, 5, 6$ (mono, dia, poly) In adiabatic process, pV^γ = constant where $\gamma = C_p/C_V$. For free expansion, pV = constant and T is constant. 2nd Law of Thermodynamics, S = Entropy $\Delta S = S_f - S_i = \int_i^f \frac{dQ}{T}$. In isothermal process ($\Delta T = 0$) $\Delta S = \frac{Q}{T}$. If ΔT is small, then $\Delta S \approx \frac{Q}{T_{AVG}}$. $\int \frac{dT}{T} = \ln\left(\frac{T_f}{T_i}\right)$

SHM Spring $x = x_m\cos(\omega t + \varphi)$, $v = -\omega x_m\sin(\omega t + \varphi)$, $a = -\omega^2 x_m\cos(\omega t+\varphi)$, $\omega = \sqrt{\frac{k}{m}}$, $T = 2\pi\sqrt{\frac{m}{k}}$. Hooke's Law: $F = -kx$, $k = \omega^2 m$ Energy in Spring $U(t) = \frac{1}{2}kx^2 = \frac{1}{2}kx_m^2\cos^2(\omega t + \varphi)$, $U + K = E = \frac{1}{2}kx_m^2$ Angular SHM, use torque $\tau = -\kappa\theta \Rightarrow T = 2\pi\sqrt{\frac{I}{\kappa}}$ Simple pendulum $T = 2\pi\sqrt{\frac{I}{mgL}}$ Physical pendulum $T = 2\pi\sqrt{\frac{I}{mgh}}$ Torque in pendulum: $\tau = -L(F_g\sin\theta) = I\alpha$ 2 springs in series $k_{eff} = \left(\frac{1}{k_1} + \frac{1}{k_2}\right)^{-1}$ 2 springs in parallel $k_{eff} = k_1 + k_2$ In spring with torque, convert find C in term of k. For approximation $\Delta x \approx \ell\theta$.

GRAVITATION Force $F = G\frac{m_1m_2}{r^2}$ Uniform Shell Theorem $F = \frac{GmM}{R^3}r$. Work $W = \int F\,dr = \int \frac{GmM}{R^3}r\,dr = \frac{GmM}{2R}$ PE $U = -\frac{GMm}{r}$ Kepler's Law of Period $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ For elliptical orbit $T^2 = \left(\frac{4\pi^2}{GM}\right)a^3$ 2nd Law is conservation of angular momentum $\frac{dA}{dt} = \frac{L}{2m} \Rightarrow L = mr^2\omega$ Energy in orbit $U = -\frac{GMm}{r}$, $K = \frac{GMm}{2r}$, $E = -\frac{GMm}{2r}$, Elliptical orbit $E = -\frac{GMm}{2a}$

Equilibrium Force $\vec{F}_{net} = 0$, Torque $\vec{\tau}_{net} = 0$. In static equilibrium $\vec{P} = 0$

Rotation Pure rotation + Pure translation = $\vec{v}_{top} = 2\vec{v}_{com}$, $\vec{v}_{com}$, $\vec{v}_{bottom} = 0$ Rolling down a ramp (wheel) $a_{com,x} = -\frac{g\sin(\theta)}{1 + I_{com}/MR^2}$ using $KE = \frac{1}{2}I_{com}\omega^2 + \frac{1}{2}mv_{com}^2$ Torque applied: Friction $ma_{com} = f_s$, $\tau - f_sR = I_{com}\alpha$, this has no sliding. With sliding $ma_{com} = \mu_k mg$, $\tau - \mu_k mgR = I_{com}\alpha$. Force applied to center, w/ friction $ma_{com} = F - f_s \Rightarrow m\alpha R = F - f_s \Rightarrow F\frac{MR^2}{I_P} = F - f_s$

Angular Momentum $L = r \times p = m(\vec{r} \times \vec{v})$ Torque/Angular momentum $\vec{\tau} = \frac{d\vec{L}}{dt}$

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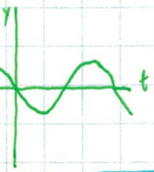
Fluids Density $\rho = \frac{m}{V}$ Pressure $p = \frac{F}{A}$ Pressure vs. Depth $p = p_0 + \rho g h$ Pascal's Principle $\Delta p = \frac{F_i}{A_i} = \frac{F_o}{A_o}$

$W = F_o d_o = F_i d_i$ Archimedes' Principle $F_{buoyant} = m_f g$ where m_{fluid} Apparent Weight $W_{app} = W - F_b$

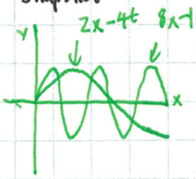
Flow Rate $R_v = Av = \frac{V}{t} = \frac{m^3}{s}$ Mass Flow Rate $R_m = \rho R_v$ Bernoulli's Equation $p + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$ KE density = KE/Volume

WAVES I $y(x,t) = y_m \sin(kx - \omega t)$, $k = \frac{2\pi}{\lambda}$, $\omega = 2\pi f$, $v = \lambda f$ Traveling Wave $y(x,t) = y_m \sin(kx + \omega t)$ move backward

Graph



Snapshot



Transverse Speed (Max) $\frac{dy}{dt}$ Velocity & Tension $v = \sqrt{\frac{\tau}{\mu}}$ τ is tension, μ is linear density kg/m

Speed of wave is ind. of frequency. Interference of waves traveling in same direction on same string

$y'(x,t) = [2y_m \cos(\frac{1}{2}\phi)] \sin(kx - \omega t + \frac{1}{2}\phi)$

Standing Wave $y(x,t) = 2y_m \sin(kx)\cos(\omega t)$ Harmonics $f = \frac{v}{\lambda} = n\frac{v}{2L}$ Tension affect frequency, not λ.

WAVES II velocity of sound (longitudinal) $v = \sqrt{\frac{B}{\rho}}$, B = bulk modulus $= -\frac{\Delta p}{\Delta V / V}$ = "PE" Displacement $s = s_m \cos(kx - \omega t)$ Pressure Change $\Delta p = \Delta p_m \sin(kx - \omega t)$ where $\Delta p_m = (v\rho\omega)s_m$ Intensity $I = \frac{P}{A} = \frac{P}{4\pi r^2}$ $\frac{I_2}{I_1} = \left[\frac{d_1}{d_2}\right]^2$ Intensity is Watt/meter² = pv

P is power, p is pressure. $I = \frac{1}{2}\rho v \omega^2 s_m^2$ Sound Level $\beta = (10\,dB)\log\left(\frac{I}{I_0}\right)$ Speed of oscillating element $v_s = \frac{\partial s}{\partial t} = -\omega s_m \sin(kx - \omega t)$

Pipe open at both end $f = \frac{v}{\lambda} = \frac{nv}{2L}$ for $n = 1, 2, 3, \ldots$ Pipe open at one end $f = \frac{v}{\lambda} = \frac{nv}{4L}$ for $n = 1, 3, 5$ (one node, one antinode at ends)

$f_{beat} = f_1 - f_2$ Doppler Effect $f' = f\left(\frac{v \pm v_D}{v \pm v_S}\right)$ Wind Speed $f' = f\left(\frac{v \pm v_{wind} \pm v_D}{v \pm v_{wind} \pm v_S}\right)$

COULOMB'S LAW Electrostatic Force $\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$ $\vec{F} = k\frac{q_1 q_2}{|r|^3}\vec{r}$ because $\hat{r} = \frac{\vec{r}}{r}$ $F = \frac{k q_1 q_2}{r^2}$

ELECTRIC FIELD $\vec{E} = \frac{\vec{F}}{q_0}$ $E = k\frac{|q|}{r^2}$ Electric Field due to dipole $E = 2k\frac{p}{z^3}$ where z is distance betw. P & midpt. of dipole. Electric Field due to Line $dq = \lambda ds$ where $\lambda = Q/L$ then $dE = \frac{k\,dq}{r^2}$, $dq = \sigma\,dA$, $dE = \frac{k\,dq\,z}{(z^2+r^2)^{3/2}}$

ELECTRIC FIELD DUE TO CHARGED RING $E = \frac{qz}{4\pi\epsilon_0(z^2+R^2)^{3/2}}$ **ELECTRIC FIELD CHARGED DISK** $E = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{z}{\sqrt{z^2+R^2}}\right)$

KINEMATIC EQs $d = d_i + v_i t + \frac{1}{2}at^2$ $v_f^2 = v_i^2 + 2ad$ $v_f = v_i + at$ $d = \frac{v_i + v_f}{2}t$ (all assume constant a)

TRIG IDs $\sin(u \pm v) = \sin(u)\cos(v) \pm \cos(u)\sin(v)$ $\cos(u \pm v) = \cos(u)\cos(v) \mp \sin(u)\sin(v)$

$\cos(2u) = \cos^2 u - \sin^2 u$ $\sin(2u) = 2\sin(u)\cos(u)$

WAVES III wave equation $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$ v is wave speed. This is one-dimensional. Wavelength $\lambda = \frac{c}{f}$ (only EM wav[e] not other waves) Phase velocity $V_p = \frac{\lambda}{T} = \frac{\omega}{k}$ ω is angular frequency. k is wave number. Group velocity $V_g = \frac{\partial \omega}{\partial k}$

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Electric Field $\vec{F} = k\frac{q_1 q_2 \hat{r}}{r^2} = \frac{k q_1 q_2 \vec{r}}{|r|^3}$ because $\hat{r} = \frac{\vec{r}}{|r|}$ and $k = \frac{1}{4\pi\epsilon_0}$ Electric Field $\vec{E} = \frac{\vec{F}}{q_0}$ Charge Distribution $\vec{E}(x,y,z) = k\int \frac{\rho(x',y',z')\hat{r}\,dx'dy'dz'}{r^2}$ Electric Field due to Dipole $E = 2k\frac{p}{z^3}$ where z is distance betw. P & midpt. of dipole. Electric Field due to Line $dq = \lambda ds$ then $dE = \frac{k\,dq}{r^2}$. Electric Field due to Area $dq = \sigma dA$

Gauss's Law Flux $d\Phi = \vec{E}\cdot d\vec{A}$ Net Flux $\Phi = \oint \vec{E}\cdot d\vec{A} = \frac{q}{\epsilon_0} = \frac{1}{\epsilon_0}\int \rho\, dv$ Flux is scalar. $E = \frac{q}{A\epsilon_0}$. Charged Isolated Conductor, internal electric field is 0. Electric field due to nonconducting sheet $E = \frac{\sigma}{2\epsilon_0}$ Electric field for spherical shell ($r \geq R$) $E = k\frac{q}{r^2}$. Electric field for uniform ~~shell~~ sphere $E =$ or $\left(\frac{kq}{\epsilon_0 R^3} r\right)$

Electric Potential Potential difference $\phi_{21} = -\int_{P_1}^{P_2}\vec{E}\cdot d\vec{s}$ (line integral) Volt $1V = \frac{1J}{1C}$ Work $\Delta K = -q\Delta V + W_{app}$ Potential differentia $\vec{E} = -\nabla\phi$ Because potential is scalar, orientation doesn't matter. $V = k\sum\frac{q_i}{r_i}$ Potential due to charge distribution $V = k\int\frac{dq}{r}$ Gauss' Theorem in diff. form $\int_S \vec{E}\cdot d\vec{A} = \int_V \mathrm{div}\,\vec{E}\cdot dv$ and $\mathrm{div}\,\vec{E} = \frac{\rho}{\epsilon_0}$. $\nabla\cdot\vec{E} = -\nabla^2\phi$ Uniqueness Theorem for Poisson's Equation $\nabla^2\phi(\vec{r}) = -4\pi\rho(\vec{r})$

Vector Calc. Review Divergence $\mathrm{div}\,\vec{F} = \lim_{V_i\to 0}\frac{1}{V_i}\int_{S_i}\vec{F}\cdot d\vec{A}_i$ Curl $\mathrm{curl}\,\vec{F}\cdot\hat{n} = \lim_{A_i\to 0}\oint_{C_i}\vec{F}\cdot d\vec{s}/A_i$ Gauss's Theorem $\int_S\vec{F}\cdot d\vec{A} = \int_V \mathrm{div}\,\vec{F}\cdot dv$ Stokes' Theorem $\int_C\vec{F}\cdot d\vec{s} = \int_S \mathrm{curl}\,\vec{F}\cdot d\vec{A}$

Capacitance capacitance $q = CV$ Parallel plate $C = \frac{\epsilon_0 A}{s}$ Sphere $C = 4\pi\epsilon_0 r$ Shell $C = 4\pi\epsilon_0\frac{ab}{b-a}$ Potential from $\vec{E}$ $\Delta V = -\int_i^f \vec{E}\cdot d\vec{s}$ Parallel $C_{eq} = \sum C_i$ Series $C_{eq}^{-1} = \left(\sum(C_i)^{-1}\right)$ Energy $U = \frac{q^2}{2C} = \frac{1}{2}CV^2$, $V = Ed$

Current current $i = \frac{dq}{dt}$, $I = nq\vec{a}\cdot\vec{u}$ $\vec{a}$ is area, $\vec{u}$ is velocity. current density $\vec{J} = \sum_k n_k q_k \vec{u}_k$ charge conservation $\mathrm{div}\,J = 0 = -\frac{\partial\rho}{\partial t}$ | $I = JA$ conductivity $\vec{J} = \sigma\vec{E}$ resistivity $\vec{E} = \rho\vec{J}$ resistance of wire $R = \rho\frac{L}{A}$ resistance $V = IR$ Ohm's Law $\rho = \frac{m}{e^2 n\tau}$ Power $P = IV = \frac{V^2}{R} = I^2R$

Circuit electromotive force $\mathcal{E} = \frac{dW}{dq}$ RC circuits $q = C\mathcal{E}(1-e^{-t/RC})$ charging. Current $i = \left(\frac{\mathcal{E}}{R}\right)e^{-t/RC}$

Magnetic Fields Electric Field in current-carrying wire $E = V/L$ Lorentz Force $\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$ Magnetic Force $|F| = |q|vB\sin\phi$, Magnetic Force ~~on~~ of Wire $\vec{F} = -\hat{y}\frac{Iqv}{2\pi\epsilon_0 rc^2}$. Magnetic Field of Wire $\vec{B} = \hat{z}\frac{I}{2\pi\epsilon_0 rc^2} = \hat{z}\frac{\mu_0 I}{2\pi r}$ Force ~~due~~ on wire $d\vec{F} = I\,d\vec{l}\times\vec{B}$ Line integral of closed path that does not enclose the wire is 0 $\int\vec{B}\cdot d\vec{s} = \mu_0\times(\text{current enclosed by path})$, $\oint_C\vec{B}\cdot d\vec{s} = \mu_0\iint_S\vec{J}\cdot d\vec{s} = \mu_0 I_{enclosed}$, $\nabla\times B = \mu_0 J$ Ampère's Law. Helmholtz Theorem $\nabla\times\vec{B} = \mu_0 J$, $\nabla\cdot B = 0$, $\nabla\times E = 0$, $\nabla\cdot E = \frac{\rho}{\epsilon_0}$. Circulating Charged Particle $|q|vB = \frac{mv^2}{r}$ where $r = \frac{mv}{|q|B}$, $f = \frac{\omega}{2\pi} = \frac{|q|B}{2\pi m}$ Torque on loop $\tau = NiAB\sin\theta$ Magnetic Dipole Moment $\vec{\tau} = \vec{\mu}\times\vec{B}$ where $\mu = NiA$ Energy of Magnetic Dipole Moment $U(\theta) = -\vec{\mu}\times\vec{B}$ Assume that $\vec{B}$ vanishes at infinity, $\nabla\times\vec{B} = \mu_0\vec{J}$ and $\nabla\cdot\vec{B} = 0$ uniquely determine $\vec{B}$ if $\vec{J}$ is given. Scalar potential $\phi(x_1,y_1,z_1) = k\int\frac{\rho(x_2,y_2,z_2)\,dv_2}{r_{12}}$ and $\vec{E} = -\nabla\phi$. Vector potential $\vec{B} = \nabla\times\vec{A}$, $(\nabla\cdot(\nabla\times\vec{A}) = 0)$ Magnetic field of wire in cylindrical coordinate $\vec{B} = \frac{\mu_0 I}{2\pi r}\hat{\theta}$ Vector Potential $\vec{A} = \frac{\mu_0}{4\pi}\int\frac{\vec{J}\,dv}{r}$ (when $\nabla\cdot\vec{A} = 0$). Vector potential of wire $\vec{A} = \frac{\mu_0 I}{4\pi}\int\frac{d\vec{l}}{r_{12}}$ Biot-Savart Law $d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l}\times\hat{r}}{r^2} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l}\times\vec{r}}{r^3}$ Magnetic Field at Center of Arc $B = \frac{\mu_0 i\phi}{4\pi R}$ where ϕ is in rad. Magnetic field inside wire $B = \left(\frac{\mu_0 i}{2\pi R^2}\right)r$ Magnetic Field inside ideal solenoid $B = \mu_0 in$ Inside ~~solenoid~~ toroid, $B = \frac{\mu_0 iN}{2\pi}\frac{1}{r}$ Net current inside solenoid $i_{enc} = i(nh)$ where n is $\frac{\#\text{ turns}}{\text{total length}}$

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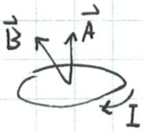
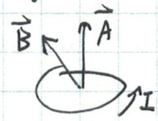
Induction & Inductance

Magnetic Flux $\Phi_B = \int \vec{B} \cdot d\vec{A}$. If magnetic flux changes, current & emf are produced $\mathcal{E} = -\frac{d\Phi_B}{dt}$

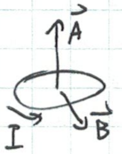
Lenz's Law: the induced current produces magnetic fields which tend to oppose the change in magnetic flux that induces such currents.



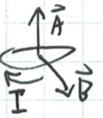
$\frac{dB}{dt} > 0$, $\Phi_B > 0$, $\frac{d\Phi_B}{dt} > 0$



$\frac{dB}{dt} < 0$, $\Phi_B > 0$, $\frac{d\Phi_B}{dt} < 0$



$\frac{dB}{dt} > 0$, $\Phi_B < 0$, $\frac{d\Phi_B}{dt} < 0$



$\frac{dB}{dt} < 0$, $\Phi_B < 0$, $\frac{d\Phi_B}{dt} > 0$

change in area also induces induction $\mathcal{E} = BLv$ where L is one side fixed in length

Faraday's Law $\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$ A changing magnetic field induces an electric field. Inside $E(2\pi r) = (\pi r^2)\frac{dB}{dt}$, Outside $E(2\pi r) = \pi R^2 \frac{dB}{dt}$

$L = \frac{N\Phi_B}{i}$ inductance defined. Inductance per unit length $\frac{L}{l} = \mu_0 n^2 A$ Energy $U_B = \frac{1}{2} L i^2$ Current & Length $qV = iX$ where x is length. Self-Induction $V = -L\frac{di}{dt}$

Maxwell's Equations; Magnetism of Matter

Gauss' Law for Magnetic Fields $\Phi_B = \oint \vec{B} \cdot d\vec{A} = 0$ Gauss' Law for Electric Fields $\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\epsilon_0}$ Induced Magnetic Fields $\oint \vec{B} \cdot d\vec{s} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$

Ampere-Maxwell Law $\oint \vec{B} \cdot d\vec{s} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$ Displacement Current $i_d = \epsilon_0 \frac{d\Phi_E}{dt}$ Faraday's Law $\oint \vec{E} \cdot d\vec{s} = \frac{-d\Phi_B}{dt}$

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\epsilon_0} \qquad \oint \vec{E} \cdot d\vec{s} = \frac{-d\Phi_B}{dt} \qquad \nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad \nabla \cdot \vec{B} = 0$$

$$\oint \vec{B} \cdot d\vec{A} = 0 \qquad \oint \vec{B} \cdot d\vec{s} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc} \qquad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{dt}$$

Electromagnetic Waves

$E = E_m \sin(kx - \omega t)$ $B = B_m \sin(kx - \omega t)$ $c = \frac{E}{B} = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ B = ~~straight~~ curled hand, E ~~curled~~ straight hand

Poynting Vector $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$ Intensity (time-avg rate per unit area at which energy is transported is $\vec{S}_{avg}$)

$I = \frac{1}{c\mu_0} E_{rms}^2$, $E_{rms} = \frac{1}{\sqrt{2}} E_m$ Point-source of EM waves $I = \frac{P_s}{4\pi r^2}$ Speed of Light $c = f\lambda$. ~~Wavelength~~ Frequency Width $\left|\Delta \frac{c}{\lambda}\right| \approx \frac{c\Delta\lambda}{\lambda^2}$ Radiation Pressure $F = \frac{IA}{c}$ If radiation is totally reflected back along its original path $F = \frac{2IA}{c}$

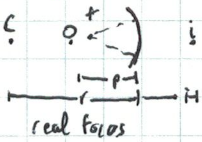
Pressure $P_r = \frac{I}{c}$ Polarization. If original light is unpolarized $I = \frac{1}{2} I_0$ If original light is polarized $I = I_0 \cos^2\theta$

Reflection & Refraction $n_2 \sin\theta_2 = n_1 \sin\theta_1$ Total Internal Reflection $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ critical angle. Polarization by Reflection $\theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right)$ ← incidence Brewster angle

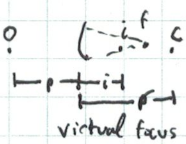
Images

Image $i = -p$ p is object distance from mirror. Spherical Mirror $\frac{1}{p} + \frac{1}{i} = \frac{1}{f} = \frac{2}{r}$

Magnitude $m = \frac{-i}{p}$ Concave

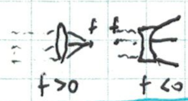


Convex



Refracting Surface $\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}$

Thin len $\frac{1}{p} + \frac{1}{i} = \frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ if $\left(\frac{1}{r_1} - \frac{1}{r_2}\right) > 0$, will converge. Else diverge



Interference

Image is real if $o > f$ (opposite side), virtual if $o < f$ (same side as object) (for converging len) Diverging len always yields virtual image (same side as object) Interference & wavelength $\lambda_n = \frac{\lambda}{n}$ Index of refraction $n = \frac{c}{v}$ $\lambda_n = \lambda\frac{v}{c} = \frac{\lambda}{n}$

Young's Interference $d\sin(\theta) = m\lambda$ (0,1,2) for maxima $d\sin(\theta) = (m + \frac{1}{2})\lambda$ (0,1,2) for minima, d is slit sep. Intensity $I = 4I_0 \cos^2(\frac{1}{2}\phi)$, $\phi = \frac{2\pi d}{\lambda}\sin(\theta)$ Interference for Thin Film $2L = m\frac{\lambda}{n_2}$ (minima), $2L = (m + \frac{1}{2})\frac{\lambda}{n_2}$ maxima

Diffraction

Single-slit $a\sin(\theta) = m\lambda$ (for $m = 1,2,3$, min) Intensity $I(\theta) = I_m\left(\frac{\sin\alpha}{\alpha}\right)^2$, $\alpha = \frac{\pi a}{\lambda}\sin(\theta)$ Circular aperture $\sin\theta = 1.22\frac{\lambda}{d}$ d is diameter. Double slit diffraction $I(\theta) = I_m(\cos^2\beta)\left(\frac{\sin\alpha}{\alpha}\right)^2$, $\alpha = \frac{\pi a}{\lambda}\sin(\theta)$, $\beta = \left(\frac{\pi d}{\lambda}\right)\sin(\theta)$

Grating $d\sin\theta = m\lambda$ ($m = 0, 1, \ldots$ max) $\Delta\theta_{hw} = \frac{\lambda}{Nd\cos\theta}$ half width Dispersion $D = \frac{\Delta\theta}{\Delta\lambda}$ Resolving Power $R = \frac{\lambda_{avg}}{\Delta\lambda} = Nm$

Grating used for line spectrum, depends on wavelength.