# Engineering Physics-PHY 1071

**Some Physical Constants**:

Planck's constant, $h = 6.625 \times 10^{-34}$ J.s

Speed of light in vacuum, $c = 3 \times 10^{8}$ $ms^{-1}$

mass of proton = $1.67 \times 10^{-27}$ kg

mass of electron: $9.1 \times 10^{-31}$ kg

Boltzmann Constant, $k = 1.38 \times 10^{-23}$ $JK^{-1}$

Stefan's constant = $5.67 \times 10^{-8}$ W $m^{-1}$ $K^{-1}$

Wien's constant = $2.898 \times 10^{-3}$ mK

Absolute Permittivity, $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

Absolute Permeability, $\mu_0 = 4\pi \times 10^{-7}$ H/m

## 1. Wave optics

Maxwell's equations

$$\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q}{\epsilon_0}$$

$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$$

$$\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d\Phi_B}{dt}$$

$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}} = \mu_0 I + \epsilon_0 \mu_0 \frac{d\Phi_E}{dt}$$

Poynting vector, $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$

Instantaneous energy densities $u_E = \frac{1}{2}\varepsilon_0 E^2$

$$u_B = \frac{B^2}{2\mu_0}$$

E - magnitude of electric field
B - magnitude of magnetic field
dA - magnitude of area element
ds - magnitude of line element
q - electric charge
$\varepsilon_0$ - absolute permittivity
$\Phi_E$ - electric flux
$\Phi_B$ - magnetic flux
I – electric current
$\mu_0$ – absolute permeability

Young's double slit expt.:
Condition for constructive and destructive interference

$d \sin \theta_{\text{bright}} = m\lambda$ ; $(m = 0, \pm 1, \pm 2, \ldots)$

$d \sin \theta_{\text{dark}} = \left(m + \frac{1}{2}\right)\lambda$ $(m = 0, \pm 1, \pm 2, \ldots)$

Linear positions of bright and dark fringes

$y_{\text{bright}} = L\frac{m\lambda}{d}$ (small angle approximation)

$y_{dark} = L\frac{\left(m + \frac{1}{2}\right)\lambda}{d}$ $(m = 0, \pm 1, \pm 2, \ldots)$

Average light intensity at a point on the screen

$I = I_{max} \cos^2\left(\frac{\varphi}{2}\right)$

$I = I_{max} \cos^2\left(\frac{\pi d \sin \theta}{\lambda}\right)$ $I = I_{max} \cos^2\left(\frac{\pi d}{\lambda L} y\right)$

$d$ : distance between the two slits
$\lambda$ : wavelength of light used
$\theta$ : angular position on the screen
$m$ : order number
$\varphi$ : phase difference
$\delta$ : path difference
$y$ : linear position on the screen
$L$ : distance between the slit and the screen
$I_{max}$: maximum intensity on the screen
$n$ : refractive index
$t$ : thickness of the film
$R$ : radius of curvature of lens

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| Condition for interference in thin films in air (reflective system)<br>Constructive interference:<br>$2nt = \left(m + \frac{1}{2}\right)\lambda \quad (m = 0,\ 1,\ 2,\ \ldots)$<br>Destructive interference:<br>$2nt = m\lambda \quad (m = 0,\ 1,\ 2,\ \ldots)$ | |
| Radius of m[th] order Newton's ring<br>$r_{dark} \approx \sqrt{mR\lambda} \quad (m = 0,\ 1,\ 2,\ \ldots)$<br>$r_{bright} \approx \sqrt{\frac{\left(m + \frac{1}{2}\right)R\lambda}{n_{film}}} \quad (m = 0,\ 1,\ 2,\ \ldots)$ | |

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| Anti-reflection coatings<br>$r = \frac{n_1(n_0 - n_s)\cos\delta + i(n_0 n_s - n_1^2)\sin\delta}{n_1(n_0 + n_s)\cos\delta + i(n_0 n_s + n_1^2)\sin\delta}$ | *r – reflection coefficient*<br>*$n_1$ – refractive index of the film*<br>*$n_s$ – refractive index of the substrate*<br>*$n_0$ – refractive index of the air*<br>*$\delta$ - phase difference*<br>*t – thickness of the film*<br>*R- reflectance* |
| $\delta = \left(\frac{2\pi}{\lambda_0}\right)n_1 t \cos\theta_{t1}$ | |
| $R = \frac{n_1^2(n_0 - n_s)^2\cos^2\delta + (n_0 n_s - n_1^2)^2\sin^2\delta}{n_1^2(n_0 + n_s)^2\cos^2\delta + (n_0 n_s + n_1^2)^2\sin^2\delta}$ | |
| Two-Layer Anti-reflecting Films<br>$R = \left(\frac{n_0 n_2^2 - n_s n_1^2}{n_0 n_2^2 + n_s n_1^2}\right)^2$ | |
| Multi-Layer Anti-reflecting Films<br>$R_{max} = \left[\frac{(n_0/n_s)(n_L/n_H)^{2N} - 1}{(n_0/n_s)(n_L/n_H)^{2N} + 1}\right]^2$ | |
| Single slit diffraction: condition for minima<br>$sin\ \ \theta_{\text{dark}} = m\frac{\lambda}{a} \qquad m = \pm 1,\ \pm 2,\ \pm 3,\ \ldots$ | a : width of single slit<br>$I_{max}$ : maximum intensity [Central maxima]<br>d : distance between the two slits<br>D : diameter of the aperture |
| Intensity due to single slit diffraction<br>$I = I_{max}\left[\frac{sin\ \ (\pi a\ \ sin\ \ \theta/\lambda)}{(\pi a\ \ sin\ \ \theta)/\lambda}\right]^2$ | |
| Intensity of two slit diffraction pattern [combined effect]<br>$I = I_{max}\, cos^2\left(\frac{\pi d\ \ sin\ \ \theta}{\lambda}\right)\left[\frac{sin\ \ (\pi a\ \ sin\ \ \theta/\lambda)}{(\pi a\ \ sin\ \ \theta)/\lambda}\right]^2$ | |
| Rayleigh's criterion: limiting angle of resolution<br>$\theta_{min} = 1.22\,\frac{\lambda}{D}$ [for circular aperture]<br>$\theta_{min} = \frac{\lambda}{a}$ [for rectangular aperture] | |
| Grating equation for maxima<br>$d\, sin\ \ \theta_{\text{bright}} = m\lambda\ ;\ \ m = 0,\ \pm 1,\ \pm 2,\ \pm 3,\ \ldots$ | |
| X-ray diffraction: Bragg's law<br>$2d\ \ sin\ \ \theta = m\lambda \qquad m = 1,\ 2,\ 3,\ \ldots$ | d : Inter-planar spacing in the crystal |

## Chapter 2. LASERS AND FIBRE OPTICS

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| $$\frac{N_2}{N_1} = e^{-(E_2-E_1)/kT}$$ | $k$ : Boltzmann constant,<br>$N_1$ : density of atoms with energy $E_1$<br>$N_2$ : density of atoms with energy $E_2$ |
| $$I_f = \frac{8\pi h f^3}{c^3}\left[\frac{1}{e^{\frac{hf}{kT}} - 1}\right]$$<br>At thermal equilibrium the equation for energy density $I_f = \frac{A}{B\left[e^{\frac{hf}{kT}} - 1\right]}$ | $I_f$ : energy density of frequency $f$.<br>$k$ : Boltzmann constant<br>c : Speed of light<br>h : Planck's constant. |
| $$\sin\theta_0 = \frac{1}{n_0}\sqrt{n_1^2 - n_2^2}$$<br>$$L_s = d\sqrt{\frac{n_1^2}{n_0^2 \sin^2\theta} - 1}$$ | $\theta_0$ : acceptance angle<br>$n_0$, $n_1$ and $n_2$ : Refractive indices<br>$L_s$ : Skip distance<br>d: diameter of the fibre |
| $$V = \frac{\pi d}{\lambda} n_0 \sqrt{n_1^2 - n_2^2}$$ | $d$ : diameter of the core<br>$\lambda$ : wavelength of the light |

## Chapter 3. Quantum Physics

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| Wien's Displacement Law<br>$\lambda_m T = 2.898 \times 10^{-3}$ m.K | $\lambda_m$ : wavelength corresponding to peak intensity.<br>$T$ : equilibrium temperature of the blackbody. |
| Stefan's Law<br>$P = \sigma A e T^4$ | $P$ : power radiated from the surface area A of the object.<br>$T$ : equilibrium surface temperature.<br>$\sigma$ : Stefan-Boltzmann constant.<br>$e$ : emissivity of the surface |
| Planck's law<br>$$I(\lambda,T) = \frac{2\pi h c^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$ | $I(\lambda,T)$ : intensity or power per unit area emitted in the wavelength interval $d\lambda$ from a blackbody at the equilibrium temperature $T$<br>$h$ : Planck's constant.<br>$k_B$ : Boltzmann's constant<br>$c$ : speed of light in vacuum |
| Einstein's photoelectric equation<br>$K_{max} = hf - \phi$ | $f$ : frequency of incident photon.<br>$K_{max}$ : kinetic energy of the most energetic photoelectron.<br>$\phi$ : work function of the photocathode material. |
| Relativistic momentum of a particle<br>p = $\gamma$ m v $\quad \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$<br>Relativistic kinetic energy of a particle<br>K = ($\gamma$ -1) m $c^2$<br>Total energy (relativistic) of the particle<br>E = $\gamma$ m $c^2$<br>$E^2 = p^2 c^2 + m^2 c^4$ | p : momentum of the particle<br>m : mass of the particle<br>v : speed of the particle<br>c : speed of light in vacuum |

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| Compton shift equation<br>$\lambda' - \lambda_o \; = \; \frac{h}{mc}(1 - \cos\theta)$ | $\lambda_o$ : wavelength of the incident photon.<br>$\lambda'$ : wavelength of the scattered photon,<br>$\theta$ :angle of scattering |
| de Broglie wavelength, $\lambda$<br><br>$\lambda \; = \; \frac{h}{p} \; = \; \frac{h}{mv} \;\; p \; = \; m\,v \; = \; \sqrt{2\,m\,q\,\Delta V}$ | $h$ : Planck's constant<br>$p$ : momentum of the quantum particle.<br>$m$ : mass of the particle<br>$v$ : speed of the particle<br>$q$ : charge of the particle<br>$\Delta V$ : accelerating voltage |
| Relation between group speed and phase speed<br>$v_g = \; v_P - \; \lambda\left(\frac{dv_P}{d\lambda}\right)$ | $v_g$ : group speed<br>$v_P$ : phase speed |
| Heisenberg uncertainty relations.<br>$(\Delta x)\,(\Delta p_x) \;\; \geq \;\; h/4\pi$<br><br>$(\Delta E)\,(\Delta t) \;\; \geq \;\; h/4\pi$ | $\Delta x$ : uncertainty in the measurement of position x of the particle.<br>$\Delta p_x$ : uncertainty in the measurement of momentum $p_x$ of the particle.<br>$\Delta E$ : uncertainty in the measurement of energy $E$<br>$\Delta t$ : time interval in the measurement of $E$. |

## Chapter 4. Quantum Mechanics

<table>
<tr><td>One dimensional time independent Schrödinger equation<br>$-\frac{\hbar^2}{2\,m}\,\frac{d^2\psi}{dx^2} + U\,\psi \;\; = \;\; E\,\psi$</td><td rowspan="4">$\hbar$ : Reduced Planck's constant<br>$m$ : mass of the particle<br>$\psi$ : wave function<br>$U(x)$ : potential energy function<br>$E$ : total energy of the system<br>$h$ : Planck's constant<br>$L$ : length of the "box".<br>$n$ : integers<br>$T$ : tunneling probability</td></tr>
<tr><td>Expectation value of x<br>$\langle x \rangle \;\; \equiv \;\; \int_{-\infty}^{+\infty} \psi^*\,x\,\psi\;\,dx$</td></tr>
<tr><td>Particle in a "box"<br>$E_n$ - quantized energy values of the particle.<br>$E_n \;\; = \;\; \left(\frac{h^2}{8\,m\,L^2}\right) n^2$</td></tr>
<tr><td>Transmission coefficient<br>$T \;\approx\; e^{-2CL}$      $C \; = \; \frac{\sqrt{2\,m\,(U-E)}}{\hbar}$</td></tr>
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## Chapter 5. Molecules and Solids

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| Total potential energy of the crystal<br>$U_{\text{total}} = -\alpha k_e \frac{e^2}{r} + \frac{B}{r^m}$ | $\alpha$ : Madelung constant<br>*r* : separation distance between ions<br>*m* : small integer<br>$E_F$ : Fermi energy<br>$k_B$ : Boltzmann constant |
| Probability of a particular energy state *E* being occupied by an electron: Fermi-Dirac distribution function<br>$f(E) = \frac{1}{exp\left(\frac{E - E_F}{k_B T}\right) + 1}$ | |
| Density-of-states function<br>$g(E)\ dE = \frac{8\sqrt{2}\ \pi\ m^{\frac{3}{2}}}{h^3} E^{\frac{1}{2}}\ dE$ | *m* : mass of the particle<br>*h* : Planck's constant |
| Fermi energy at 0K<br>$E_F(0) = \frac{h^2}{2\ m}\left(\frac{3\ n_e}{8\ \pi}\right)^{\frac{2}{3}}$ | $n_e$: electron density<br>*m* : mass of the electron |
| Lennard–Jones potential equation<br>$U(r) = -\frac{A}{r^n} + \frac{B}{r^m}$ | *r* : inter nuclear separation distance between the two atoms<br>*A* : is associated with the attractive force<br>*B* : with the repulsive force<br>*J* : rotational quantum number<br>I : Moment of inertia of the molecule<br>*k* : effective spring constant<br>$\mu$ : reduced mass<br>*f* : frequency of spectra<br>$n_0$ : number of molecules in the *J*=0 state<br>$k_B$ : Boltzmann constant<br>*n*, *m* : small integers |
| Molecule's angular momentum<br>$L = \sqrt{J(J+1)}\,\hbar \qquad J = 0,\ 1,\ 2,\ \ldots$ | |
| Energies of the absorbed photons in rotational transitions<br>$E_{\text{photon}} = \frac{\hbar^2}{I} J = \frac{h^2}{4\pi^2 I} J \qquad J = 1,\ 2,\ 3,\ \ldots$ | |
| Vibrational energies<br>$E_{\text{vib}} = \left(v + \frac{1}{2}\right)\frac{h}{2\pi}\sqrt{\frac{k}{\mu}} \qquad v = 0,\ 1,\ 2,\ \ldots$ | |
| Combined [rotational + vibrational] spectra<br>$E_{\text{photon}} = \Delta E = hf + \frac{\hbar^2}{I}(J+1)$<br>$J = 0,\ 1,\ 2,\ ..$ | |
| Number of molecules in an excited rotational state<br>$n = n_0 e^{\frac{-\hbar^2 J(J+1)}{2 I k_B T}}$<br><br>Intensity of spectral lines<br>$Intensity \propto (2J+1) e^{\frac{-\hbar^2 J(J+1)}{2 I k_B T}}$ | |