Engineering Physics

Short notes for 1st year B.Tech (all branches) · BCA · GATE

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1. Interference

- **Interference** = two coherent light waves overlap and make bright and dark bands (fringes).
- **Coherent sources**: same frequency and a constant phase difference. Made by dividing one source.
  - Division of wavefront: Young's double slit, Fresnel biprism.
  - Division of amplitude: thin films, Newton's rings, Michelson interferometer.
- Path difference Δ and phase difference ϕ: $\phi = (2\pi/\lambda)\,\Delta$.

Condition	Path difference	Result
Constructive	$n\lambda$	Bright
Destructive	$(2n + 1)\,\lambda/2$	Dark

FORMULA Young's double slit fringe width $\beta = \lambda D / d$ (D = slit-to-screen distance, d = slit gap).

EXAMPLE $\lambda = 600$ nm, $D = 1$ m, $d = 0.5$ mm. $\beta = (600 \times 10^{-9} \times 1) / (0.5 \times 10^{-3}) =$ 1.2 mm.

➤ Thin films and Newton's rings

- Reflected light from a film of thickness t, index μ: bright when $2\mu t \cos r = (2n - 1)\,\lambda/2$ (extra $\lambda/2$ from reflection at the denser surface).
- **Newton's rings** (reflected light): centre is dark.
  - Diameter of nth dark ring: $D_n^2 = 4n\lambda R$ (R = radius of curvature of the lens).

FORMULA $\lambda = (D_{n+p}^2 - D_n^2) / (4pR)$.

2. Diffraction

- **Diffraction** = bending of light around the edges of an obstacle or slit of size near λ.
- **Fresnel**: source or screen at a finite distance. **Fraunhofer**: both at infinity (use lenses).
- Single slit (width a): minima at $a \sin\theta = n\lambda$, $n = 1, 2, 3, \ldots$ Central maximum is widest and brightest.
- **Diffraction grating**: $(a + b) \sin\theta = n\lambda$, where $(a + b)$ = grating element = $1/N$ (N lines per unit length).

FORMULA Resolving power of grating = $\lambda/d\lambda = nN$ (n = order, N = total lines).

FORMULA Rayleigh criterion: two images are just resolved when the maximum of one falls on the first minimum of the other.

3. Polarisation

- Light is a **transverse** wave, so it can be polarised. Sound (longitudinal) cannot.
- **Plane polarised** light: vibrations in one plane only.
- **Malus' law**: $I = I_0 \cos^2\theta$.
- **Brewster's law**: $\tan\theta_p = \mu$. At Brewster angle, reflected and refracted rays are at 90°.
- **Double refraction** (calcite, quartz): one ray splits into O-ray (obeys Snell's law) and E-ray (does not).
- Quarter wave plate thickness $t = \lambda / (4(\mu_o - \mu_e))$. Half wave plate: $t = \lambda / (2(\mu_o - \mu_e))$.

EXAMPLE For glass $\mu = 1.5$, Brewster angle $\theta_p = \tan^{-1}(1.5) \approx 56.3°$.

4. Quantum Mechanics Basics

➤ Why quantum?

- Classical physics failed to explain: black body radiation, photoelectric effect, Compton effect, line spectra.

- **Planck**: energy comes in packets, $E = h\nu$ ($h = 6.626 \times 10^{-34}$ J s).
- **Photoelectric effect**: $h\nu = \phi + KE_{max}$ (ϕ = work function). No emission below threshold frequency.
- **Compton shift**: $\Delta\lambda = (h / m_0 c)(1 - \cos\theta)$. Compton wavelength h/m_0c = 0.00243 nm.

➤ Matter waves

FORMULA de Broglie wavelength $\lambda = h / p = h / mv = h / \sqrt{2mE}$. For an electron through V volts: $\lambda = 1.227 / \sqrt{V}$ nm.

EXAMPLE Electron accelerated by 100 V: $\lambda = 1.227 / 10 =$ 0.1227 nm (similar to X-ray size, so electrons diffract from crystals).

➤ Heisenberg uncertainty principle

- $\Delta x \cdot \Delta p \geq h / 4\pi$. Also $\Delta E \cdot \Delta t \geq h / 4\pi$.
- We cannot know exact position and exact momentum at the same time.

➤ Schrödinger equation

- Time-independent (1D): $d^2\psi/dx^2 + (2m/\hbar^2)(E - V)\psi = 0$, with $\hbar = h/2\pi$.
- **Wave function ψ**: $|\psi|^2$ = probability density. Normalisation: $\int |\psi|^2 dx = 1$.
- ψ must be single valued, finite and continuous.

➤ Particle in a 1D box (width L, infinite walls)

FORMULA $E_n = n^2 h^2 / (8 m L^2)$, $\psi_n = \sqrt{2/L} \sin(n\pi x/L)$, $n = 1, 2, 3, \ldots$

- Energy is **quantised**. Lowest energy ($n = 1$) is not zero (zero point energy).
- Energy levels are in the ratio 1 : 4 : 9 : 16.

REMEMBER Quantum tunnelling: a particle can cross a barrier higher than its energy. Used in tunnel diode and STM.

5. Lasers

- **LASER** = Light Amplification by Stimulated Emission of Radiation.

Process	What happens
Absorption	Atom takes a photon, goes up
Spontaneous emission	Atom comes down by itself, random photon
Stimulated emission	Incoming photon makes the atom come down; new photon is identical (same phase, direction, frequency)

- **Population inversion**: more atoms in the upper level than the lower. Needs a **metastable state** (long life ~ 10^-3 s).
- **Pumping**: optical (ruby), electrical discharge (He-Ne, CO2), forward bias (semiconductor laser).
- **Optical resonator**: two mirrors (one fully, one partly reflecting) for feedback.
- Einstein coefficients: A21 / B21 = 8π h ν^3 / c^3.

Laser	Type	Wavelength
Ruby	Solid state, 3-level, pulsed	694.3 nm
He-Ne	Gas, 4-level, continuous	632.8 nm
CO2	Molecular gas	10.6 μm
Nd:YAG	Solid state, 4-level	1064 nm
Semiconductor (GaAs)	Diode	about 850–900 nm

- Properties: monochromatic, coherent, directional, high intensity.
- Uses: fibre communication, surgery (eye, LASIK), cutting and welding, barcode scanners, holography, LIDAR.

EXAM POINT 3-level lasers (ruby) give pulsed output; 4-level lasers (He-Ne) give continuous output because inversion is easier.

6. Fibre Optics

- Works on total internal reflection (TIR): light goes from denser core (n1) to rarer cladding (n2), angle > critical angle.
- Critical angle: sin θc = n2 / n1.

FORMULA Numerical aperture NA = sqrt(n1^2 - n2^2) = sin θa (acceptance angle).

FORMULA Fractional index change $\Delta = (n1 - n2)/n1$, $NA \approx n1 \sqrt{2\Delta}$. V-number $V = (2\pi a/\lambda)\, NA$ (single mode if $V < 2.405$).

EXAMPLE $n1 = 1.50$, $n2 = 1.47$. $NA = \sqrt{2.25 - 2.1609} = \sqrt{0.0891} \approx 0.30$. Acceptance angle ≈ 17.3°.

Type	Core	Use
Single mode step index	Very thin (~8–10 μm)	Long distance, high bandwidth
Multimode step index	Thick (~50–100 μm)	Short links, more dispersion
Multimode graded index	Index falls from centre	Less modal dispersion

- **Attenuation** (dB/km) = (10/L) log10(Pin / Pout). Causes: absorption, scattering, bending.
- **Dispersion**: pulse spreads (intermodal, material, waveguide).
- Advantages: huge bandwidth, low loss, no electromagnetic interference, light and small.

7. Semiconductor Basics

- **Band theory**: valence band, conduction band, forbidden gap Eg.

Material	Band gap	Example
Conductor	Bands overlap	Copper
Semiconductor	Small (~1 eV)	Si 1.12 eV, Ge 0.67 eV
Insulator	Large (> 3 eV)	Diamond ~5.5 eV

- **Intrinsic**: pure, $n = p = n_i$. **Extrinsic**: doped.
  - **n-type**: pentavalent donor (P, As). Majority carriers electrons.
  - **p-type**: trivalent acceptor (B, Al). Majority carriers holes.
- **Fermi level**: middle of gap in intrinsic; near conduction band in n-type; near valence band in p-type.
- Conductivity $\sigma = n\, e\, \mu n + p\, e\, \mu p$. **Mass action law**: $n\, p = ni^2$.
- **Hall effect**: magnetic field across a current-carrying slab gives a Hall voltage. Tells carrier type and density. Hall coefficient $R_H = 1/(nq)$, so $|R_H| = 1/(ne)$.
- **p-n junction**: depletion layer and barrier potential (~0.7 V Si, ~0.3 V Ge). Forward bias conducts, reverse bias blocks.

- **LED**: forward biased junction emits light (direct band gap like GaAs). **Solar cell**: light makes electron-hole pairs, gives voltage.

EXAMPLE Hall coefficient negative ⇒ carriers are electrons (n-type). Positive ⇒ holes (p-type).

➤ Solved example (particle in a box)

- Electron in a box of width L = 1 nm. m = 9.11 x 10^-31 kg, h = 6.626 x 10^-34 J s.
- E1 = h^2 / (8 m L^2) = (4.39 x 10^-67) / (8 x 9.11 x 10^-31 x 10^-18) = 6.02 x 10^-20 J.
- In eV: 6.02 x 10^-20 / 1.6 x 10^-19 ≈ 0.376 eV. Then E2 = 4E1 ≈ 1.50 eV.

REMEMBER Constants: h = 6.626 x 10^-34 J s, c = 3 x 10^8 m/s, e = 1.6 x 10^-19 C, m_e = 9.11 x 10^-31 kg, 1 eV = 1.6 x 10^-19 J.

8. Most Asked Questions (practice)

1. Explain Newton's rings and derive the formula for wavelength.
2. Differentiate Fresnel and Fraunhofer diffraction. Give the grating equation.
3. State Malus' law and Brewster's law with an example.
4. Derive de Broglie wavelength for an electron accelerated through V volts.
5. Solve the Schrödinger equation for a particle in a 1D box.
6. Explain stimulated emission and population inversion. Describe the He-Ne laser.
7. Find NA and acceptance angle for n1 = 1.48, n2 = 1.46.
8. Single mode vs multimode fibre. What are the losses in optical fibres?
9. Explain the Hall effect and its uses.
10. Explain the position of the Fermi level in intrinsic and extrinsic semiconductors.

TIP Exams always have one numerical each from fringe width / Newton's rings, de Broglie wavelength, particle in a box and NA of fibre. Learn units and constants (h, e, m_e, c) well.