Optoelectronics Devices & Circuits (MEC-166)

UNIT-I

By

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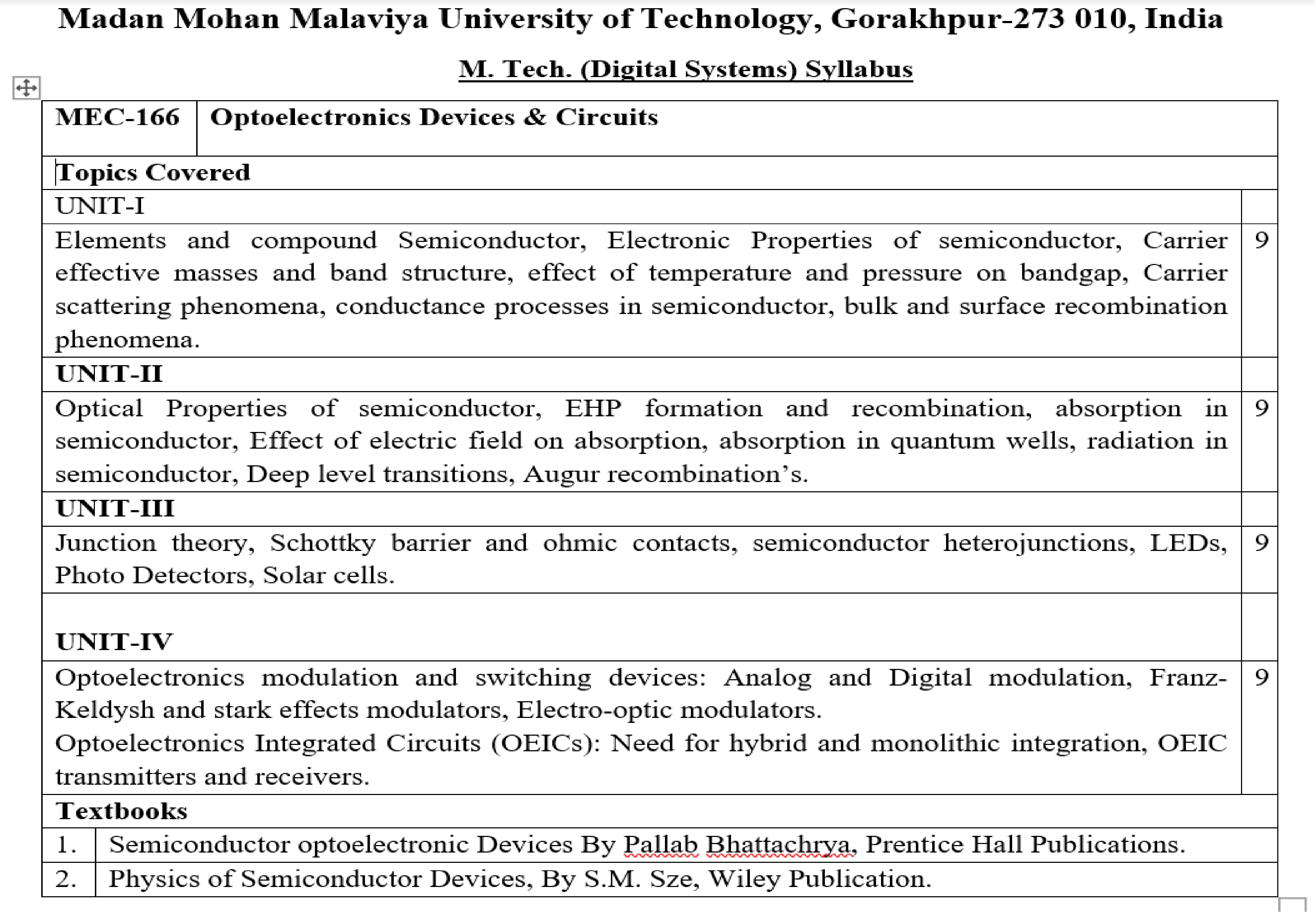
SYLLABUS



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M. Tech. (Digital Systems) Syllabus

MEC-166	**Optoelectronics Devices & Circuits**
Topics Covered	
UNIT-I	
Elements and compound Semiconductor, Electronic Properties of semiconductor, Carrier effective masses and band structure, effect of temperature and pressure on bandgap, Carrier scattering phenomena, conductance processes in semiconductor, bulk and surface recombination phenomena.	9
UNIT-II	
Optical Properties of semiconductor, EHP formation and recombination, absorption in semiconductor, Effect of electric field on absorption, absorption in quantum wells, radiation in semiconductor, Deep level transitions, Augur recombination's.	9
UNIT-III	
Junction theory, Schottky barrier and ohmic contacts, semiconductor heterojunctions, LEDs, Photo Detectors, Solar cells.	9
UNIT-IV	
Optoelectronics modulation and switching devices: Analog and Digital modulation, Franz-Keldysh and stark effects modulators, Electro-optic modulators. Optoelectronics Integrated Circuits (OEICs): Need for hybrid and monolithic integration, OEIC transmitters and receivers.	9
Textbooks	
1.	Semiconductor optoelectronic Devices By Pallab Bhattachrya, Prentice Hall Publications.
2.	Physics of Semiconductor Devices, By S.M. Sze, Wiley Publication.

Key Points

- ❖Introduction to Optoelectronics Devices
- ❖Energy bands in solids, E-k diagram
- ❖Elemental and Compound Semiconductor
- ❖Semiconductor optoelectronic materials
- ❖Carrier effective mass
- ❖Effect of Temperature and Pressure on bandgap
- ❖Carrier scattering
- ❖Effect of scattering om mobility of carriers
- ❖Conductance process in semiconductor
- ❖Bulk and surface recombination phenomena

Carrier scattering phenomena in Semiconductors

- The charge carrier, electron or holes in a semiconductor is usually not stationary.
- They are always in random thermal motion, thus the net displacement is zero.
- Electrons & holes within a crystal are scattered by phonons, or lattice vibration.

- There are other source of carrier scattering such as:
- Mechanism of Carrier Scattering:

1. Phonon or lattice Scattering
2. Impurity ion (dopant) Scattering

- In general anything that perturbs the periodic crystal potential in lattice which in turns alters the band edge potential will scatter carrier.

Relation b/w the relaxation time for carrier scattering & resulting mobility of carrier

- We define a scattering cross section $\sigma_S(\theta,\varphi)d\Omega$, which is the probability that an electron is scattered from $(\theta,\varphi)=0$ to some angle (θ,φ), within an incremental solid angle $d\Omega$ as in fig 1.6.
- The total cross section is then

$$\boldsymbol{\sigma_{st}} = \int \boldsymbol{\sigma_s(\theta,\phi)d\Omega} \qquad (1.6)$$

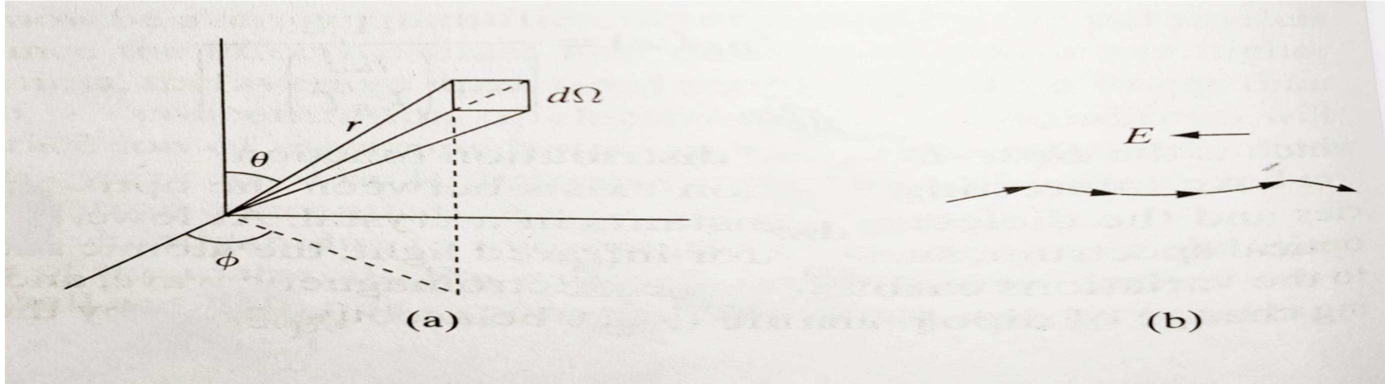
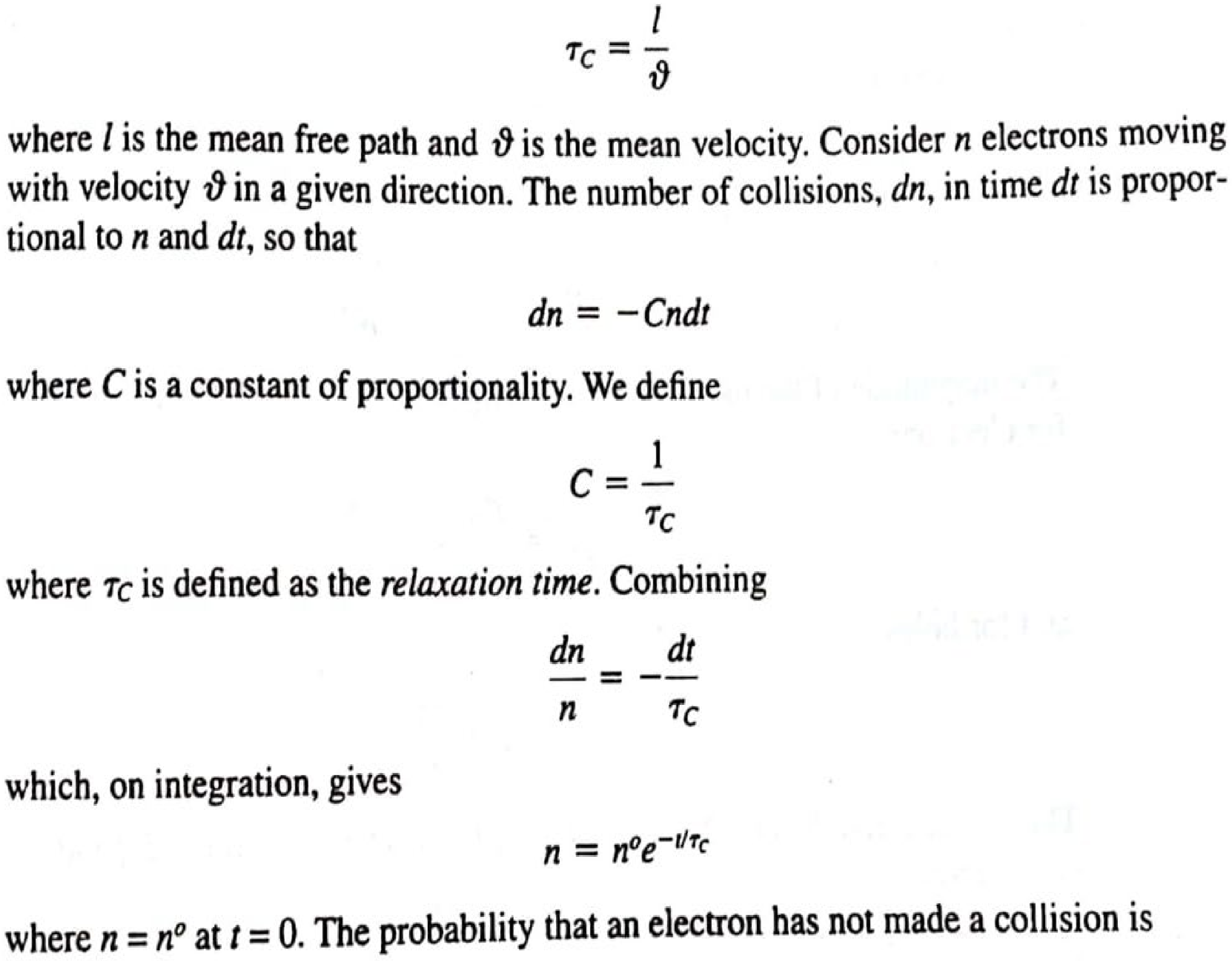


Fig 1.6 (a) Scattering geometry in polar coordinates (b) motion of an electron under the influence of an electric field.

- The motion is a superposition of drift and random motion with thermal velocity.
- As the field increases, the drift component becomes more dominant.

We also define a mean time τ_c between the successive collision such that:



$$\tau_C = \frac{l}{\vartheta}$$

where l is the mean free path and ϑ is the mean velocity. Consider n electrons moving with velocity ϑ in a given direction. The number of collisions, dn, in time dt is proportional to n and dt, so that

$$dn = -Cndt$$

where C is a constant of proportionality. We define

$$C = \frac{1}{\tau_C}$$

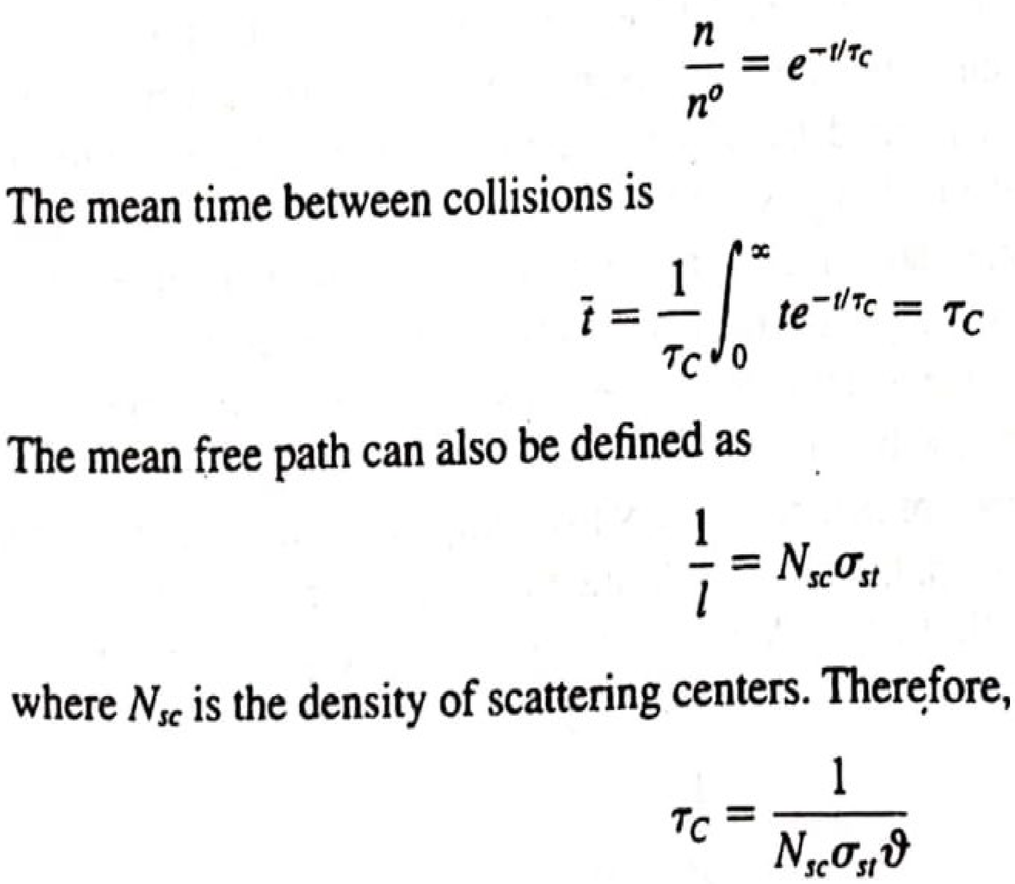
where τ_C is defined as the *relaxation time*. Combining

$$\frac{dn}{n} = -\frac{dt}{\tau_C}$$

which, on integration, gives

$$n = n^o e^{-t/\tau_C}$$

where $n = n^o$ at $t = 0$. The probability that an electron has not made a collision is



$$\frac{n}{n^o} = e^{-t/\tau_C}$$

The mean time between collisions is

$$\bar{t} = \frac{1}{\tau_C}\int_0^\infty te^{-t/\tau_C} = \tau_C$$

The mean free path can also be defined as

$$\frac{1}{l} = N_{sc}\sigma_{st}$$

where N_{sc} is the density of scattering centers. Therefore,

$$\tau_C = \frac{1}{N_{sc}\sigma_{st}\vartheta}$$

Consider now an electron under the influence of an electric field and suffering collisions, as depicted in Fig. 2.6(b). At time $t = 0$, its velocity is ϑ_0 and the velocity ϑ at time t, when it suffers collision, is given by

$$\vartheta = \vartheta_0 - \frac{qEt}{m_e^*}$$

where E is the applied field. This equation must be averaged over all time knowing that $\frac{1}{\tau_C} e^{-t/\tau_C}$ is the probability that a collision will occur after t seconds. Thus, the time-averaged velocity is given by

$$\overline{\vartheta} = \overline{\vartheta}_0 - \frac{qE}{\tau_C m_e^*} \int_0^{\infty} t e^{-t/\tau_C} dt$$

$$= \overline{\vartheta}_0 - \frac{qE\tau_C}{m_e^*}$$

If the collisions are truly random, $\overline{\vartheta}_0 = 0$ and the mean drift velocity is given by

$$\overline{\vartheta} = \overline{\vartheta}_D = -\frac{qE\tau_C}{m_e^*}$$

The magnitude of the mean drift velocity per unit field is defined as *mobility*, such that for electrons

$$\mu_e = \frac{\overline{\vartheta}_D}{E} = -\frac{q\tau_{C_e}}{m_e^*}$$

and for holes

$$\mu_h = \frac{q\tau_{C_h}}{m_h^*}$$

Therefore, through the effective masses, the carrier mobilities depend on the dispersion curve.

Effect of Scattering on Mobility Of Carriers

- In a very pure crystal the mobility is limited at high temperature by carrier scattering or phonon scattering.
- The lattice vibration depends on the temperature.

- It is explained by two phenomena:
- (a)Impurity scattering (b)Lattice or phonon scattering

➢Lattice or phonon scattering:

- As the phonon moves through the crystal, the bandgap develops periodic perturbation
- As the temperature increases the lattice vibrational frequency will increase and the effect of this cause the lattice scattering.
- When the temperature increases thermal vibration increases which decreases the mobility and lattice scattering occurs.
- Due to future increase in the temperature the lattice scattering increases and mobility of carrier decrease which is given by :

$$\mu_P \ \alpha \ T^{-3/2}$$

➢Impurity Scattering:

- Even in a pure crystals there are impurities and other electrically active defects
- Due to impurity doping in semiconductor the atoms or the electrons are deviated from the path i.e. the motion of electron will be changed and deviation path will take place.
- As the temperature will increase the effect of impurity scattering will decrease.
- When the temperature increases the mobility of the carrier increase then the carrier does not deviate from the path .

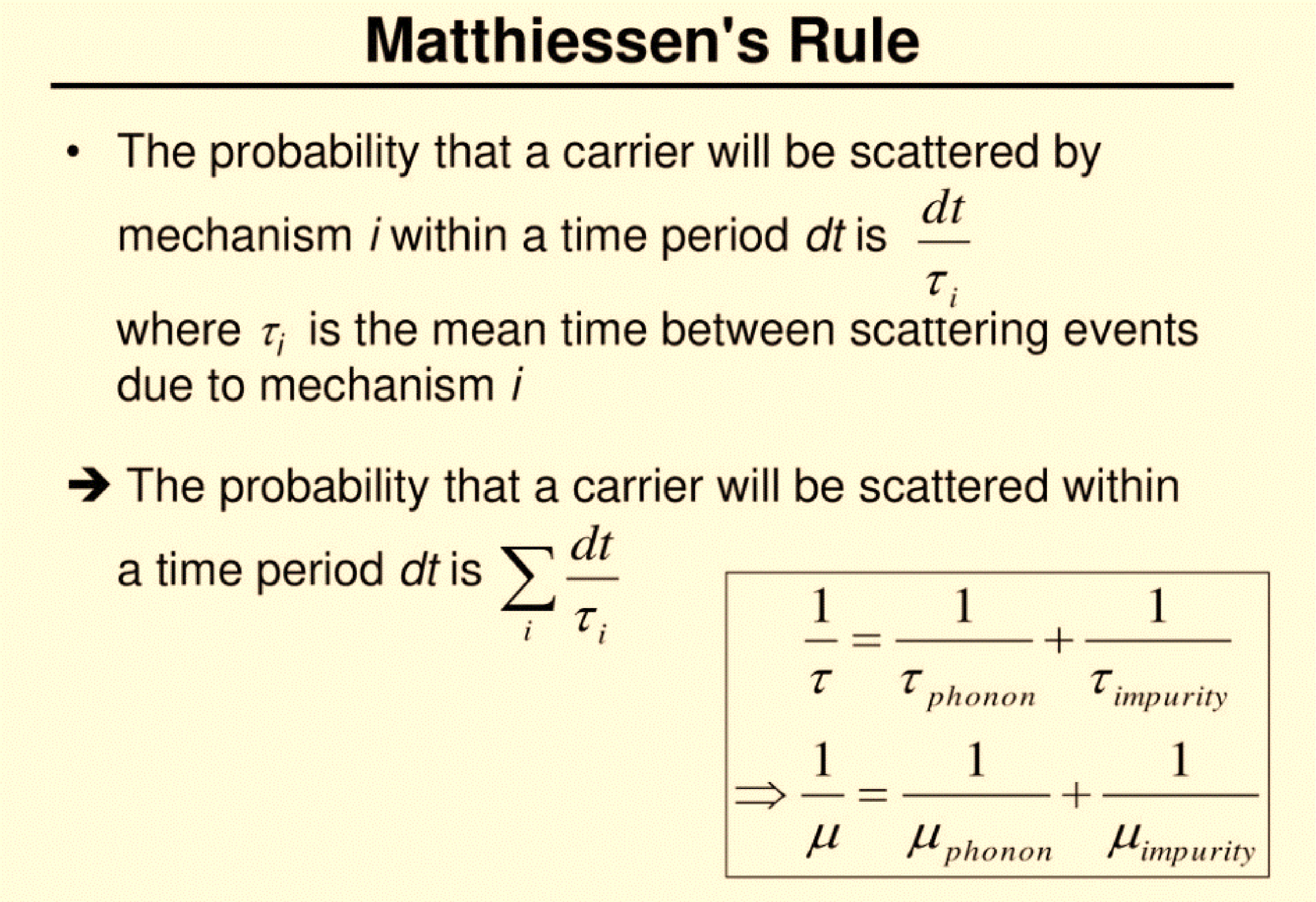
The mobility of carrier as the temperature increases impurity scattering increases is given by:

$$\mu_I \propto T^{3/2}$$

➢ The total mobility as a function of temperature, is then given by Mattheisen’s rule as:

$$\frac{1}{\mu} = \frac{1}{\mu_I} + \frac{1}{\mu_P}$$

Where μ_I is the mobility limited by impurity scattering and μ_P is the mobility limited by phonon scattering



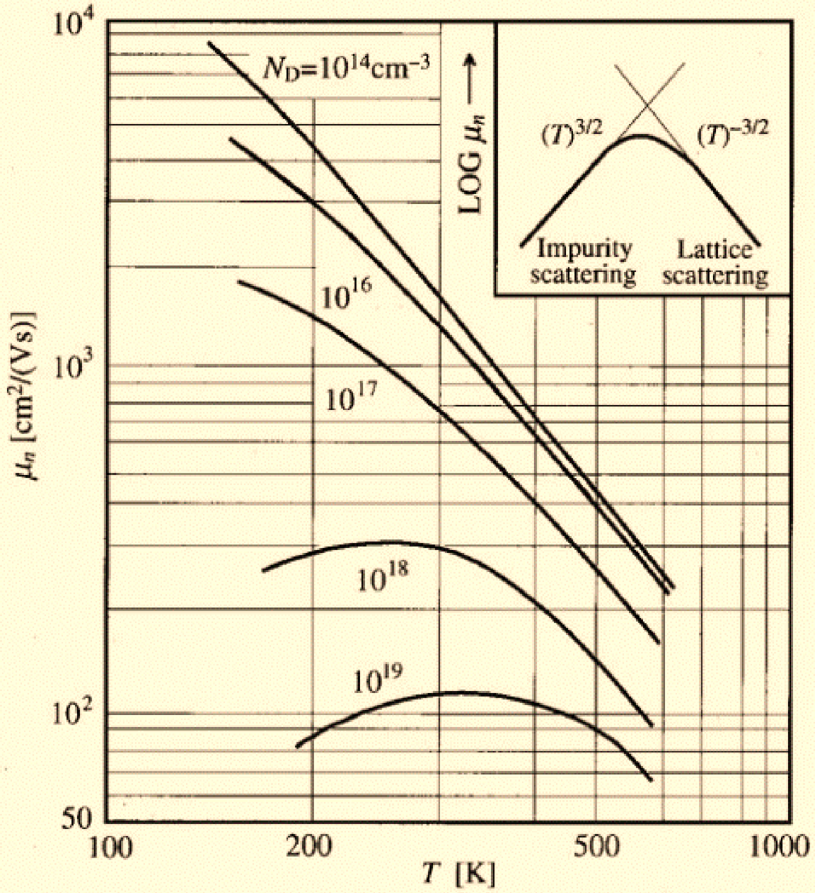
Matthiessen's Rule

- The probability that a carrier will be scattered by mechanism *i* within a time period *dt* is $\frac{dt}{\tau_i}$ where τ_i is the mean time between scattering events due to mechanism *i*

➔ The probability that a carrier will be scattered within a time period *dt* is $\sum_i \frac{dt}{\tau_i}$

$$\boxed{\begin{aligned} \frac{1}{\tau} &= \frac{1}{\tau_{phonon}} + \frac{1}{\tau_{impurity}} \\ \Rightarrow \frac{1}{\mu} &= \frac{1}{\mu_{phonon}} + \frac{1}{\mu_{impurity}} \end{aligned}}$$

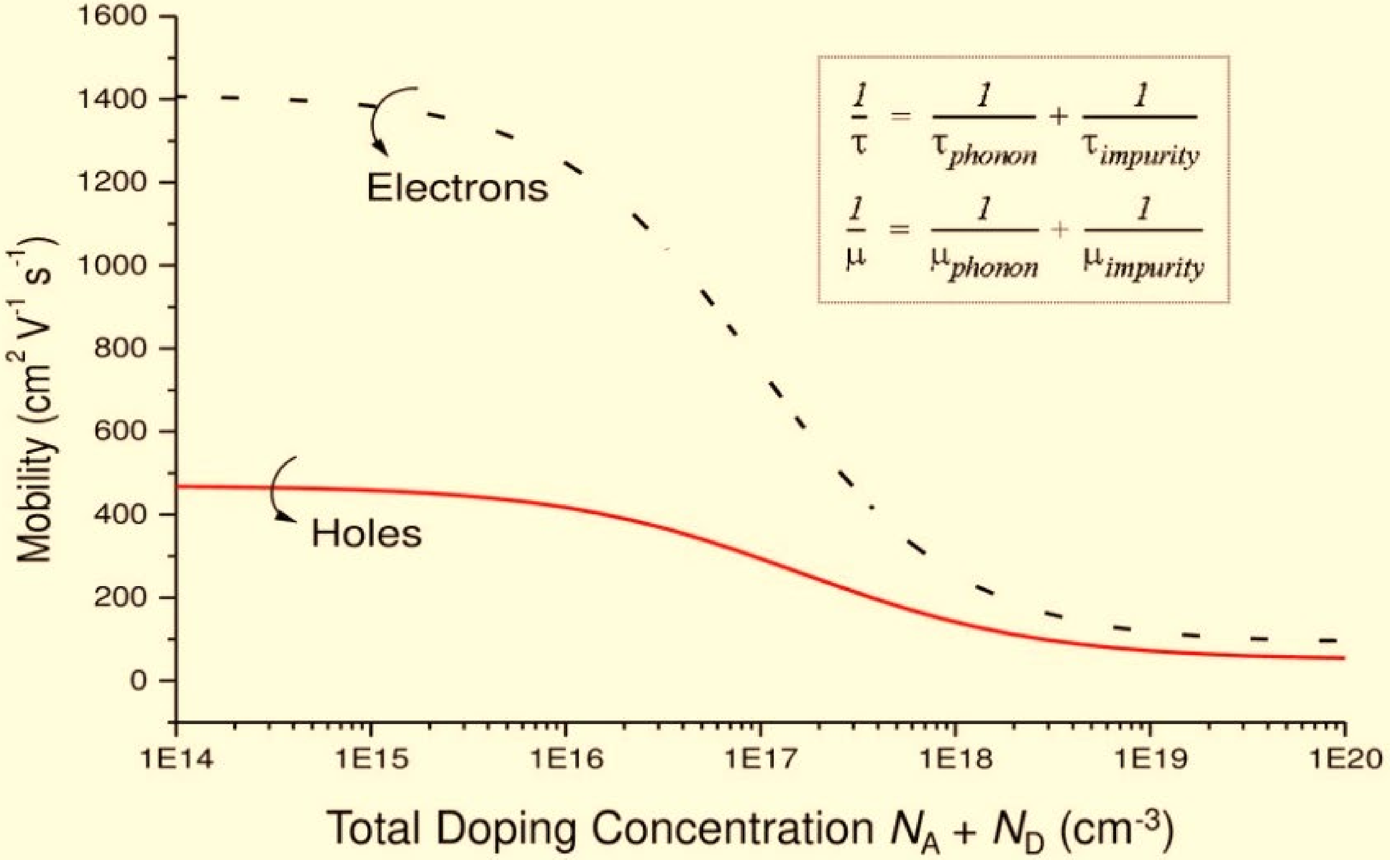
Temperature Effect on Mobility



$$\frac{1}{\tau} = \frac{1}{\tau_{phonon}} + \frac{1}{\tau_{impurity}}$$

$$\frac{1}{\mu} = \frac{1}{\mu_{phonon}} + \frac{1}{\mu_{impurity}}$$

Mobility Dependence on Doping



$$\frac{1}{\tau} = \frac{1}{\tau_{phonon}} + \frac{1}{\tau_{impurity}}$$

$$\frac{1}{\mu} = \frac{1}{\mu_{phonon}} + \frac{1}{\mu_{impurity}}$$

THANK YOU