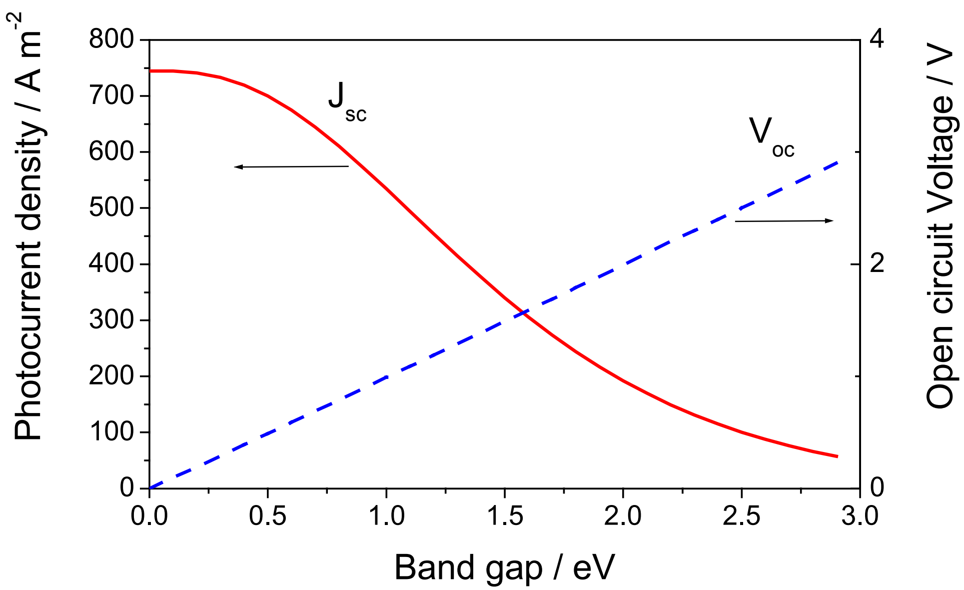
Summary of Lecture 19

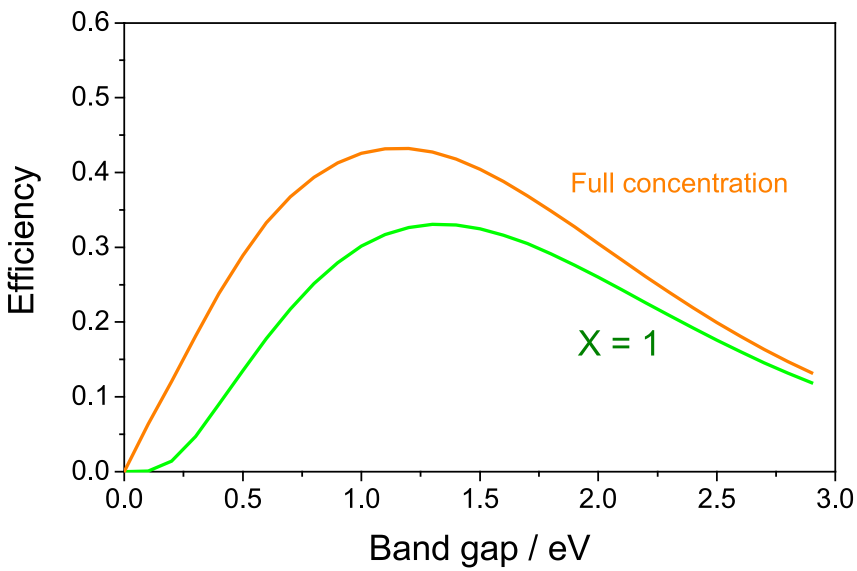
- Ideal solar photovoltaic converter at concentration X:
  - Absorbs all photons with E > Eg
  - Emits like black body with chemical potential $\Delta\mu > 0$
  - Every net absorbed photon $\rightarrow$ one electron in external circuit (QE = 1)
  - Delivers power density P = JV for $\Delta\mu = eV > 0$ (c.f. $dW/dt = \Delta\mu \, dN/dt$)

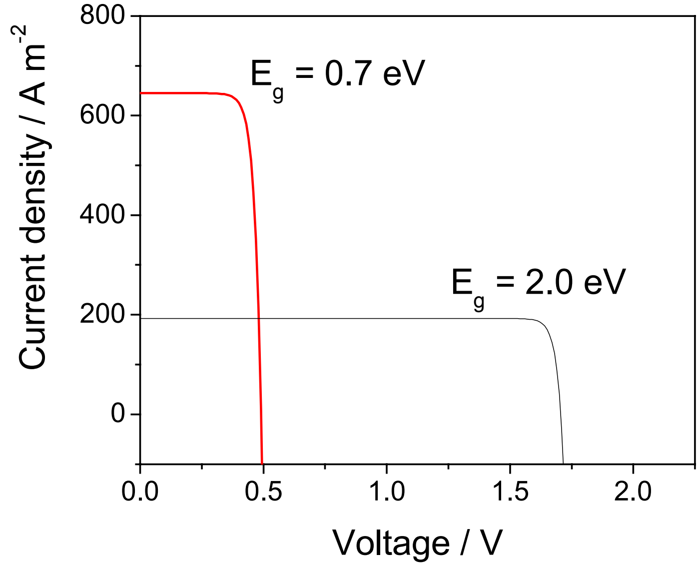
- J contains light dependent photocurrent and V dependent dark current

$$J = J_{sc} - J_o(\exp(eV/kT)-1)$$

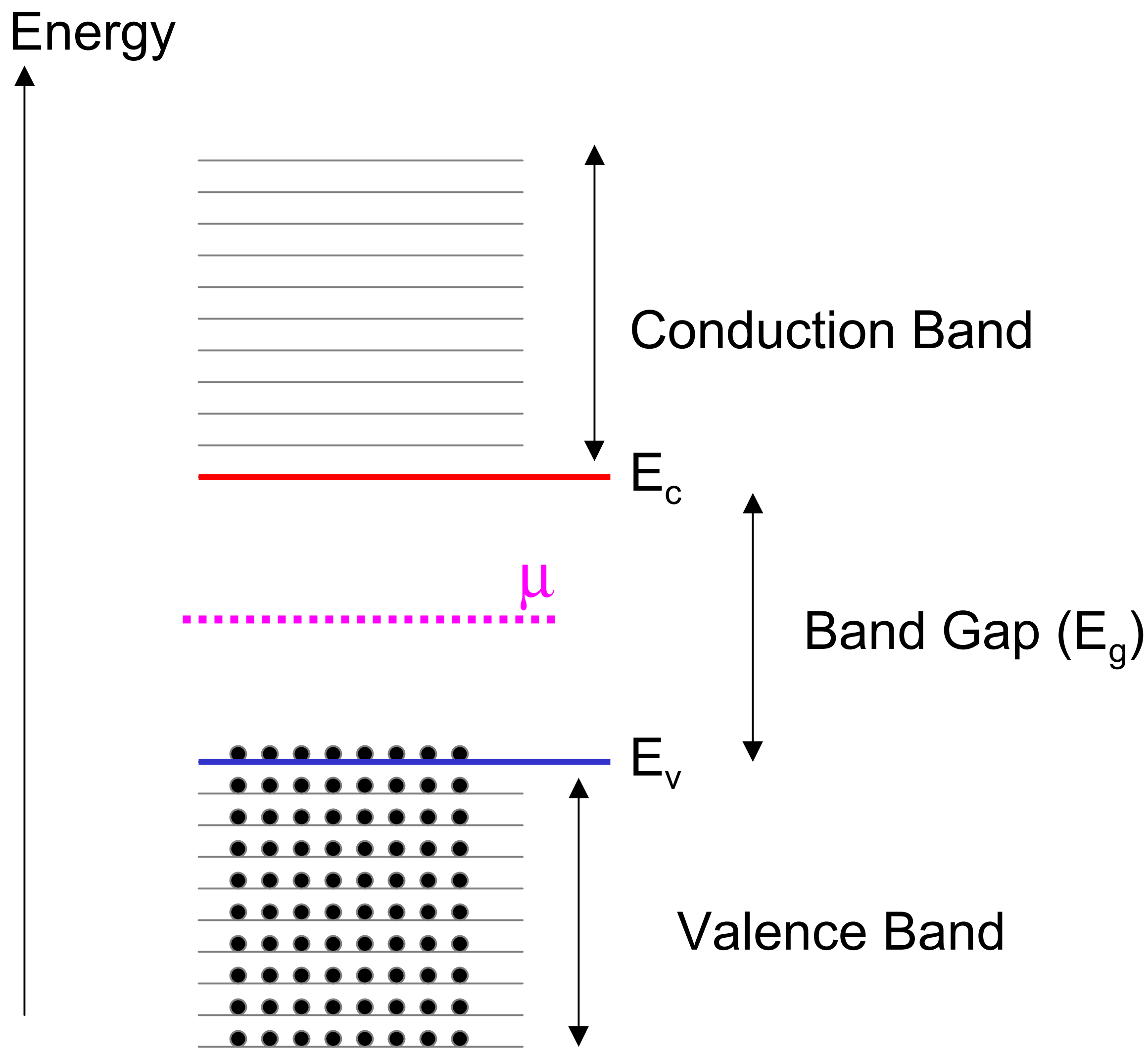
- Efficiency depends on E_g.
  - Max 31% at Eg = 1.4 eV for X = 1


Photocurrent density / A m^{-2}
Open circuit Voltage / V
Band gap / eV
J_{sc}
V_{oc}


Efficiency
Band gap / eV
Full concentration
X = 1

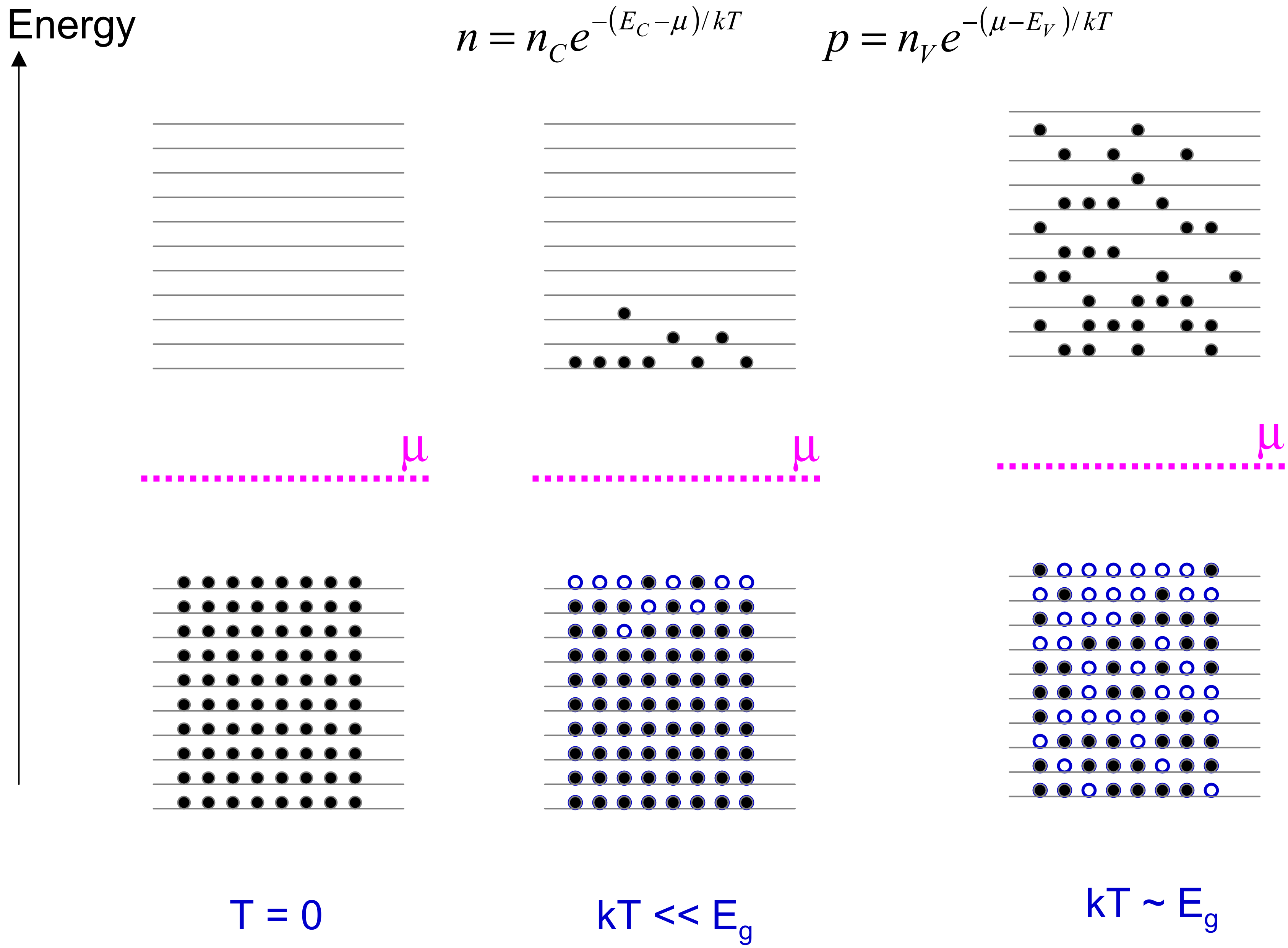

Current density / A m^{-2}
Voltage / V
E_g = 0.7 eV
E_g = 2.0 eV

Env Phys JN



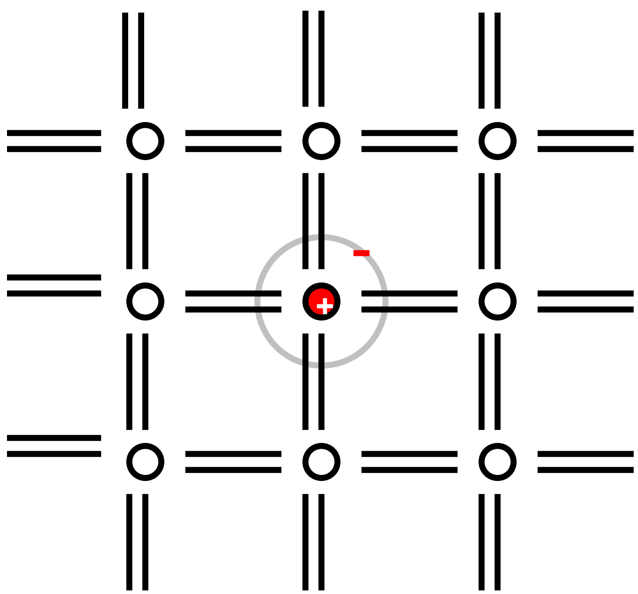
intrinsic

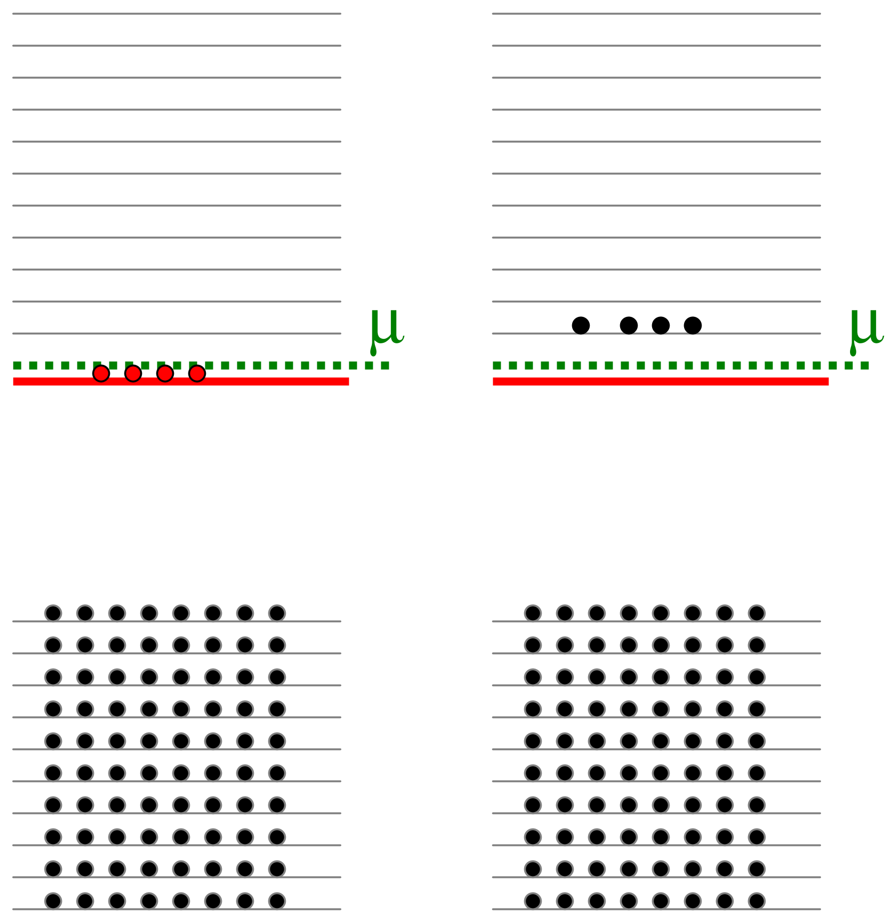
$$n = n_C e^{-(E_C - \mu)/kT} \qquad p = n_V e^{-(\mu - E_V)/kT}$$



n type doping

$$n = N_D$$





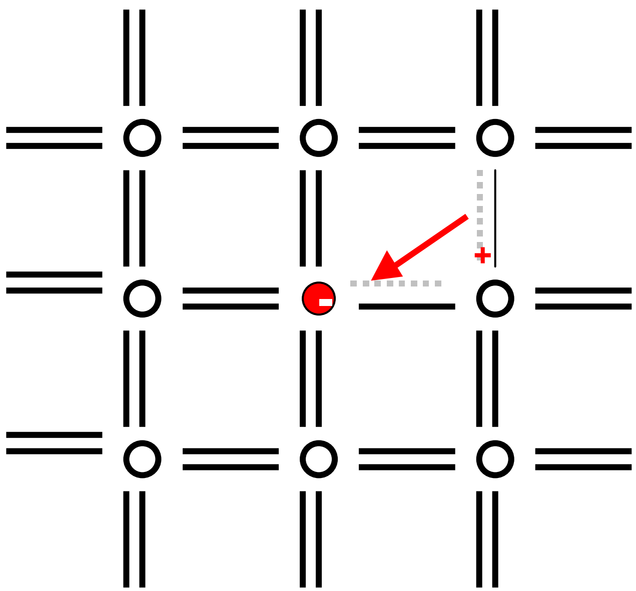
T = 0

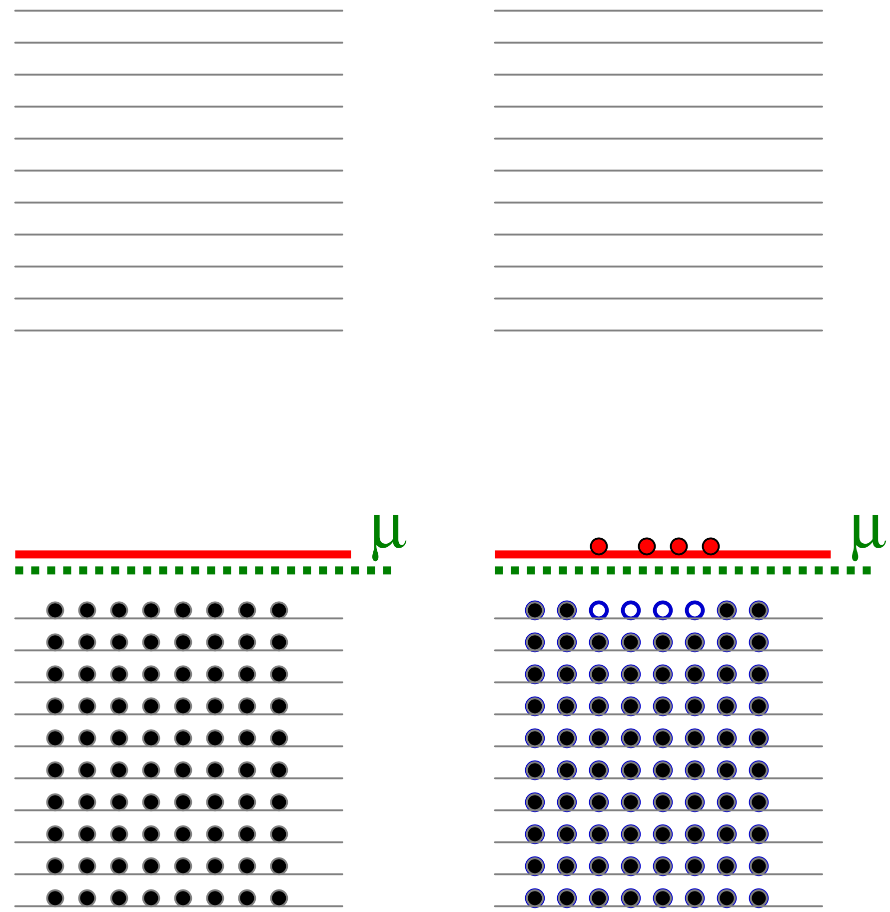
kT << Eg

N_D electron donors
All ionise at room temperature
Electron density = N_D

p type doping

$$p = N_A$$

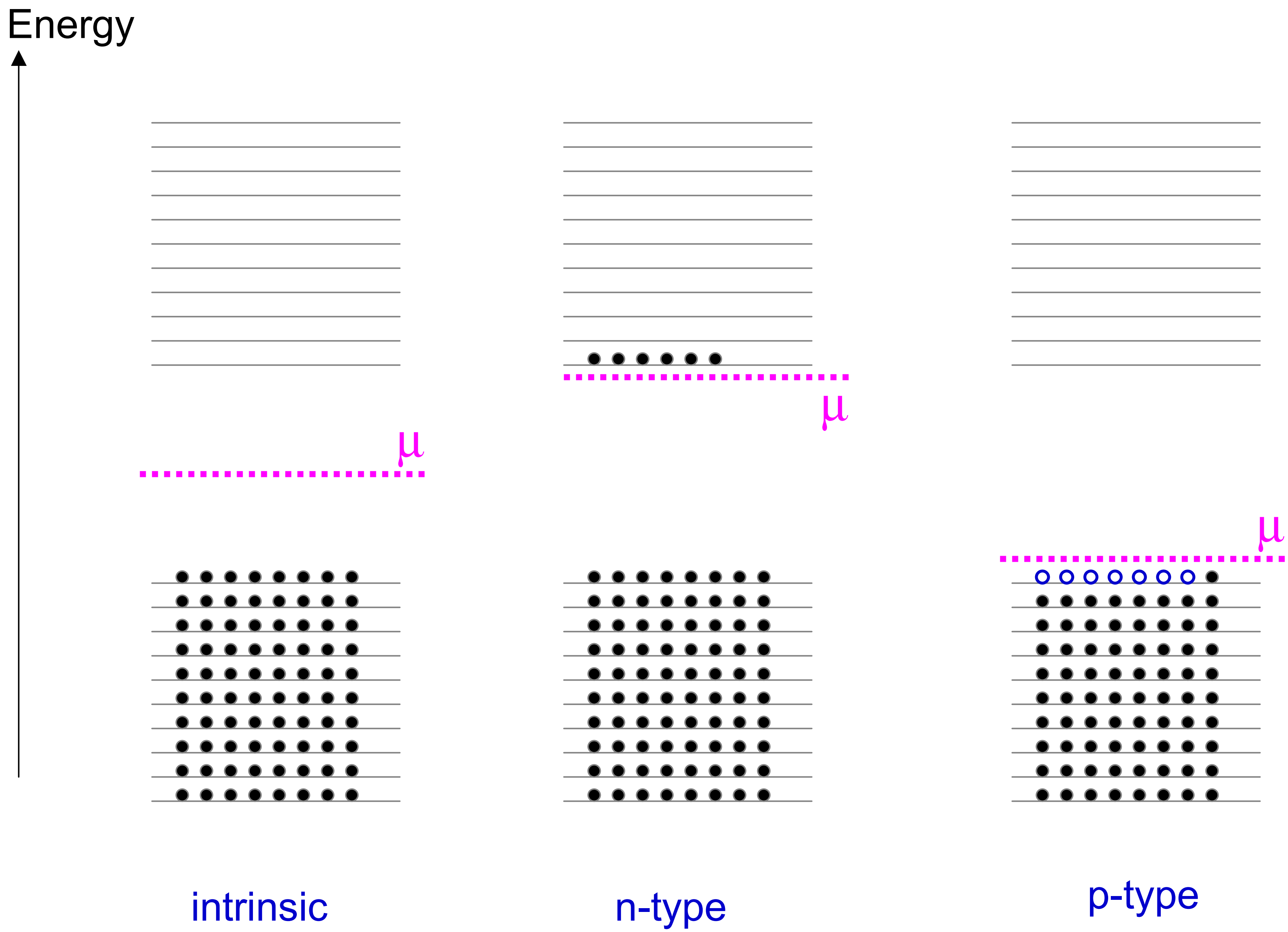




N_A electron acceptors
All ionise at room temperature
Hole density = N_A

T = 0

kT << Eg


Energy
μ
μ
μ
intrinsic
n-type
p-type

n type doping

N_D donor impurities

$$n = N_D$$

$$p = \frac{n_i^2}{N_D}$$

μ moves *up* (towards CB)

p type doping

N_A acceptor impurities

$$p = N_A$$

$$n = \frac{n_i^2}{N_A}$$

μ moves *down* (towards VB)

Summary of Lecture 20

- Semiconductor has
  - electron density $n = n_C \exp(-(E_C-\mu)/kT)$
  - hole density $p = n_V \exp(-(\mu - E_V)/kT)$
- Doping changes μ and n/p ratio
- μ constant in equilibrium
- Photogeneration causes $\mu_e > \mu_n$
- For electrons in p-type semiconductor:
  - Photogeneration rate $G = \int \alpha \, b \, dE$
  - Recombination rate $R = n / t_n$
  - Diffusion current $J_n = e D_n \, dn/dx$
  - Continuity equation $$\frac{1}{e}\frac{dJ_n}{dx} + G - R = 0$$