FYS3410 - Vår 2011 (Kondenserte fasers fysikk)

http://www.uio.no/studier/emner/matnat/fys/FYS3410/index-eng.xml

Based on Introduction to Solid State Physics by Kittel

Course content

- Periodic structures, understanding of diffraction experiment and reciprocal lattice
- Imperfections in crystals: diffusion, point defects, dislocations
- Crystal vibrations: phonon heat capacity and thermal conductivity
- Free electron Fermi gas: density of states, Fermi level, and electrical conductivity
- Electrons in periodic potential: energy bands theory classification of metals, semiconductors and insulators
- Semiconductors: band gap, effective masses, charge carrier distributions, doping, pn-junctions
- Metals: Fermi surfaces, temperature dependence of electrical conductivity

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FYS3410 lecture schedule and exams: Spring 2011

W/19/1/2011:	Introduction and motivation. Periodicity and lattices	1h
M/24/1/2011:	Index system for crystal planes. Crystal structures	2h
W/26/1/2011:	Reciprocal space, Laue condition and Ewald construction	1h
M/31/1/2011:	Brillouin Zones. Interpretation of a diffraction experiment	2h
W/02/2/2011:	Crystal binding, elastic strain and waves	1h
M/07/2/2011:	Elastic waves in cubic crystals; defects in crystals	2h
W/09/2/2011:	Defects in crystals; case study – vacancies; diffusion	2h
M/14/2/2011:	Crystal vibrations and phonons	2h
W/16/2/2011:	Lattice heat capacity: Dulong-Petit and Einstein models	2h
M/21/2/2011:	Phonon density of states (DOS) and Debye model	2h
W/23/2/2011:	General result for DOS; role of anharmonic interactions	2h
M/28/2/2011:	Thermal conductivity and repetition of crystal vibrations	2h
W/02/3/2011:	no lectures	
M/07/3/2011:	no lectures	
W/09/3/2011:	no lectures	
M/14/3/2011:	Free electron Fermi gas in 1D and 3D – ground state	2h
W/17/3/2011:	Density of states, effect of temperature – FD distribution	1h
M/21/3/2011:	Heat capacity of FEFG	2h
W/23/3/2011:	Repetition	1h
M/28/3/2011:	Mid-term exam	

M/04/4/2011:	**Electrical and thermal conductivity in metals**	**2h**
W/06/4/2011:	**Bragg reflection of electron waves at the boundary of BZ**	**2h**
M/11/4/2011:	**Energy bands, Kronig - Penny model**	**2h**
W/13/4/2011:	**Empty lattice approximation; number of orbitals in a band**	**2h**
Påsk uppehåll		
W/27/4/2011	**no lectures**	
M/02/5/2011:	**no lectures**	
W/04/5/2011:	**no lectures**	
M/09/5/2010:	**Semiconductors, effective mass method, intrinsic carriers**	**2h**
W/11/4/2010:	**Impurity states in semiconductors and carrier statistics**	**2h**
M/16/5/2010:	**p-n junctions, Schottky contacts and heterojunctions**	**2h**
W/18/5/2010:	**Metals and Fermi surfaces**	**1h**
M/23/5/2010:	**Repetition**	**2h**
26-27/5/2010:	**Final Exam (sensor:???)**	

Lecture 6: Elastic waves in cubic crystals; defects in crystals

- elastic waves in cubic crystals
- defects in crystals

Lecture 6: Elastic waves in cubic crystals; defects in crystals

- **elastic waves in cubic crystals**
- **defects in crystals**

$$stress \quad \sigma = \frac{load \;\; W}{area \;\; A}$$

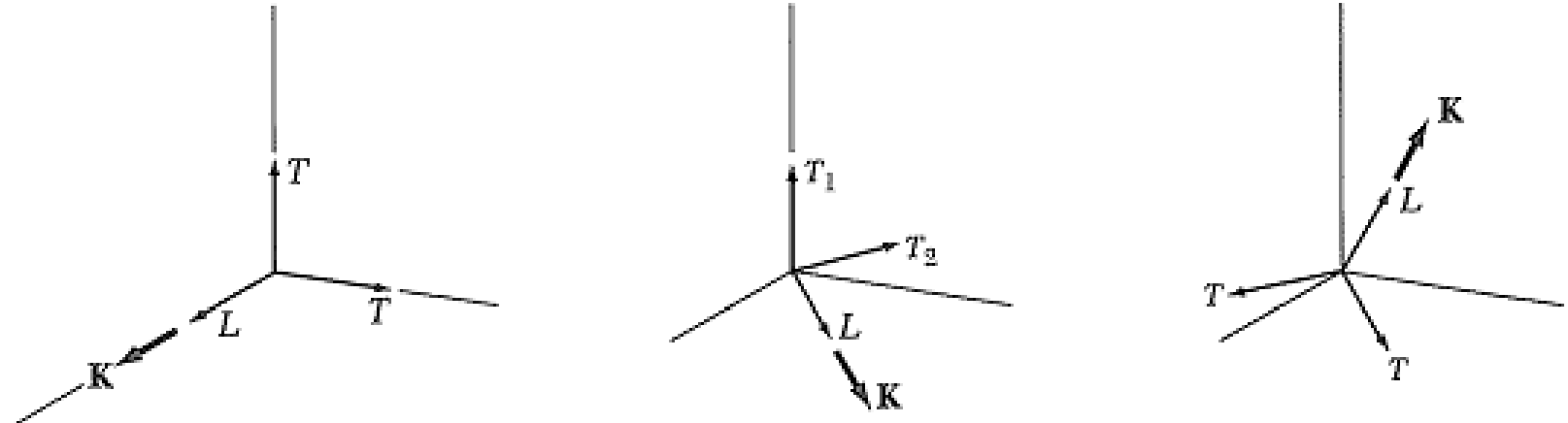
$$strain \quad \varepsilon = \frac{increase\ in\ length \;\; x}{original\ length \;\; L}$$

$$\varepsilon_{ij} = S_{ij} \bullet \sigma_{ij}$$

Hooke's law

$$\sigma_{ij} = C_{ij} \bullet \varepsilon_{ij}$$

See Eqs 37 and 38 in Kittel, p.77



Wave in [100] direction
$L : C_{11}$
$T : C_{44}$

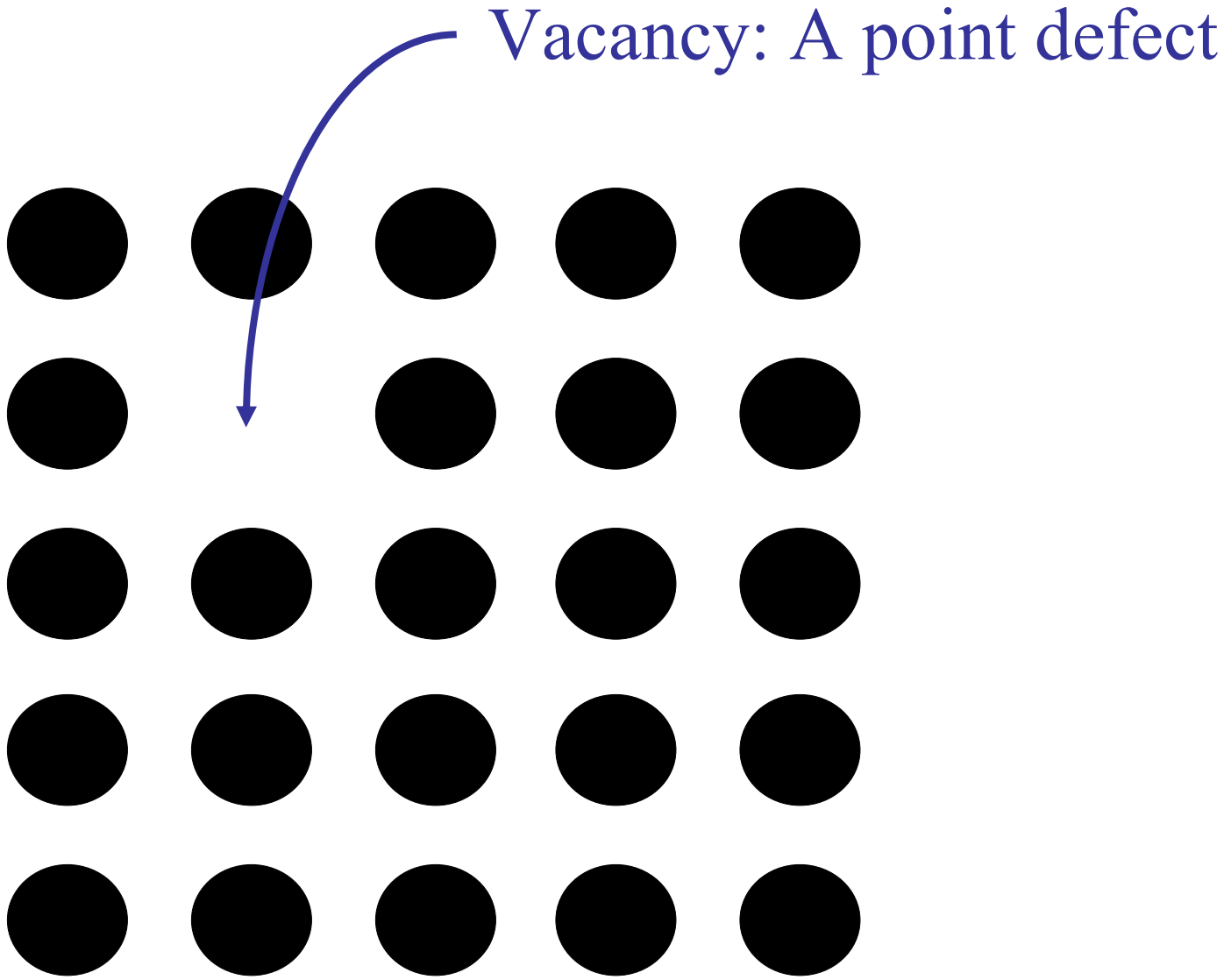
Wave in [110] direction
$L : \frac{1}{2}(C_{11} + C_{12} + 2C_{44})$
$T_1 : C_{44}$
$T_2 : \frac{1}{2}(C_{11} - C_{12})$

Wave in [111] direction
$L : \frac{1}{3}(C_{11} + 2C_{12} + 4C_{44})$
$T : \frac{1}{3}(C_{11} - C_{12} + C_{44})$

Figure 20 Effective elastic constants for the three modes of elastic waves in the principal propagation directions in cubic crystals. The two transverse modes are degenerate for propagation in the [100] and [111] directions.

Lecture 6: Elastic waves in cubic crystals; defects in crystals

- elastic waves in cubic crystals
- **defects in crystals**


Vacancy: A point defect

Defects	*Dimensionality*	*Examples*
Point	0	Vacancy
Line	1	Dislocation
Surface	2	Free surface, Grain boundary

Case study: vacancy

Fact

There *may* be vacant sites in a crystal

Surprising Fact

There *must* be a certain fraction of vacant sites in a crystal in *equilibrium.*

Case study: vacancy

- Crystal in equilibrium
- Minimum Gibbs free energy *G* at constant *T* and *P*
- A certain concentration of vacancy lowers the free energy of a crystal

Case study: vacancy

Gibbs free energy G involves two terms:

1. Enthalpy $H = E + PV$

E internal energy
P pressure
V volume

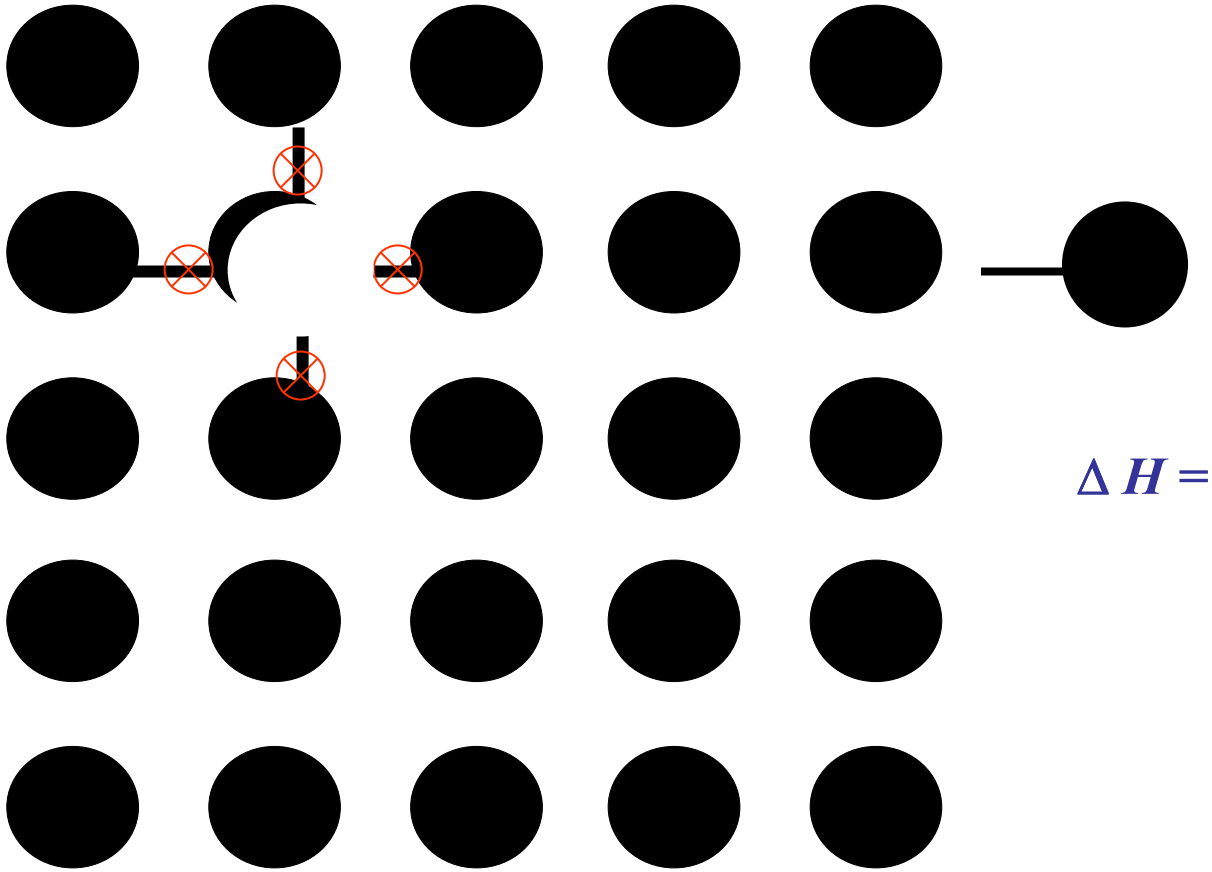
2. Entropy $S = k \ln W$

k Boltzmann constant
W number of microstates

$$G = H - T S$$

T Absolute temperature

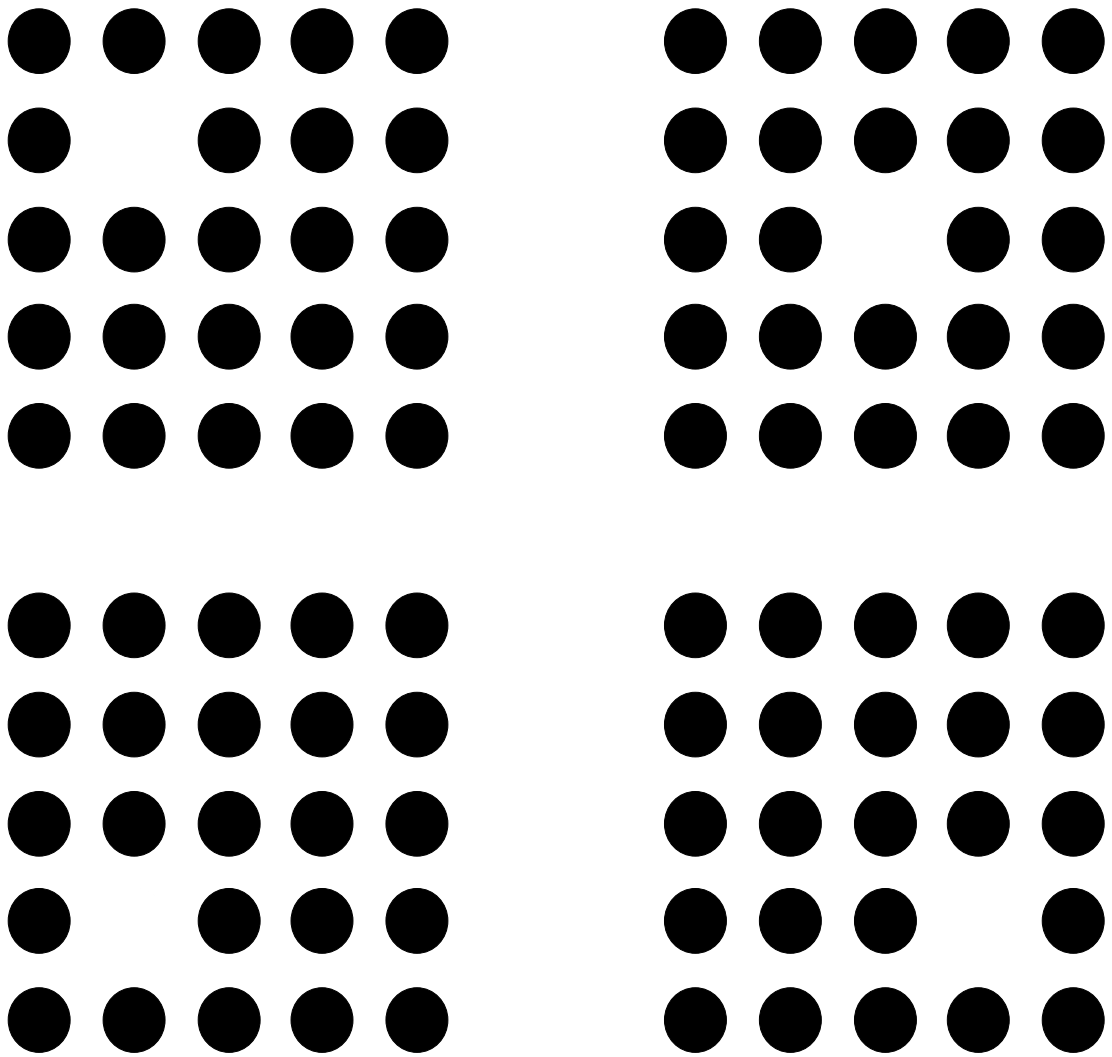
Case study: vacancy



$$\Delta H = n \Delta H_f$$

Vacancy increases *H* of the crystal due to energy required to break bonds

Configurational entropy due to vacancy



Configurational entropy due to vacancy

Number of atoms: N

Number of vacacies: n

Total number of sites: $N+n$

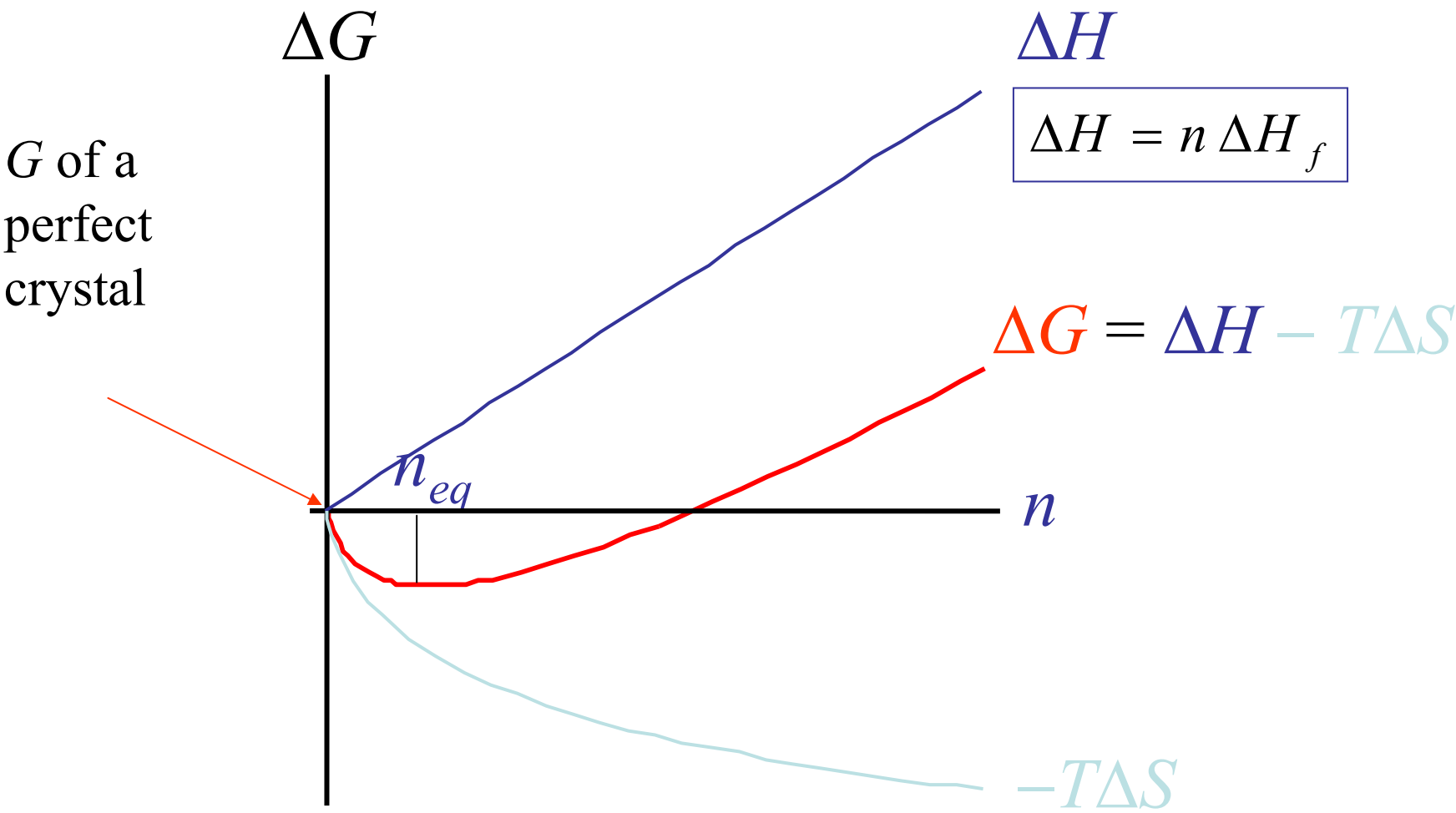
How many distinguished configurations, so called microstates?

We calculate this explicitly

Configurational entropy due to vacancy

N	$\ln N!$	$N \ln N - N$
1	0	−1
10	15.10	13.03
100	363.74	360.51

Equilibrium concentration of vacancy



Equilibrium concentration of vacancy

$$\left.\frac{\partial \Delta G}{\partial n}\right|_{n=n_{eq}} = 0$$

$$\frac{n_{eq}}{N} = \exp\left(-\frac{\Delta H_f}{kT}\right)$$