Perspective Understanding of Various Kinds of Material

By

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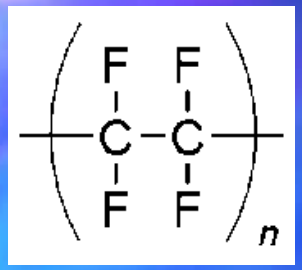
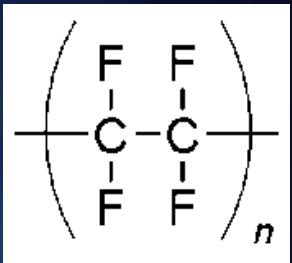
Questions



		s		d									p					
		1	2	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6
		IA	IIA	IIIA	IVA	VA	VIA	VIIA		VIII		IB	IIB	IIIB	IVB	VB	VIB	BIIB	0
1		H																	He
2		Li	Be											B	C	N	O	F	Ne
3		Na	Mg											Al	Si	P	S	Cl	Ar
4		K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5		Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6		Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7		Fr	Ra	**															

		f														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
6	*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
7	**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

1. Why inert gasses are non-reactive ?
2. Why Teflon© (poly-tetra-fluoro-ethylene, PTFE) is used for coating ?
3. Why liquid Oxygen is magnetic ?
4. Why W has the highest melting point ?
5. Why the Fe – (Cr, Mo, Mn,,,) alloy can be used at high temp. ?
6. Why alkali metals are ductile ? Why ceramics, diamond are brittle ?
7. Why transient metals such as Cu, Ag, Au, etc… are ductile ?
8. What is the difference between metallic materials, covalent materials, and ionic materials ?
9. What is the difference between conductors, semi-conductors, and insulators ?
10. What is the most ionic compound ?
11. Why left side materials in transient metals (ex. Ti, Zr) are used for the ceramics as oxides, nitrides, etc… ?
12. How we can evaluate the surface tension of solids ?
13. Why diodes rectifies ? Why they emits lights ?
14. Why transistor amplify currents ? Why they work as a switch ?
15. etc…



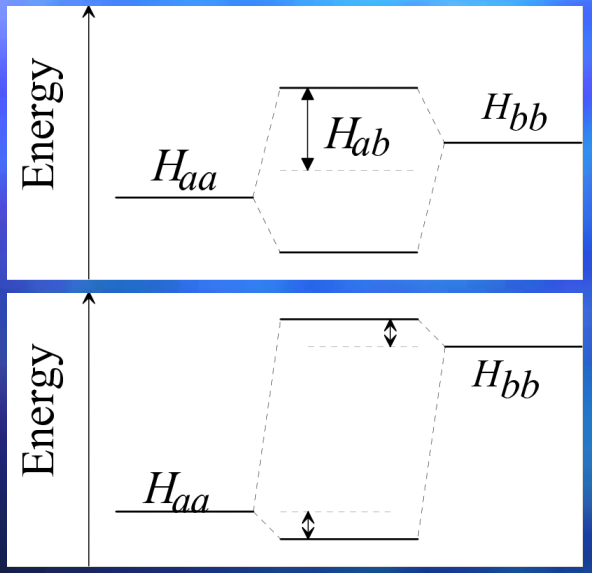
	s 1	2	*d* 1	2	3	4	5	6	7	8	9	10	*p* 1	2	3	4	5	6
	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIII			IB	IIB	IIIB	IVB	VB	VIB	BIIB	0
1	H																	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	**															

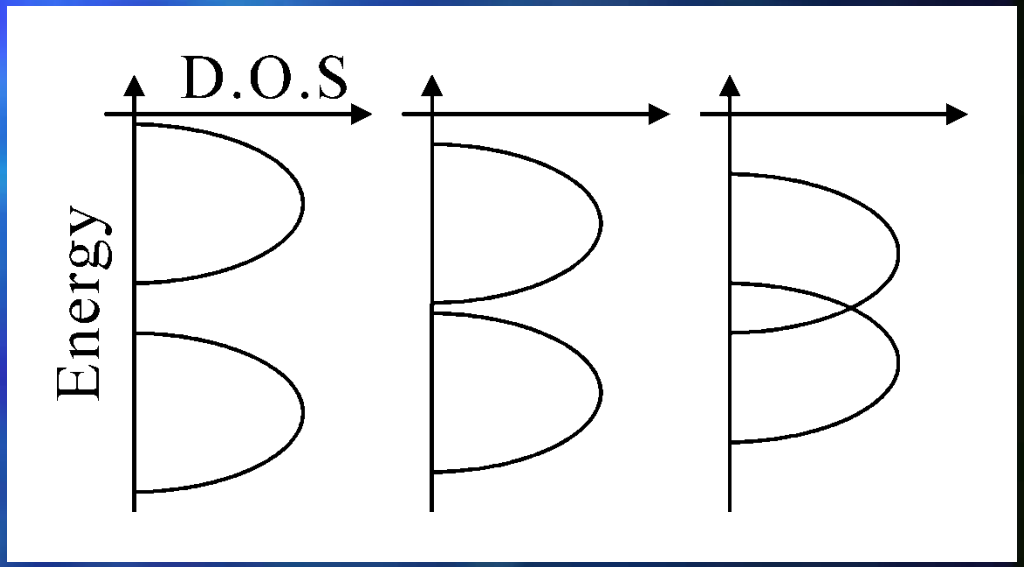
		f 1	2	3	4	5	6	7	8	9	10	11	12	13	14	
6	*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
7	**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Electric conductivity

Di-atomic molecule -> Multi-atomic materials

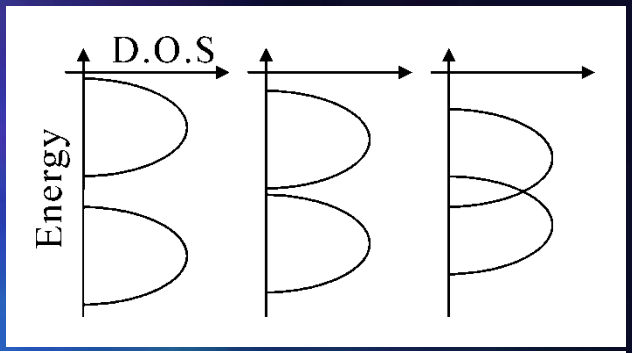
Orbitals -> Density Of States (DOS)





Insulator Semi-conductor Metal

Why "Semi-"conductive ?



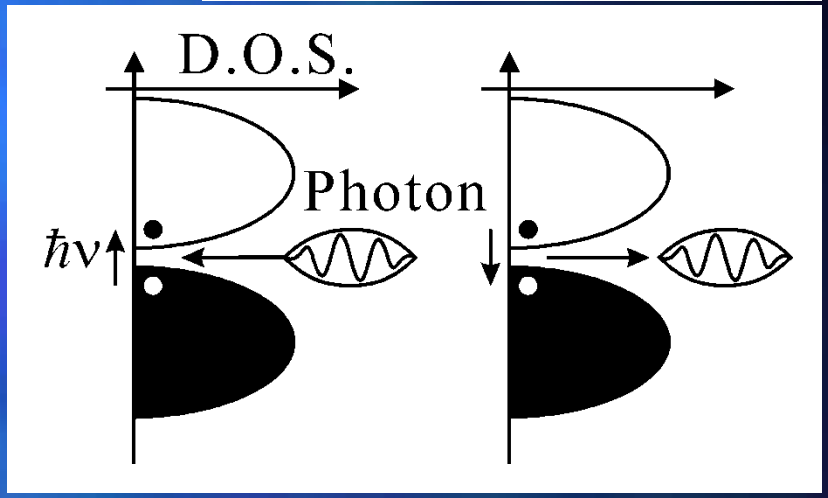
- Photon

  Energy 10 ~ 1 (eV)

  Wave length 100 ~ 1000 (nm)

  (Violet ≈400nm

  Red ≈700nm)

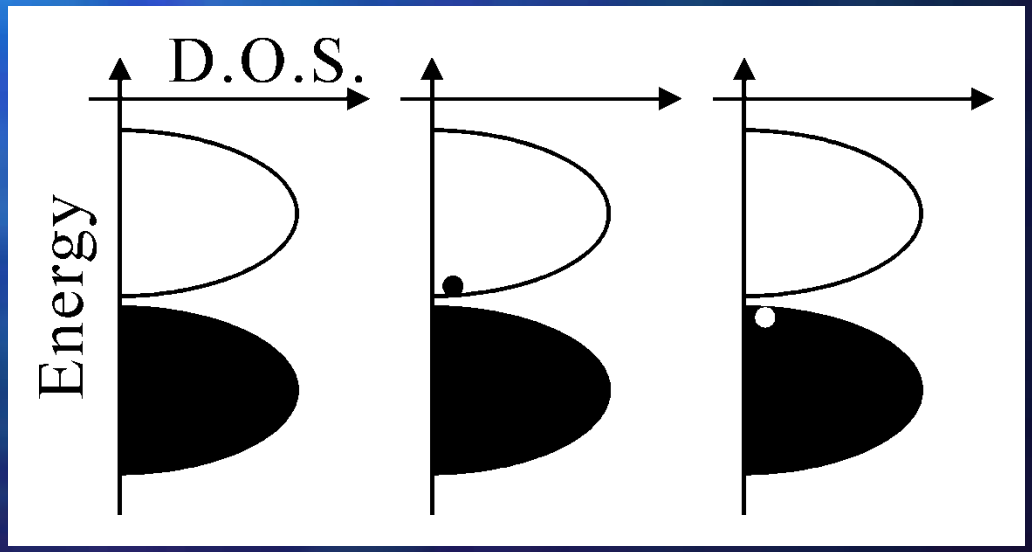


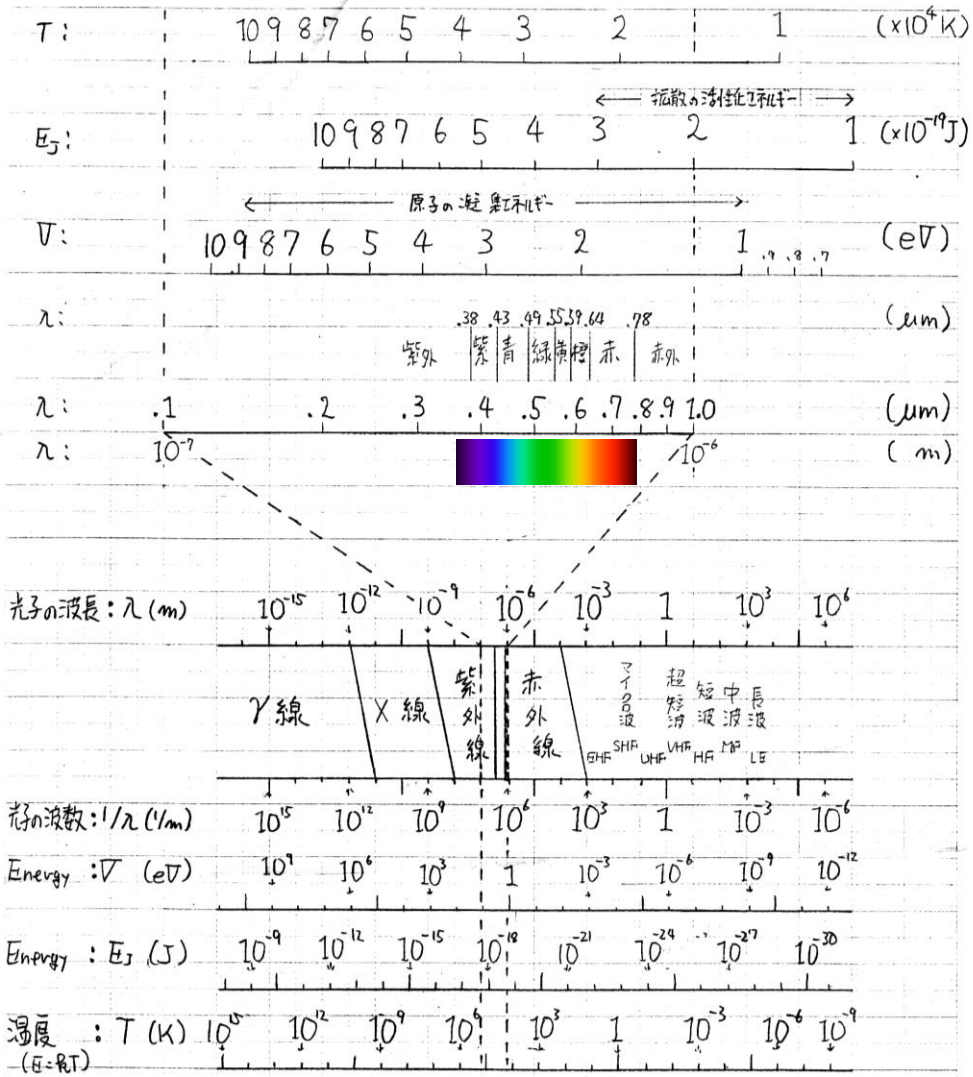
- Doping element

  N, P, As, Sb, Bi -> n-type

  B, Al, Ga, In Tl -> p-type

			p					
	9	10	1	2	3	4	5	6
	IB	IIB	IIIB	IVB	VB	VIB	BIIB	0
								He
			B	C	N	O	F	Ne
			Al	Si	P	S	Cl	Ar
i	Cu	Zn	Ga	Ge	As	Se	Br	Kr
d	Ag	Cd	In	Sn	Sb	Te	I	Xe
t	Au	Hg	Tl	Pb	Bi	Po	At	Rn



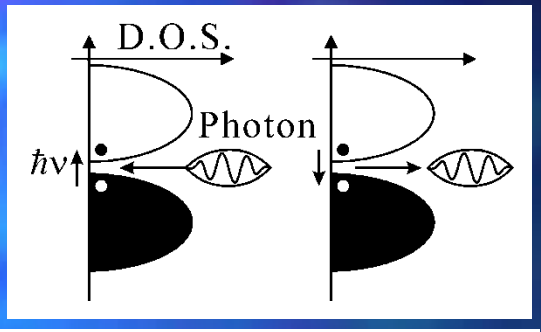


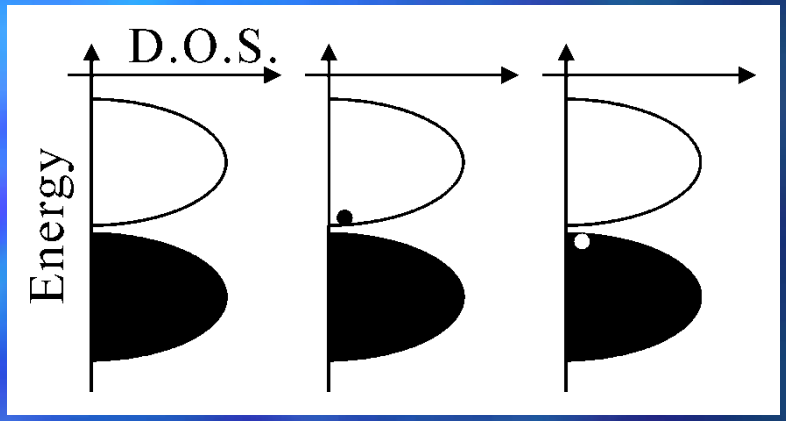
1/λ (1/m)	Ej (J)	V (eV)	T (K)
1	1.99×10^{-25}	1.24×10^{-6}	1.44×10^{-2}
5.03×10^{24}	1	6.23×10^{18}	7.24×10^{22}
8.07×10^{5}	1.60×10^{-19}	1	1.16×10^{4}
6.94×10^{1}	1.38×10^{-23}	8.61×10^{-5}	1

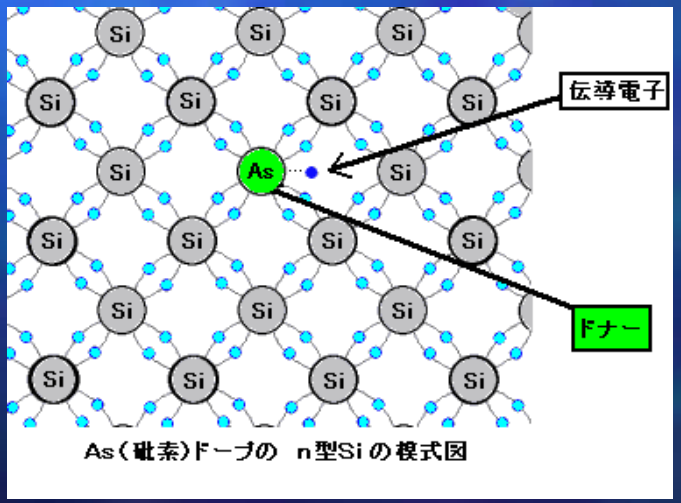
$R\nu = Rc\cdot\left(\frac{1}{\lambda}\right) = E_J = eV = RT$

Diode (p/n diode)

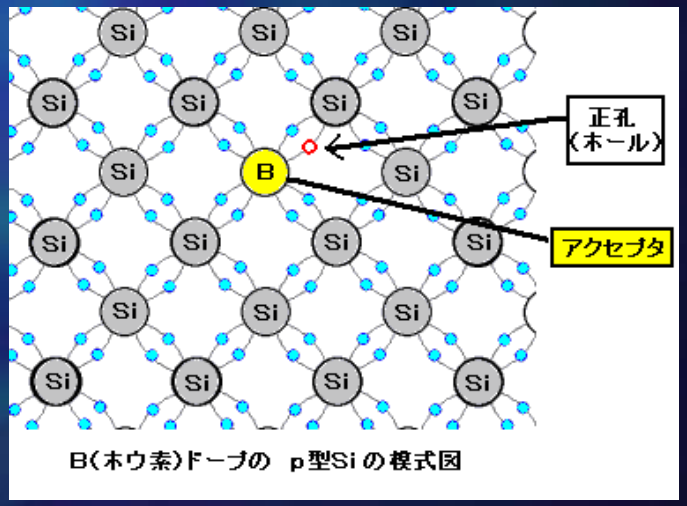
- Light emitting property
- Rectifying property



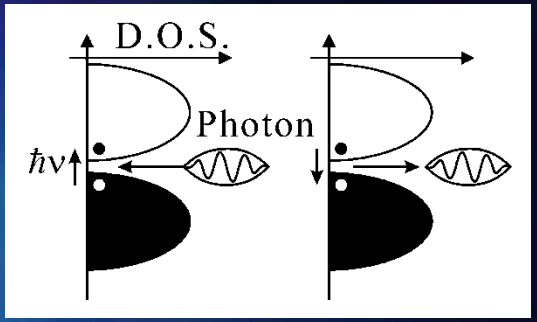




As(砒素)ドープの n型Si の模式図



B(ホウ素)ドープの p型Si の模式図



Light emitting

- Band gap
- Wavelength of light

Rectification

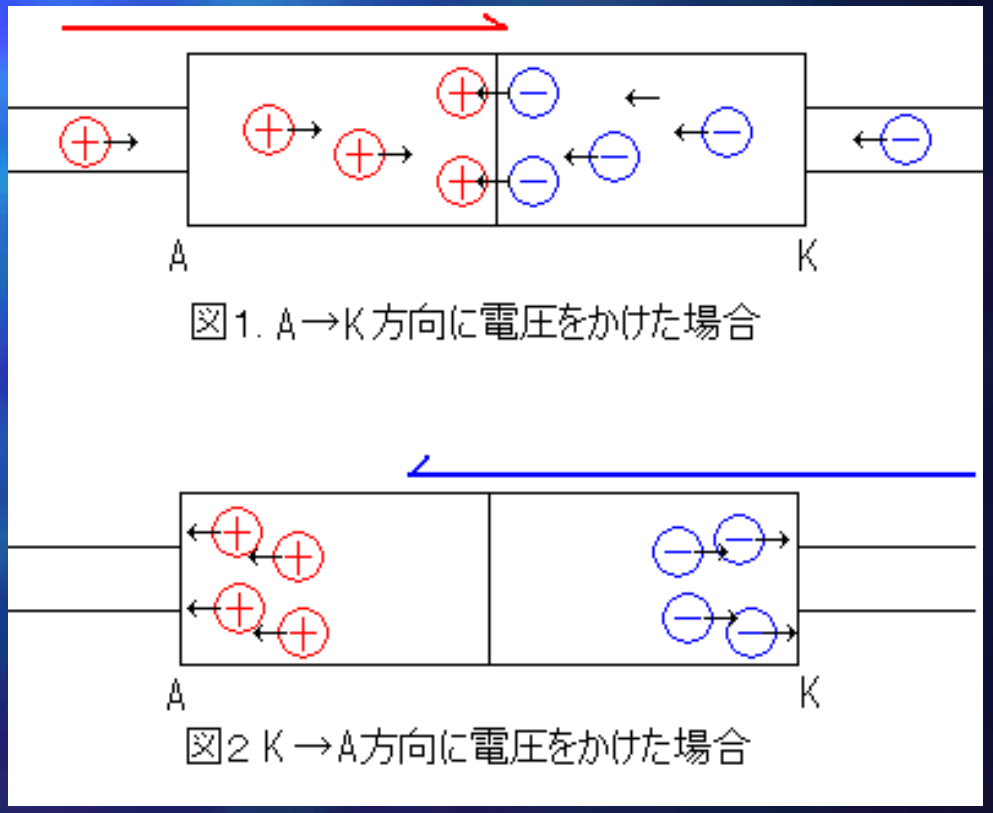
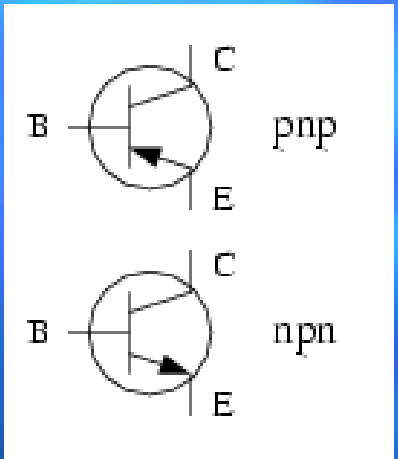


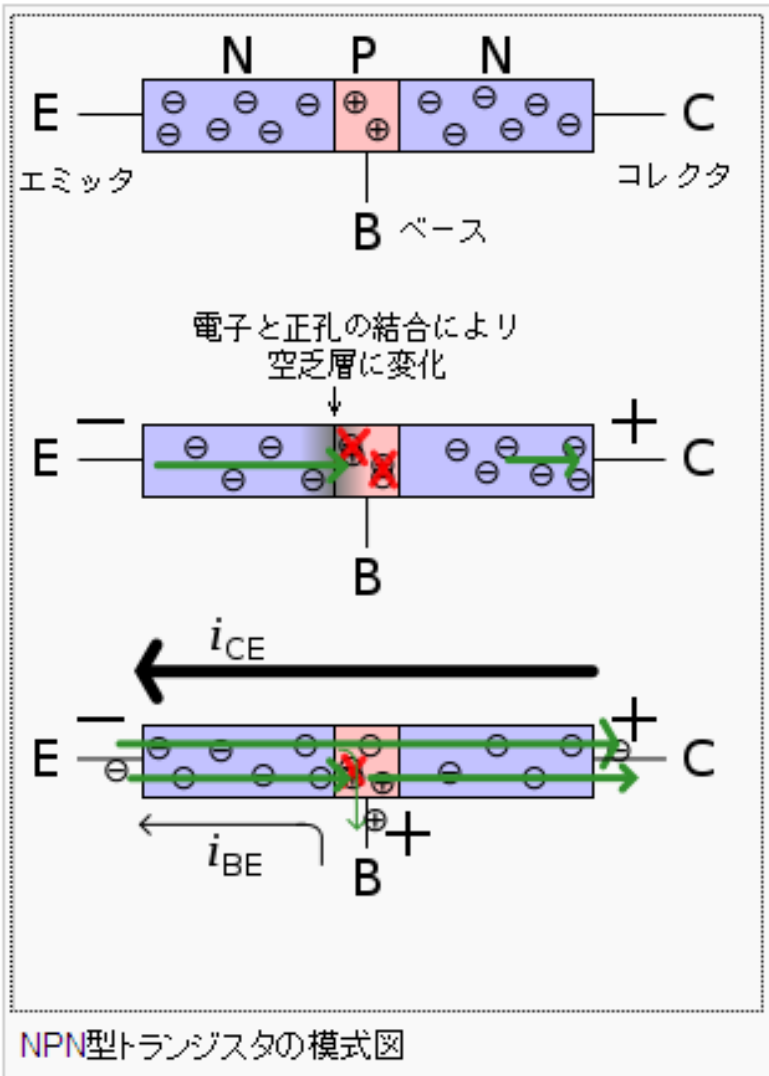
図1. A→K方向に電圧をかけた場合

図2 K→A方向に電圧をかけた場合

Transistor, Photo-transistor

- NPN, PNP

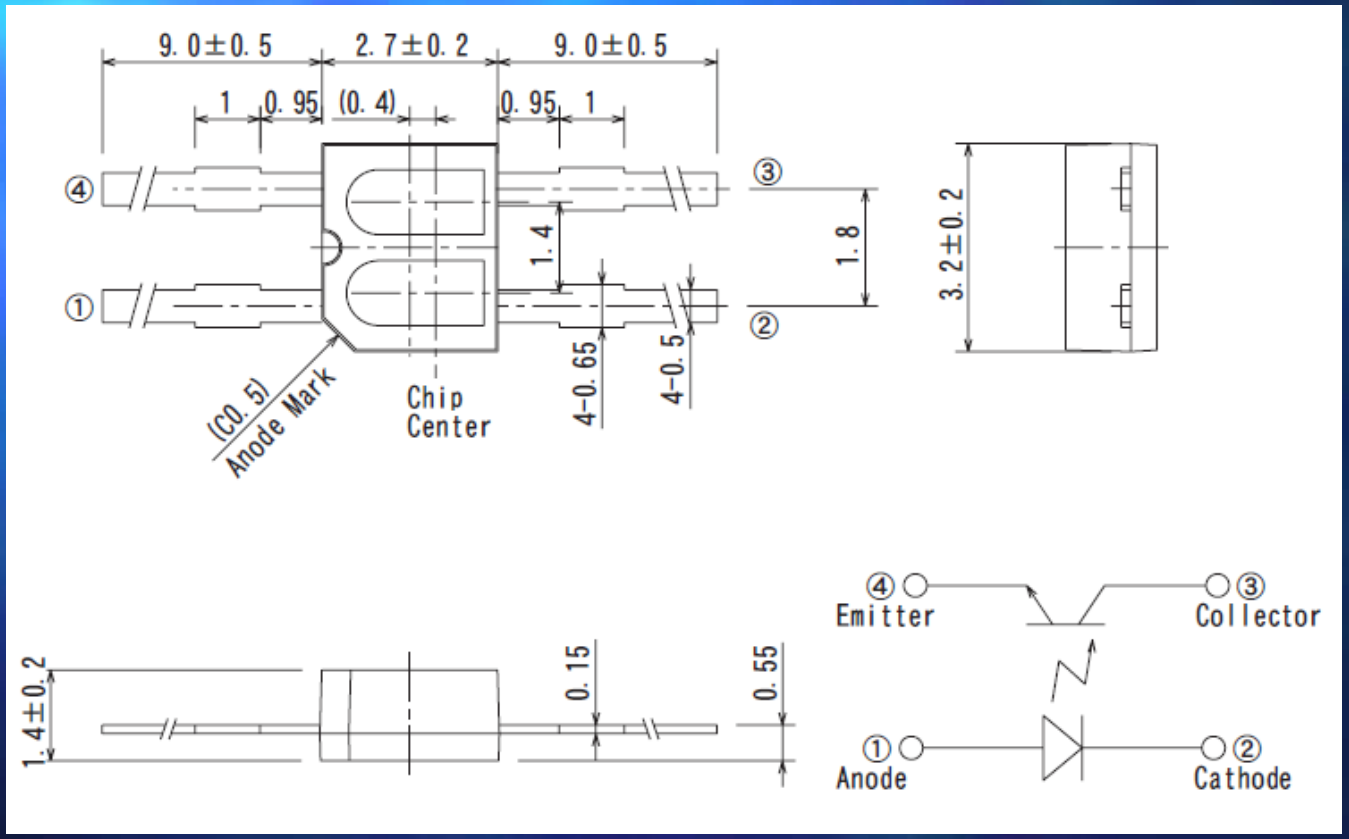




NPN型トランジスタの模式図

Photo-coupler/interrupter and their applications

- Diode + Photo-transistor = Photo-coupler or Photo-interrupter



Thermal conductivity

Energy is carried by the electron, therefore

For metal, Wiedemann-Franz law

$$\frac{K}{\sigma} = LT$$

K : Thermal conductivity

σ : Electrical conductivity

Temperature

Lorenz's constant $L = 2.45 \times 10^{-8} (\mathrm{W\Omega/K^2})$

Except for

- Diamond: by phonon
- Liquid He in Super-fluidity

Thermal conductivity

$$\frac{K}{\sigma} = LT$$

	T.C.(W/mK)	E.C.(1/Ωm)	K/σ
Ag	420	61 x10^{6}	6.9 x10^{-6}
Cu	398	59 x10^{6}	6.7 x10^{-6}
Au	320	45 x10^{6}	7.1 x10^{-6}
Al	236	37 x10^{6}	6.4 x10^{-6}
Fe	84	10 x10^{6}	8.4 x10^{-6}
Pt	70	9 x10^{6}	7.8 x10^{-6}
Diamond	1000~2000	≈0	≈∞
Si	168	10 x10^{6}	16.8 x10^{-6}

Transport Equation : conservative density of state

$$\left(\frac{\partial f}{\partial t}\right)_{\text{scat.}} + \left(\frac{\partial f}{\partial t}\right)_{\text{field}} = 0$$

（ボルツマンの輸送方程式）

- 電子の流れ：$\boldsymbol{J} = e^2 K_0 \cdot \boldsymbol{E} + \frac{e}{T} K_1 \cdot (-\operatorname{grad} T)$
- 熱の流れ：$\boldsymbol{U} = eK_1 \cdot \boldsymbol{E} + \frac{1}{T} K_2 \cdot (-\operatorname{grad} T)$

但し，

$$K_n \equiv \frac{1}{4\pi^3 \eta} \iint \tau(\boldsymbol{k}, T) \boldsymbol{v}\boldsymbol{v} (\varepsilon - \zeta)^n \left(-\frac{\partial f^0}{\partial \varepsilon}\right) \frac{dS}{v} d\varepsilon$$

$$f^0(\varepsilon(\boldsymbol{k})) \equiv \frac{1}{\exp\{(\varepsilon(\boldsymbol{k}) - \zeta)/kT\} + 1}$$

＜注意＞

- Relaxation time
- 「緩和時間 $\tau(\boldsymbol{k}, T)$ を計算するための直接的な手続きは無い」J.M.Ziman

電気伝導度

$$\sigma = e^2 K_0 \approx 3\left(\frac{e}{\pi k}\right)^2 \frac{K_2}{T^2}$$

熱伝導度（J=0よりE消去）

$$\lambda = \frac{K_2 - K_1 K_0^{-1} K_1}{T} \approx \frac{K_2}{T}$$

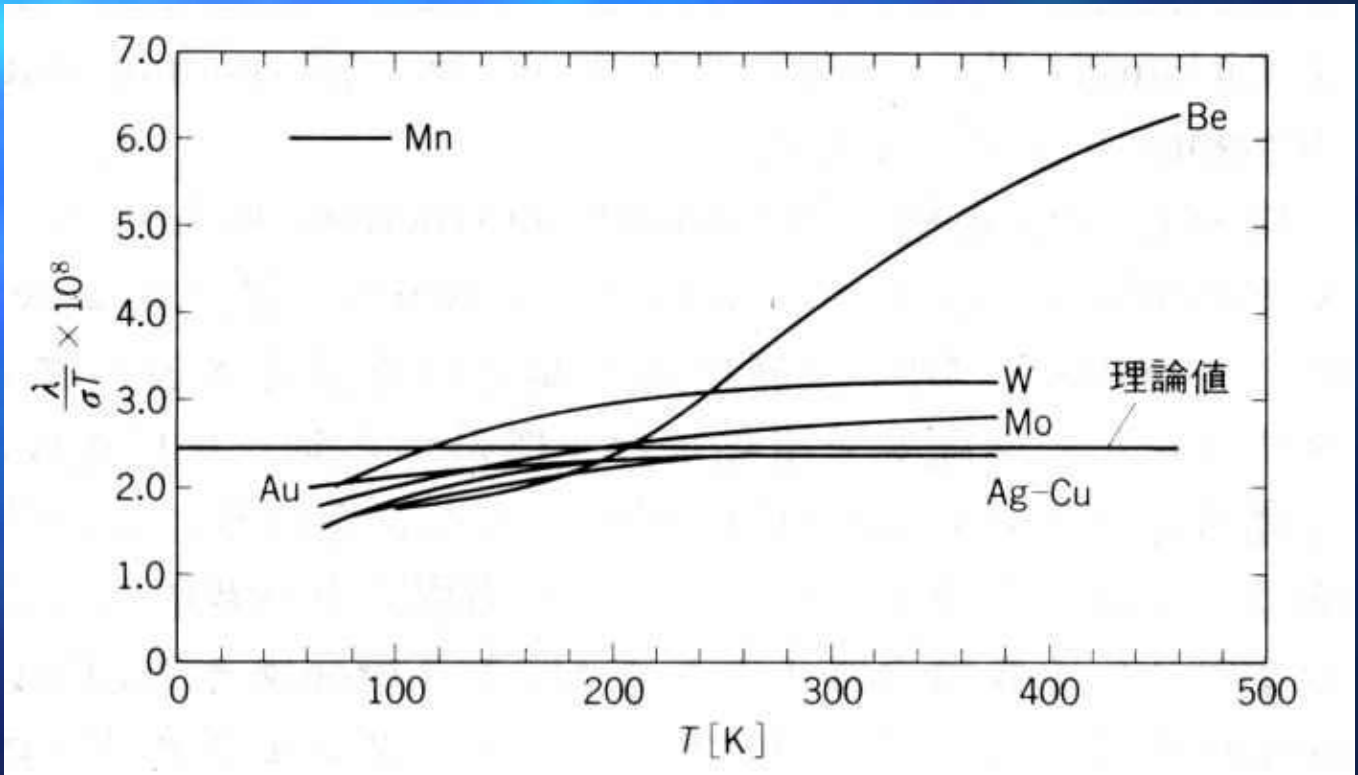
金属の場合：
Wiedemann-Franz 則が成り立つ

$$\lambda = \frac{\pi^2}{3} \frac{k^2}{e^2} T\sigma \approx 2.45 \times 10^{-8} T\sigma \propto T\sigma$$

Wiedemann-Franz's Law (WFL)

$$\lambda = \frac{\pi^3}{3}\frac{k^2}{e^2}T\sigma \approx 2.45\times10^{-8}T\sigma \propto T\sigma$$

- Lorentz ratio



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Electron

Phonon

Deformation

- Elasticity
- Ductility, Brittleness
- …

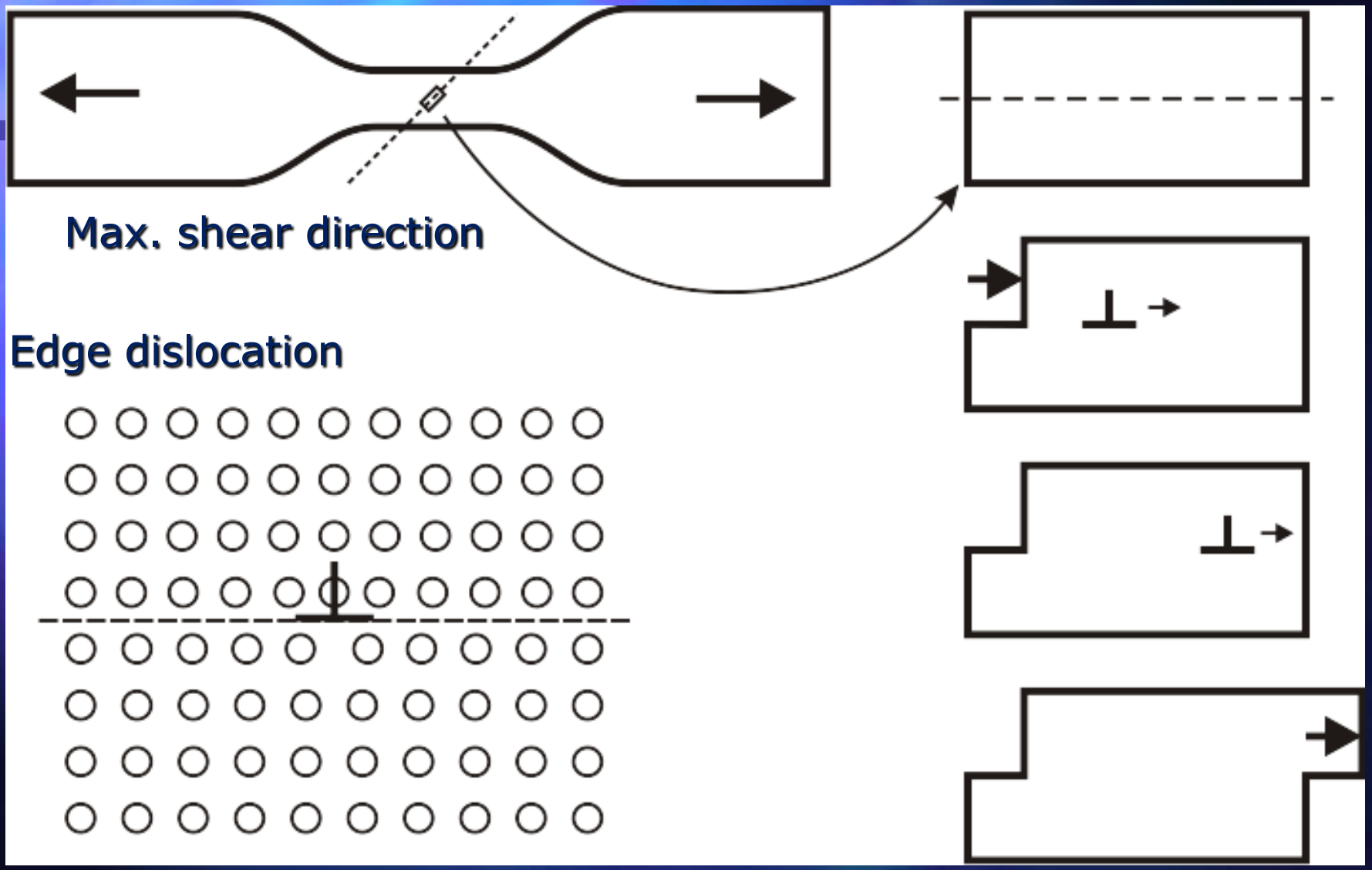
- Thermal expansion

Motion of dislocation

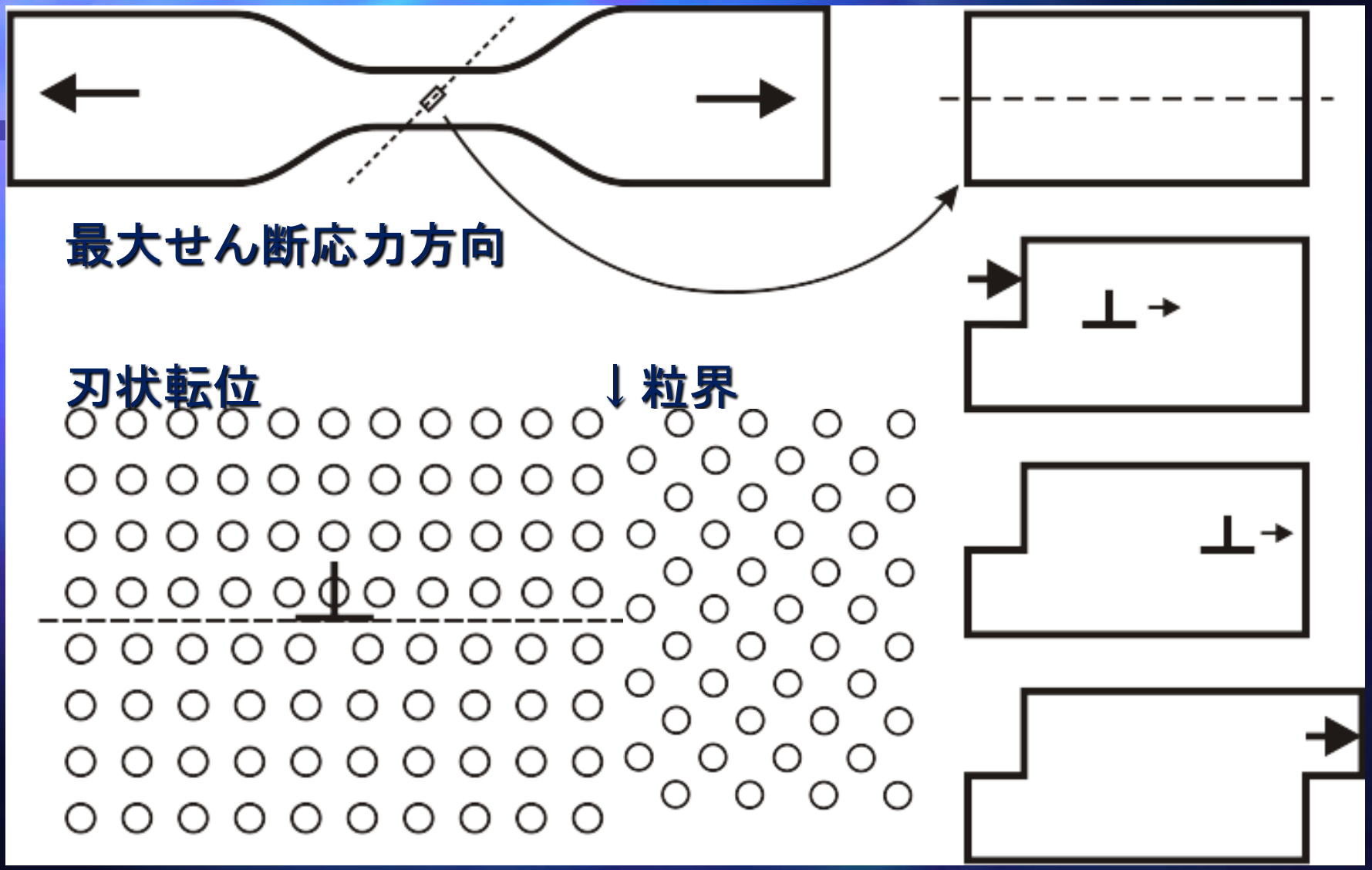
- Edge dislocation and screw dislocation

Energy change in the motion

Deformation by motion of dislocation



変形＝転位の動き



Thermal expansion

- Why it arise ?

Specific heat (capacity)

Definition : Energy required to increase the temperature of an unit quantity of the material by an unit temperature

J/(g K), J/(mol K) or J/K

- Gas

  depending on pressure and volume

$$C_p = \left(\frac{\partial U}{\partial T}\right)_p = \left(\frac{\partial H}{\partial T}\right)_p \qquad C_V = \left(\frac{\partial U}{\partial T}\right)_V \qquad C_p - C_V = kN_A (= R)$$

- Liquid

- Solid

  Dulong-Petit's law