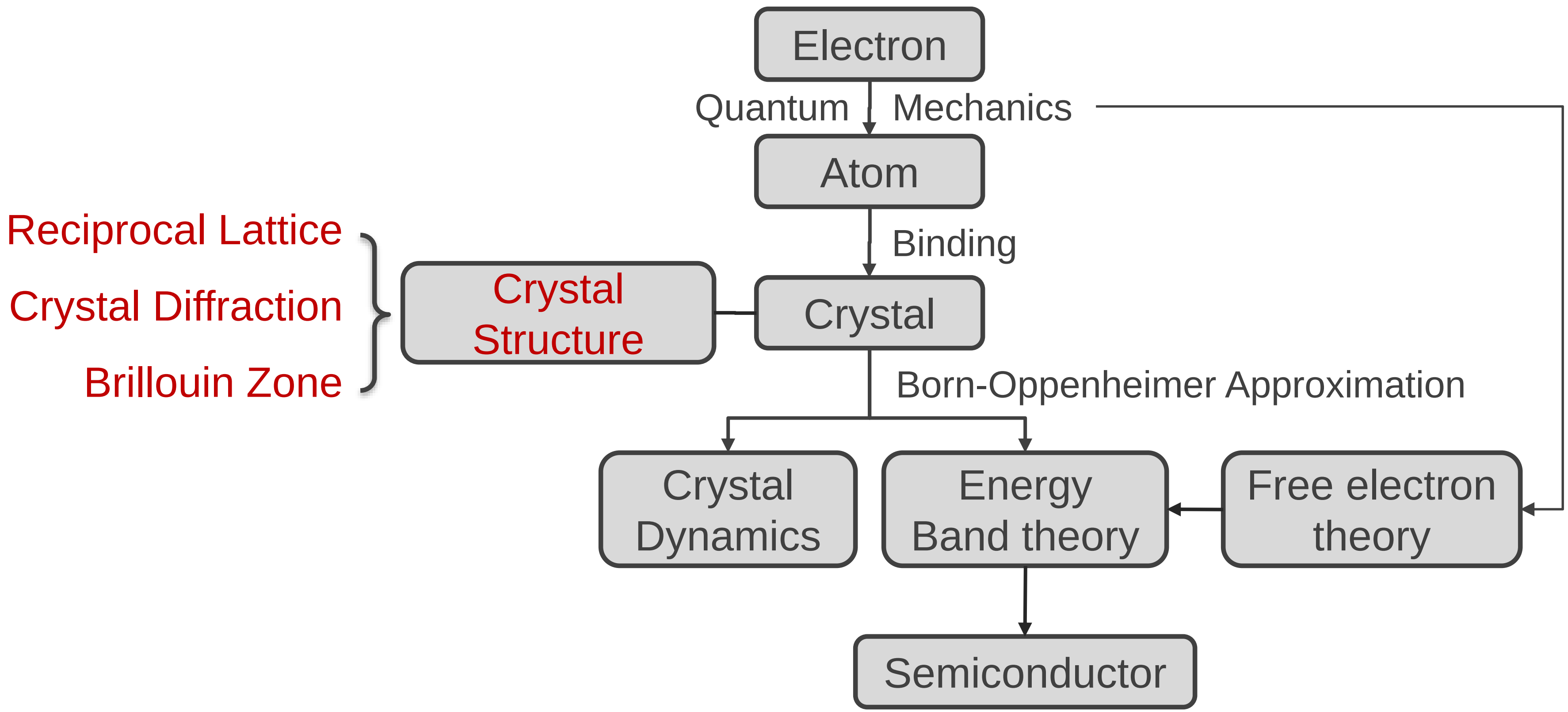
Chapter 1

Formation of Crystal

Profile


Electron
Quantum Mechanics
Atom
Binding
Reciprocal Lattice
Crystal Diffraction
Brillouin Zone
Crystal Structure
Crystal
Born-Oppenheimer Approximation
Crystal Dynamics
Energy Band theory
Free electron theory
Semiconductor

Chapter 1 Formation of Crystal

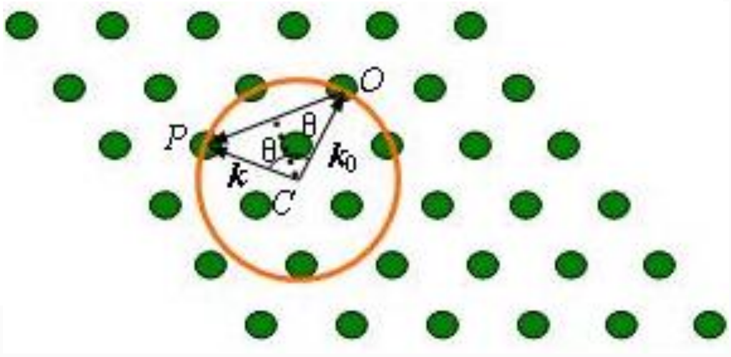
1.1 Quantum Mechanics and atomic structure

1.2 Interatomic bonding in solids

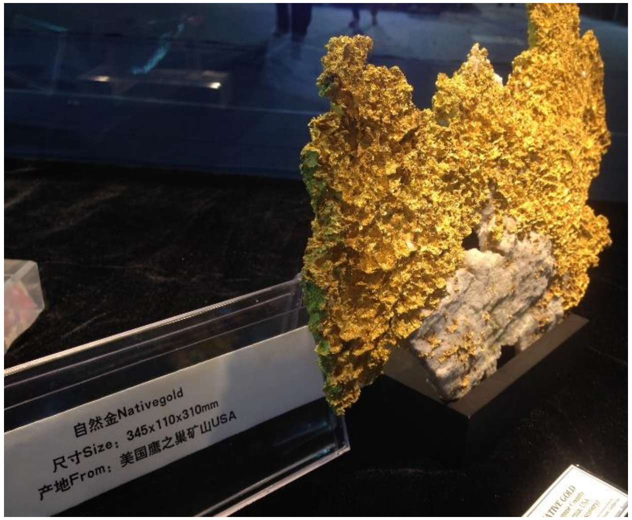
1.3 Crystal structure and typical crystals

1.4 Reciprocal Lattice and Brillouin Zone

- 1.4.1 Reciprocal Lattice
- 1.4.2 Crystal Diffraction
- 1.4.3 Brillouin Zone



·Fourier series ·Reciprocal lattice (space) ·Reciprocal space & wave-vector space (k-space)



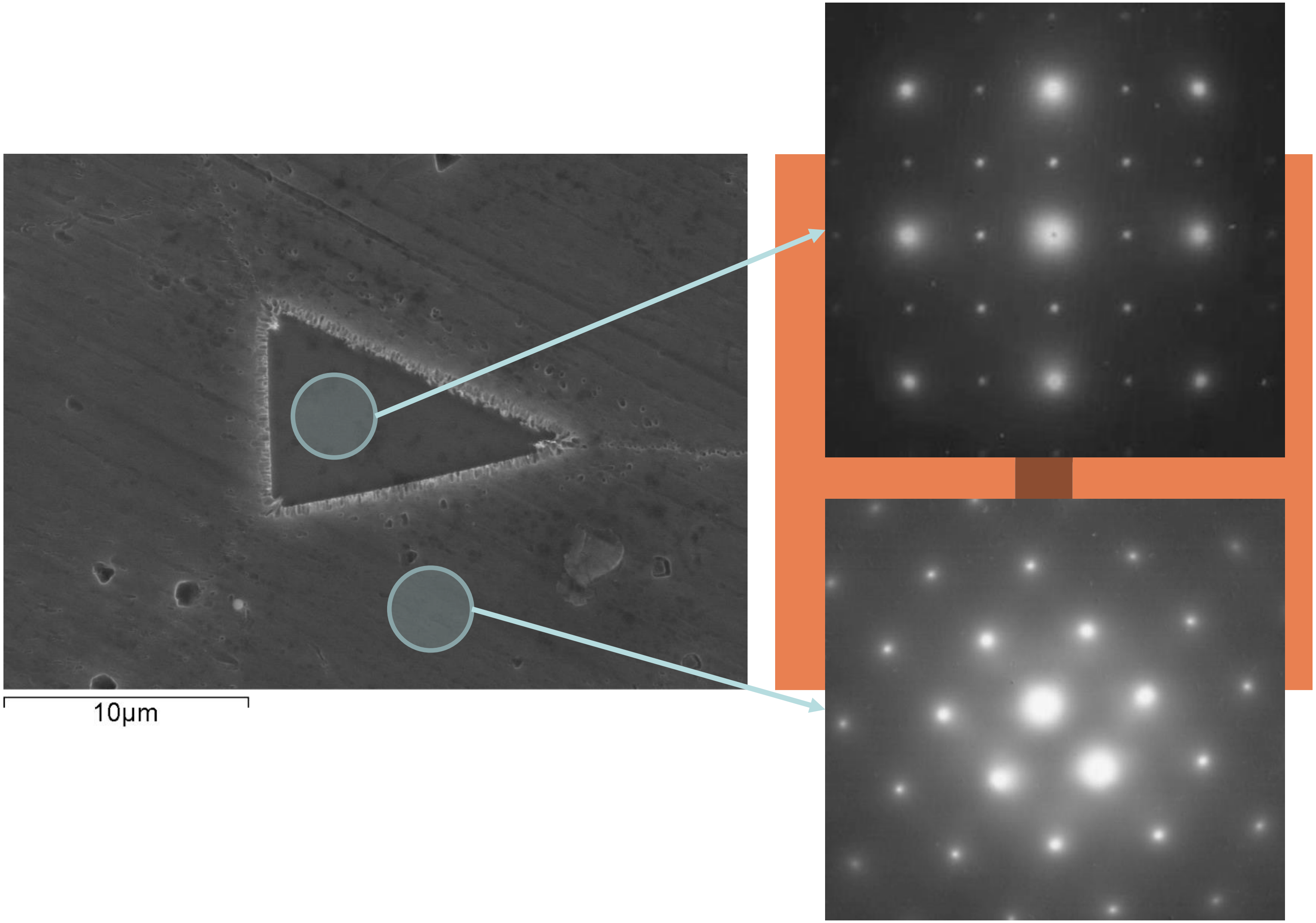
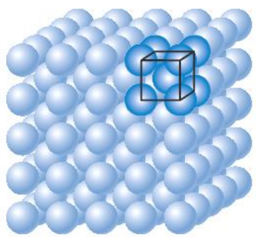
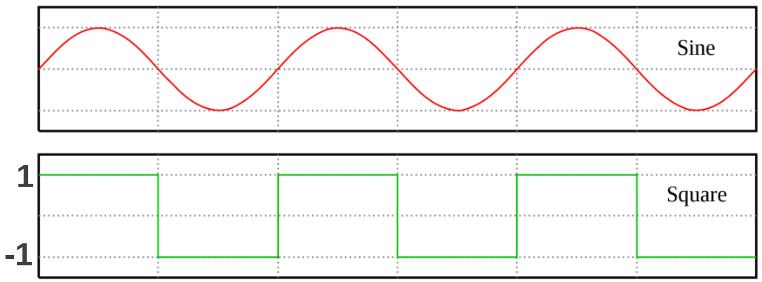


Image of Reciprocal lattice



$$n(\mathbf{r}+\mathrm{T}) = n(\mathbf{r})$$

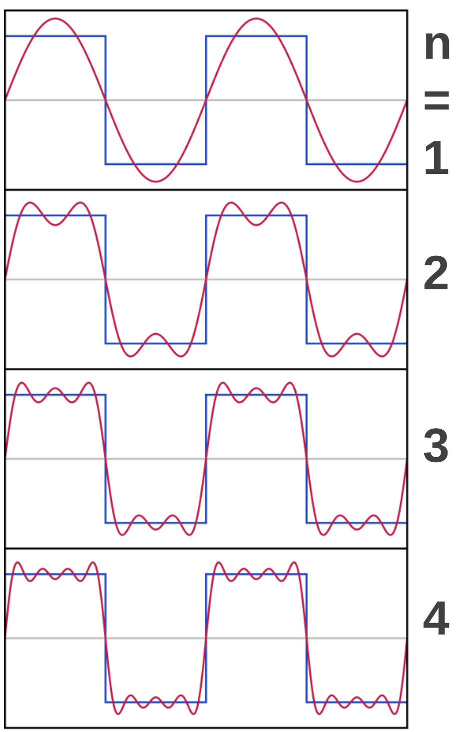


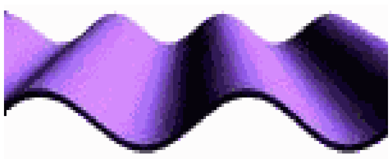
$$f(x) = \sin x$$

$$f(x) = \begin{cases} -1 & (2k-1)\pi \le x < 2k\pi \\ 1 & 2k\pi \le x < (2k+1)\pi \end{cases}$$

$$f(x) \sim \frac{4}{\pi}\sin x + \frac{4}{3\pi}\sin 3x + \frac{4}{5\pi}\sin 5x + \frac{4}{7\pi}\sin 7x + \ldots$$

$$= \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{\sin(2n-1)x}{2n-1}$$

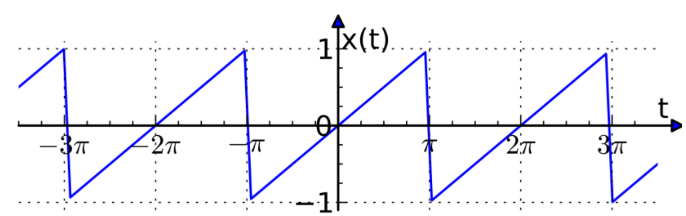


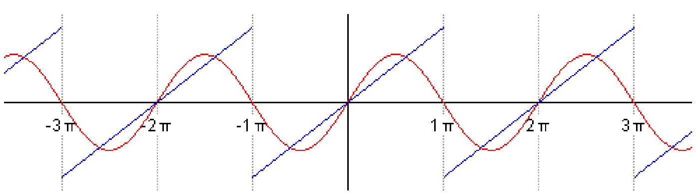


First four Fourier approximations for a square wave

$$f(x+2\pi) = f(x)$$

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n \cos nx + b_n \sin nx)$$





$$f(x+2\pi)=f(x)$$

$$f(x)=\frac{a_0}{2}+\sum_{n=1}^{\infty}(a_n\cos nx+b_n\sin nx)$$

$$a_0=\frac{1}{\pi}\int_{-\pi}^{\pi}f(x)\mathrm{d}x$$

$$a_n=\frac{1}{\pi}\int_{-\pi}^{\pi}f(x)\cos nx\mathrm{d}x$$

$$b_n=\frac{1}{\pi}\int_{-\pi}^{\pi}f(x)\sin nx\mathrm{d}x$$

$$\mathrm{e}^{\pm\mathrm{i}x}=\cos x\pm\mathrm{i}\sin x$$

$$\mathrm{e}^{\mathrm{i}\pi}+1=0$$

$$\cos nx=\frac{1}{2}(\mathrm{e}^{\mathrm{i}nx}+\mathrm{e}^{-\mathrm{i}nx})$$

$$\sin nx=-\frac{\mathrm{i}}{2}(\mathrm{e}^{\mathrm{i}nx}-\mathrm{e}^{-\mathrm{i}nx})$$

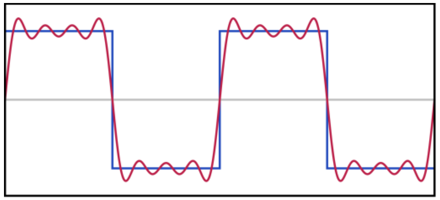
$$f(x)=\sum_n c_n\mathrm{e}^{\mathrm{i}nx}$$

$$c_n=\frac{1}{2\pi}\int_{-\pi}^{\pi}f(x)\mathrm{e}^{-\mathrm{i}nx}\mathrm{d}x$$

$$n(x+a)=n(x)$$

$$n(x)=\sum_{p} n_p e^{i\frac{2\pi p}{a}x}$$

1 $n(x+a)=n(x)$



$$n(x)=\sum_p n_p e^{i\frac{2\pi p}{a}x}$$

3

$$\vec{\mathbf{x}} = x\hat{i}$$

$$\vec{\mathbf{G}} = \frac{2\pi p}{a}\hat{i}$$

$$n(x)=\sum_p n_p e^{i\mathbf{G}\cdot\mathbf{x}}$$

$$=\sum_G n_G e^{i\mathbf{G}\cdot\mathbf{x}}$$

2

i

$-2a$ $-a$ 0 a $2a$

$$\mathbf{a} = a\hat{i}$$

$$\mathbf{R} = ma\hat{i} = m\mathbf{a}$$

4

$-4\pi/a$ $-2\pi/a$ 0 $2\pi/a$ $4\pi/a$

$$\mathbf{b} = \frac{2\pi}{a}\hat{i}$$

$$\mathbf{G} = \frac{2\pi p}{a}\hat{i} = p\mathbf{b}$$

倒易点阵
倒易空间
波矢空间

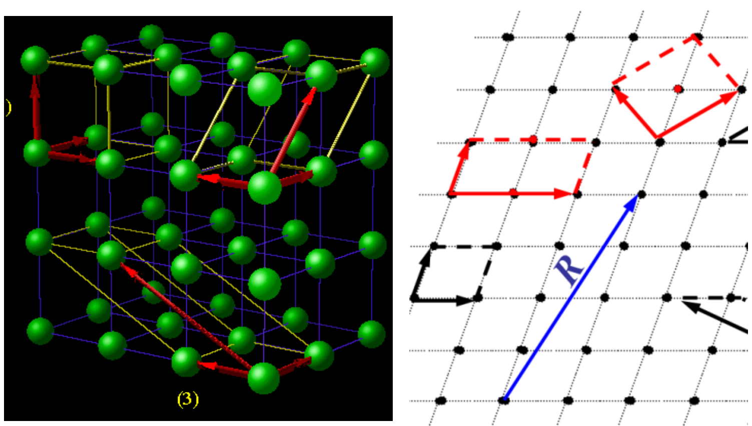
1 **1D** $$n(\mathbf{x}+\mathbf{a}) = n(\mathbf{x})$$

$$n(\mathbf{x}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{x}}$$

$$\mathbf{a} = a\hat{i} \qquad \mathbf{R} = ma\hat{i} = m\mathbf{a}$$

$$\mathbf{b} = \frac{2\pi}{a}\hat{i} \qquad \mathbf{G} = \frac{2\pi p}{a}\hat{i} = p\mathbf{b}$$

2



$$\mathbf{R} = u_1\mathbf{a}_1 + u_2\mathbf{a}_2 + u_3\mathbf{a}_3$$

3 **3D** $$n(\mathbf{r}+\mathbf{R}) = n(\mathbf{r})$$

$$n(\mathbf{r}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{r}}$$

4 $$n(\mathbf{r}+\mathbf{R}) = \sum_G n_G e^{i\mathbf{G}\cdot(\mathbf{r}+\mathbf{R})} = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{r}} e^{i\mathbf{G}\cdot\mathbf{R}}$$

$$=$$

$$n(\mathbf{r}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{r}}$$

$$e^{\pm ix} = \cos x \pm i\sin x$$

$$e^{i\mathbf{G}\cdot\mathbf{R}} = 1 \qquad \mathbf{G}\cdot\mathbf{R} = 2\pi m, \quad m - \text{integers}$$

5

$$\mathbf{G} = v_1\mathbf{b}_1 + v_2\mathbf{b}_2 + v_3\mathbf{b}_3$$

$$\mathbf{R} = u_1\mathbf{a}_1 + u_2\mathbf{a}_2 + u_3\mathbf{a}_3$$

$$\mathbf{b}_i\cdot\mathbf{a}_j = 2\pi\delta_{ij} \qquad \delta_{ij} = \begin{cases} 0 & i \neq j \\ 1 & i = j \end{cases} (i, j = 1, 2, 3)$$

$$\mathbf{G}\cdot\mathbf{R} = (u_1\mathbf{a}_1 + u_2\mathbf{a}_2 + u_3\mathbf{a}_3)\cdot(v_1\mathbf{b}_1 + v_2\mathbf{b}_2 + v_3\mathbf{b}_3) = (u_1v_1\mathbf{a}_1\cdot\mathbf{b}_1 + u_2v_2\mathbf{a}_2\cdot\mathbf{b}_2 + u_3v_3\mathbf{a}_3\cdot\mathbf{b}_3) = 2\pi m$$

0

$$\mathbf{G} = v_1\mathbf{b}_1 + v_2\mathbf{b}_2 + v_3\mathbf{b}_3$$

$$\mathbf{b}_i \cdot \mathbf{a}_j = 2\pi\delta_{ij} \qquad \delta_{ij} = \begin{cases} 0 & i \neq j \\ 1 & i = j \end{cases} (i, j = 1, 2, 3)$$

1

$$\mathbf{b}_1 \perp (\mathbf{a}_2, \mathbf{a}_3)$$

$$\mathbf{b}_1 = (\mathbf{a}_2 \times \mathbf{a}_3)$$

$$\mathbf{b}_1 = c \cdot (\mathbf{a}_2 \times \mathbf{a}_3)$$

2

$$\mathbf{a}_1 \cdot \mathbf{b}_1 = c\mathbf{a}_1 \cdot (\mathbf{a}_2 \times \mathbf{a}_3)$$

$$2\pi = cv$$

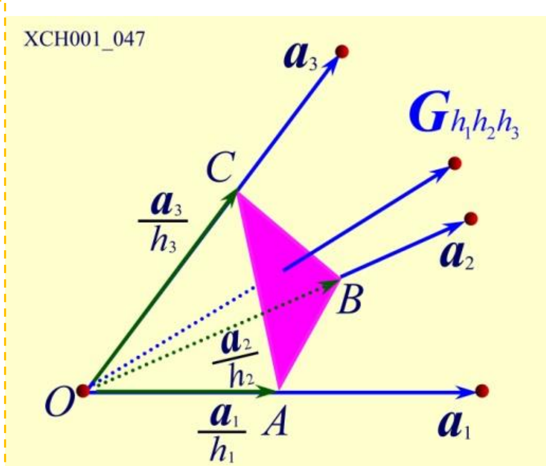
$$c = 2\pi / v$$

3

$$= \frac{2\pi}{v}\mathbf{a}_2 \times \mathbf{a}_3$$

$$\mathbf{b}_2 = \frac{2\pi}{v}\mathbf{a}_3 \times \mathbf{a}_1$$

$$\mathbf{b}_3 = \frac{2\pi}{v}\mathbf{a}_1 \times \mathbf{a}_2$$



$$n(\mathbf{r} + \mathbf{R}) = n(\mathbf{r})$$

$$n(\mathbf{r}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{r}}$$

1

$$v_a = \mathbf{a}_1 \cdot (\mathbf{a}_2 \times \mathbf{a}_3)$$

$$v_b = \mathbf{b}_1 \cdot (\mathbf{b}_2 \times \mathbf{b}_3)$$

$$v_a = \frac{(2\pi)^3}{v_b}$$

2

$$\mathbf{G}_{h_1h_2h_3} \perp (h_1h_2h_3)$$

$$\left|\mathbf{G}_{h_1h_2h_3}\right| = \frac{2\pi}{d_{h_1h_2h_3}}$$

$$d_{h_1h_2h_3} = \mathbf{OA} \bullet \frac{\vec{\mathbf{G}}_{h_1h_2h_3}}{G_{h_1h_2h_3}} = \frac{\mathbf{a}_1}{h_1} \bullet \frac{(h_1\mathbf{b}_1 + h_2\mathbf{b}_2 + h_3\mathbf{b}_3)}{G_{h_1h_2h_3}} = \frac{2\pi}{G_{h_1h_2h_3}}$$

3

SC-SC FCC-BCC BCC-FCC

1D

$$n(\mathbf{x}+\mathbf{a}) = n(\mathbf{x})$$

$$n(\mathbf{x}) = \sum_{G} n_G e^{i\mathbf{G}\cdot\mathbf{x}}$$

$$\mathbf{b} = \frac{2\pi}{a}\hat{i}$$

$$\mathbf{G} = \frac{2\pi p}{a}\hat{i} = p\mathbf{b}$$

1D

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$$n(\mathbf{x}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{x}}$$

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3D

$$n(\mathbf{r}+\mathbf{R}) = n(\mathbf{r})$$

$$n(\mathbf{r}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{r}}$$

$$\mathbf{b}_i \cdot \mathbf{a}_j = 2\pi\delta_{ij} \quad \delta_{ij} = \begin{cases} 0 & i \neq j \\ 1 & i = j \end{cases} (i, j = 1, 2, 3)$$

$$\mathbf{G} = v_1\mathbf{b}_1 + v_2\mathbf{b}_2 + v_3\mathbf{b}_3$$

$$\mathbf{b}_i \cdot \mathbf{a}_j = 2\pi\delta_{ij} \qquad \delta_{ij} = \begin{cases} 0 & i \neq j \\ 1 & i = j \end{cases} (i, j = 1, 2, 3)$$

	Real lattice	Reciprocal lattice		Volume
SC	$\begin{cases} \mathrm{a}_1 = a\hat{\mathrm{x}} \\ \mathrm{a}_2 = a\hat{\mathrm{y}} \\ \mathrm{a}_3 = a\hat{\mathrm{z}} \end{cases}$	$\begin{cases} \mathrm{b}_1 = (2\pi/a)\hat{\mathrm{x}} \\ \mathrm{b}_2 = (2\pi/a)\hat{\mathrm{y}} \\ \mathrm{b}_3 = (2\pi/a)\hat{\mathrm{z}} \end{cases}$	SC	$(2\pi/a)^3$
FCC	$\begin{cases} \mathrm{a}_1 = \frac{1}{2}a(\hat{\mathrm{y}} + \hat{\mathrm{z}}) \\ \mathrm{a}_2 = \frac{1}{2}a(\hat{\mathrm{z}} + \hat{\mathrm{x}}) \\ \mathrm{a}_3 = \frac{1}{2}a(\hat{\mathrm{x}} + \hat{\mathrm{y}}) \end{cases}$	$\begin{cases} \mathrm{b}_1 = \frac{2\pi}{a}(-\hat{\mathrm{x}} + \hat{\mathrm{y}} + \hat{\mathrm{z}}) \\ \mathrm{b}_2 = \frac{2\pi}{a}(\hat{\mathrm{x}} - \hat{\mathrm{y}} + \hat{\mathrm{z}}) \\ \mathrm{b}_3 = \frac{2\pi}{a}(\hat{\mathrm{x}} + \hat{\mathrm{y}} - \hat{\mathrm{z}}) \end{cases}$	BCC	$4(2\pi/a)^3$
BCC	$\begin{cases} \mathrm{a}_1 = \frac{1}{2}a(-\hat{\mathrm{x}} + \hat{\mathrm{y}} + \hat{\mathrm{z}}) \\ \mathrm{a}_2 = \frac{1}{2}a(\hat{\mathrm{x}} - \hat{\mathrm{y}} + \hat{\mathrm{z}}) \\ \mathrm{a}_3 = \frac{1}{2}a(\hat{\mathrm{x}} + \hat{\mathrm{y}} - \hat{\mathrm{z}}) \end{cases}$	$\begin{cases} \mathrm{b}_1 = \frac{2\pi}{a}(\hat{\mathrm{y}} + \hat{\mathrm{z}}) \\ \mathrm{b}_2 = \frac{2\pi}{a}(\hat{\mathrm{x}} + \hat{\mathrm{z}}) \\ \mathrm{b}_3 = \frac{2\pi}{a}(\hat{\mathrm{x}} + \hat{\mathrm{y}}) \end{cases}$	FCC	$2(2\pi/a)^3$

1D

$$n(\mathbf{x}+\mathbf{a}) = n(\mathbf{x})$$

$$n(\mathbf{x}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{x}}$$

$$\mathbf{b} = \frac{2\pi}{a}\hat{i}$$

$$\mathbf{G} = \frac{2\pi p}{a}\hat{i} = p\mathbf{b}$$

3D

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$$\mathbf{G} = v_1\mathbf{b}_1 + v_2\mathbf{b}_2 + v_3\mathbf{b}_3$$

$$\mathbf{b}_1 = \frac{2\pi}{v}\mathbf{a}_2 \times \mathbf{a}_3$$

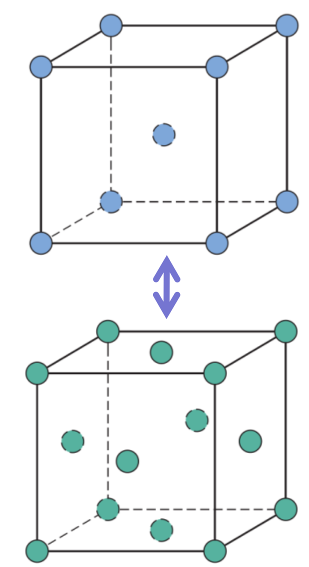
$$\mathbf{b}_2 = \frac{2\pi}{v}\mathbf{a}_3 \times \mathbf{a}_1$$

$$\mathbf{b}_3 = \frac{2\pi}{v}\mathbf{a}_1 \times \mathbf{a}_2$$

$$v_b = \frac{(2\pi)^3}{v_a}$$

$$\mathbf{G}_{v_1v_2v_3} \perp (v_1v_2v_3)$$

$$\left|\mathbf{G}_{v_1v_2v_3}\right| = \frac{2\pi}{d_{v_1v_2v_3}}$$

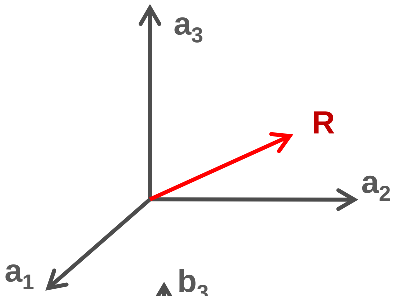


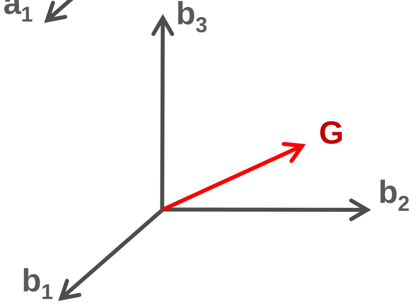
$$\mathbf{R} = u_1\mathbf{a}_1 + u_2\mathbf{a}_2 + u_3\mathbf{a}_3$$

$$n(\mathbf{r}+\mathbf{R}) = n(\mathbf{r}) \qquad n(\mathbf{r}) = \sum_G n_G e^{i\mathbf{G}\cdot\mathbf{r}}$$

$$\mathbf{b}_i \cdot \mathbf{a}_j = 2\pi\delta_{ij} \qquad \delta_{ij} = \begin{cases} 0 & i \neq j \\ 1 & i = j \end{cases} (i, j = 1, 2, 3)$$

$$\mathbf{G} = v_1\mathbf{b}_1 + v_2\mathbf{b}_2 + v_3\mathbf{b}_3$$

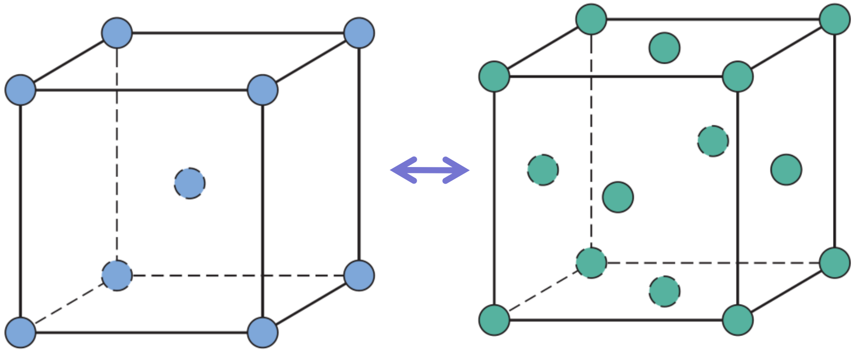


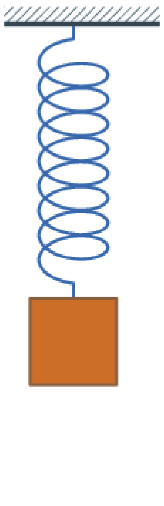


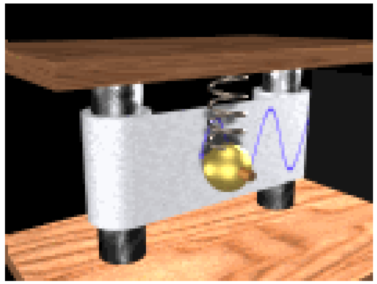
$$v_b = \frac{(2\pi)^3}{v_a}$$

$$\mathbf{G}_{v_1v_2v_3} \perp (v_1v_2v_3)$$

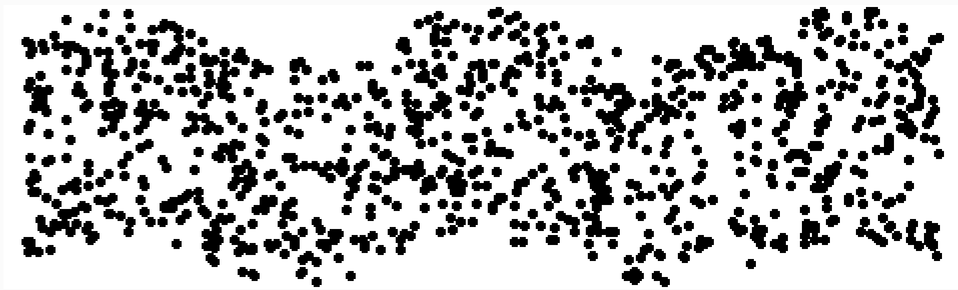
$$\left|\mathbf{G}_{v_1v_2v_3}\right| = \frac{2\pi}{d_{v_1v_2v_3}}$$

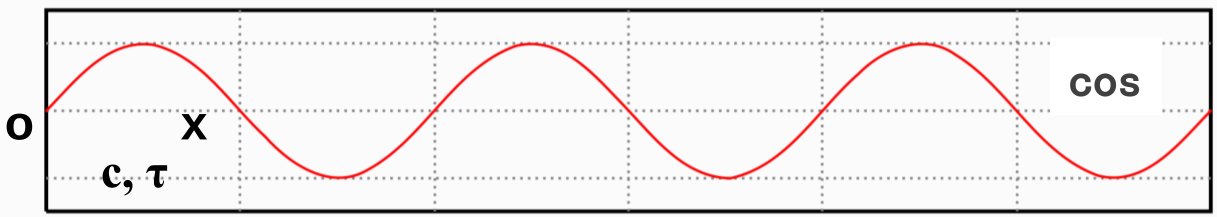






$$u(x=0,t)=A\cos(\omega t+\varphi_0)$$





$$u(x,t)=A\cos[\omega(t-\tau)+\varphi_0]=A\cos[\omega(t-\frac{x}{c})+\varphi_0]$$

$$=A\cos(\omega t-\frac{2\pi}{T}\frac{x}{c}+\varphi_0)=A\cos(\omega t-\frac{2\pi}{\lambda}x+\varphi_0)=A\cos(\omega t-kx+\varphi_0)$$

$$u(x,t) = A\cos(\omega t - \frac{2\pi}{\lambda}x + \varphi_0)$$
$$= A\cos(\omega t - kx + \varphi_0)$$

$$\tilde{u}(x,t) = \tilde{A}e^{i(\omega t - kx)}$$

$$\nu = \frac{1}{T}$$

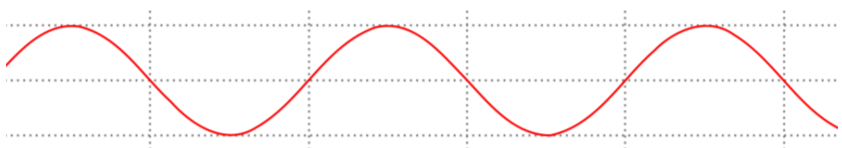
$$\lambda = cT = \frac{c}{\nu}$$

$$T = \frac{2\pi}{\omega}$$

$$\omega = \frac{2\pi}{T} = 2\pi\nu$$

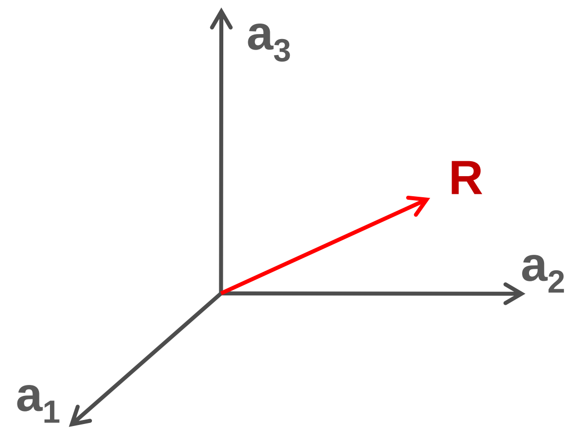
$$c = \frac{\lambda}{T} = \frac{\omega}{2\pi}\lambda = \frac{\omega}{k}$$

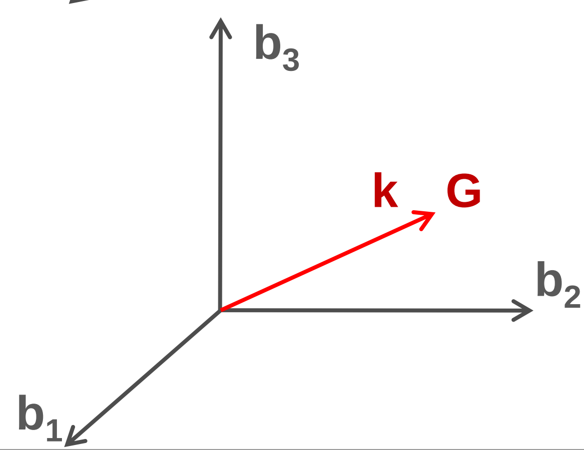
$$k = \frac{2\pi}{\lambda} \qquad \mathbf{k} = \frac{2\pi}{\lambda}\hat{\mathrm{n}}$$



$$\mathbf{p} = \hbar\mathbf{k}$$

$$E_k = \frac{(\hbar k)^2}{2m}$$





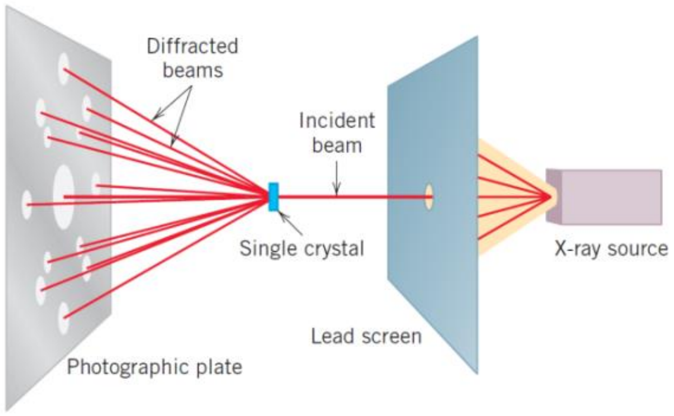
$$\mathbf{k} = \frac{2\pi}{\lambda}\hat{\mathrm{n}} \quad \mathbf{b} = \frac{2\pi}{a}\hat{\mathrm{i}} \quad \mathbf{G} = \frac{2\pi p}{a}\hat{\mathrm{i}}$$

How to learn?

1 Basic Concept

2 Train of Thought

- Periodic function
- Fourier series
- Reciprocal vector
- Reciprocal lattice
- Wave-vector space



Chapter 1 Formation of Crystal

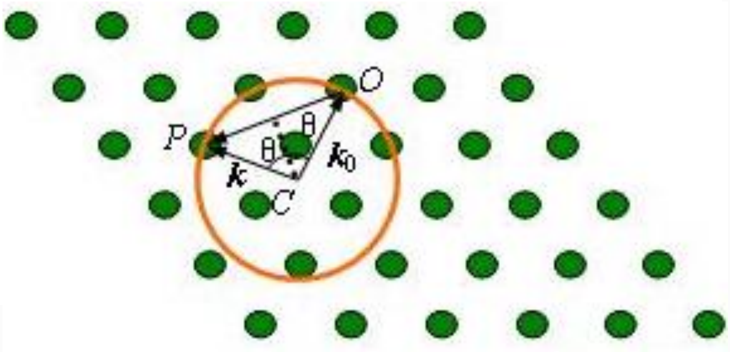
1.1 Quantum Mechanics and atomic structure

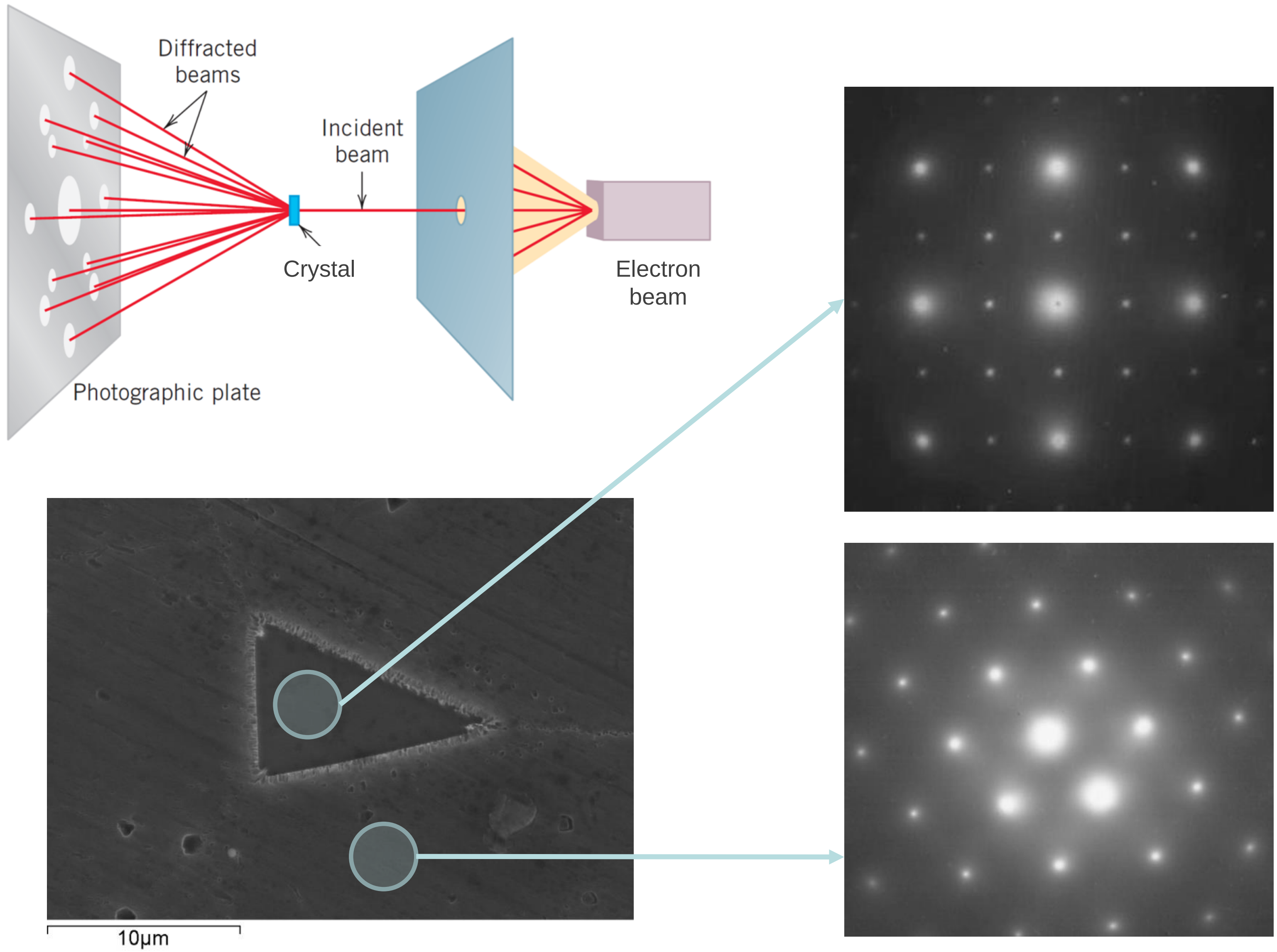
1.2 Interatomic bonding in solids

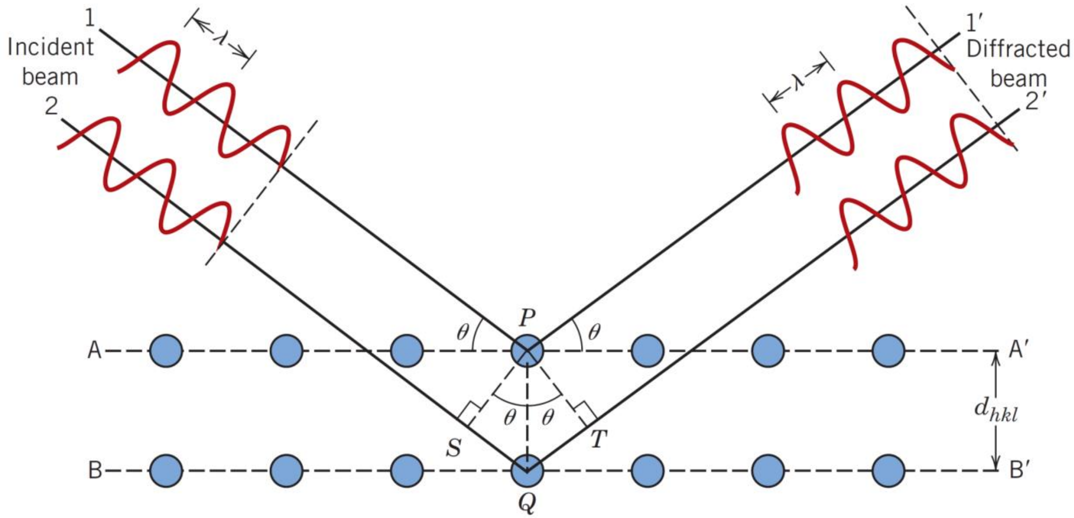
1.3 Crystal structure and typical crystals

1.4 Reciprocal Lattice and Brillouin Zone

- 1.4.1 Reciprocal Lattice
- 1.4.2 Crystal Diffraction
- 1.4.3 Brillouin Zone

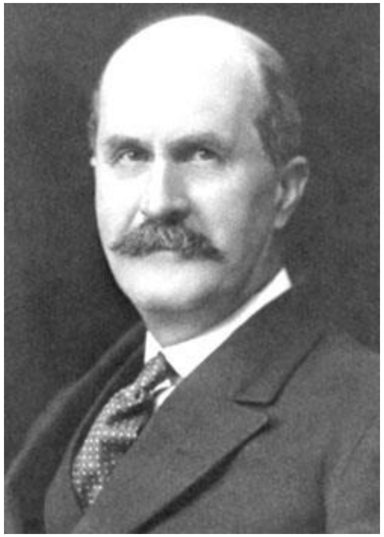



Diffracted beams
Incident beam
Crystal
Electron beam
Photographic plate
10μm

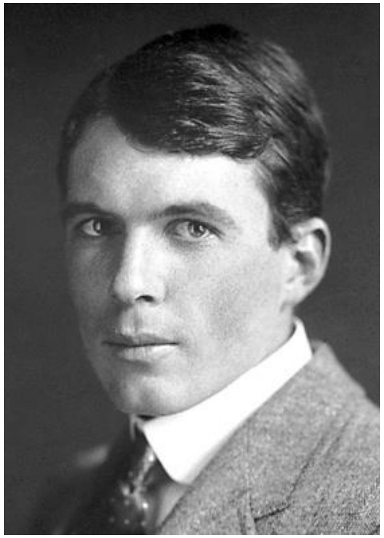


$$2d\sin\theta = n\lambda$$

Nobel Prize 1915



Sir William Henry Bragg (1862-1942)



William Lawrence Bragg (1890-1971)

A. Piccard, E. Henriot, P. Ehrenfest, E. Herzen, Th. De Donder, E. Schrödinger, J.E. Verschaffelt, W. Pauli, W. Heisenberg, R.H. Fowler, L. Brillouin;
A. P. Debye, M. Knudsen, W.L. Bragg, H.A. Kramers, P.A.M. Dirac, A.H. Compton, L. de Broglie, M. Born, N. Bohr;
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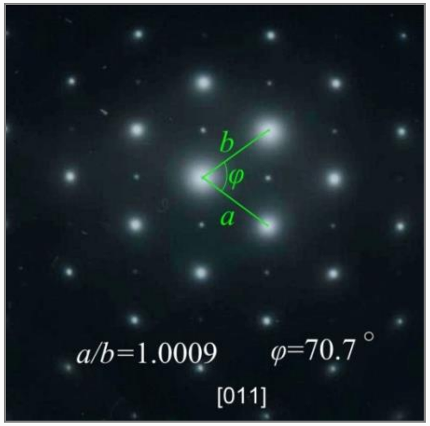
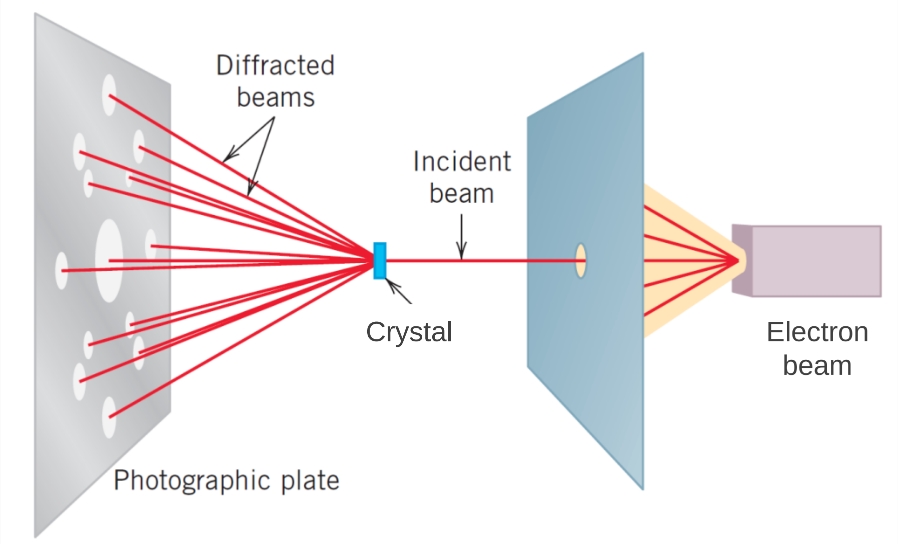
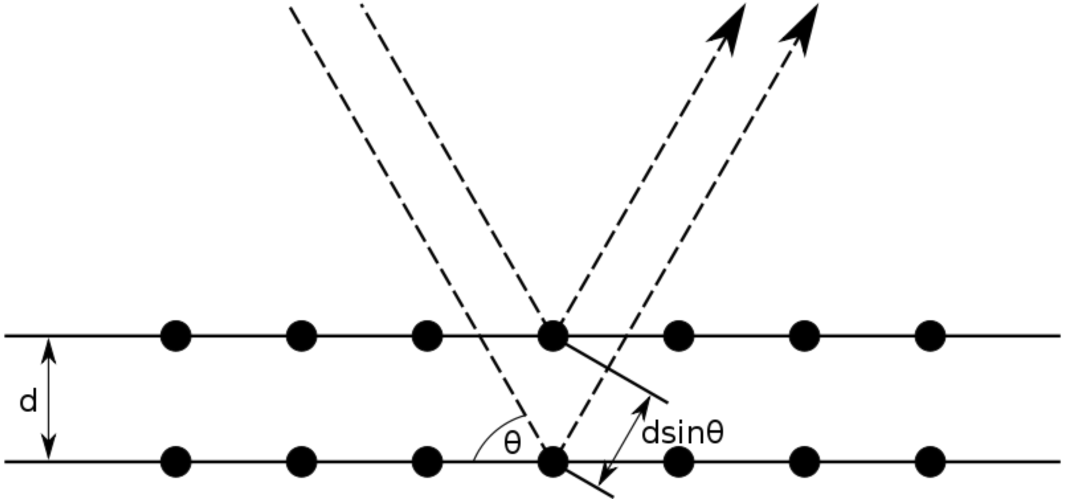
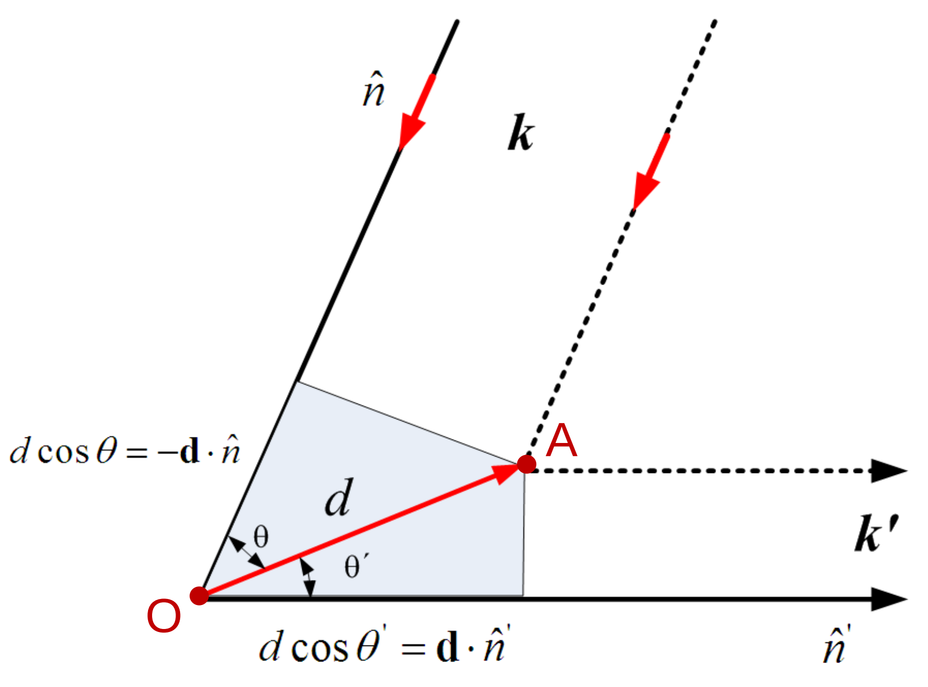
·The Bragg law ·Laue equation ·Ewald structure







$$2d\sin\theta = n\lambda$$



$$\mathbf{k} = \frac{2\pi}{\lambda}\hat{n}$$

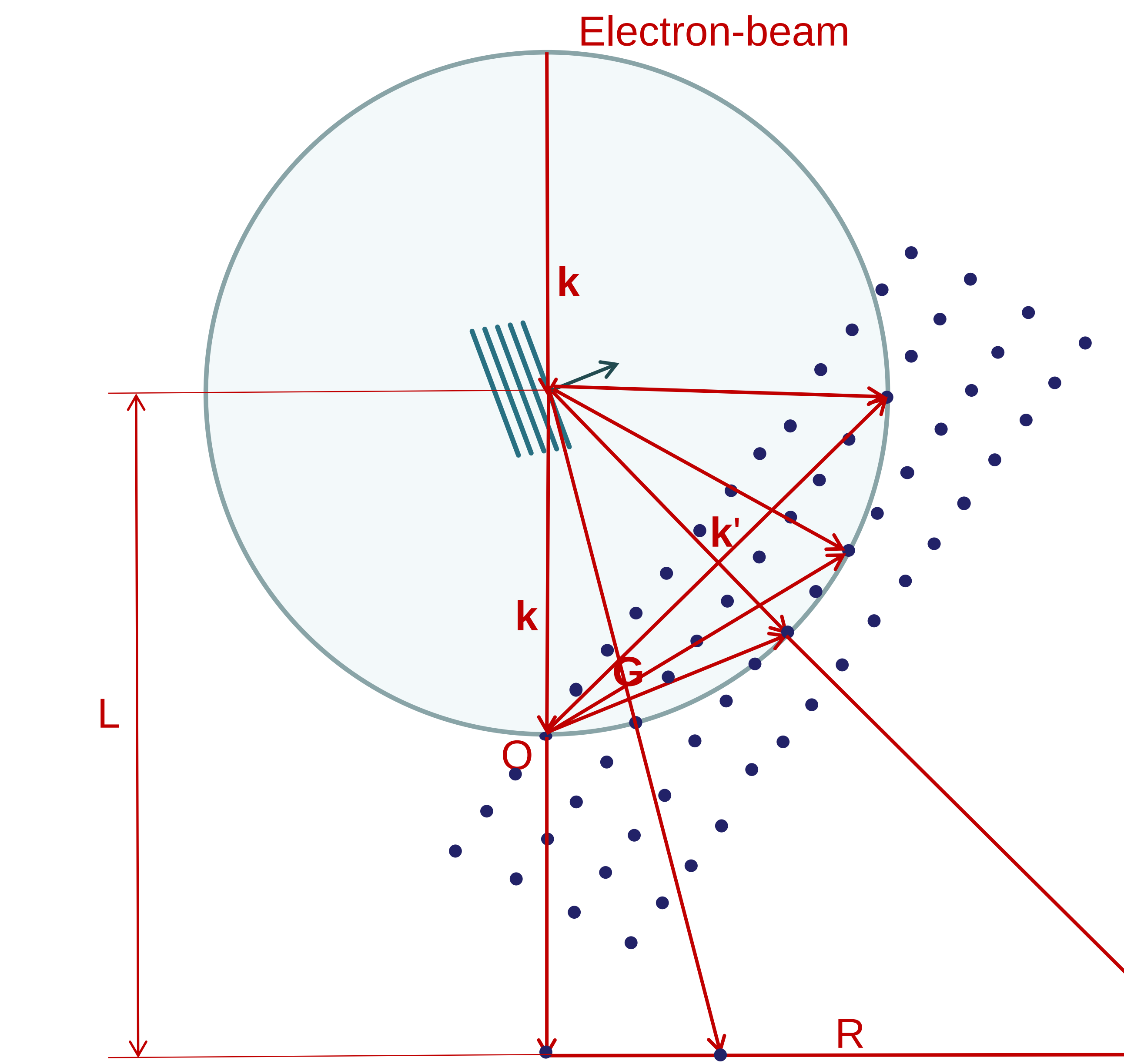
$$\mathbf{k}' = \frac{2\pi}{\lambda}\hat{n}'$$

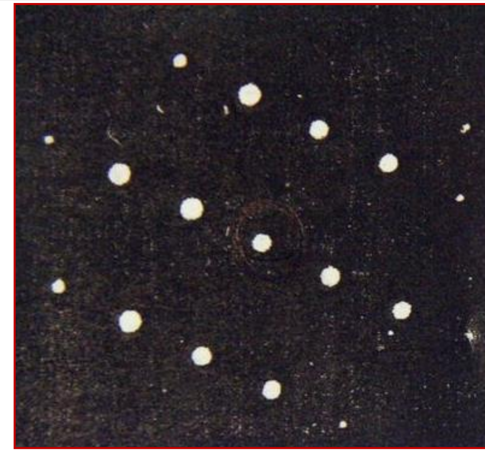
$$d\cos\theta + d\cos\theta' = \mathbf{d}\cdot(\hat{\mathbf{n}}' - \hat{\mathbf{n}}) = m\lambda$$

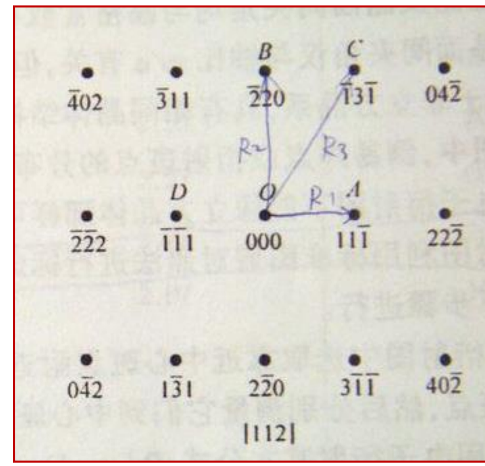
$$\mathbf{d}\cdot(\mathbf{k}' - \mathbf{k}) = 2\pi m$$

$$\mathbf{d}\cdot\mathbf{G} = 2\pi n$$

$$\mathbf{k}' - \mathbf{k} = \mathbf{G} \quad \Delta\mathbf{k} = \mathbf{G}$$

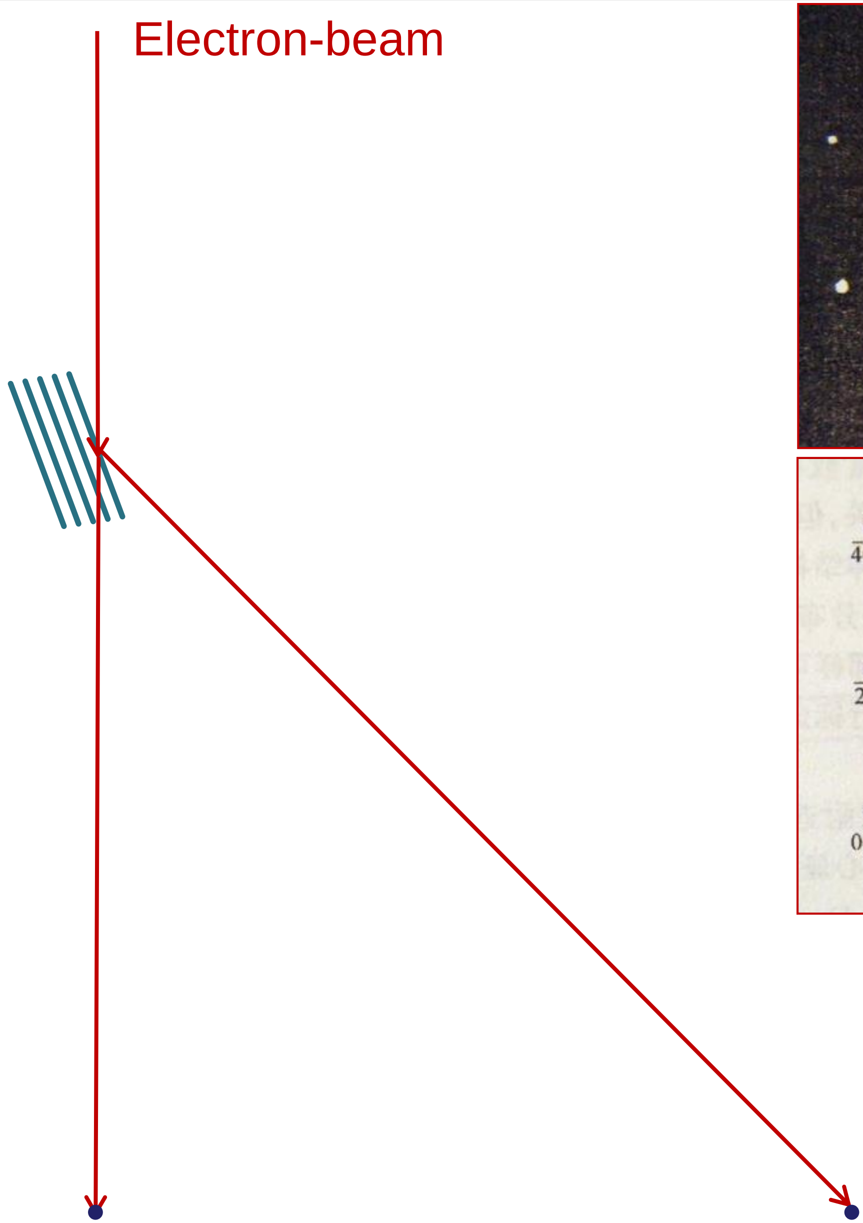


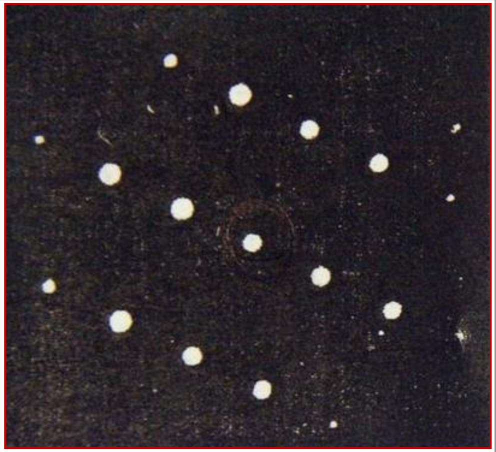


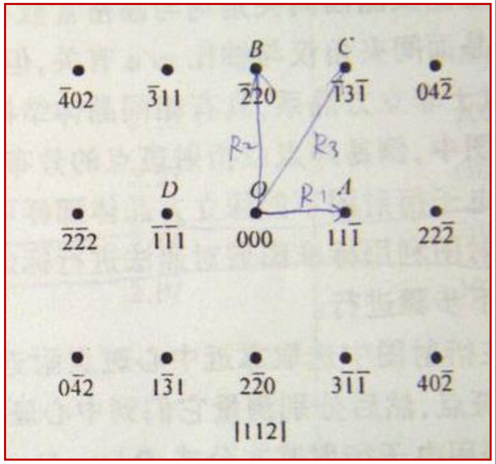


$$\mathbf{k'-k=G}$$

$$Rd=L\lambda$$

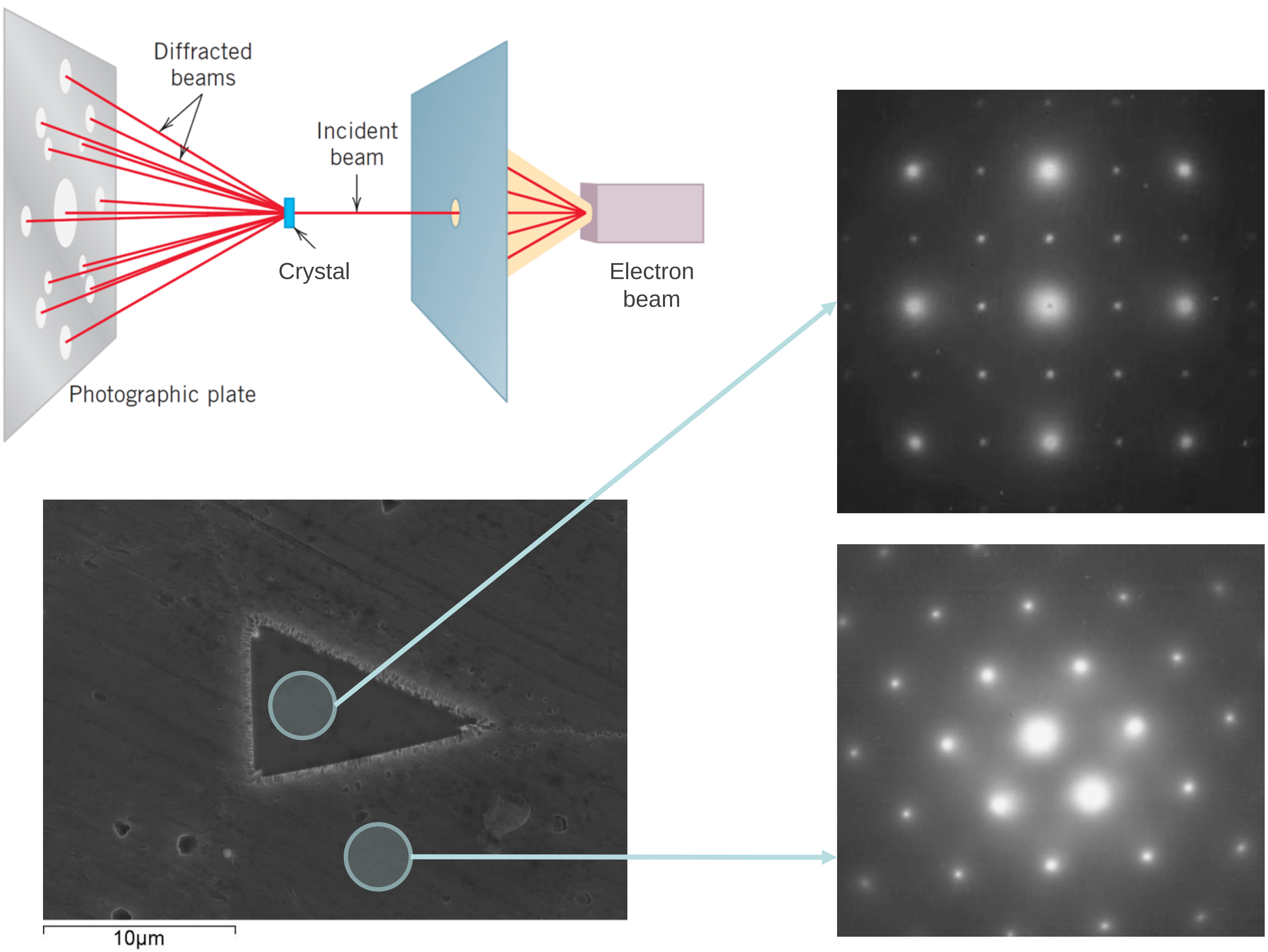

Electron-beam




B
C
$\bar{4}02$
$\bar{3}11$
$\bar{2}20$
$\bar{1}3\bar{1}$
$04\bar{2}$
R_2
R_3
D
O
R_1
A
$\bar{2}22$
$\bar{1}11$
000
$11\bar{1}$
$22\bar{2}$
$0\bar{4}2$
$1\bar{3}1$
$2\bar{2}0$
$3\bar{1}\bar{1}$
$40\bar{2}$
[112]

k'-k=G

Rd=Lλ


Diffracted beams
Incident beam
Crystal
Electron beam
Photographic plate
10μm

How to learn?

1 **Basic Concept**

2 **Train of Thought**

- Periodic function
- Fourier series
- Reciprocal vector
- Reciprocal lattice
- Wave-vector space
- The Bragg law
- Laue equation
- Ewald structure
- Brillouin Zone

Chapter 1 Formation of Crystal

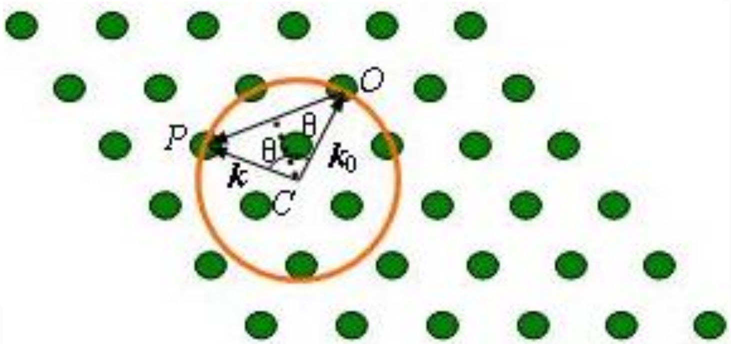
1.1 Quantum Mechanics and atomic structure

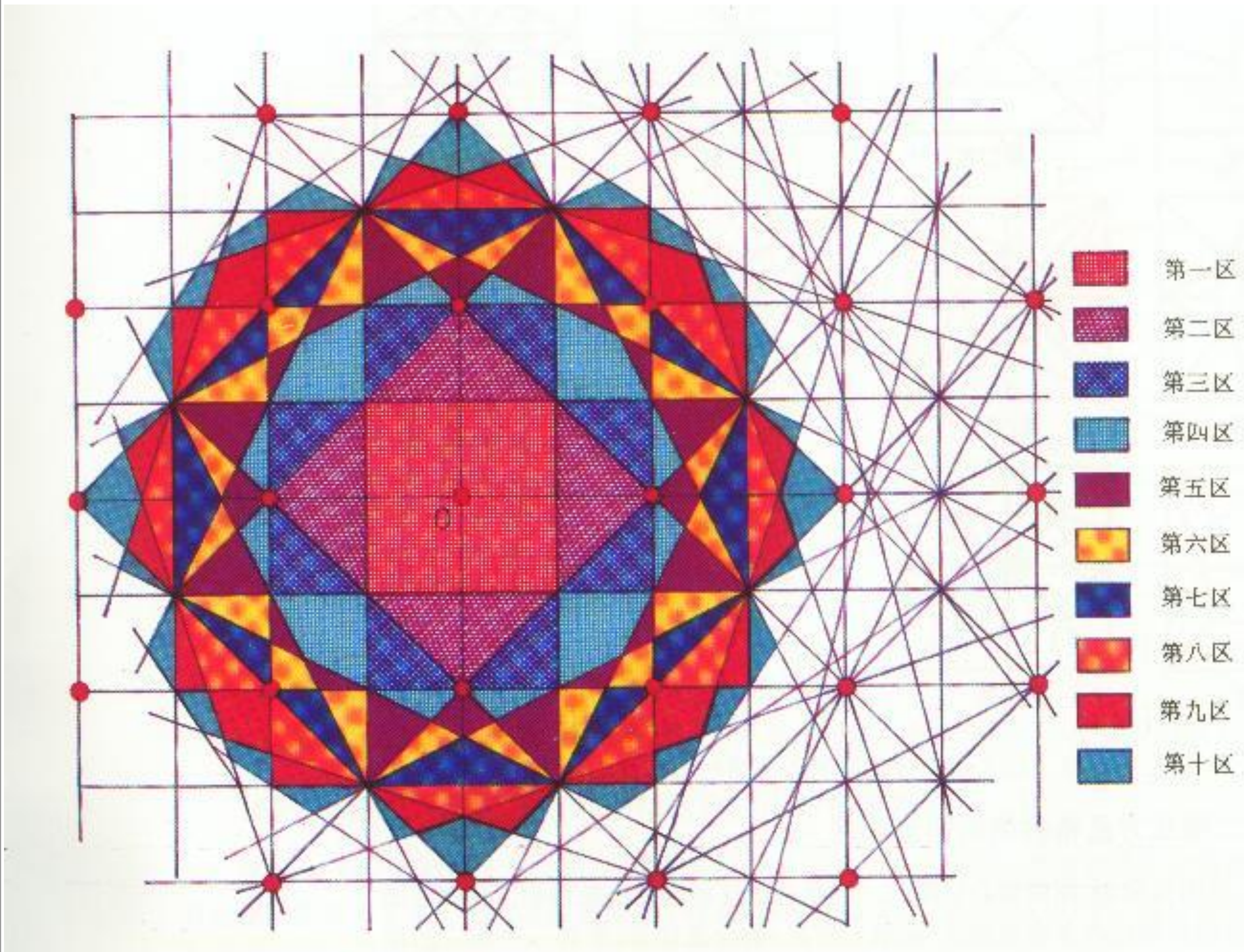
1.2 Interatomic bonding in solids

1.3 Crystal structure and typical crystals

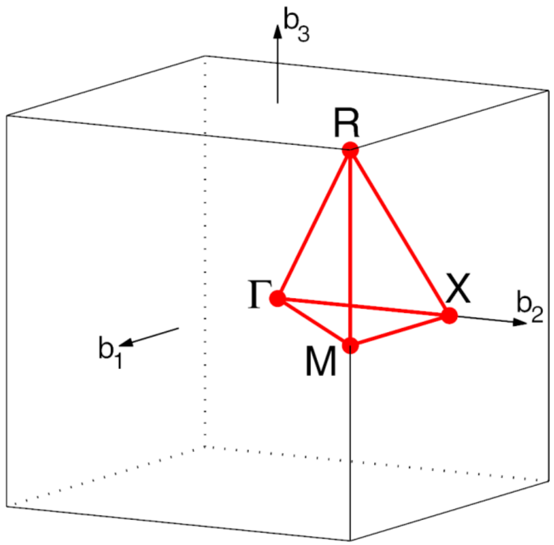
1.4 Reciprocal Lattice and Brillouin Zone

- 1.4.1 Reciprocal Lattice
- 1.4.2 Crystal Diffraction
- 1.4.3 Brillouin Zone



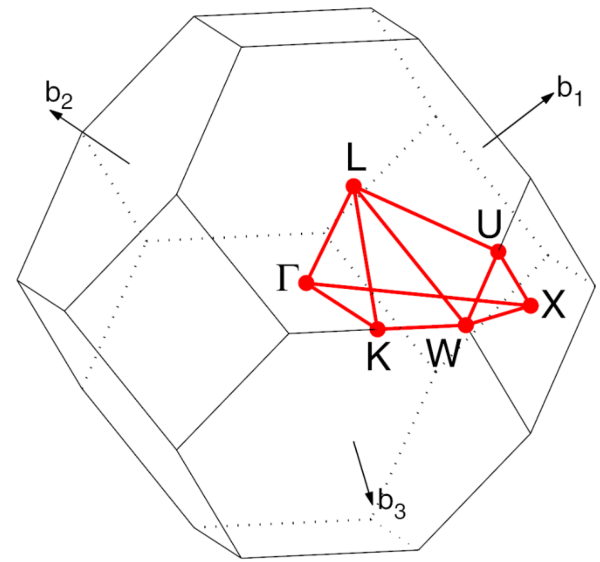


- **The reciprocal lattice point is in the middle of its first BZ.**
- **All BZs have the same volume.**
- **Every BZ just contains one lattice point.**



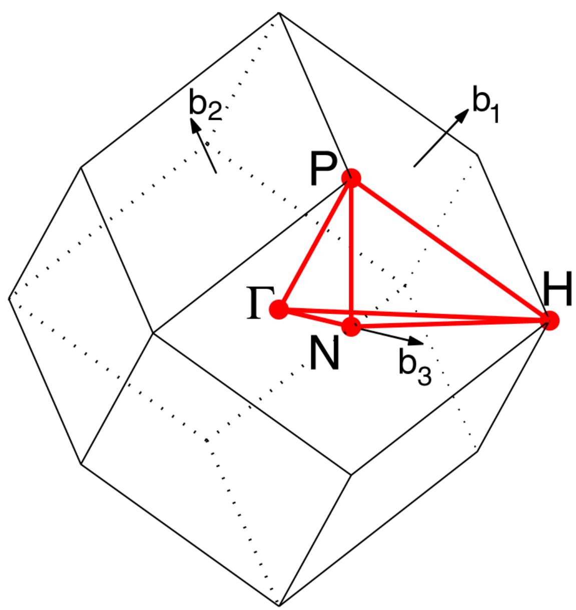
CUB path: Γ-X-M-Γ-R-X|M-R

[Setyawan & Curtarolo, DOI: 10.1016/j.commatsci.2010.05.010



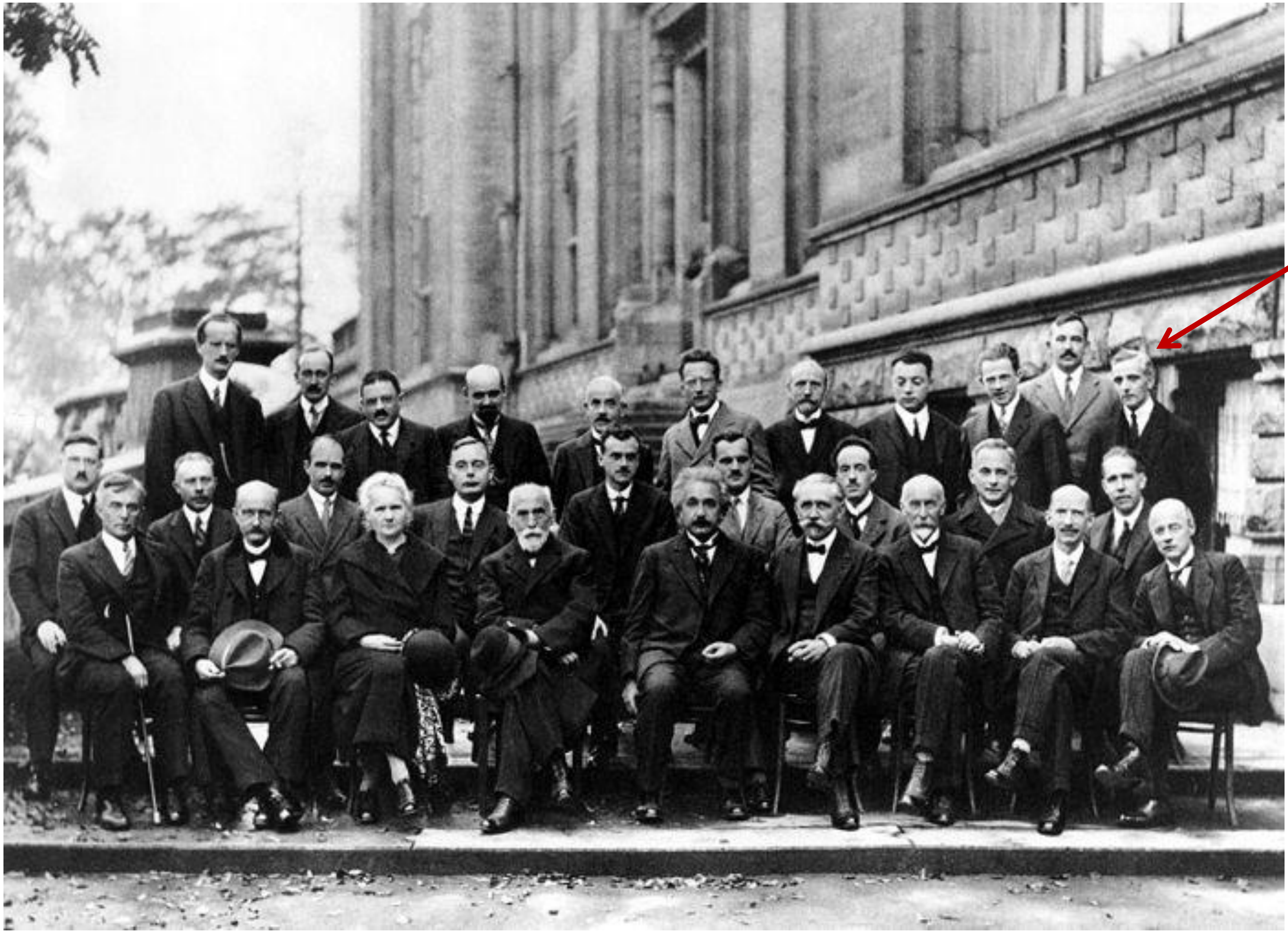
FCC path: Γ-X-W-K-Γ-L-U-W-L-K|U-X

[Setyawan & Curtarolo, DOI: 10.1016/j.commatsci.2010.05.010]



BCC path: Γ-H-N-Γ-P-H|P-N

[Setyawan & Curtarolo, DOI: 10.1016/j.commatsci.2010.05.010]



A. Piccard, E. Henriot, P. Ehrenfest, E. Herzen, Th. De Donder, E. Schrödinger, J.E. Verschaffelt, W. Pauli, W. Heisenberg, R.H. Fowler, L. Brillouin;
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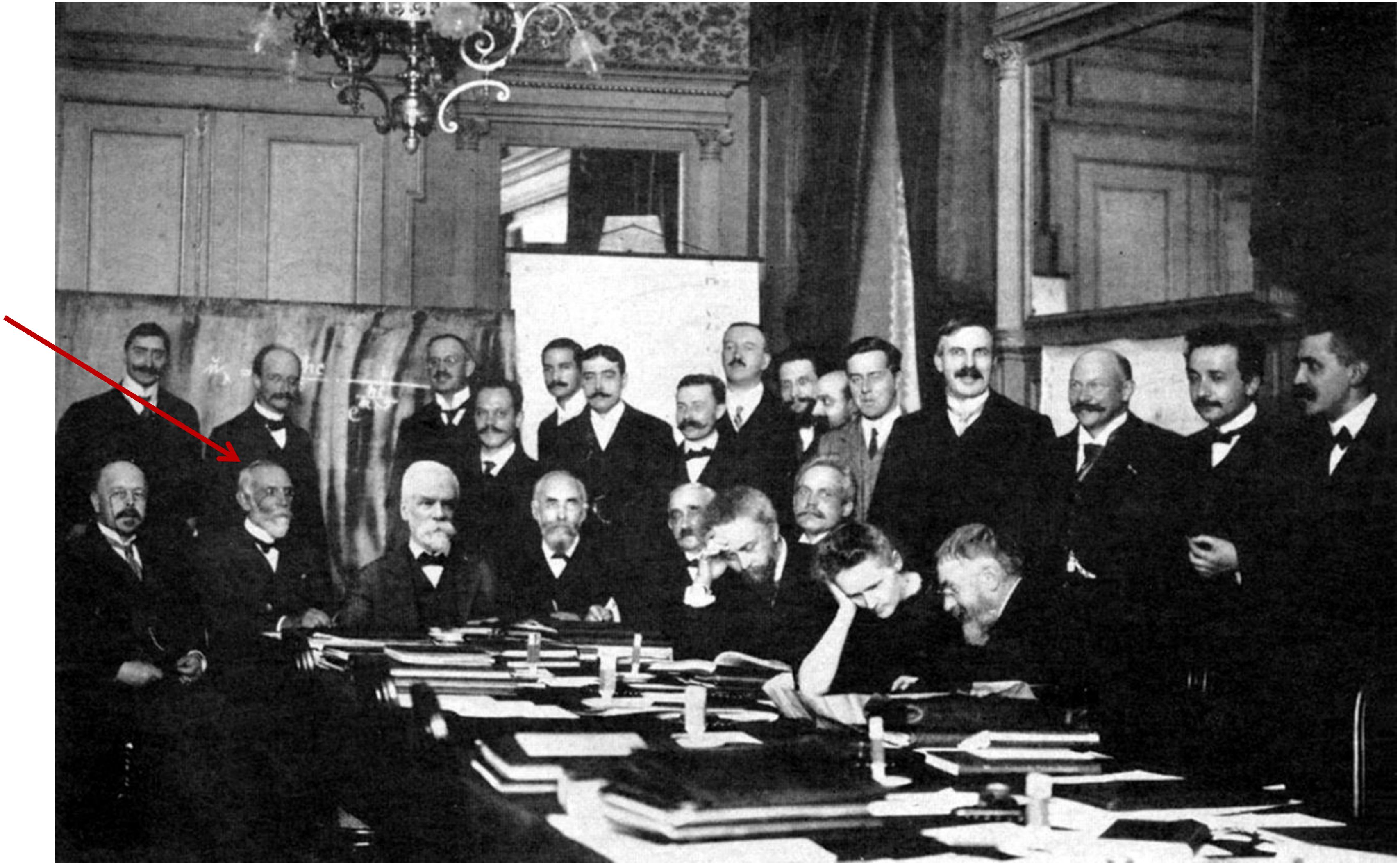
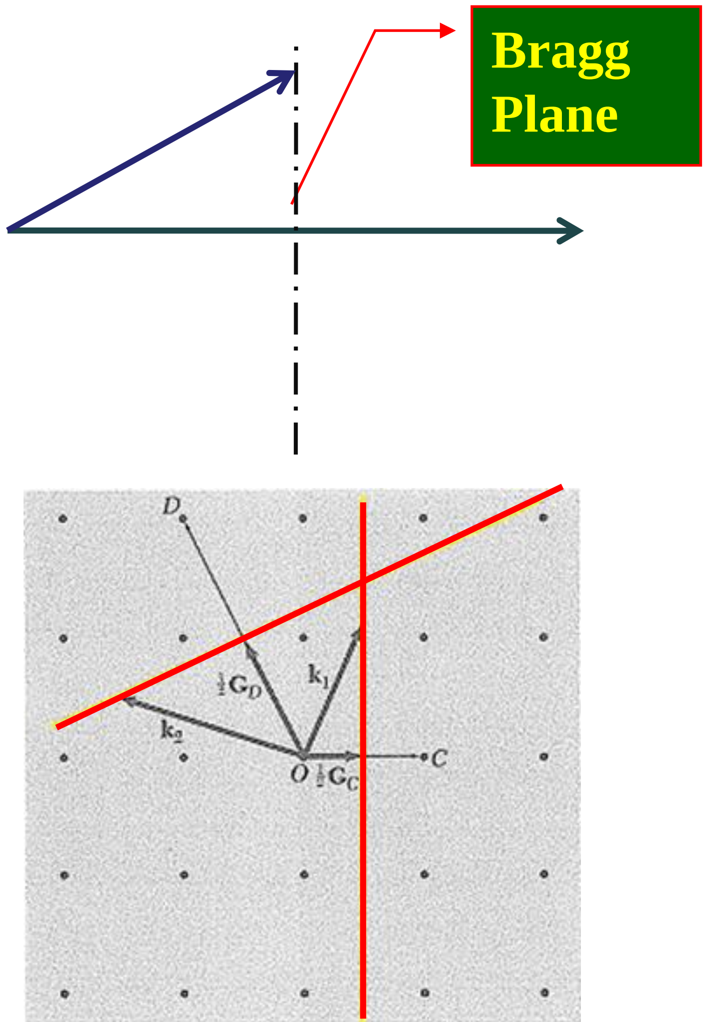
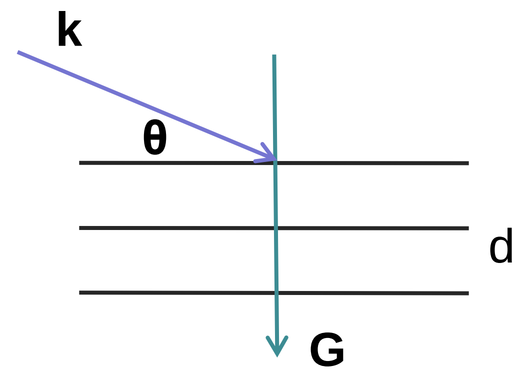


Photograph of the first conference in 1911 at the Hotel Metropole. Seated (L-R): W. Nernst, M. Brillouin, E. Solvay, H. Lorentz, E. Warburg, J. Perrin, W. Wien, M. Skłodowska-Curie, and H. Poincaré. Standing (L-R): R. Goldschmidt, M. Planck, H. Rubens, A. Sommerfeld, F. Lindemann, M. de Broglie, M. Knudsen, F. Hasenöhrl, G. Hostelet, E. Herzen, J.H. Jeans, E. Rutherford, H. Kamerlingh Onnes, A. Einstein and P. Langevin.





$$\mathbf{k}\cdot\frac{\mathbf{G}}{G}=\frac{1}{2}G$$

$$2\mathbf{k}\cdot\mathbf{G}=G^2$$

$$2kG\sin\theta=G^2$$

$$2\frac{2\pi}{\lambda}\sin\theta=\frac{2\pi}{d}$$

$$2d\sin\theta=\lambda$$

All wave vectors *k* which tips are on the boundary of BZ can be Bragg reflected.
Only waves whose wave vector drawn from the origin of k-space terminates on the boundary of BZ will satisfy the condition for diffraction.

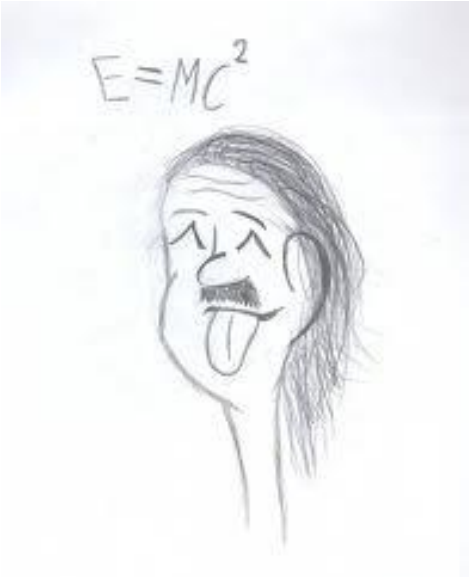
How to learn?

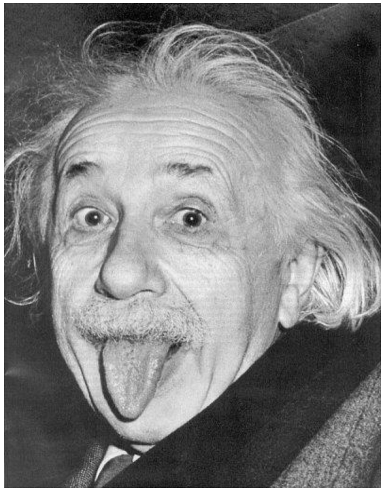
1 Train of Thought

2 Conclusions

3 Basic Concept

4 Math and physical Details





Summary & Basic Concepts

1 Basic Concept

- Periodic function
- Fourier series
- Reciprocal vector
- Reciprocal lattice
- Wave-vector space
- The Bragg law
- Laue equation
- Ewald structure
- Brillouin Zone

2 Train of Thought

Fourier series

3 Conclusions

We know
and
we see.

Thank you for your attention!