Constant mag. field = on transition ①

electromagnetic field ノ z方向 = constant mag field H.

$$A_x = \frac{1}{2} y H \qquad A_y = -\frac{1}{2} x H \qquad A_z = 0 \qquad A_0 = 0.$$

U ガ 存在スル トキ U ト Electromagnetic field ノ interaction.

$$H'_U = \frac{4\pi i e c}{\hbar}\left(U^{+} A \operatorname{div} \tilde{U}^{+} - \tilde{U}^{+} A \operatorname{div} U^{+}\right)$$

$$+ \frac{1}{4\pi\kappa^2}\frac{ie}{\hbar c}\left([A\tilde{U}] \operatorname{curl} U - [AU] \operatorname{curl} \tilde{U}\right)$$

$$H''_U = -\frac{4\pi e^2}{\hbar^2}(AU^{+})(A\tilde{U}^{+}) + \frac{e^2}{4\pi\hbar^2 c^2 \kappa^2}[AU][A\tilde{U}].$$

$$\operatorname{div} U^{+} = \sum_k (-ik) p_k e^{-i\vec{k}\vec{r}}.$$

$$H'_U = \sum_k \sum_j \Big[\frac{4\pi i e c}{\hbar} \Big\{ (p_k l + p_k^{(1)} l_1 + p_k^{(2)} l_2)(+ij) p_j^{*} \cdot \frac{1}{2} H \int y\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dV$$

$$- (p_k m + p_k^{(1)} m_1 + p_k^{(2)} m_2)(ij) p_j^{*} \cdot \frac{1}{2} H \int x\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dV.$$

$$- (p_k^{*} l + p_k^{*(1)} l_1 + p_k^{*(2)} l_2)(-ij) p_j \cdot \frac{1}{2} H \int y\, e^{-i(\vec{j}-\vec{k})\vec{r}}\, dV$$

$$+ (p_k^{*} m + p_k^{*(1)} m_1 + p_k^{*(2)} m_2)(-ij) p_j \cdot \frac{1}{2} H \int x\, e^{-i(\vec{j}-\vec{k})\vec{r}}\, dV \Big\}$$

$$[A\tilde{U}]_x = A_y \tilde{U}_z - A_z \tilde{U}_y = -\frac{1}{2} x H\, \tilde{U}_z$$

$$[A\tilde{U}]_y = A_z \tilde{U}_x - A_x \tilde{U}_z = -\frac{1}{2} y H\, \tilde{U}_z$$

$$\operatorname{curl} U = \sum_k (ik)(-q_k^{(2)} \vec{t}_k^{(1)} + q_k^{(1)} \vec{t}_k^{(2)}) e^{ikr}$$

$$[A\tilde{U}]_z = A_x \tilde{U}_y - A_y \tilde{U}_x = \frac{1}{2} y H \tilde{U}_y + \frac{1}{2} x H \tilde{U}_x$$

$$+ \frac{1}{4\pi\kappa^2}\frac{ie}{\hbar c}\Big\{ -(q_k^{*} n + q_k^{*(1)} n_1 + q_k^{*(2)} n_2)(ij)(-q_j^{(2)} l'_1 + q_j^{(1)} l'_2) \cdot \frac{1}{2} H \int x\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dV.$$

$$- (q_k^{*} n + q_k^{*(1)} n_1 + q_k^{*(2)} n_2)(ij)(-q_j^{(2)} m'_1 + q_j^{(1)} m'_2) \cdot \frac{1}{2} H \int y\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dV.$$

$$+ (q_k^{*} m + q_k^{*(1)} m_1 + q_k^{*(2)} m_2)(ij)(-q_j^{(2)} n'_1 + q_j^{(1)} n'_2) \frac{1}{2} H \int y\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dV.$$

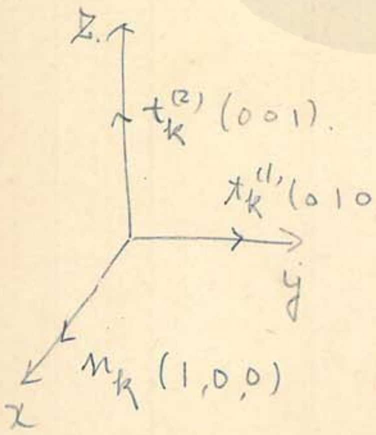
$$+ (q_k^{*} l + q_k^{*(1)} l_1 + q_k^{*(2)} l_2)(ij)(-q_j^{(2)} n'_1 + q_j^{(1)} n'_2) \frac{1}{2} H \int x\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dV.$$

$$- \text{conj compl.} \Big\}$$

$$H_u' = \sum_k \sum_j \Big[\frac{4\pi e c}{\hbar} \frac{1}{2} j H \Big\{ -(p_k l + p_k^{(1)} l_1 + p_k^{(2)} l_2) p_j^* \cdot y_{kj}$$
$$+ (p_k m + p_k^{(1)} m_1 + p_k^{(2)} m_2) p_j^* \cdot x_{kj}$$
$$- (p_k^* l + p_k^{*(1)} l_1 + p_k^{*(2)} l_2) p_j \cdot y_{jk}$$
$$+ (p_k^* m + p_k^{*(1)} m_1 + p_k^{*(2)} m_2) p_j \cdot x_{jk} \Big\}$$

$$\boxed{\begin{aligned} x_{kj} &= \int x\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dv \\ y_{kj} &= \int y\, e^{-i(\vec{k}-\vec{j})\vec{r}}\, dv \end{aligned}}$$

$$+ \frac{1}{4\pi\kappa^2} \frac{e}{\hbar c} \frac{1}{2} j H \Big\{ (q_k^* n + q_k^{*(1)} n_1 + q_k^{*(2)} n_2)(-q_j^{(2)} l_1' + q_j^{(1)} l_2') \cdot x_{kj}$$
$$+ (q_k^* n + q_k^{*(1)} n_1 + q_k^{*(2)} n_2)(-q_j^{(2)} m_1' + q_j^{(1)} m_2') \cdot y_{kj}$$
$$- (q_k^* m + q_k^{*(1)} m_1 + q_k^{*(2)} m_2)(-q_j^{(2)} n_1' + q_j^{(1)} n_2') \cdot y_{kj}$$
$$- (q_k^* l + q_k^{*(1)} l_1 + q_k^{*(2)} l_2)(-q_j^{(2)} n_1' + q_j^{(1)} n_2') \cdot x_{kj}$$
$$+ (q_k n + q_k^{(1)} n_1 + q_k^{(2)} n_2)(-q_j^{*(2)} l_1' + q_j^{*(1)} l_2') \cdot x_{jk}$$
$$+ (q_k n + q_k^{(1)} n_1 + q_k^{(2)} n_2)(-q_j^{*(2)} m_1' + q_j^{*(1)} m_2') \cdot y_{jk}$$
$$- (q_k m + q_k^{(1)} m_1 + q_k^{(2)} m_2)(-q_j^{*(2)} n_1' + q_j^{*(1)} n_2')\, y_{jk}$$
$$- (q_k l + q_k^{(1)} l_1 + q_k^{(2)} l_2)(-q_j^{*(2)} n_1' + q_j^{*(1)} n_2') \cdot x_{jk} \Big\} \Big]$$



$$\left\{ \begin{array}{lll} l = 1 & m = 0 & n = 0 \\ l_1 = 0 & m_1 = 1 & n_1 = 0 \\ l_2 = 0 & m_2 = 0 & n_2 = 1 \end{array} \right.$$

$$H_u' = \sum_k \sum_j \Big[\frac{4\pi e c}{\hbar} \frac{1}{2} j H \Big\{ -p_k p_j^*\, y_{kj} + p_k^{(1)} p_j^*\, x_{kj}$$
$$- p_k^* p_j\, y_{jk} + p_k^{*(1)} p_j\, x_{jk} \Big\}$$

$$+ \frac{1}{4\pi\kappa^2} \frac{e}{\hbar c} \frac{1}{2} j H \Big\{ q_k^{*(2)} (-q_j^{(2)} l_1' + q_j^{(1)} l_2')\, x_{kj} + q_k^{*(2)} (-q_j^{(2)} m_1' + q_j^{(1)} m_2') \cdot y_{kj}$$
$$- q_k^{*(1)} (-q_j^{(2)} n_1' + q_j^{(1)} n_2')\, y_{kj} - q_k^* (-q_j^{(2)} n_1' + q_j^{(1)} n_2')\, x_{kj}$$
$$+ \text{comp conj} \Big\}.$$

$$H_4' = \sum_k \sum_j \Big[\frac{4\pi e c}{\hbar} \frac{1}{2} H \Big\{ - \frac{\hbar}{8\pi c} \frac{j}{\sqrt{k_0}\sqrt{j_0}} (a_k^* + b_k)(a_j + b_j^*)\, y_{kj}$$

$$- \frac{\hbar}{8\pi c} \frac{j}{\sqrt{k_0}\sqrt{j_0}} (a_k + b_k^*)(a_j^* + b_j)\, y_{jk}$$

$$+ \frac{\hbar}{8\pi\kappa c} \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} (a_k^{(1)*} + b_k^{(1)})(a_j + b_j^*)\, x_{kj}$$

$$+ \frac{\hbar}{8\pi\kappa c} \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} (a_k^{(1)} + b_k^{(1)*})(a_j^* + b_j)\, x_{jk} \Big\}$$

$$+ \frac{1}{4\pi\kappa^2} \frac{e}{\hbar c} \frac{1}{2} H \Big\{ + 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (a_k^{*(2)} - b_k^{(2)})(-a_j^{(2)} + b_j^{*(2)})(l_1' x_{kj} + m_1' y_{kj})$$

$$+ 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (-a_k^{(2)} + b_k^{*(2)})(a_j^{*(2)} - b_j^{(2)})(l_1' x_{jk} + m_1' y_{jk})$$

$$- 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (a_k^{*(2)} - b_k^{(2)})(-a_j^{(1)} + b_j^{*(1)})(l_2' x_{kj} + m_2' y_{kj})$$

$$- 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (-a_k^{(2)} + b_k^{*(2)})(a_j^{*(1)} - b_j^{(1)})(l_2' x_{jk} + m_2' y_{jk})$$

$$- 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (a_k^{*(1)} - b_k^{(1)})(-a_j^{(2)} + b_j^{*(2)})\, n_1' y_{kj}$$

$$- 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (-a_k^{(1)} + b_k^{*(1)})(a_j^{*(2)} - b_j^{(2)})\, n_1' y_{jk}$$

$$+ 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (a_k^{*(1)} - b_k^{(1)})(-a_j^{(1)} + b_j^{*(1)})\, n_2' y_{kj}$$

$$+ 2\pi\hbar c\kappa^2 \frac{j}{\sqrt{k_0}\sqrt{j_0}} (-a_k^{(1)} + b_k^{*(1)})(a_j^{*(1)} - b_j^{(1)})\, n_2' y_{jk}$$

$$- 2\pi\hbar c\kappa \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} (a_k^* - b_k)(-a_j^{(2)} + b_j^{*(2)})\, n_1' x_{kj}$$

$$- 2\pi\hbar c\kappa \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} (-a_k + b_k^*)(a_j^{*(2)} - b_j^{(2)})\, n_1' x_{jk}$$

$$+ 2\pi\hbar c\kappa \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} (a_k^* - b_k)(-a_j^{(1)} + b_j^{*(1)})\, n_2' x_{kj}$$

$$+ 2\pi\hbar c\kappa \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} (-a_k + b_k^*)(a_j^{*(1)} - b_j^{(1)})\, n_2' x_{jk} \Big\} \Big]$$

$$\frac{4\pi e c}{\hbar} \frac{\hbar}{\hbar\kappa 8\pi c} = \frac{e\hbar}{2m_u c}$$

$$\frac{1}{4\pi\kappa^2} \frac{e}{\hbar c} \cdot 2\pi\hbar c\kappa^2 = \frac{e}{2\kappa} = \frac{e\hbar}{2m_u c}$$

logitudinal k が入ってる a_k term.

$$H_4' = \sum_j \frac{e\hbar}{2m_u c}\,\frac{1}{2}H\Big[-\frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}}\,a_k\,(a_j^* + b_j)\,y_{jk}$$

$$+\frac{\sqrt{k_0}\,j}{\sqrt{j_0}}\,a_k\,(a_j^{*(2)} - b_j^{(2)})\,n_1'\,x_{jk}$$

$$-\frac{\sqrt{k_0}\,j}{\sqrt{j_0}}\,a_k\,(a_j^{*(1)} - b_j^{(1)})\,n_2'\,x_{jk}\Big]$$

transversal k が入ってる $a_k^{(1)}$, term.

$$H_4' = \sum_j \frac{e\hbar}{2m_u c}\,\frac{1}{2}H\Big[\frac{\sqrt{k_0}\,j}{\sqrt{j_0}}\,a_k^{(1)}\,(a_j^* + b_j)\,x_{jk}$$

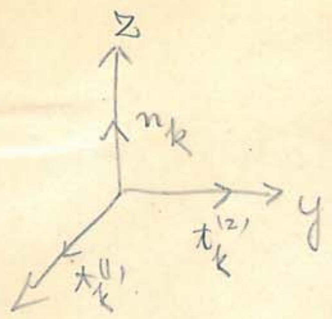
$$+\frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}}\,a_k^{(1)}\,(a_j^{*(2)} - b_j^{(2)})\,n_1'\,y_{jk}$$

$$-\frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}}\,a_k^{(1)}\,(a_j^{*(1)} - b_j^{(1)})\,n_2'\,y_{jk}\Big]$$

trans $a_k^{(2)}$, term.

$$H_4' = \sum_j \frac{e\hbar}{2m_u c}\,\frac{1}{2}H\Big[-\frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}}\,a_k^{(2)}\,(a_j^{*(2)} - b_j^{(2)})(l_1' x_{jk} + m_1' y_{jk})$$

$$+\frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}}\,a_k^{(2)}\,(a_j^{*(1)} - b_j^{(1)})(l_2' x_{jk} + m_2' y_{jk})\Big]$$



$l = m = 0, \quad n = 1.$

$l_1 = 1 \quad m_1 = n_1 = 0.$

$l_2 = n_2 = 0, \quad m_2 = 1$

$$H_4' = \sum_k \sum_j \Big[\frac{4\pi ec}{\hbar} \frac{1}{2} j H \Big\{ - p_k^{(1)} p_j^{*} y_{kj} + p_k^{(2)} p_j^{*} x_{kj}$$

$$- p_k^{*(1)} p_j \, y_{jk} + p_k^{*(2)} p_j \, x_{jk} \Big\}$$

$$+ \frac{1}{4\pi\kappa^2} \frac{e}{\hbar c} \frac{1}{2} j H \Big\{ q_k^{*} (- q_j^{(2)} l_1' + q_j^{(1)} l_2') x_{kj} + q_k^{*} (- q_j^{(2)} m_1' + q_j^{(1)} m_2') y_{kj}$$

$$- q_k^{*(2)} (- q_j^{(2)} n_1' + q_j^{(1)} n_2') \, y_{kj} + q_k^{*(1)} (- q_j^{(2)} n_1' + q_j^{(1)} n_2') x_{kj}$$

$$+ \text{comple conj} \Big\}$$

$$= \sum_k \sum_j \frac{e\hbar}{2m_L c} \frac{1}{2} H \Big[- \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} \Big\{ (a_k^{(1)*} + b_k^{(1)})(a_j + b_j^{*}) y_{kj} + (a_k^{(1)} + b_k^{*(1)})(a_j^{*} + b_j) y_{jk} \Big\}$$

$$+ \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} \Big\{ (a_k^{(2)*} + b_k^{(2)})(a_j + b_j^{*}) x_{kj} + (a_k^{(2)} + b_k^{*(2)})(a_j^{*} + b_j) x_{jk} \Big\}$$

$$+ \frac{\sqrt{k_0}\, j}{\sqrt{j_0}} \Big\{ (a_k^{*} - b_k)(- a_j^{(2)} + b_j^{*(2)})(l_1' x_{kj} + m_1' y_{kj})$$

$$+ (- a_k + b_k^{*})(a_j^{*(2)} + b_j^{(2)})(l_1' x_{jk} + m_1' y_{jk})$$

$$- (a_k^{*} - b_k)(- a_j^{(1)} + b_j^{*(1)})(l_2' x_{kj} + m_2' y_{kj})$$

$$- (- a_k + b_k^{*})(a_j^{*(1)} + b_j^{(1)})(l_2' x_{jk} + m_2' y_{jk}) \Big\}$$

$$+ \frac{\kappa\, j}{\sqrt{k_0}\sqrt{j_0}} \Big\{ - (a_k^{*(2)} - b_k^{(2)})(- a_j^{(2)} + b_j^{*(2)}) n_1' y_{kj} - (- a_k^{(2)} + b_k^{*(2)})(a_j^{*(2)} - b_j^{(2)}) n_1' y_{jk}$$

$$+ (a_k^{*(2)} - b_k^{(2)})(- a_j^{(1)} + b_j^{*(1)}) n_2' y_{kj} + (- a_k^{(2)} + b_k^{*(2)})(a_j^{*(1)} - b_j^{(1)}) n_2' y_{jk}$$

$$+ (a_k^{*(1)} - b_k^{(1)})(- a_j^{(2)} + b_j^{*(2)}) n_1' x_{kj} + (- a_k^{(1)} + b_k^{*(1)})(a_j^{*(2)} - b_j^{(2)}) n_1' x_{jk}$$

$$- (a_k^{*(1)} - b_k^{(1)})(- a_j^{(1)} + b_j^{*(1)}) n_2' x_{kj} - (- a_k^{(1)} + b_k^{*(1)})(a_j^{*(1)} - b_j^{(1)}) n_2' x_{jk} \Big\} \Big]$$

Ⓒ

longitudinal k から put す a_k term

$$H_u' = \sum_j \frac{e\hbar}{2m_u c}\frac{1}{2}H\Big[i - \frac{\sqrt{k_0 j}}{\sqrt{j_0}} a_k (a_j^{*(2)} + b_j^{(2)})(l_1' x_{jk} + m_1' y_{jk})$$

$$+ \frac{\sqrt{k_0 j}}{\sqrt{j_0}} a_k (a_j^{*(1)} + b_j^{(1)})(l_2' x_{jk} + m_2' y_{jk}) \Big]$$

transversal k から put す. $a_k^{(1)}$ term.

$$H_u' = \sum_j \frac{e\hbar}{2m_u c}\frac{1}{2}H\Big[- \frac{\sqrt{k_0 j}}{\sqrt{j_0}} a_k^{(1)} (a_j^* + b_j) y_{jk}$$

$$- \frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}} a_k^{(1)} (a_j^{*(2)} - b_j^{(2)}) n_1' x_{jk} + \frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}} a_k^{(1)} (a_j^{*(1)} - b_j^{(1)}) n_2' x_{jk} \Big]$$

$a_k^{(2)}$ term.

$$H_u' = \sum_j \frac{e\hbar}{2m_u c}\frac{1}{2}H\Big[+ \frac{\sqrt{k_0 j}}{\sqrt{j_0}} a_k^{(2)} (a_j^* + b_j) x_{jk}$$

$$+ \frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}} a_k^{(2)} (a_j^{*(2)} - b_j^{(2)}) n_1' y_{jk} - \frac{\varkappa j}{\sqrt{k_0}\sqrt{j_0}} a_k^{(2)} (a_j^{*(1)} - b_j^{(1)}) n_2' y_{jk} \Big]$$

$$\xi = (x+iy) \qquad \xi + \bar{\xi} = x$$

$$= r\sin\theta\, e^{i\phi} \qquad \xi - \bar{\xi} = y$$

$$\bar{\xi} = r\sin\theta\, e^{-i\phi}$$

$$\vec{k} - \vec{j} = \vec{p}$$

$$\int x e^{-i p_{kj} r\cos\Theta} dV = \int r\sin\theta (e^{i\phi} + e^{-i\phi}) e^{-i\vec{p}\vec{r}} r^2 \sin\theta\, dr\, d\theta\, d\phi$$

$$= \int r^3 \sin^2\theta \left\{ e^{i(\phi - \vec{p}\vec{r})} + e^{-i(\phi + \vec{p}\vec{r})} \right\} dr\, d\theta\, d\phi$$

Constant magnetic field $= \infty$

$\sqcup$, transition