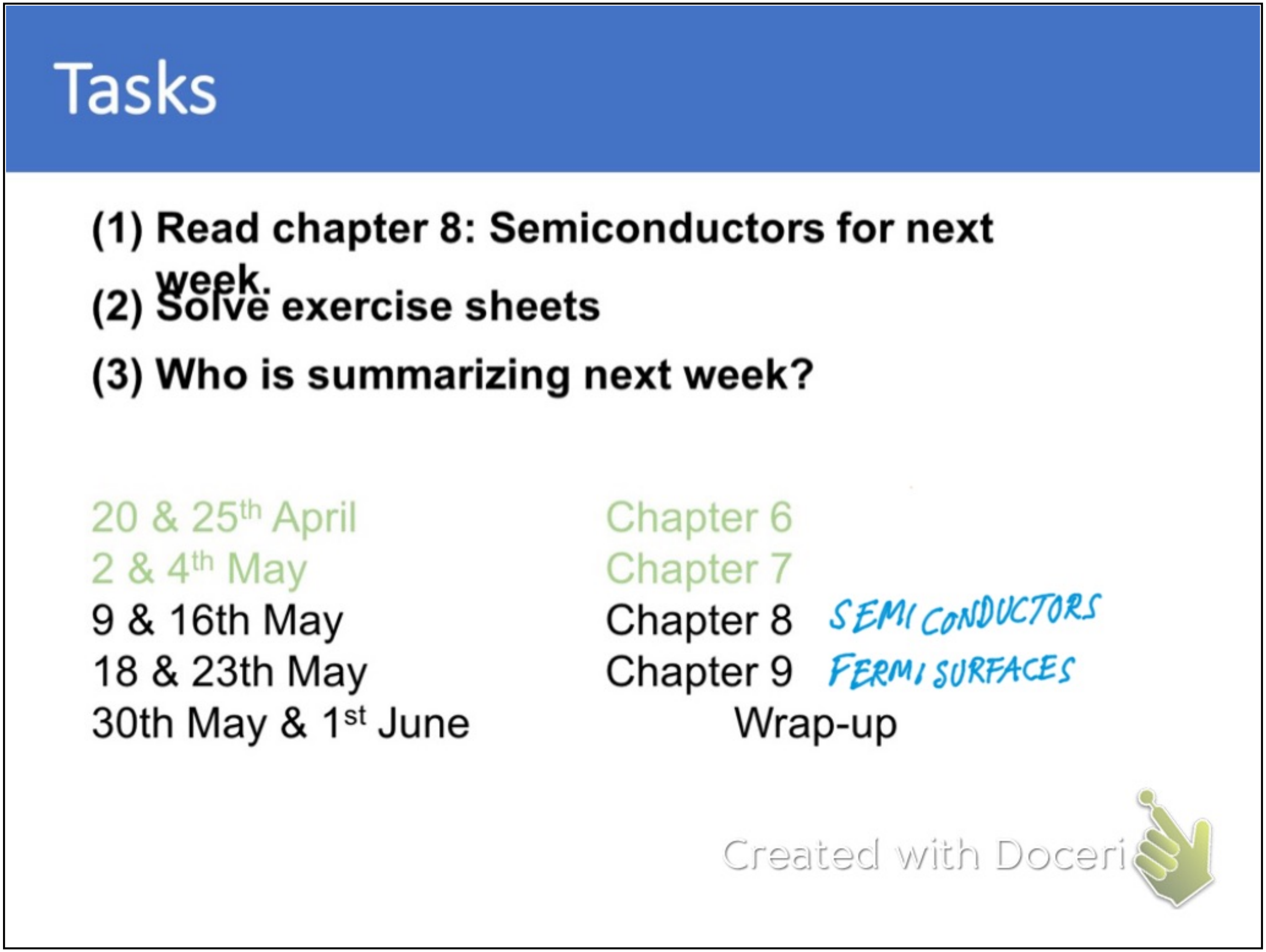


Tasks

(1) **Read chapter 8: Semiconductors for next week.**

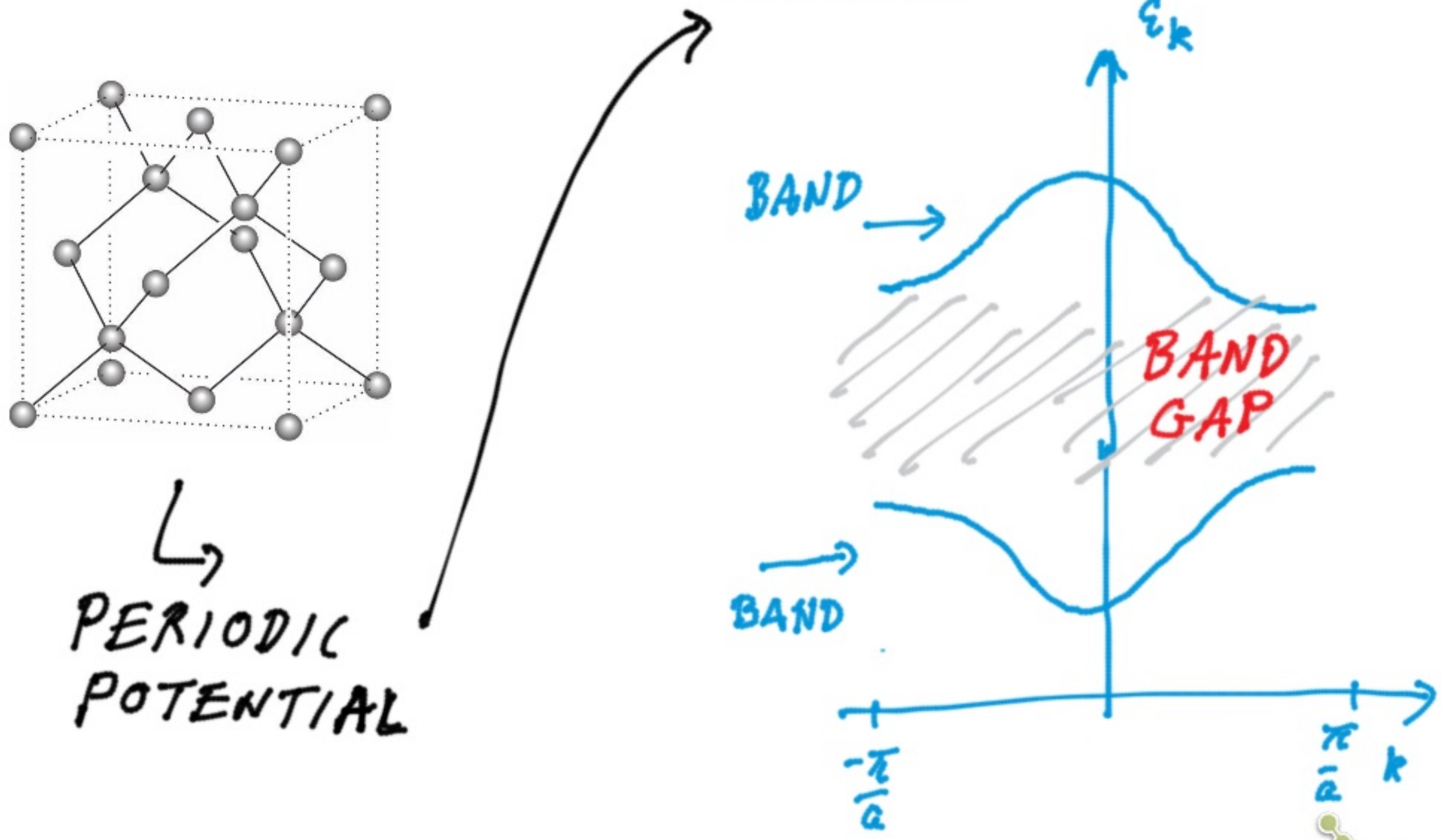
(2) **Solve exercise sheets**

(3) **Who is summarizing next week?**

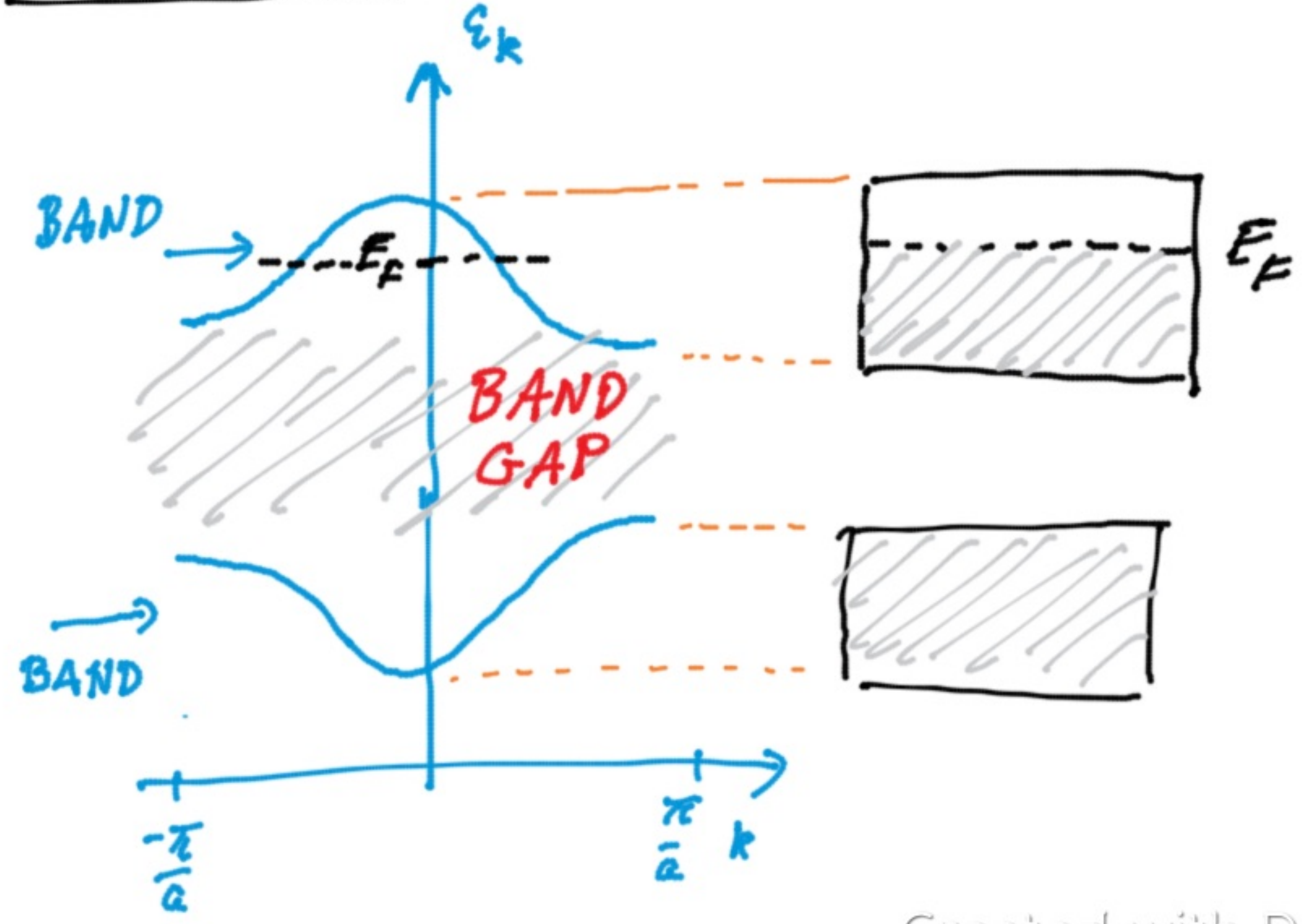
20 & 25th April	Chapter 6	
2 & 4th May	Chapter 7	
9 & 16th May	Chapter 8	SEMI CONDUCTORS
18 & 23th May	Chapter 9	FERMI SURFACES
30th May & 1st June	Wrap-up	

CRYSTAL STRUCTURE

BAND STRUCTURE



BAND STRUCTURE



Created with Doceri

Electronic classification

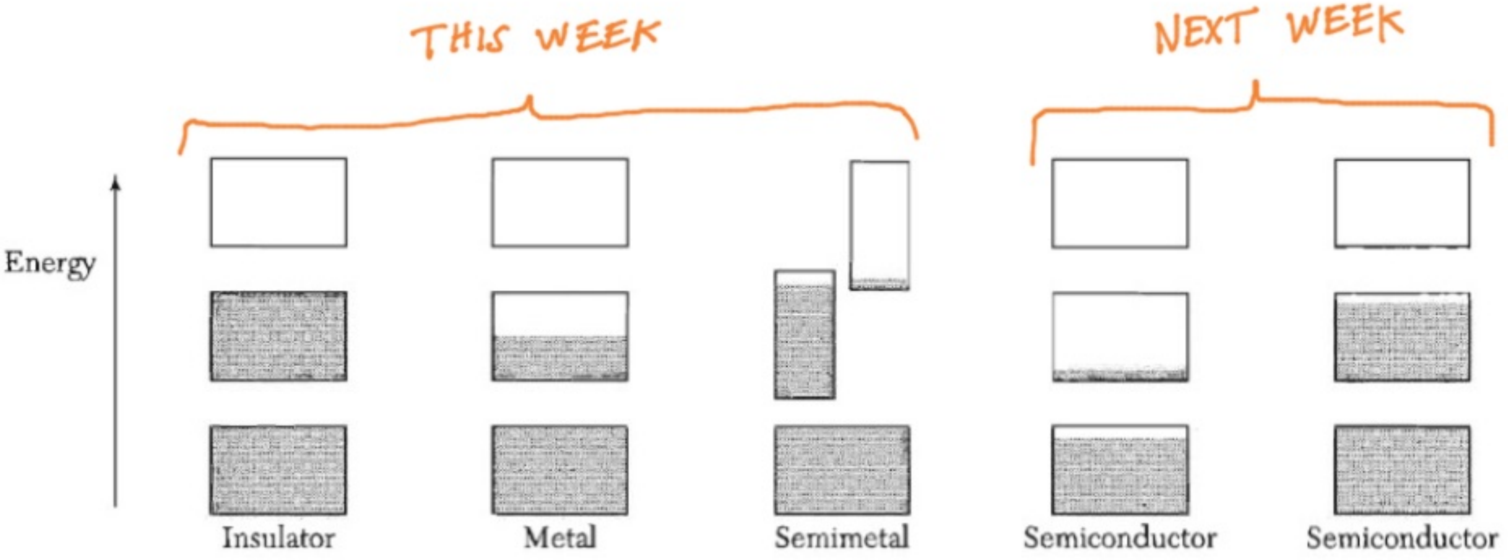
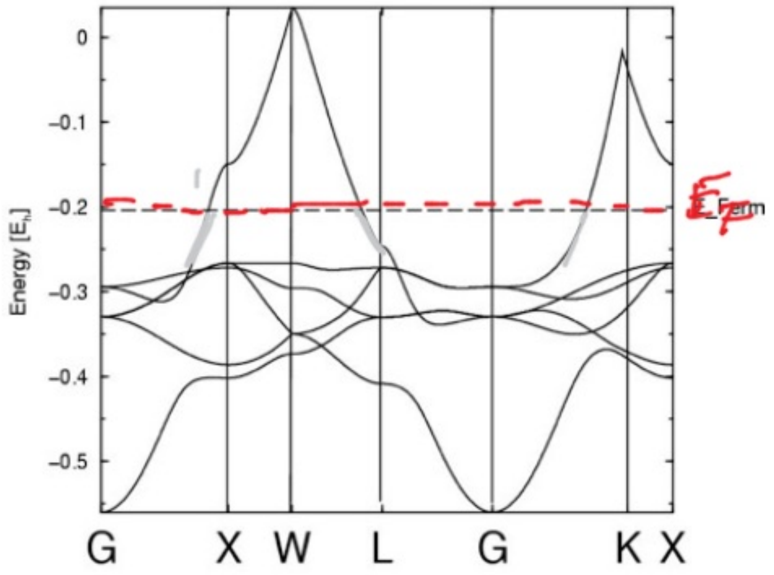


Figure 1 Schematic electron occupancy of allowed energy bands for an insulator, metal, semimetal, and semiconductor. The vertical extent of the boxes indicates the allowed energy regions; the shaded areas indicate the regions filled with electrons. In a **semimetal** (such as bismuth) one band is almost filled and another band is nearly empty at absolute zero, but a pure **semiconductor** (such as silicon) becomes an insulator at absolute zero. The left of the two semiconductors shown is at a finite temperature, with carriers excited thermally. The other semiconductor is electron-deficient because of impurities.

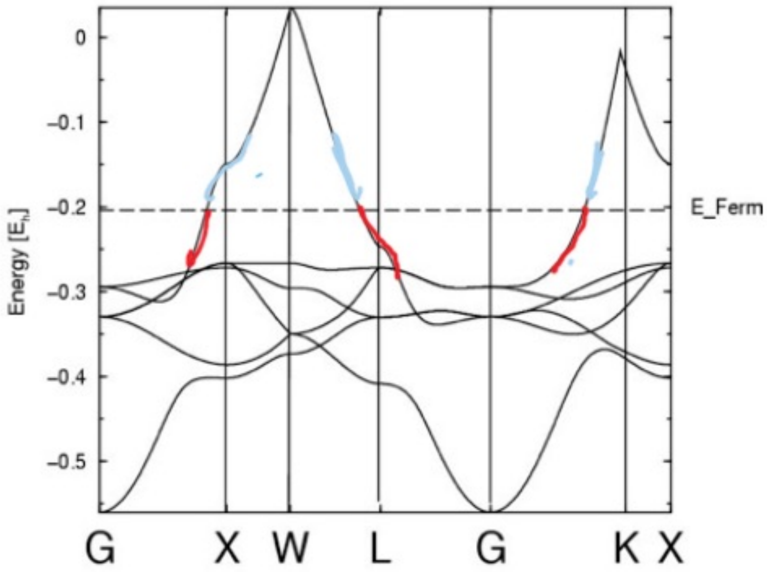
QUIZ

Metal or Insulator?

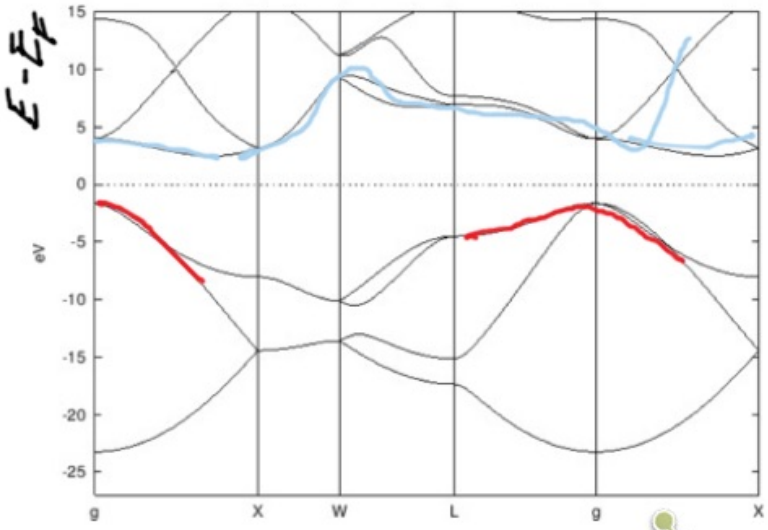


Quiz

Metal or Insulator?

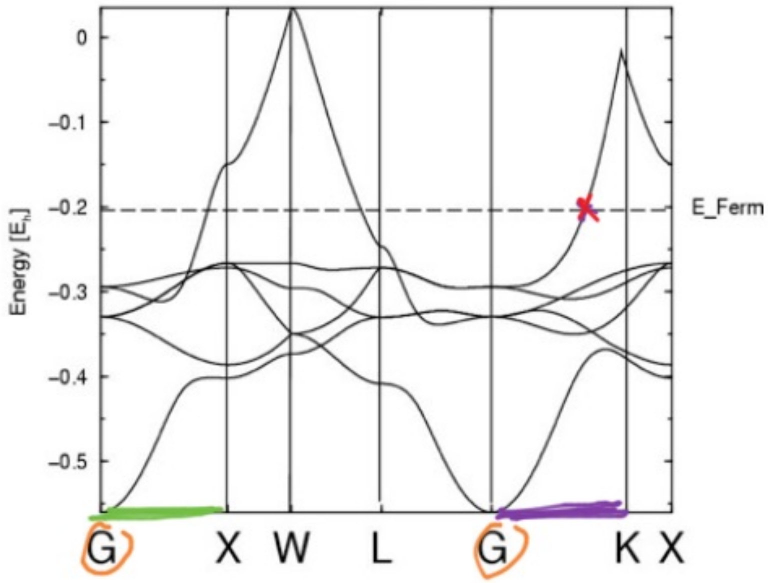


Metal or Insulator?

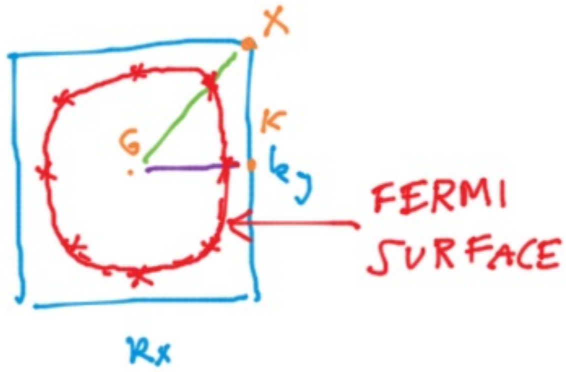


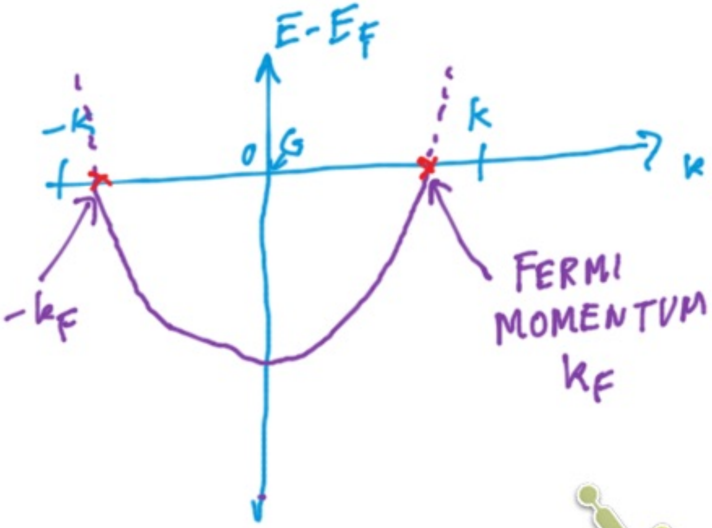
FERMI SURFACE

Metal or Insulator?

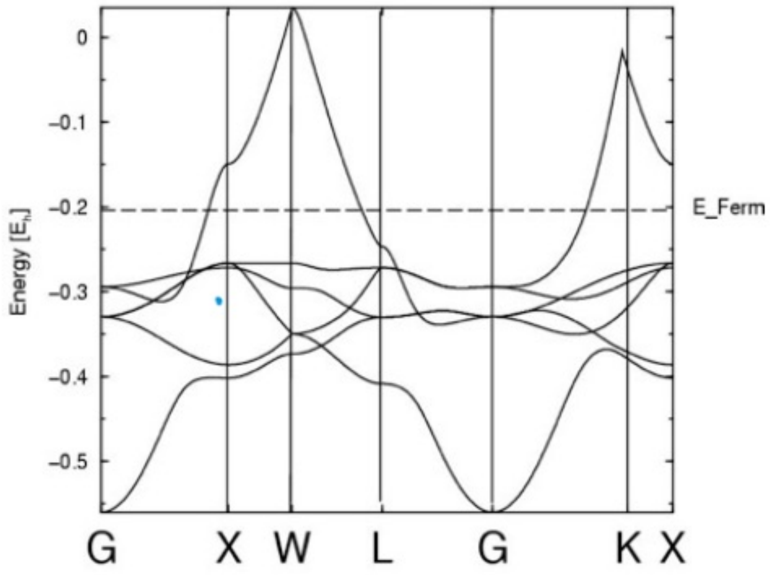


Schematic BZ



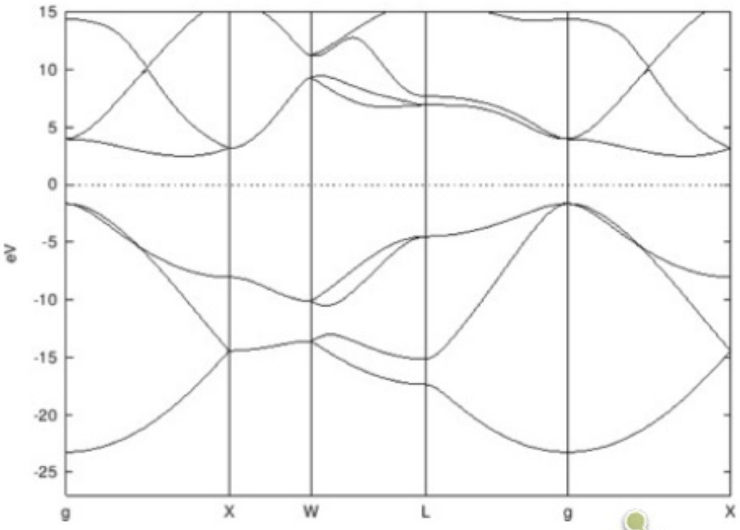


Metal ~~or Insulator?~~



FERMI SURFACE ? YES!

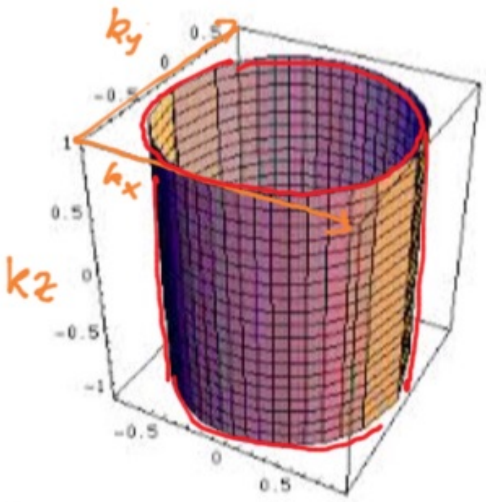
~~Metal or~~ Insulator?

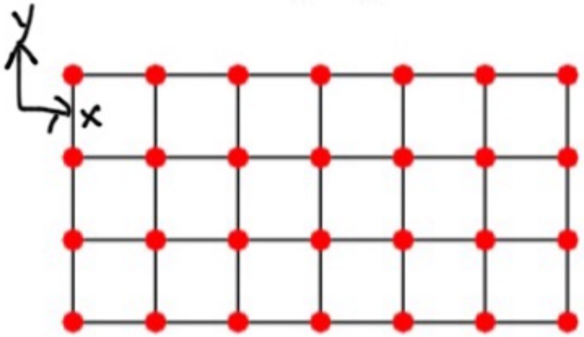


FERMI SURFACE ? NO!

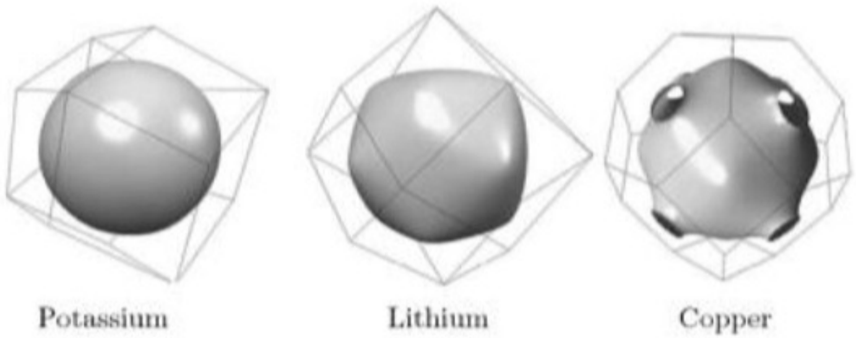
2D and 3D Fermi surfaces

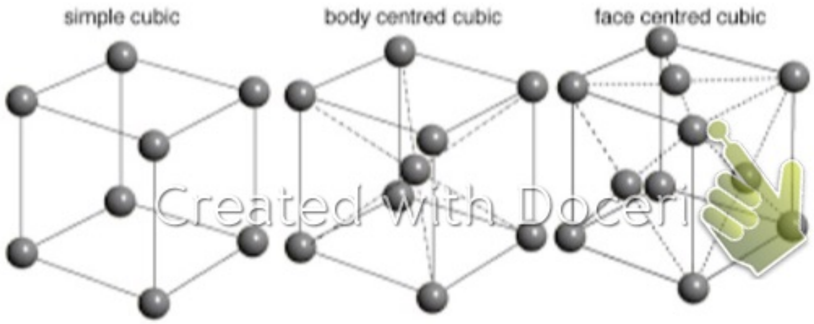
Layered Materials

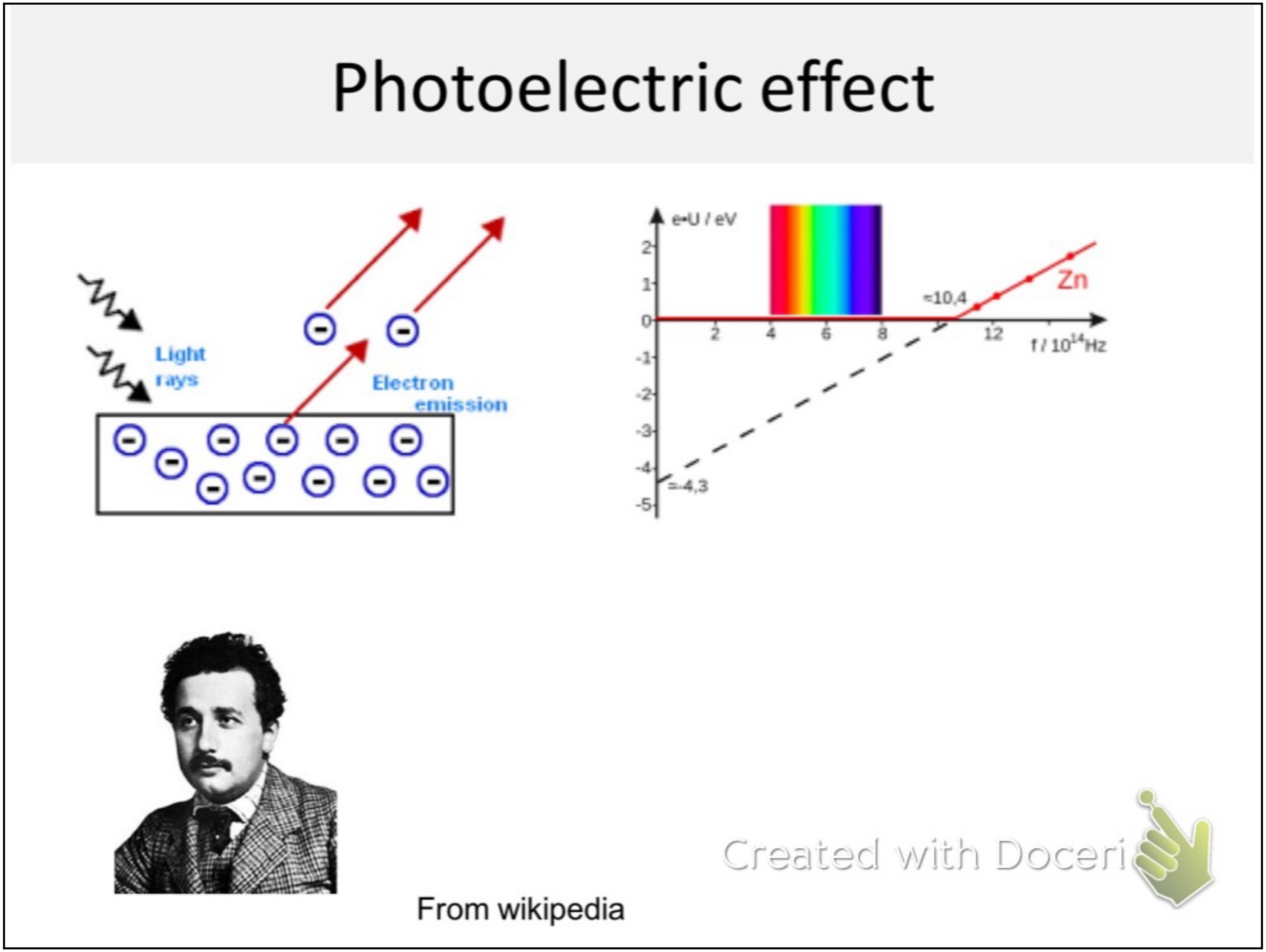




Cubic Materials



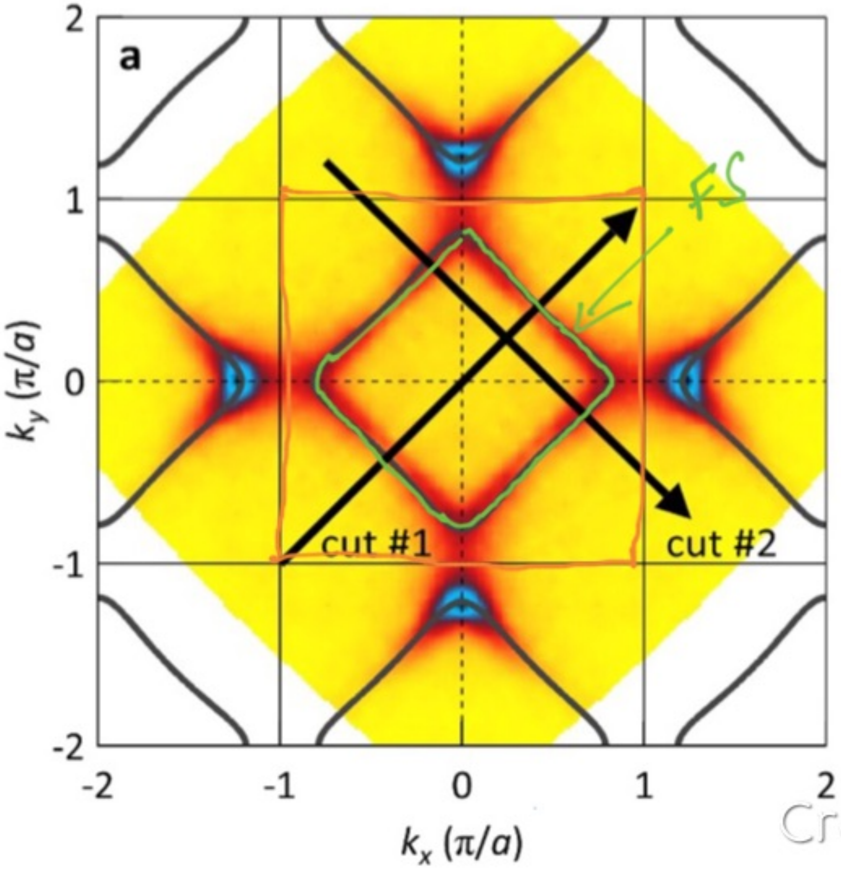




Photoelectric effect

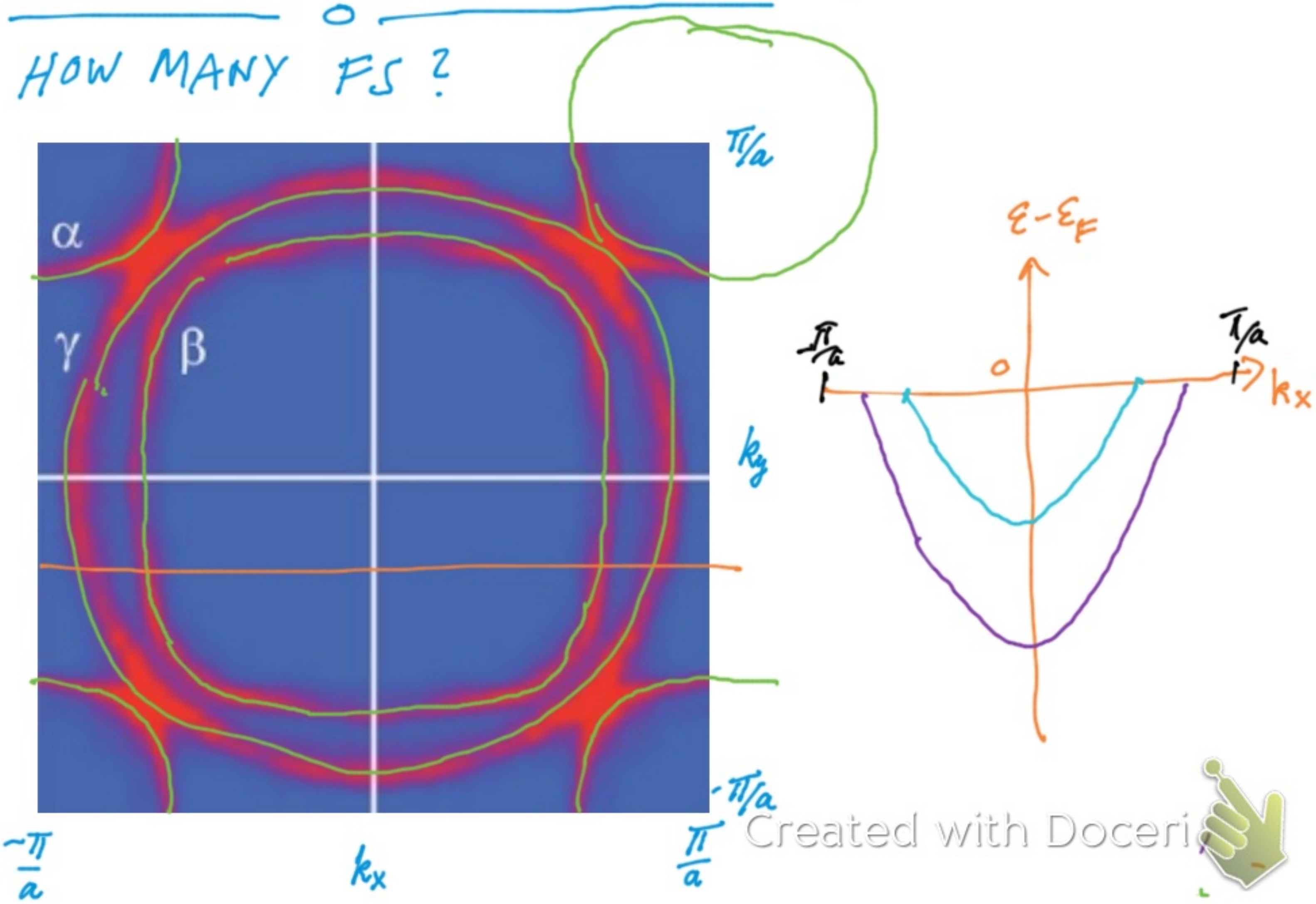
From wikipedia

Fermi surface of $La_{2-x}Sr_xCuO_4$

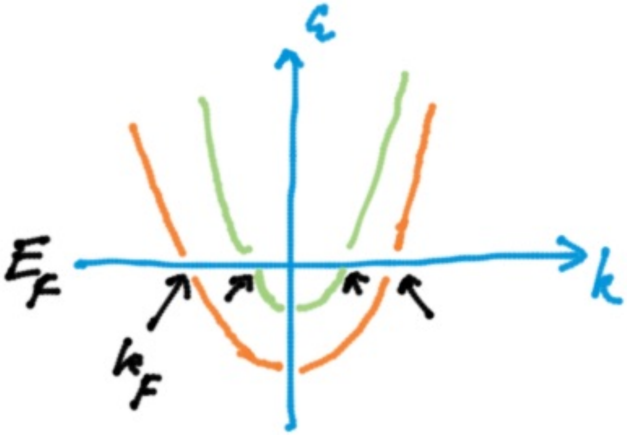


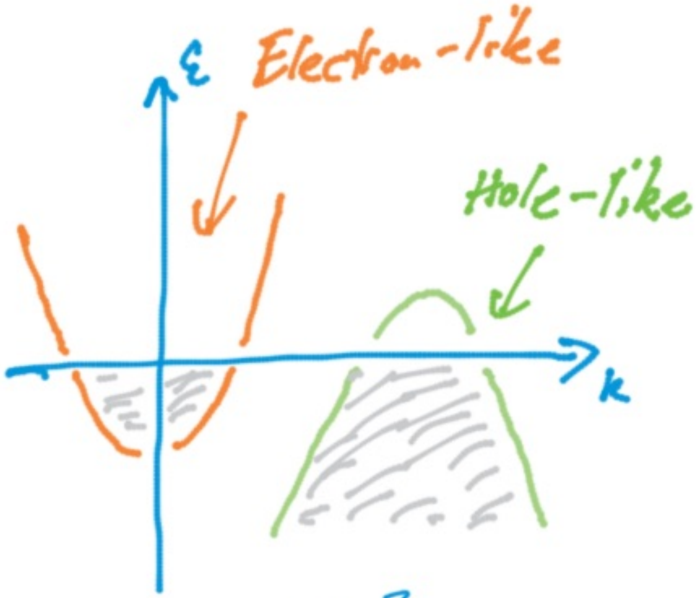
FERMI SURFACE OF Sr_2RuO_4

HOW MANY FS ?



MULTI-BAND SCENARIO





Two bands

Two Fermi surfaces

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

DEFINING ELECTRON MASS

(1) $$\mathcal{E}_k = \frac{(\hbar k)^2}{2m} \Rightarrow \frac{d\mathcal{E}_k}{dk} = \frac{\hbar^2 k}{m} = \frac{\hbar\,\hbar k}{m} = \hbar v$$

velocity

$$\Rightarrow v = \frac{1}{\hbar}\frac{d\mathcal{E}_k}{dk}$$

(2) $$\frac{dv}{dt} = \frac{1}{\hbar}\frac{d^2\mathcal{E}}{dk\,dt} = \frac{1}{\hbar}\frac{d^2\mathcal{E}}{dk^2}\frac{dk}{dt}$$

FORCE

(3) FORCE FORMULATION: $F = \frac{d}{dt}\hbar k \Rightarrow \frac{dk}{dt} = \frac{1}{\hbar}\cdot F$

(4) COMBINE (2) & (3)

$$\frac{dv}{dt} = \underbrace{\frac{1}{\hbar^2}\frac{d^2\mathcal{E}}{dk^2}}_{\frac{1}{m^*}} F$$

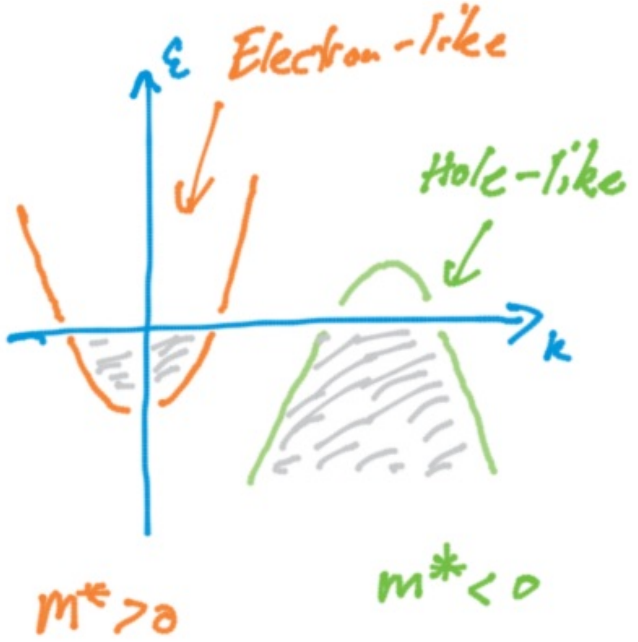
acceleration

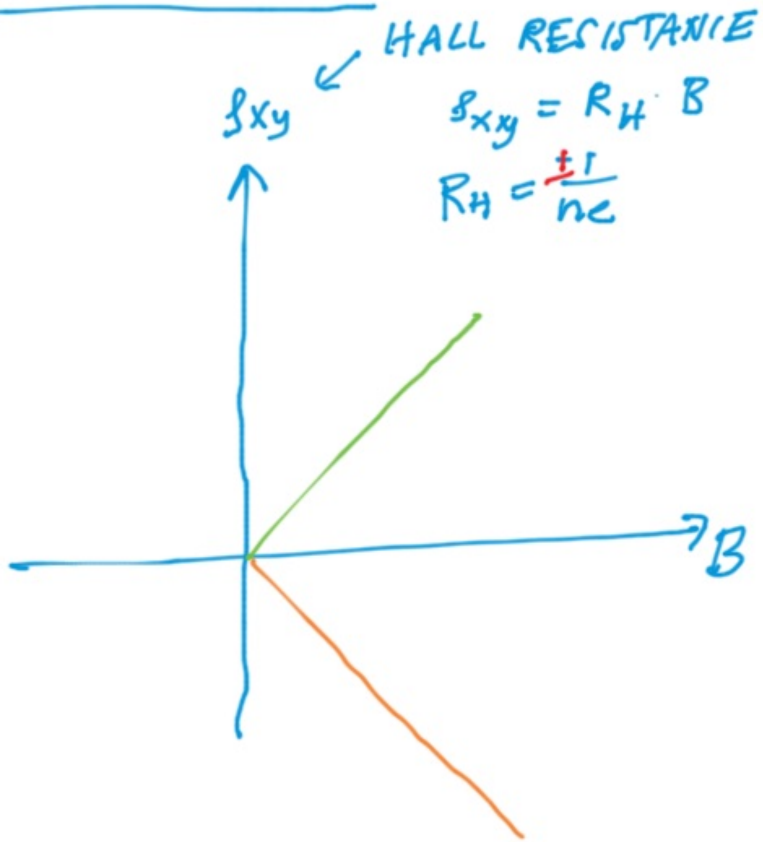
FORCE

EFFECTIVE MASS

$$m^* = \frac{\hbar^2}{\frac{d^2\mathcal{E}}{dk^2}}$$

REASONING FOR "HOLE" VOCABULARY





$\rho_{xy} = R_H \cdot B$

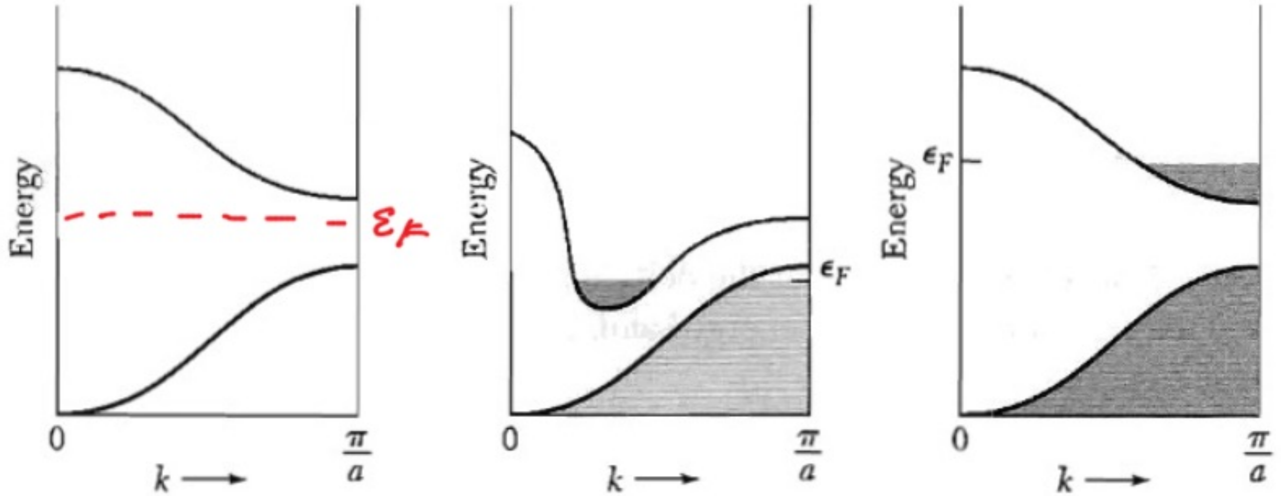
$R_H = \frac{\pm 1}{ne}$

$m^* \frac{dv}{dt} = -eE$

$\Downarrow$

$\frac{dv}{dt} = \frac{-e}{m} E$

ELECTRONIC CLASSIFICATION



(a) (b) (c)

SEMI-METAL

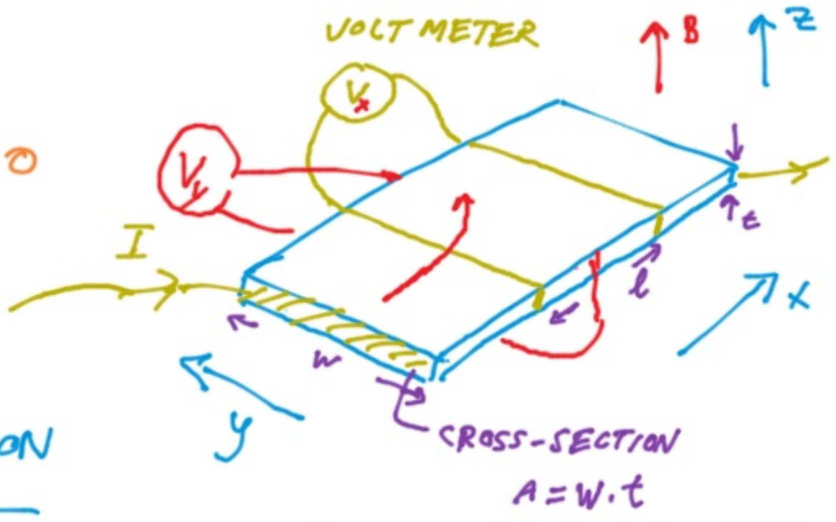
METAL

Small FS of
Hole & Electron-like
character

MAGNETO-RESISTANCE

$\rho_{xx} = \frac{E_x}{j_x}$; $\sigma_{xx} = \frac{1}{\rho_{xx}}$ for $B=0$

$\rho_{xy} = \frac{E_y}{j_x} = R_H \cdot B$



GENERAL FORMULATION

$\vec{E} = \bar{\rho} \cdot \vec{j}$ where $\bar{\rho} \equiv \begin{pmatrix} \rho_{xx} & -\rho_{xy} \\ \rho_{xy} & \rho_{xy} \end{pmatrix} = \begin{pmatrix} \rho_{xx} & -R_H \cdot B \\ R_H \cdot B & \rho_{xx} \end{pmatrix}$

$\vec{E} = \begin{pmatrix} E_x \\ E_y \end{pmatrix}$; $\vec{j} = \begin{pmatrix} j_x \\ j_y \end{pmatrix}$

$\vec{j} = \bar{\rho}^{-1} \vec{E} = \bar{\sigma} \vec{E}$ where $\sigma = \begin{pmatrix} \sigma_{xx} & -\sigma_{xy} \\ \sigma_{xy} & \sigma_{xx} \end{pmatrix}$

POINT 1

$\sigma_{xx} \neq 1/\rho_{xx}$ for $B \neq 0$

MULTI-BAND SYSTEM : N- FERMI SURFACES

σ

$$\vec{j}_n = \bar{\rho}_n^{-1} \vec{E}$$

$$\vec{j}_{total} = \sum_{n=1}^{N} \bar{\rho}_n^{-1} \vec{E}$$

$$\vec{E} = \bar{\rho} \cdot j_{total} \quad \text{where} \quad \bar{\rho} = \left(\sum_{n=1}^{N} \rho_n^{-1} \right)^{-1}$$

EXERCISE:

(b) If only two bands are crossing the Fermi level, show that:

$$R_H = \frac{R_{H,1}\rho_2^2 + R_{H,2}\rho_1^2 + R_{H,1}R_{H,2}(R_{H,1}+R_{H,2})B^2}{(\rho_1+\rho_2)^2 + (R_{H,1}+R_{H,2})^2B^2} \tag{3}$$

$$\rho = \frac{\rho_1\rho_2(\rho_1+\rho_2) + (\rho_1 R_{H,2}^2 + \rho_2 R_{H,1}^2)B^2}{(\rho_1+\rho_2)^2 + (R_{H,1}+R_{H,2})^2B^2} \tag{4}$$

Hint: It is allowed to use Mathematica. If you do so, print out the code and the output.

(c) Magnetic field dependence of resistivity is called magneto-resistance. If the two-band system has both electron-like and hole-like carries so that $|R_{H,1}| \approx |R_{H,2}|$, what is the field dependence of ρ.

B=0 limit

$$\rho_{xx} = \frac{\rho_1\rho_2}{\rho_1+\rho_2} \Rightarrow \sigma_{xx} = \frac{1}{\rho_{xx}} = \frac{1}{\rho_1} + \frac{1}{\rho_2} = \sigma_1 + \sigma_2$$

EXERCISE :

(b) If only two bands are crossing the Fermi level, show that:

$$R_H = \frac{R_{H,1}\rho_2^2 + R_{H,2}\rho_1^2 + R_{H,1}R_{H,2}(R_{H,1} + R_{H,2})B^2}{(\rho_1 + \rho_2)^2 + (R_{H,1} + R_{H,2})^2 B^2} \tag{3}$$

$$\rho = \frac{\rho_1\rho_2(\rho_1 + \rho_2) + (\rho_1 R_{H,2}^2 + \rho_2 R_{H,1}^2)B^2}{(\rho_1 + \rho_2)^2 + (R_{H,1} + R_{H,2})^2 B^2} \tag{4}$$

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Assume Electron-like & Hole-like FS.

$R_{H,1} = -R_{H,2}$; $R_{H,1} = \frac{1}{pe}$; $R_{H,2} = \frac{-1}{ne}$ + $\rho_1 = p \cdot e \mu_h$

$\rho_2 = n \cdot e \cdot \mu_e$

density of hole

$\Downarrow$

$$R_H = \frac{p\mu_h^2 - n\mu_e^2}{e(p\mu_h + n\mu_e)^2}$$

More complicated than R_H [illegible]