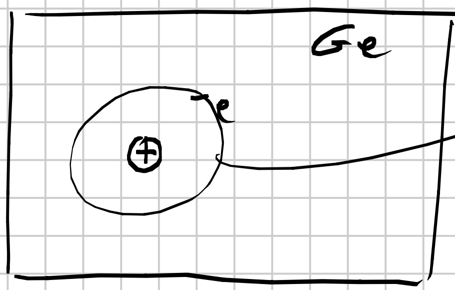
LECTURE # 23

Note Title 12/3/2007

→ DONORS

Ge $(4s)^2(4p)^2$

As $(4s)^2(4p)^3$



→ Hydrogenic System

$$E_b \sim \frac{e^2}{2\varepsilon a_B} \qquad a_B^* = \frac{\varepsilon \hbar^2}{m^* e^2}$$

$E_b \sim 10$ meV

$T = 0$ $\sigma = 0$

Finite T

$$n = \underbrace{n_0 \, e^{-\frac{E_g}{2k_BT}}}_{n_i} + N_D \, e^{-\frac{E_b}{k_BT}}$$

$E_g \sim 1 \text{ eV}$

$E_b \sim 10 \text{ meV}$

AT 300 K $\quad n_i \sim 5 \cdot 10^{13} \text{ cm}^{-3}$

$n_0 = DOS(E = k_BT)$

1 ppm DOPING of As

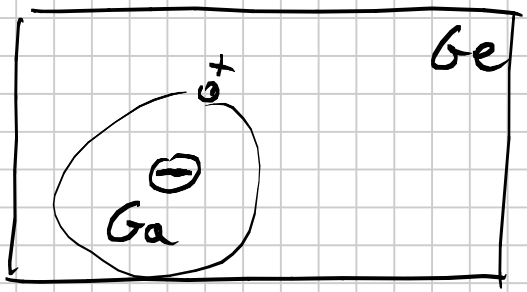
$N_D \sim 10^{-6} \rho_{Ge} \sim 10^{-6} \; 5 \cdot 10^{22} \text{ cm}^{-3}$

$N_D \sim 5 \cdot 10^{16} \text{ cm}^{-3}$ $\qquad$ 1% number of ionized donors

$\Rightarrow \quad 5 \cdot 10^{14} \text{ cm}^{-3}$

Ge $\qquad$ p-like material

Ga $\quad (4s)^2 (4p)^1$



ACCEPTOR

$$J = n q \langle v \rangle$$

$$\dot{\vec{p}} = q\vec{E} - \frac{m\langle v \rangle}{\tau}$$

$$J = \frac{n q^2 \tau}{m} E$$

$$\langle v \rangle = \boxed{\frac{\tau q}{m}} E$$

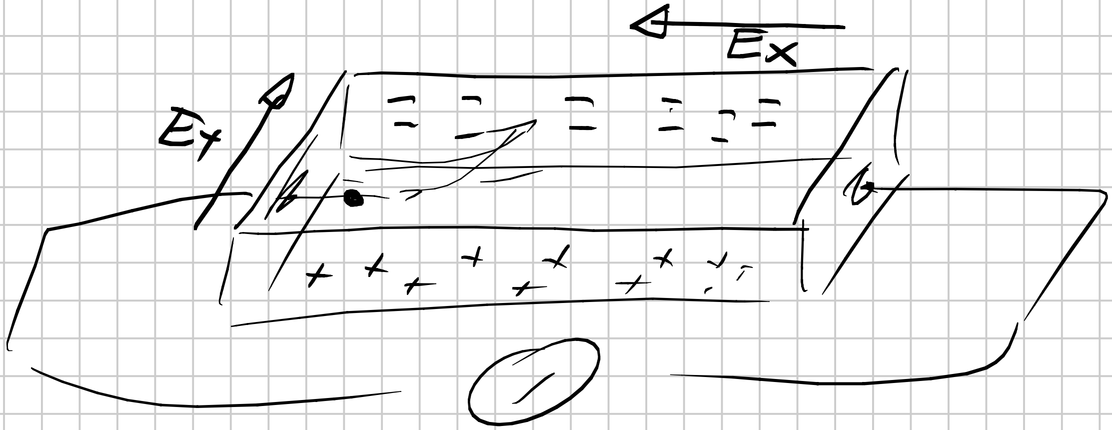
$$v = \mu E$$

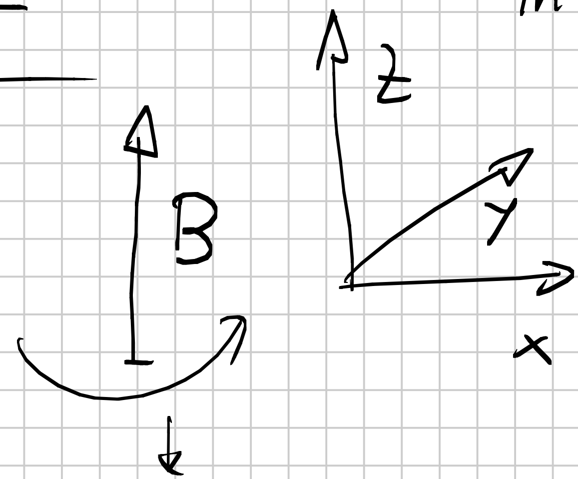
$\mu =$ mobility

How can we distinguish between types of carriers?

HALL MEASUREMENT

n DOPED SYSTEM





↓ Lorentz force

$$m\dot{\vec{v}} = -e\left(\vec{E} + \vec{v}\times\vec{B}\right) - \frac{m\vec{v}}{\tau}$$

Steady state $\Rightarrow$ $\dot{\vec{v}} = 0$

$$v_x = -\frac{e\tau}{m}\left(E_x + v_y B\right)$$

$$v_y = -\frac{e\tau}{m}\left(E_y - v_x B\right)$$

is needed to compensate Lorentz force

and obtain $\boxed{v_y = 0}$

$$E_y = v_x B$$

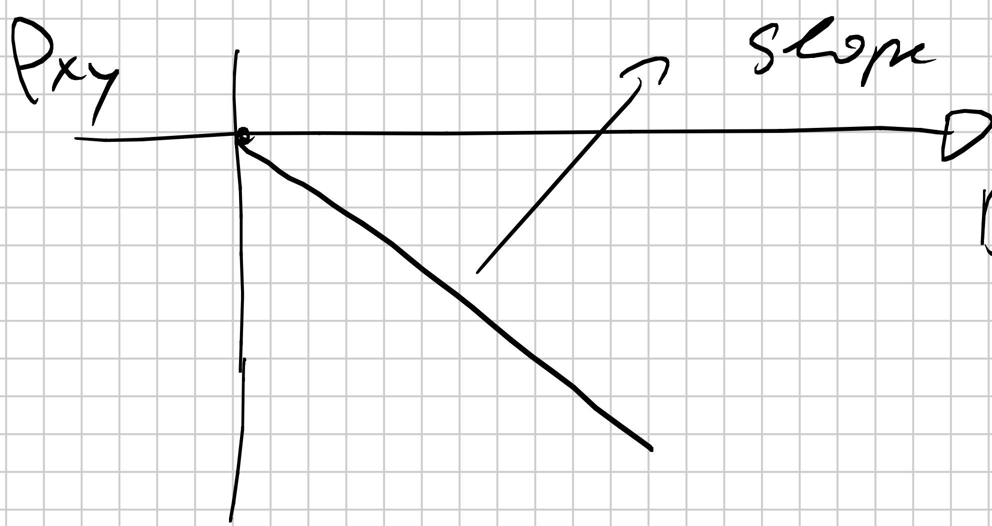
① Measure current $J_x = -en\,v_x$

② Measure Voltage in y direction (measure E_y)

$$E = \rho J$$

$$\rho_{xy} = \frac{E_y}{J_x}$$ Hall resistivity

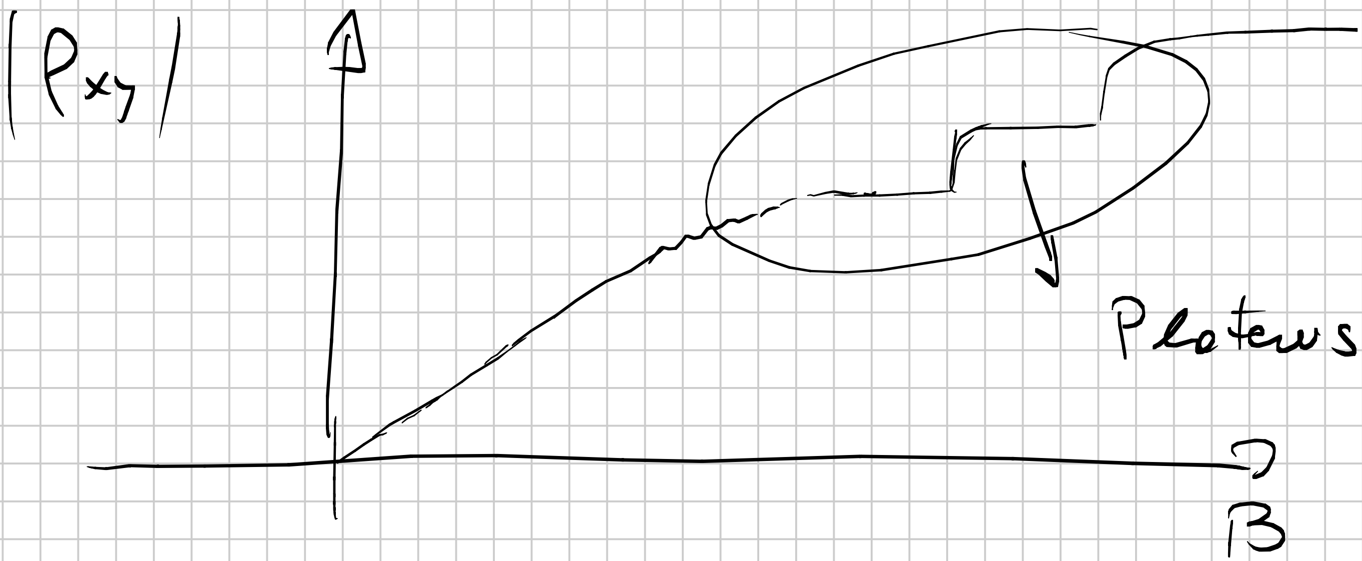
$$\rho_{xy} = \frac{\cancel{E_y}}{-en\frac{\cancel{E_y}}{B}} = \rho \qquad \rho_{xy} = \frac{1}{-en} B$$



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

HALL COEFFICIENT

CLASSICAL HALL



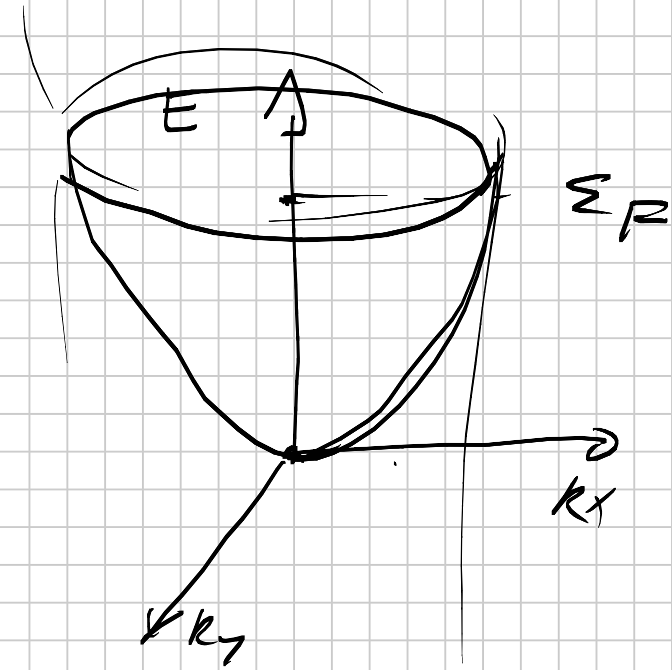
$T \to 0$

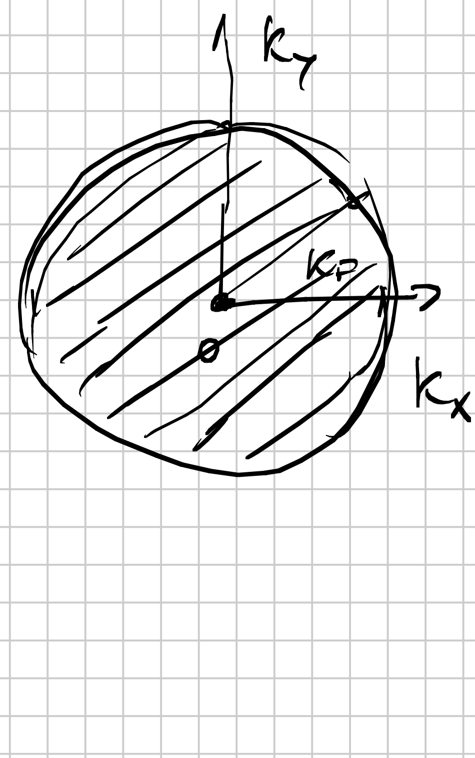
B HIGH

$\boxed{\text{2D electron gas}}$

$B = 0$

$$\varepsilon = \varepsilon_0 + \frac{\hbar^2 k_x^2}{2m} + \frac{\hbar^2 k_y^2}{2m}$$





$B \neq 0$

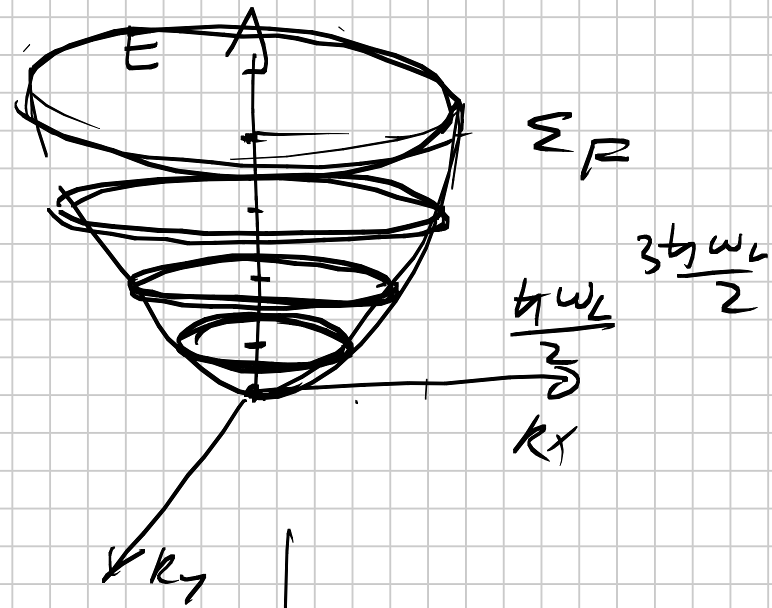
$$H = H_0 + \overbrace{s g \mu_B B}^{\text{Zeeman}} + \overbrace{\frac{1}{2} m \left(\frac{eB}{2m}\right)^2 (x^2+y^2)}^{\text{Diamagnetic shift}}$$

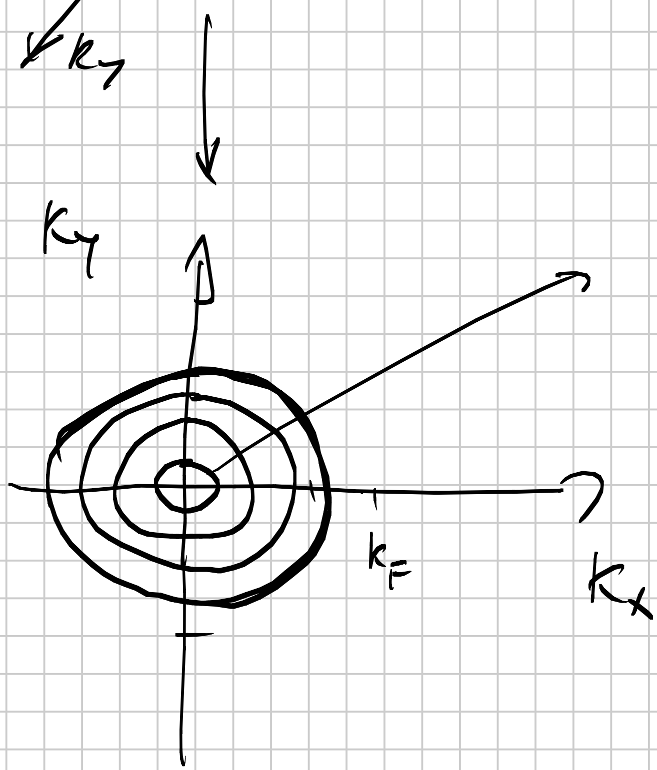
$$\Rightarrow \frac{1}{2} m \omega_L^2 (x^2+y^2)$$

$\Rightarrow$ this is an harmonic potential

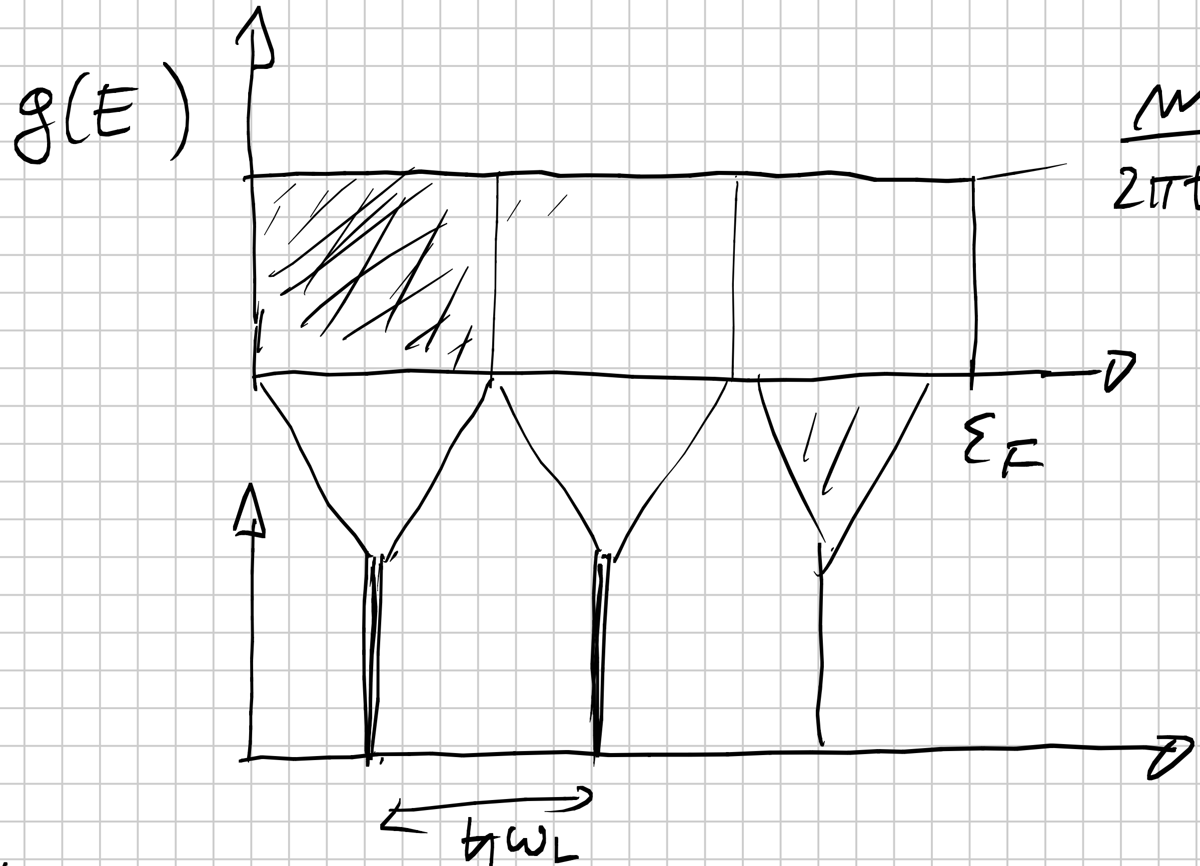
$\Rightarrow$ Quantum limit $\Rightarrow$ quantize energy levels for the electrons

$$E_n = \hbar \omega_L \left(n + \frac{1}{2}\right)$$





LANDAU ORBITS



B = 0

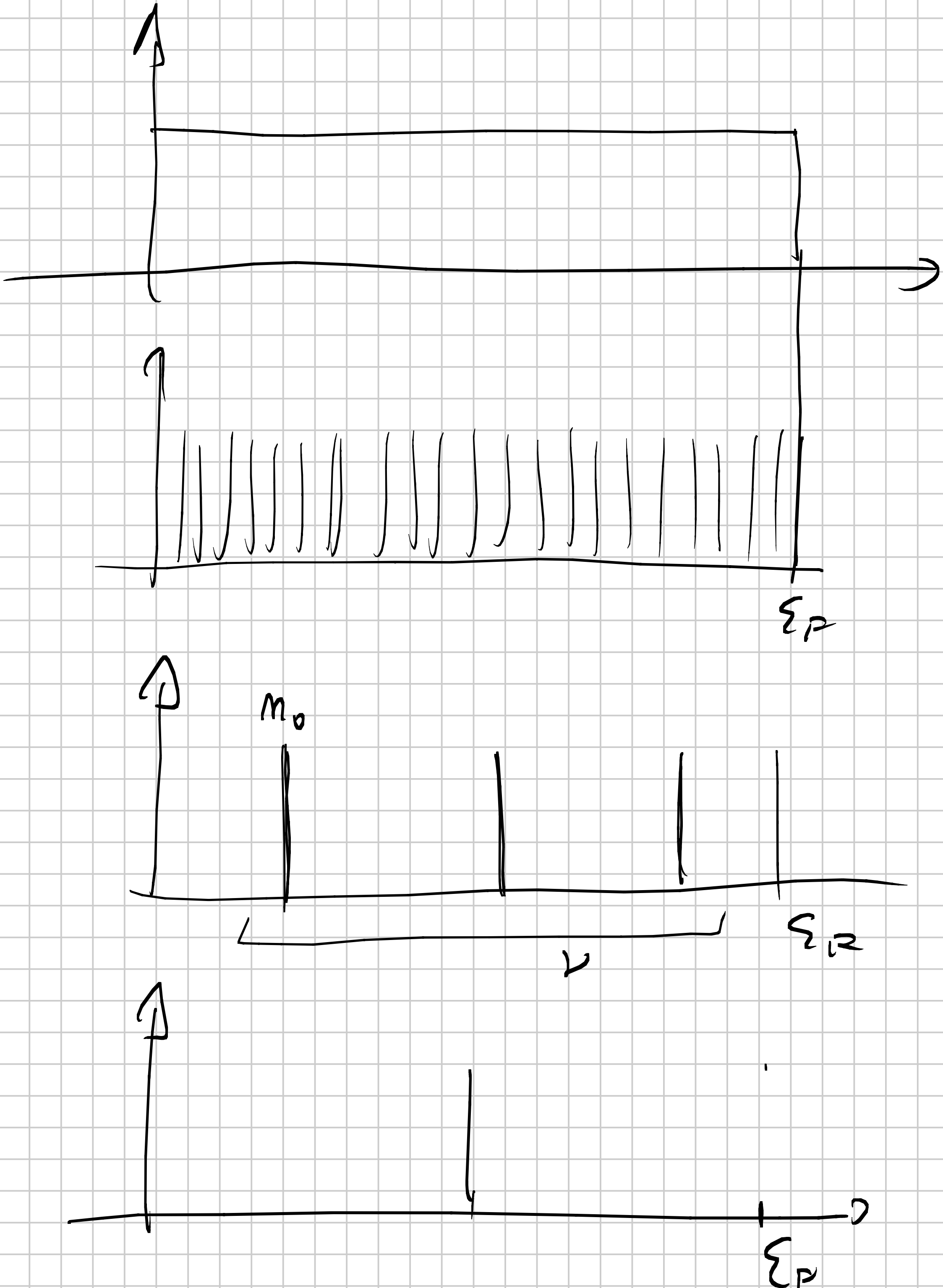
B ≠ 0

states in one LANDAU ORBIT ARE

$$g(E)\cdot\hbar\omega_L = n_0 = \frac{m}{2\pi\hbar^2}\,\hbar\,\frac{eB}{2m}\times 2^{\text{spin}} = 0$$

$$n_0 = \frac{eB}{h}$$ Degeneracy of each Landau orbit

B



$$\boxed{n \sim \nu n_0}$$

$$n_0 = \frac{eB}{h}$$

$$\rho_{xy} = -\frac{1}{ne}B = -\frac{h}{e^2\cancel{B}\nu}\cancel{B} \rightarrow \text{constant}$$

$\Rightarrow$ Plateau in ρ_{xy}

$\nu = 1$ $\quad \rho_{xy} - \frac{h}{e^2} \rightarrow \frac{h}{e^2}$

$\nu = 2$ $\quad \rho_{xy} - -\frac{h}{2e^2}$ $\quad$ RATIO