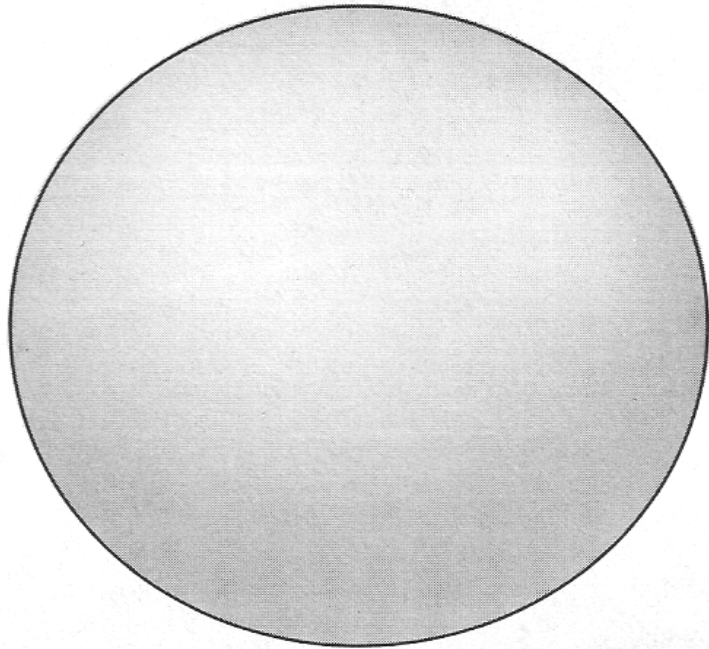
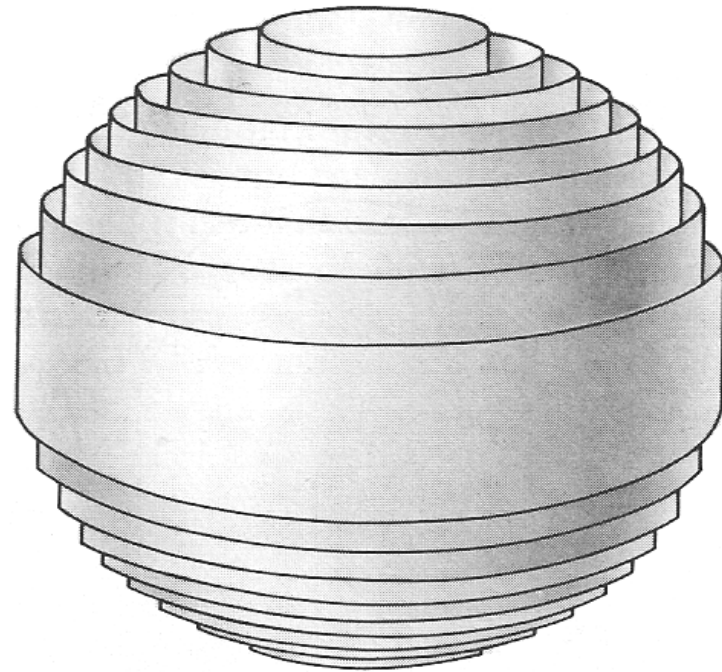


Fermi surfaces

Fermi sphere in a magnetic field



$B = 0$

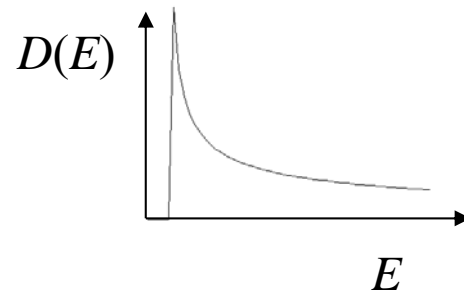


$B \neq 0$

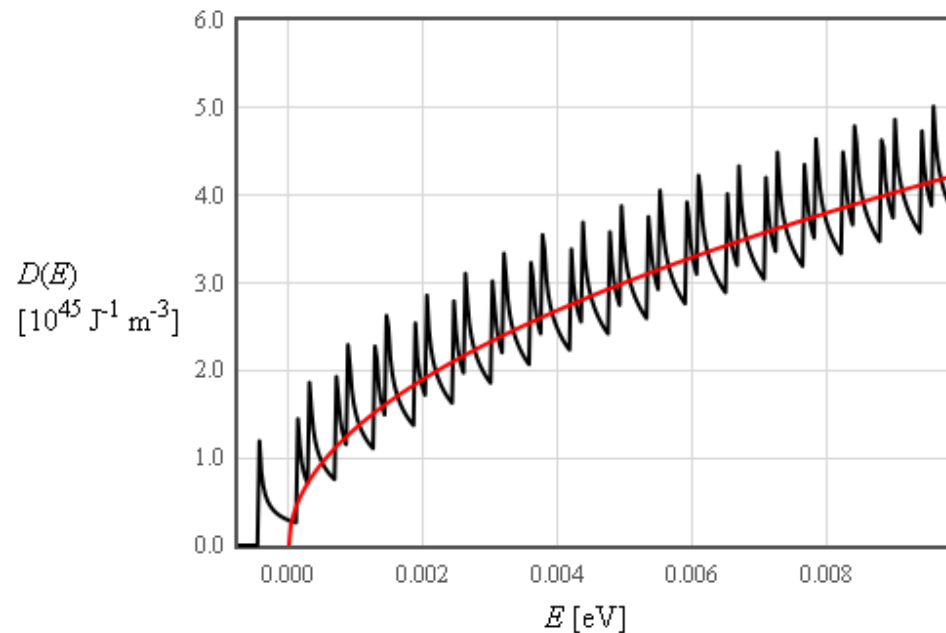
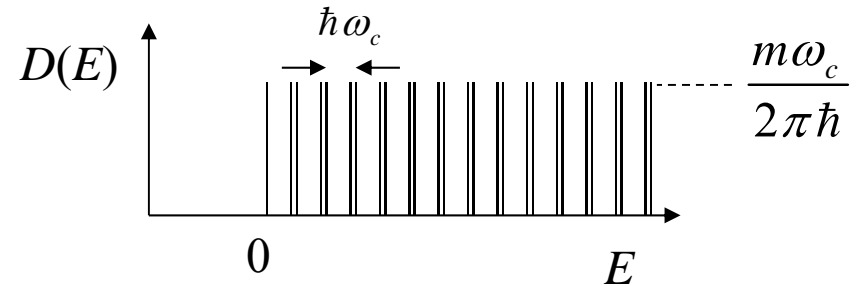
Landau cylinders

Density of states 3d

convolution of

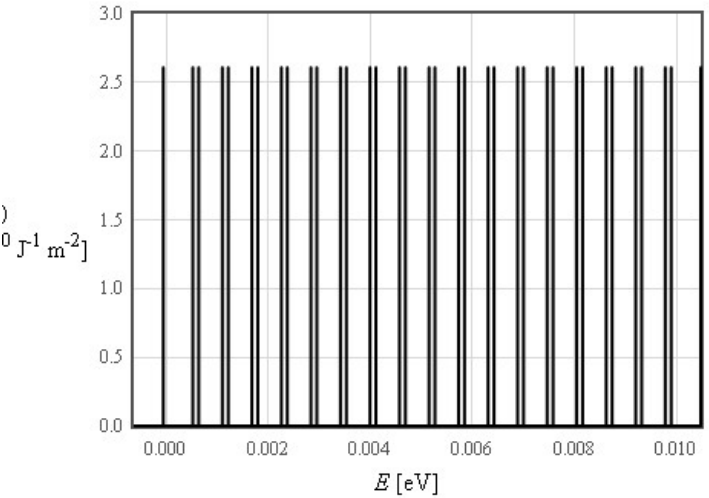
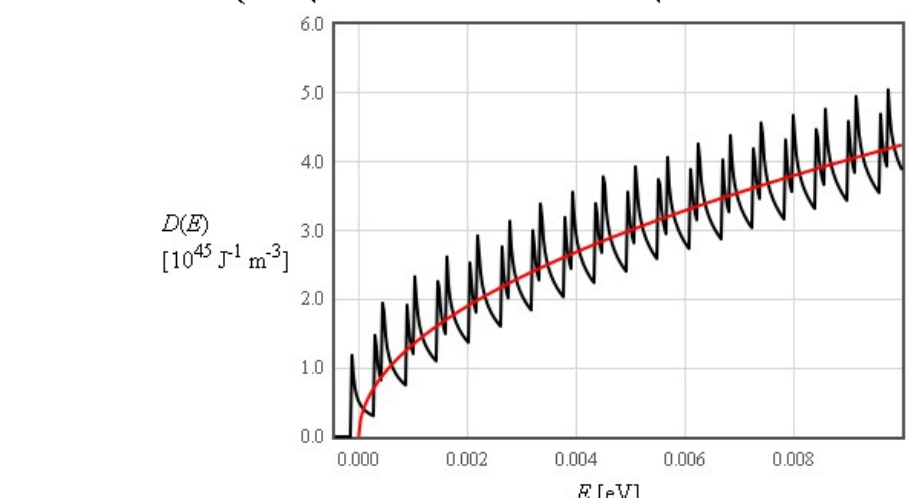


and



$$D(E) = \frac{(2m)^{3/2} \omega_c}{8\pi^2 \hbar^2} \left(\sum_{\nu=0}^{\infty} \frac{H(E - \hbar\omega_c (\nu + \frac{1}{2} - g/4))}{\sqrt{E - \hbar\omega_c (\nu + \frac{1}{2} - g/4)}} + \frac{H(E - \hbar\omega_c (\nu + \frac{1}{2} + g/4))}{\sqrt{E - \hbar\omega_c (\nu + \frac{1}{2} + g/4)}} \right) \text{ J}^{-1} \text{ m}^{-3}$$

Equation for free electrons in a magnetic field in 2 and 3 dimensions.

<p>2-D Schrödinger equation</p> $i\hbar \frac{d\psi}{dt} = \frac{1}{2m} (-i\hbar \nabla - e \vec{A})^2 \psi$	<p>3-D Schrödinger equation</p> $i\hbar \frac{d\psi}{dt} = \frac{1}{2m} (-i\hbar \nabla - e \vec{A})^2 \psi$
$\psi = g_v(x) \exp(ik_y y)$ <p>$g_v(x)$ is a harmonic oscillator wavefunction</p>	$\psi = g_v(x) \exp(ik_y y) \exp(ik_z z)$ <p>$g_v(x)$ is a harmonic oscillator wavefunction</p>
$E = \hbar \omega_c \left(v + \frac{1}{2} \right) \text{ J}$ $v = 0, 1, 2, \dots \quad \omega_c = \frac{ eB_z }{m}$	$E = \frac{\hbar^2 k_z^2}{2m} + \hbar \omega_c \left(v + \frac{1}{2} \right) \text{ J}$ $v = 0, 1, 2, \dots \quad \omega_c = \frac{ eB_z }{m}$
$\sum_{v=0}^{\infty} \delta \left(E - \hbar \omega_c \left(v + \frac{1}{2} \right) - \frac{g \mu_B}{2} B \right) + \delta \left(E - \hbar \omega_c \left(v + \frac{1}{2} \right) + \frac{g \mu_B}{2} B \right) \text{ J}^{-1} \text{ m}^{-2}$  <p style="text-align: center;">Calculate DoS</p>	$D(E) = \frac{(2m)^{3/2} \omega_c}{8\pi^2 \hbar^2} \left(\sum_{v=0}^{\infty} \frac{H(E - \hbar \omega_c (v + \frac{1}{2} - g/4))}{\sqrt{E - \hbar \omega_c (v + \frac{1}{2} - g/4)}} + \frac{H(E - \hbar \omega_c (v + \frac{1}{2} + g/4))}{\sqrt{E - \hbar \omega_c (v + \frac{1}{2} + g/4)}} \right) \text{ J}^{-1} \text{ m}^{-3}$  <p style="text-align: center;">Calculate DoS</p>

$$E_n = \hbar \omega \left(\text{Int} \left(\frac{\pi \hbar n}{\dots} \right) + \frac{1}{2} \right)$$

Practically all properties are periodic in $1/B$

Internal energy

$$u = \int_{-\infty}^{\infty} ED(E)f(E)dE$$

Specific heat

$$c_v = \left(\frac{\partial u}{\partial T} \right)_{V=\text{const}}$$

Entropy

$$s = \int \frac{c_v}{T} dT$$

Helmholtz free energy

$$f = u - Ts$$

Pressure

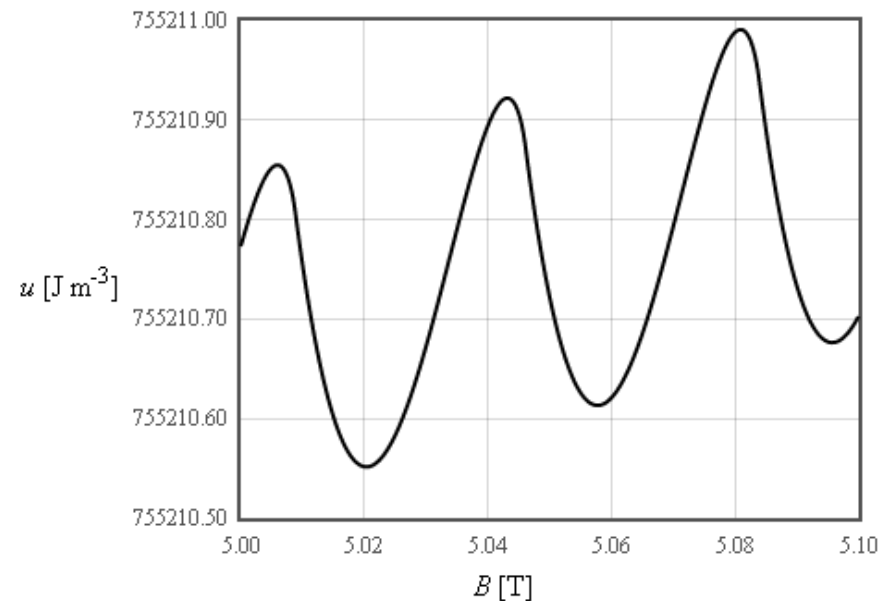
$$P = - \left(\frac{\partial F}{\partial V} \right)_{T=\text{const}}$$

Bulk modulus

$$B = -V \frac{\partial P}{\partial V}$$

Magnetization

$$M = - \frac{dU}{dH}$$



Fermi sphere in a magnetic field

Cross sectional area $S = \pi k_F^2$

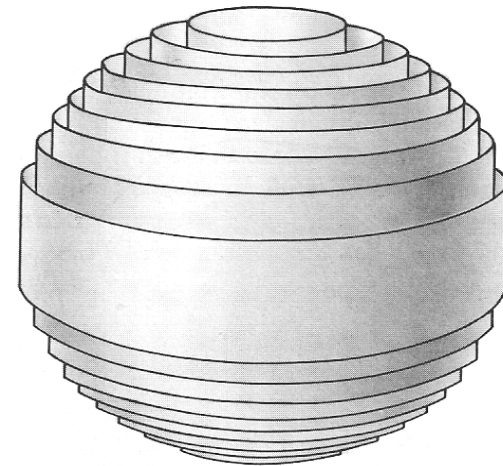
$$\hbar \omega_c \left(\nu + \frac{1}{2} \right) = \frac{\hbar^2 k_F^2}{2m}$$

$$\hbar \frac{eB_\nu}{m} \left(\nu + \frac{1}{2} \right) = \frac{\hbar^2 k_F^2}{2m}$$

$$\frac{2\pi e}{\hbar} \left(\nu + 1 + \frac{1}{2} \right) = \frac{S}{B_{\nu+1}} \qquad \frac{2\pi e}{\hbar} \left(\nu + \frac{1}{2} \right) = \frac{S}{B_\nu}$$

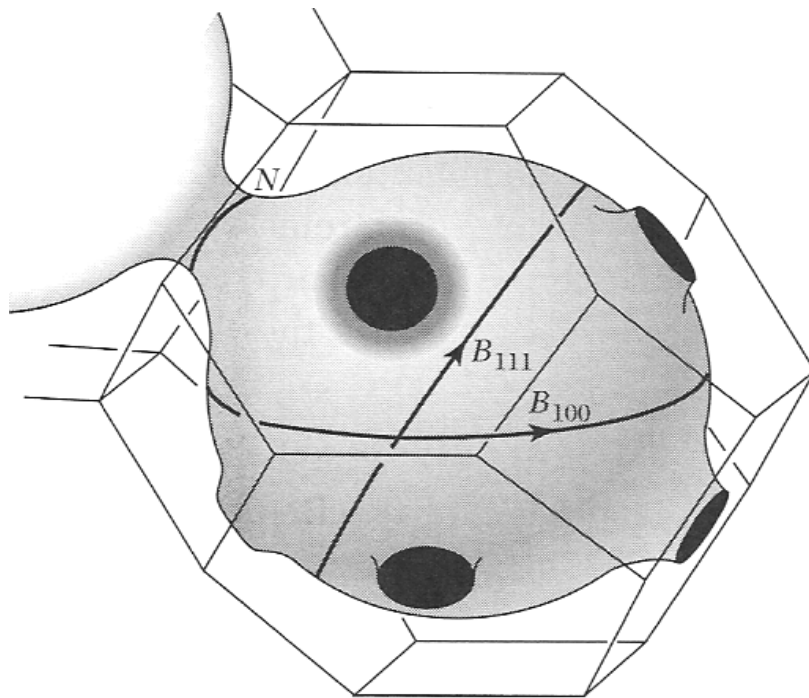
Subtract right from left

$$S \left(\frac{1}{B_{\nu+1}} - \frac{1}{B_\nu} \right) = \frac{2\pi e}{\hbar}$$

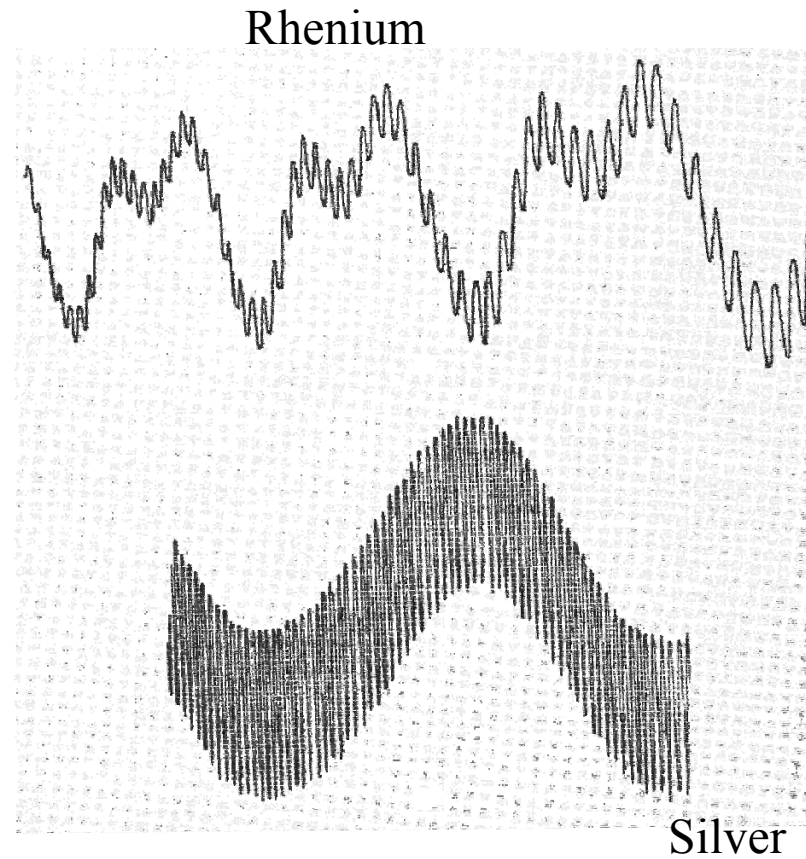


From the period of the oscillations, you can determine the cross sectional area S .

Experimental determination of the Fermi surface



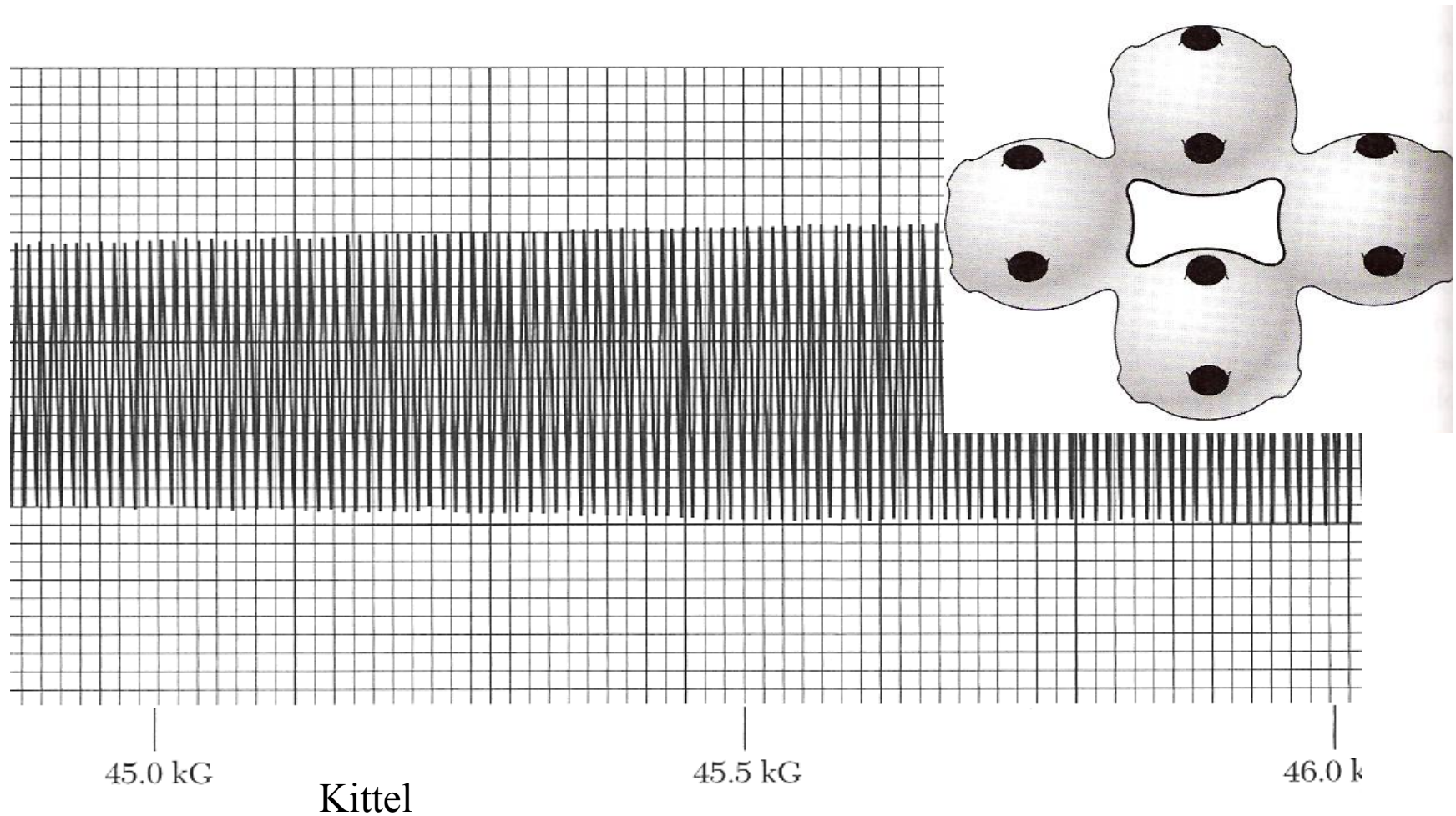
Kittel



de Haas - van Alphen

De Haas - van Alphen effect

The magnetic moment of gold oscillates periodically with $1/B$

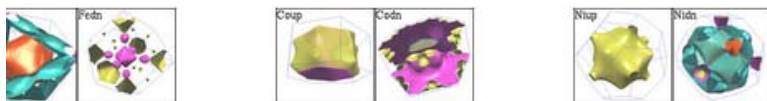


1A 2A 3B 4B 5B 6B 7B 8 1B 2B 3A 4A 5A 6A 7A NG

<http://www.phys.ufl.edu/fermisurface/>

H																	He																												
Li	Be											B	C	N	O	F	Ne																												
Na	Mg											Al	Si	P	S	Cl	Ar																												
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Cu	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																												
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe																												
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn																												
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Uut	Uuq	Uub	Uut	Uuq	Uup	Uub	Uus	Uuo																												
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> <p>•</p> <p>••</p> </div> <table border="1"> <tr> <td>La</td><td>Ce</td><td>Pr</td><td>Nd</td><td>Pm</td><td>Sm</td><td>Eu</td><td>Gd</td><td>Tb</td><td>Dy</td><td>Ho</td><td>Er</td><td>Tm</td><td>Yb</td> </tr> <tr> <td>Ac</td><td>Th</td><td>Pa</td><td>U</td><td>Np</td><td>Pu</td><td>Am</td><td>Cm</td><td>Bk</td><td>Cf</td><td>Es</td><td>Fm</td><td>Md</td><td>No</td> </tr> </table> </div>																La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb																																
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No																																

magnets :



native Structures :

