

# $^3\text{He}$ library

vladislav.zavyalov@aalto.fi

November 27, 2014

## Usage

This library provides constant and functions for various  $^3\text{He}$  properties. Supported Languages:

- Fortran-77. You should use `he3.fh` include file and `libhe3` library for fortran programs. All functions and arguments are `real*8`. Use `-fno-range-check` compiler flag to allow NaN values.
- Fortran-90. You should include `he3.f90h` instead.
- C. You should use `he3.h` include file and `libhe3` library in C programs. Lowercase names with underscore should be used (like `he3_pf_`). Type of arguments is always `double*`, type of returned value is `double`.
- Matlab, Octave. `mex` files are located in the `matlab` folder. Lowercase names should be used. In function arguments you can mix numbers with arrays or matrices of the same size. Example:

```
ttc=0:0.1:1; p=10;
I = he3_nu_b(p, ttc);
```

To build `mex` files you can use `make octave`, `make matlab` or `make matlab64` in the `matlab` folder. Fixed `rpath` is used for the library. For building this documentation octave files are needed.

- **Command line.** You can use all the functions via a command line interface. To get a list of all functions run the program `he3` without arguments:

```
> he3
```

To get information about specific function run the program with the function name as an argument:

```
> he3 he3_nu_b
```

You can use matlab-style vectors (`value1:step:value2`) to get a table of values (if step is missing then 20 points will be printed):

```
> he3 he3_nu_b 0.1:0.1:1 0
```

will give you Leggett frequency vs temperature at zero pressure.

## Location

GIT <https://github.com/slazav/he3lib>

ROTA `/home/slazav/he3lib/lib`

`/rota/programs/src/he3lib` – old, “stable” version.

Use “`addpath /rota/programs/src/he3lib/matlab`” in Matlab.

## General

<code>const_na</code>	Avogadro constant $N_A = 6.02214129 \cdot 10^{23}$ [1/mol]
<code>const_kb</code>	Boltsman constant $k_B = 1.3806488 \cdot 10^{-16}$ [erg/K]
<code>const_r</code>	R-gas constant $R = 8.314472 \cdot 10^7$ [sgs]
<code>const_h</code>	Plank constant $h = 6.62606957 \cdot 10^{27}$ [sgs]
<code>const_hbar</code>	$\hbar = h/2\pi = 1.054571726 \cdot 10^{27}$ [sgs]
<code>const_pi</code>	$\pi = 3.1415926535897932$
<code>const_2pi</code>	$2\pi$
<code>he3_amass</code>	$^3\text{He}$ atom mass, $m_3 = 5.0079 \cdot 10^{-24}$ [g]
<code>he3_mmass</code>	$^3\text{He}$ molar mass, $\mu = N_A m_3 = 3.0158$ [g/mol]
<code>he3_gyro</code>	$^3\text{He}$ gyromagnetic ratio $\gamma = 20378$ [(G s) $^{-1}$ ],

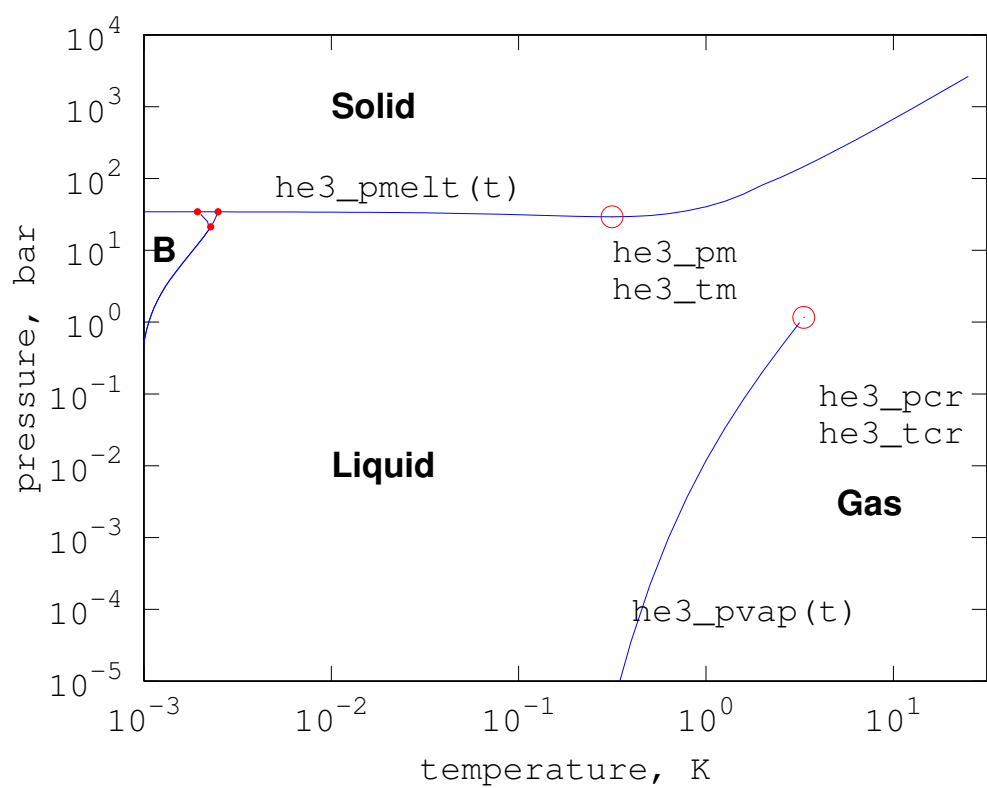
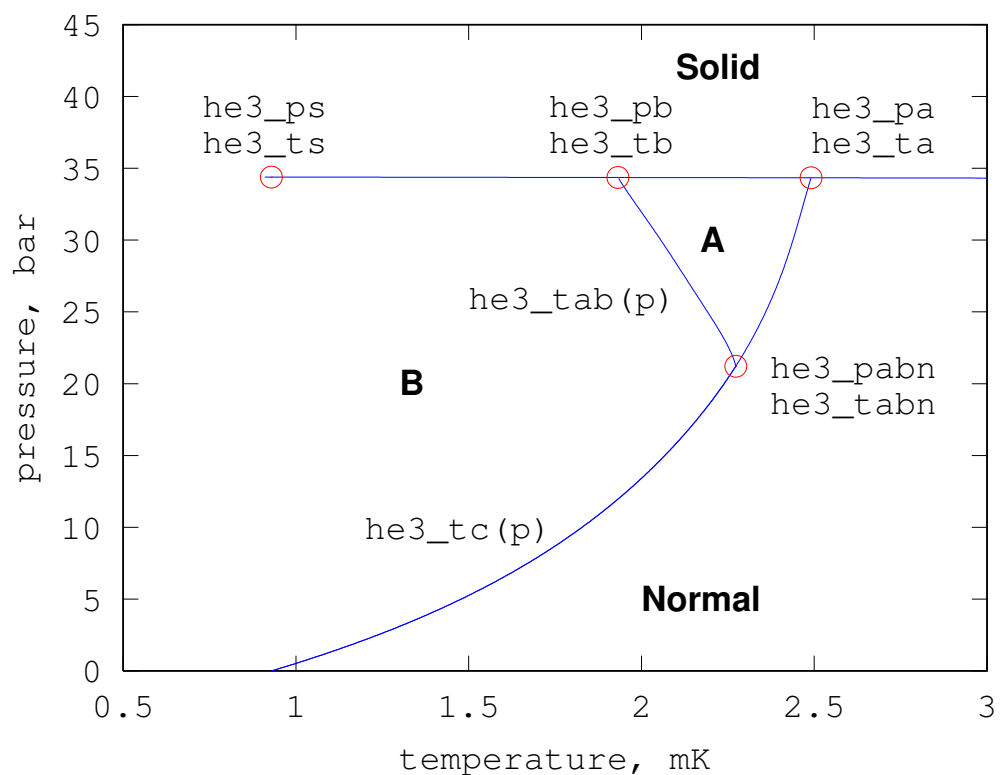
## Phase diagram

Vapor pressure and critical point are from the 1962  $^3\text{He}$  scale of temperatures. Melting curve  $P_m(T)$  at 0.9 – 250 mK,  $T_c(P)$ ,  $T_{AB}(P)$  and all tricritical points are from Greywall-86 temperature scale. Melting curve minimum is from PLTS-2000 temperature scale. Melting curve for higher temperatures is from Osborne, Abraham, Weinstock-1951 and Mills, Grilly-1955 with interpolation in the regions 0.25–0.5K and 1.5–2.0K. PLTS-2000 melting curve and critical points on it are also available. See more information in the source file `he3_phase.f`.

<code>he3_pvap(T)</code>	Vapor pressure [bar] vs temperature [K], $T = 0.2 - 3.324$ K
<code>he3_pcr</code>	Gas-liquid critical point pressure, 1.16317 [bar]
<code>he3_tcr</code>	Gas-liquid critical point temperature, 3.324 [K]
<code>he3_pmelt(T)</code>	Melting pressure [bar] vs temperature [K], $T = 0.0009 - 31$ K
<code>he3_pm</code>	Melting curve minimum pressure, 29.3113 [bar]
<code>he3_tm</code>	Melting curve minimum temperature, 0.31524 [K]
<code>he3_pa</code>	Superfluid trans. at melting curve, pressure, 34.3380 [bar]
<code>he3_ta</code>	Superfluid trans. at melting curve, temp., 2.491 [mK]
<code>he3_pb</code>	A-B trans. at melting curve, pressure, 34.3580 [bar]
<code>he3_tb</code>	A-B trans. at melting curve, temp., 1.932 [mK]
<code>he3_ps</code>	Neel transition at melting curve, pressure, 34.3905 [bar]
<code>he3_ts</code>	Neel transition at melting curve, temp., 0.9291 [mK]
<code>he3_tc(P)</code>	Superfluid transition temperature [mK] vs pressure [bar], $P = 0 - 34.358$ bar
<code>he3_tab(P)</code>	A-B transition temperature [mK] vs pressure [bar], $P = 0 - 34.3609$ bar, below 21.22 bar is equal to <code>he3_tc</code>
<code>he3_tabn</code>	A-B-Normal point temperature, 2.2311 [mK]
<code>he3_pabn</code>	A-B-Normal point pressure, 21.22 [bar]

PLTS-2000 temperature scale:

<code>he3_pmelt_plts(T)</code>	PLTS-2000 melting pressure [bar] vs temperature [K].
<code>he3_pa_plts</code>	Superfluid trans. at melting curve, pressure, 34.3407 [bar]
<code>he3_ta_plts</code>	Superfluid trans. at melting curve, temp., 2.444 [mK]
<code>he3_pb_plts</code>	A-B trans. at melting curve, pressure, 34.3609 [bar]
<code>he3_tb_plts</code>	A-B trans. at melting curve, temp., 1.896 [mK]
<code>he3_ps_plts</code>	Neel transition at melting curve, pressure, 34.3934 [bar]
<code>he3_ts_plts</code>	Neel transition at melting curve, temp., 0.902 [mK]



## Fermi-liquid parameters

Fermi-liquid parameters according to Wheatley-75 table. Values are calculated using experimental data for molar volume, speed of sound, magnetic temperature  $T^*$ , collected by Wheatley-75 and heat capacity ( $\gamma_f = C/RT$ ) measured by Graywall-86. Argument is pressure, [bar] in the range 0 – 34.4. See more information in the source file `he3_fermi.f`.

Measured values:

<code>he3_vm(P)</code>	Molar volume $v_m$ , [cm <sup>3</sup> /mol]
<code>he3_c1(P)</code>	First sound velocity, $c_1$ , [cm/s]
<code>he3_gammaf(P)</code>	R-gas constant $\gamma_f = C/RT$ , [1/(K mol)]
<code>he3_tmag(P)</code>	Magnetic temperature $T^*$ , [K]

Derived values:

<code>he3_rho(P)</code>	Density $\rho = \mu/v_m$ , [g/cm <sup>3</sup> ]
<code>he3_2n0(P)</code>	$2N(0) = \frac{\gamma_f}{v_m} \frac{3N_A}{k_B\pi^2}$ , [1/(erg cm <sup>3</sup> )]
<code>he3_pf(P)</code>	$p_F = h \left( \frac{3}{8\pi} \frac{N_A}{v_m} \right)^{1/3}$ , [g cm/s]
<code>he3_meff(P)</code>	$m^* = \frac{h^3}{8\pi} \frac{2N(0)}{p_F}$ , [g]
<code>he3_mm(P)</code>	$m^*/m_3$
<code>he3_vf(P)</code>	$v_F = p_F/m^*$ , [cm/s]
<code>he3_chi_n(P)</code>	$\chi_N = 2N(0) \frac{(\gamma\hbar)^2}{4(1 + F_0^a)}$
<code>he3_f0s(P)</code>	$F_0^s = 3 m^* m_3 c_1^2/p_F^2 - 1$
<code>he3_f1s(P)</code>	$F_1^s = 3(m^*/m_3 - 1)$
<code>he3_f0a(P)</code>	$F_0^a = Z_0/4 = 3k_B T^* m^*/p_F^2 - 1$
<code>he3_f1a(P)</code>	$F_1^a$
<code>he3_a(P)</code>	Average atomic spacing, $a = (v_m/N_A)^{1/3}$ , Å
<code>he3_gdk(P)</code>	Average dipolar coupling enegy, $g_d/k_B = \frac{2\pi\gamma^2\hbar^2}{3v_m k_B}$ , [K]
<code>he3_tfeff(P)</code>	Effective Fermi temperature, $T_{F_{eff}} = \frac{\pi^2}{2\gamma_f}$ , [K]

TODO:

Recalculate  $F_0^a$   $F_1^a$  from experimantal data (Now there are some extra not-consistent data)! (see Ramm-1970, Halperin-92 ...). Add  $F_2^a$  (zero or from Halperin-95). Check  $g_d$ .

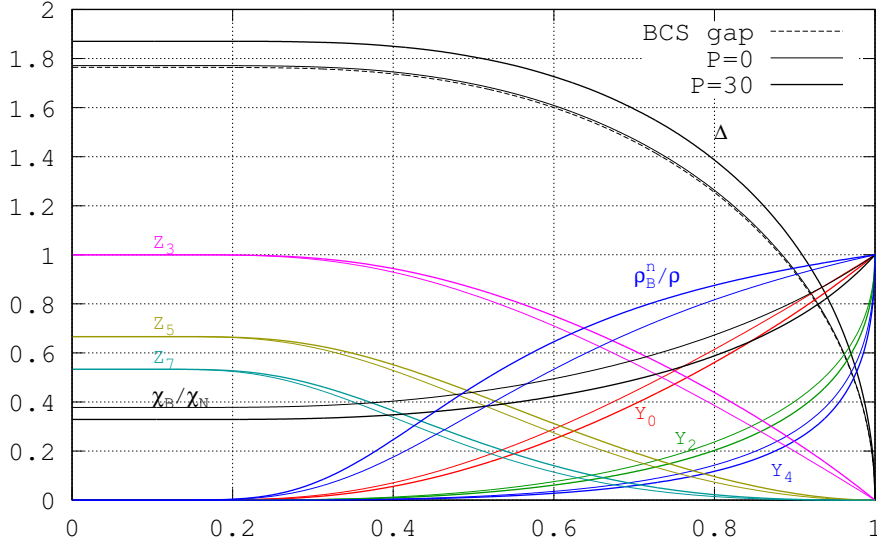
Pressure-dependent values:

P, bar	0	3	6	9	12	15	18	21	24	27	30	33
$T_c$ , mK	0.929	1.290	1.560	1.769	1.934	2.067	2.177	2.267	2.339	2.395	2.438	2.474
$T_{AB}$ , mK	—	—	—	—	—	—	—	—	2.217	2.137	2.056	1.969
$v_m$ , cm <sup>3</sup> /mol	36.84	33.95	32.03	30.71	29.71	28.89	28.18	27.55	27.01	26.56	26.17	25.75
$c_1$ , m/s	182.9	227.4	259.9	285.8	307.9	327.3	344.8	360.6	375.2	389.2	402.9	416.1
$\gamma_f$ , 1/(K mol)	2.784	2.981	3.158	3.321	3.475	3.625	3.772	3.918	4.065	4.211	4.355	4.496
$T^*$ , mK	358.8	305.8	276.2	255.7	238.7	224.0	212.4	204.0	197.8	191.9	184.9	178.4
$\rho$ , g/cm <sup>3</sup>	0.082	0.089	0.094	0.098	0.102	0.104	0.107	0.109	0.112	0.114	0.115	0.117
$2N(0)$ , 10 <sup>38</sup>	1.002	1.164	1.307	1.434	1.551	1.663	1.774	1.885	1.995	2.102	2.207	2.315
$p_F$ , 10 <sup>-20</sup> g cm/s	8.280	8.509	8.675	8.798	8.896	8.979	9.054	9.122	9.182	9.234	9.280	9.330
$m^*$ , 10 <sup>-23</sup> g	1.401	1.584	1.744	1.887	2.018	2.144	2.269	2.392	2.515	2.635	2.753	2.872
$m^*/m_3$	2.797	3.162	3.482	3.767	4.030	4.282	4.530	4.777	5.022	5.261	5.497	5.735
$v_F$ , m/s	59.11	53.73	49.74	46.64	44.08	41.87	39.91	38.13	36.51	35.05	33.71	32.49
$\chi_N$ , 10 <sup>-9</sup>	38.1	48.5	56.9	64.1	71.0	77.8	84.1	89.6	94.2	98.8	104.1	109.7
$F_0^s$	9.27	15.99	22.52	28.91	35.32	41.81	48.43	55.17	62.10	69.32	76.95	84.82
$F_1^s$	5.39	6.49	7.45	8.30	9.09	9.85	10.59	11.33	12.07	12.78	13.49	14.21
$F_0^a$	-0.70	-0.72	-0.73	-0.74	-0.75	-0.75	-0.76	-0.76	-0.76	-0.75	-0.76	-0.76
$F_1^a$	-0.55	-0.73	-0.80	-0.85	-0.90	-0.95	-0.99	-1.00	-0.99	-0.99	-0.99	-1.00
$a$ , Å	3.940	3.834	3.761	3.708	3.668	3.634	3.604	3.577	3.553	3.533	3.516	3.497
$g_d/k_B$ , μK	114.5	124.3	131.7	137.4	142.0	146.0	149.7	153.1	156.2	158.8	161.2	163.9
$T_{Feff}$ , K	1.773	1.656	1.563	1.486	1.420	1.361	1.308	1.260	1.214	1.172	1.133	1.098
$\langle W \rangle$	83.4	104.1	116.0	123.7	130.7	137.2	141.6	142.4	140.6	139.0	140.3	141.8
$\langle W_I \rangle$	10.92	14.68	16.37	17.32	18.23	19.08	19.48	19.19	18.41	17.73	17.63	17.60
$\langle W_D \rangle$	24.89	29.75	32.62	34.42	35.98	37.41	38.38	38.56	38.18	37.88	38.23	38.60
$\langle W_L \rangle$	-11.42	-8.14	-6.53	-4.70	-2.28	0.29	2.38	3.62	4.10	4.25	4.53	5.19
$\gamma_0$	0.131	0.141	0.141	0.140	0.139	0.139	0.138	0.135	0.131	0.127	0.126	0.124
$\delta_0$	0.298	0.286	0.281	0.278	0.275	0.273	0.271	0.271	0.272	0.272	0.272	0.272
$w_0$	1.211	1.192	1.187	1.185	1.182	1.180	1.179	1.181	1.184	1.187	1.189	1.189
$\lambda_1^a$	-0.137	-0.078	-0.056	-0.038	-0.017	0.002	0.017	0.025	0.029	0.031	0.032	0.037
$\tau_N(0, T_c)$ , μs	0.609	0.237	0.137	0.095	0.072	0.057	0.048	0.043	0.039	0.036	0.034	0.031
$\Delta_{WC+}(T=0)/T_c$	1.771	1.795	1.813	1.825	1.834	1.843	1.850	1.856	1.861	1.866	1.870	1.875
$\chi_B(T=0)/\chi_N$	0.378	0.357	0.346	0.340	0.335	0.331	0.328	0.327	0.328	0.329	0.329	0.328
$\nu_B(T=0)$ , kHz	125.3	161.9	188.0	208.5	225.7	241.2	255.7	269.8	283.5	296.6	308.7	320.5
$c_\perp(T=0)$ , cm/s	2190	1901	1724	1594	1485	1393	1315	1253	1202	1157	1111	1068
$c_\parallel(T=0)$ , cm/s	2509	2172	1967	1817	1692	1585	1497	1426	1368	1316	1264	1215
P, bar	0	3	6	9	12	15	18	21	24	27	30	33

## Energy gap

BCS energy gap + trivial strong coupling correction + some values derived from energy gap. See more information in the source file `he3_gap.f`.

<code>he3_bcsgap(ttc)</code>	BCS gap for 3He-B in $T_c$ units, $\Delta_{\text{BCS}}/k_B T_c$
<code>he3_bcsgap_fast(ttc)</code>	Einzel approximation for BCS gap (0.5% accuracy, 70 times faster) (Einzel-1991, f.68)
<code>he3_trivgap(ttc, P)</code>	Trivial strong-coupling correction to the BCS gap
<code>he3_todogap(ttc, P)</code>	Gap based on Todoschenko's measurements: linear interpolation in density between BCS value at zero bar and measured value 1.99 at melting pressure + temperature behaviour as in <code>he3_trivgap</code>
<code>he3_gap(ttc, P)</code>	Wrapper which is used everywhere in the lib (trivgap by default)
<code>he3_yosida(ttc, gap, n)</code>	Yosida functions $Y_n(T/T_c, \Delta) = \int_{-\infty}^{\infty} \left( \frac{\xi_k}{E_k} \right)^n \frac{1}{2T/T_c} \text{ch}^{-2} \left( \frac{E_k}{2T/T_c} \right) d\xi_k$  Low temperature limit: $Y_n(T, \Delta) = 2\Gamma \left( \frac{n+1}{2} \right) \left( \frac{T}{\Delta} \right)^{\frac{n-1}{2}} \exp \left( -\frac{\Delta}{T} \right)$ Note: type of n parameter in fortran should be real*8 (this was done for standard function handling). If n is integer, result is unpredictable!
<code>he3_yosida_par(ttc, gap)</code>	$Y_q^{\parallel}(T/T_c, \Delta)$
<code>he3_yosida_perp(ttc, gap)</code>	$Y_q^{\perp}(T/T_c, \Delta)$
<code>he3_z3(ttc, gap)</code>	
<code>he3_z5(ttc, gap)</code>	
<code>he3_z7(ttc, gap)</code>	
<code>he3_lambda(ttc, gap)</code>	
<code>he3_rho_nb(ttc, p)</code>	B-phase normal component density: $\frac{\rho_B^n}{\rho_N} = \frac{(3 + F_1^s)Y_0}{3 + F_1^s Y_0}$
<code>he3_chi_b(ttc, p)</code>	B-phase susceptibility (ratio of he3_chi_n): $\frac{\chi_B}{\chi_N} = \frac{(1 + F_0^a)(2 + Y_0)}{3 + F_0^a(2 + Y_0)}$
<code>he3_chi_bp(ttc, P)</code>	B-phase Cooper pair susceptibility (ratio of he3_chi_b): $\frac{\chi_B^p}{\chi_B} = \frac{2(1 - Y_2)}{(2 + Y_0)}$



## Dipole energy and Leggett frequency

Values are given according to Thuneberg's paper JLTP 122, p657 (2001). Temperature independent  $g_d$  parameter is restored from experimental data for  $\Omega_B$ , measured in transverse and longitudinal NMR. See more information in the source file `he3_dipole.f`.

Dipolar energy:

$$F_D = \lambda_D \int (R_{ii}R_{jj} + R_{ij}R_{ji}) d^3r = 4\lambda_D \int \cos\theta(1 + 2\cos\theta) d^3r$$

$$\lambda_D = \Delta^2 g_d, \quad \Omega_B = \gamma \sqrt{15\lambda_D/\chi_B}$$

Note: In old papers (Leggett, ...)  $g_D/5$  is used instead of  $\lambda_G$ .

`he3_gd(p)`  $g_d$ , [1/(erg cm<sup>3</sup>)]

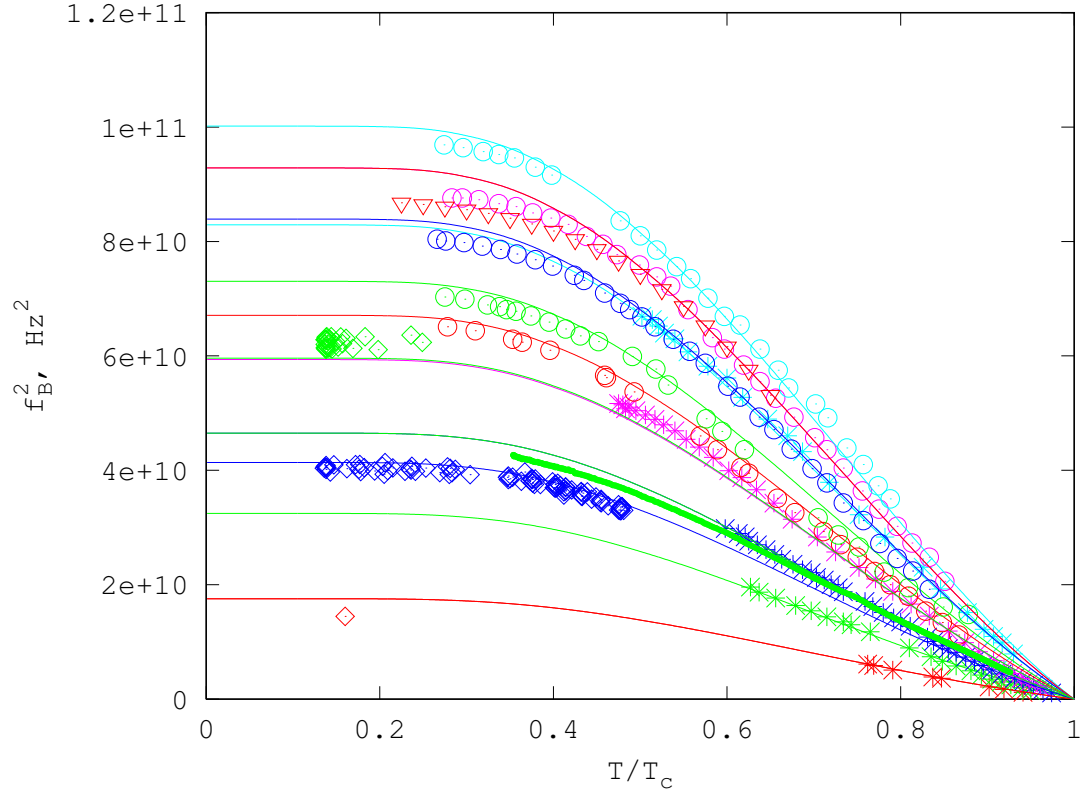
`he3_ld(p)`  $\lambda_D = \Delta^2 g_d$ , [erg/cm<sup>3</sup>]

`he3_nu_b(ttc, p)` B-phase Leggett frequency  $\nu_B = \frac{\gamma}{2\pi} \sqrt{15\Delta^2 g_d/\chi_B}$ , Hz

`he3_nu_b1(ttc, p)` Less accurate formula without using  $g_d$ , Hz

$$\nu_B = \frac{1}{2\pi} \sqrt{\frac{3\pi}{2\chi}} \frac{\gamma^2 \hbar}{2} N(0) \Delta \log \frac{e_f}{\Delta}$$



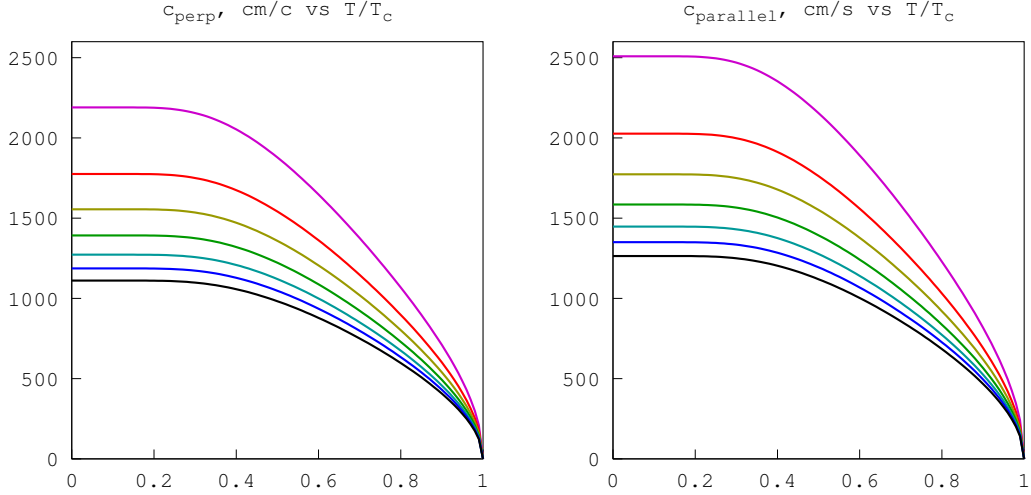


## Gradient energy and spin wave velocity

Gradient energy coefficients and derived values, including spin wave velocities. See more information in the source file `he3_grad.f`.

$$F_{\nabla} = \frac{1}{2} \Delta^2 [K_1 (\nabla_j R_{ak}) (\nabla_j R_{ak}) + K_2 (\nabla_j R_{ak}) (\nabla_k R_{aj}) + K_3 (\nabla_j R_{aj}) (\nabla_k R_{ak})]$$

he3_grad_K0(ttc, p)	$K_1 = K_2 = K_3$ without fermi-liquid corrections, see VW7.23m
he3_grad_c(ttc, p)	$c$ and $\delta$ paramters calculated with fermi-liquid corrections (Cross-1975),
he3_grad_delta(ttc, p)	see VW7.25. These values are used to calculate all other things: $c = -\frac{\rho_s}{10} \frac{3 + F_1^a}{3 + F_1^s} \frac{1}{1 + F_1^a(5 - 3\rho_s/\rho)/15}, \quad \delta = \frac{F_1^a \rho_s / \rho}{3 + F_1^s(1 - \rho_s/\rho)}$
he3_grad_K12(ttc, p)	$K_1 = K_2 = -\frac{2}{\Delta^2} \left( \frac{\hbar}{2m} \right)^2 c,$
he3_grad_K3(ttc, p)	$K_3 = -\frac{2}{\Delta^2} \left( \frac{\hbar}{2m} \right)^2 (1 + \delta)c$
he3_grad_K(ttc, p)	$K = 2K_1 + K_2 + K_3,$
he3_grad_Kp(ttc, p)	$K' = K_2 + K_3$
he3_grad_lg1(ttc, p)	Thunebergs $\lambda_{G1}, \lambda_{G2}$ and $\lambda_{SG}^b$ :
he3_grad_lg2(ttc, p)	$\lambda_{G1} = \frac{1}{2}\Delta^2(K_2 + K_3),$
he3_grad_lsgb(ttc, p)	$\lambda_{G2} = \frac{1}{2}\Delta^2 K_1, \quad \lambda_{SG}^b = \Delta^2 K_2$
he3_cpar(ttc, p)	velocity of transverse spin waves parallel and perpendicular to the $l$
he3_cperp(ttc, p)	direction [cm/s]: $c_{\parallel}^2 = \frac{\gamma^2 \Delta^2}{\chi_B} K, \quad c_{\perp}^2 = \frac{\gamma^2 \Delta^2}{\chi_B} (K - K'/2), \quad c_{\parallel}^2 / c_{\perp}^2 \approx 4/3$
he3_clpar(ttc, p)	same for longitudinal waves [cm/s]:
he3_clperp(ttc, p)	$C_{\parallel}^2 = \frac{\gamma^2 \Delta^2}{\chi_B} (K - K'), \quad C_{\perp}^2 = \frac{\gamma^2 \Delta^2}{\chi_B} K, \quad C_{\parallel}^2 / C_{\perp}^2 \approx 1/2$



## Other textural parameters

Values are given according to Thuneberg's paper JLTP 122, p657 (2001). High order Fermi liquid parameters ( $F_2^a$ ,  $F_3^a$ ) are set to 0. See more information in the source file `he3_text.f`.

Bulk terms:

$$\begin{aligned}
 F_{DH} &= -a \int_V (\mathbf{n} \cdot \mathbf{H})^2 d^3r \\
 F_{DV} &= -\lambda_{DV} \int_V [\mathbf{n} \cdot (\mathbf{v}_s - \mathbf{v}_n)]^2 d^3r \ll F_{HV} \text{ at } H \approx 200 \text{ Oe} \\
 F_{HV} &= -\lambda_{HV} \int_V [\mathbf{H} \cdot R \cdot (\mathbf{v}_s - \mathbf{v}_n)]^2 d^3r
 \end{aligned}$$

Surface terms:

$$\begin{aligned}
 F_{SH} &= -d \int_S [\mathbf{H} \cdot R \cdot \mathbf{s}]^2 d^2r \\
 F_{SG} &= -\lambda_{SG} \int_S s_j R_{\alpha j} \frac{\partial R_{\alpha i}}{\partial r_i} d^2r
 \end{aligned}$$

Vortex term:

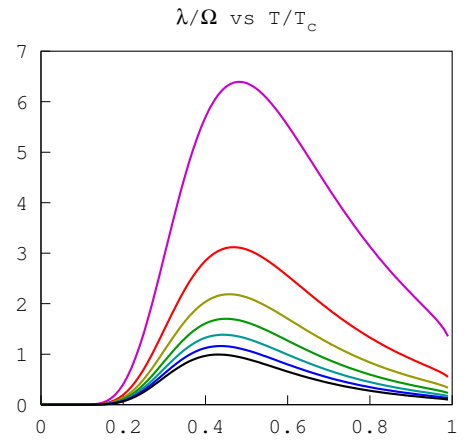
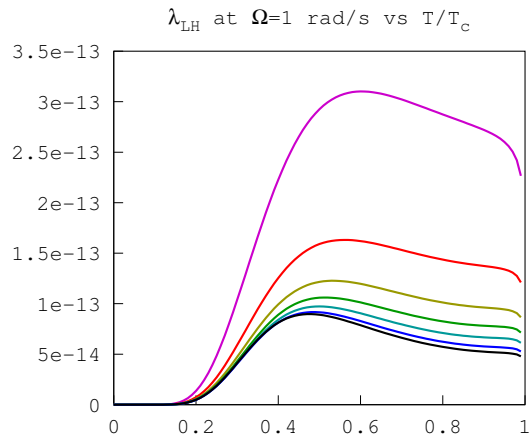
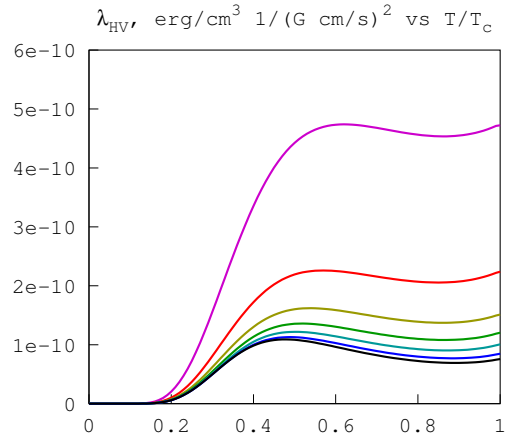
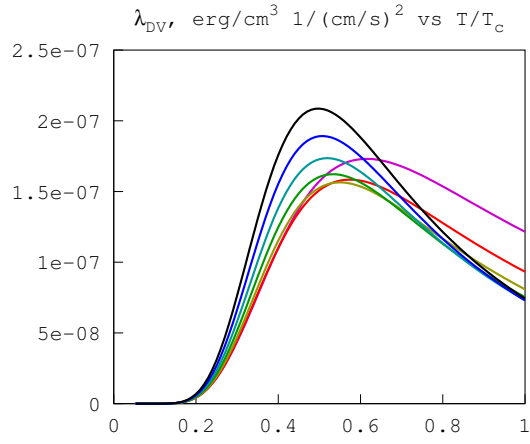
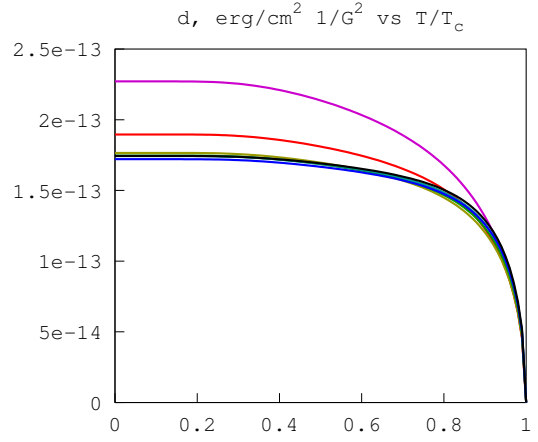
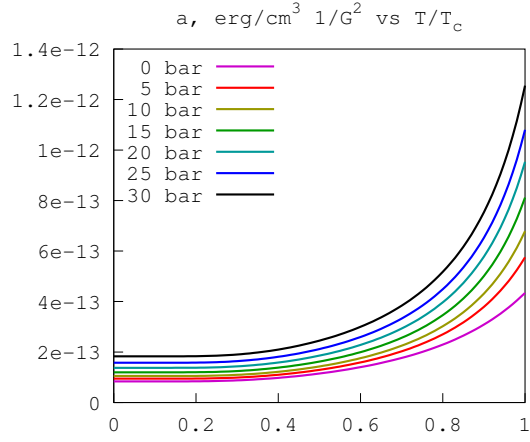
$$F_{LH} = \frac{\lambda_{LH}}{2\Omega} \int_L |\omega_s| [\mathbf{H} \cdot R \cdot \mathbf{l}]^2 d^3r$$

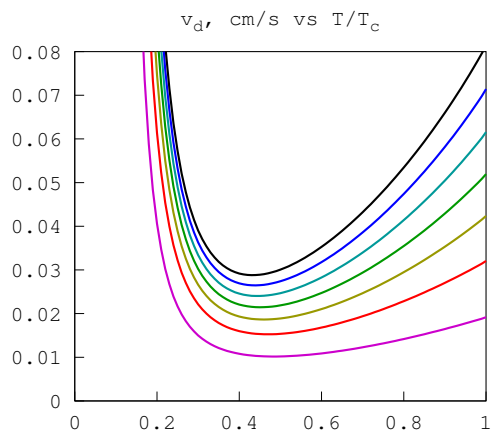
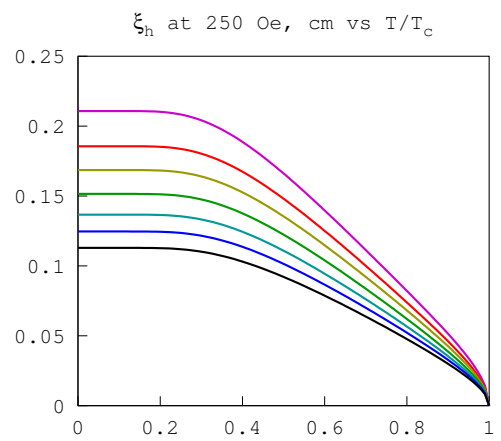
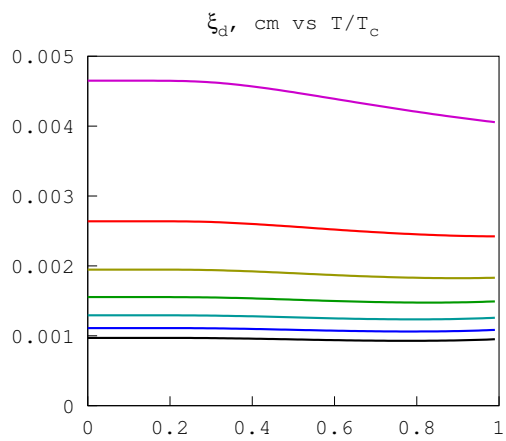
---

<code>he3_text_a(ttc, p)</code>	$a = \frac{5g_d}{2} \left[ \frac{\hbar\gamma/2}{1 + F_0^a(2 + Y_0)/3} \right]^2 \left( 5 - 3\frac{Z_3}{Z_5} \right), [\text{erg}/\text{cm}^3 \text{ G}^{-2}]$
<code>he3_text_d(ttc, p)</code>	$d, [\text{erg}/(\text{cm}^2 \text{ G}^2)] - \text{GL extrapolation!}$
<code>he3_text_ldv(ttc, p)</code>	$\lambda_{DV} = 5g_d \left( \frac{m^*v_F}{1 + F_1^s Y_0/3} \right)^2 \left( 1 - \frac{3Z_5}{2Z_3} \right), [\text{erg}/\text{cm}^3 (\text{cm}/\text{s})^{-2}]$
<code>he3_text_lhv(ttc, p)</code>	$\lambda_{HV} = \frac{\rho}{\Delta^2} \frac{1 + F_1^s/3}{(1 + F_1^s Y_0/3)^2} \left( \frac{\hbar\gamma/2}{1 + F_0^a(2 + Y_0)/3} \right)^2 \left( Z_3 - \frac{9}{10}Z_5 + \frac{9}{10} \frac{Z_5^2}{Z_3} - \frac{3}{2}Z_7 \right)$
<code>he3_text_llh(ttc, p, omega)</code>	$\lambda_{LH} = \frac{\hbar}{2m} \Omega \lambda_{HV} \left( \ln \frac{R}{r} - \frac{3}{4} \right), [\text{erg}/(\text{cm}^3 \text{ G}^2 \text{ s})] - \text{counterflow part only!}$
<code>he3_text_lo(ttc, p, omega)</code>	lambda/omega used in the texture library: $\frac{\lambda}{\Omega} = \frac{5\lambda_{LH}}{2a\Omega}, (\text{rad}/\text{s})^{-1}$

---

<code>he3_text_xih(ttc, p, h)</code>	Magnetic length $\xi_H = \sqrt{65\lambda_{G2}/(8aH^2)}$
<code>he3_text_xid(ttc, p)</code>	Dipolar length (according to Hakonen-1989) $\xi_D = \sqrt{13\lambda_{G2}/12\lambda_D}$ . Note: in Thuneberg's paper $\xi_D = \sqrt{\lambda_{G2}/\lambda_D}$ is used.
<code>he3_text_vd(ttc, p)</code>	Dipolar velocity (according to Thuneberg-2001) $v_D = \sqrt{2a/5\lambda_{HV}}$





## Transport properties in the normal phase

See more information in the source file `he3_transp.n.f`.

Crossections and scattering factors:

<code>he3_scatt_w(P)</code>	Scattering crossection $\langle W \rangle$ (Einzel-1978, f.82)
<code>he3_scatt_wi(P)</code>	$\langle W_I \rangle$ (Einzel-1978, f.82)
<code>he3_scatt_wd(P)</code>	$\langle W_D \rangle$ (Einzel-1978, f.82)
<code>he3_scatt_wl(P)</code>	$\langle W_L \rangle$ (Einzel-1978, f.71)
<code>he3_scatt_g0(P)</code>	Scattering factor $\gamma_0 = \langle W_I \rangle / \langle W \rangle$ (Einzel-1978, f.66)
<code>he3_scatt_d0(P)</code>	Scattering factor $\delta_0 = \langle W_D \rangle / \langle W \rangle$ (Einzel-1978, f.67)
<code>he3_scatt_w0(P)</code>	$w_0 = 1 - 3/2\gamma_0 + \delta_0$ (Einzel-1978, f.79)
<code>he3_scatt_l1a(P)</code>	Scattering factor $\lambda_1^a$ used in spin diffusion transport time. Can be neglected. (Einzel-1978, f.74, p.350).

<code>he3_tau_n0(ttc,p)</code>	Normal state quasiparticle lifetime at the Fermi level, s. $\tau_N(0, T) = \tau_N(0, T_c) \left( \frac{T_c}{T} \right)^2 = \frac{32E_F\hbar}{\langle W \rangle (\pi k_B T)^2}$ (Einzel-1991, p.325)
<code>he3_tau_n_av(ttc,p)</code>	Thermal average of normal state quasiparticle lifetime, s. $\bar{\tau}_N = \left\langle \frac{\tau_N(0, T)}{1 + (\xi_k/\pi T)^2} \right\rangle = \frac{3}{4} \tau_N(0, T) \quad (\text{Einzel-1991, f.4-5})$
<code>he3_tau_nd(ttc,p)</code>	Spin diffusion transport time for a normal Fermi-liquid, s $\tau_{ND} = \tau_1 = \bar{\tau}_N / (1 - \lambda_1^a)$ (Einzel-1991, p.328)
<code>he3_diffn_hydr(ttc, p)</code>	Hydrodynamic spin diffusion in normal liquid, $D_0$ , cm <sup>2</sup> /s (Einzel JLTP84 (1991) f.23)
<code>he3_diffn_perp(ttc, p, nu0)</code>	Perpendicular component of spin diffusion, reduced because of the Leggett-Rice effect, $D_N^\perp$ , cm <sup>2</sup> /s (Einzel JLTP84 (1991) f.22)

TODO: Temperature is measured in  $T_c$  units which is strange for the normal phase. Maybe it is better to use K of  $T_F$  units here.

## Transport properties in the B phase

Values for `he3_tau0`, `he3_tau_av`, `he3_diff_*` are extended to  $T > T_c$  region using normal phase functions. See more information in the source file `he3_transp_b.f` and in `doc_tech/spin.diff.pdf`.

Collision integral for Bogoliubov quasiparticles:

<code>he3_coll_int(xi, ttc, gap, g0, d0)</code>	Full temperature range approximation (Einzel, Wolffe, Hirschfeld, JLTP80 (1990), p.66)
<code>he3_coll_int_lt(xi, ttc, gap, g0, d0)</code>	Collision integral for low temp (good for $< 0.7T_c$ ) (Einzel, JLTP84 (1991), f.76)
<code>he3_coll_int_ht(xi, ttc, gap, g0, d0)</code>	Collision integral for high temp (Einzel, JLTP84 (1991), f.75)

Bogoliubov quasiparticles lifetime and mean free path:

<code>he3_tau0(ttc, p)</code>	Lifetime at the Fermi level, s. $1/\tau(0) = \frac{I(0, T)}{\tau_N(0, T)}$ , (Einzel-1991, f.74,76. Einzel-1990 f.A1)
<code>he3_tau0lt(ttc, p)</code>	$1/\tau, T \rightarrow 0$ limit (does not depend on energy). (Einzel-1978, f.79)
<code>he3_tau_av(ttc, p)</code>	Thermal average lifetime, s. $1/\bar{\tau} = \frac{1}{Y_0} \int_{-\infty}^{\infty} \frac{\phi_k d\xi}{\tau}$ (Einzel-1991, f.77)
<code>he3_fpath(ttc, p)</code>	Mean free path, cm (Einzel JLTP32 (1978) f.84)
<code>he3_tau_dperp(ttc, p)</code>	Spin diff. transport time, s. $\tau_D^{\perp, \parallel} = \bar{\tau} / (1 - \lambda_1^q Y^{\perp, \parallel})$
<code>he3_tau_dpar(ttc, p)</code>	(Einzel-1991, f.90,96)

Spin diffusion:

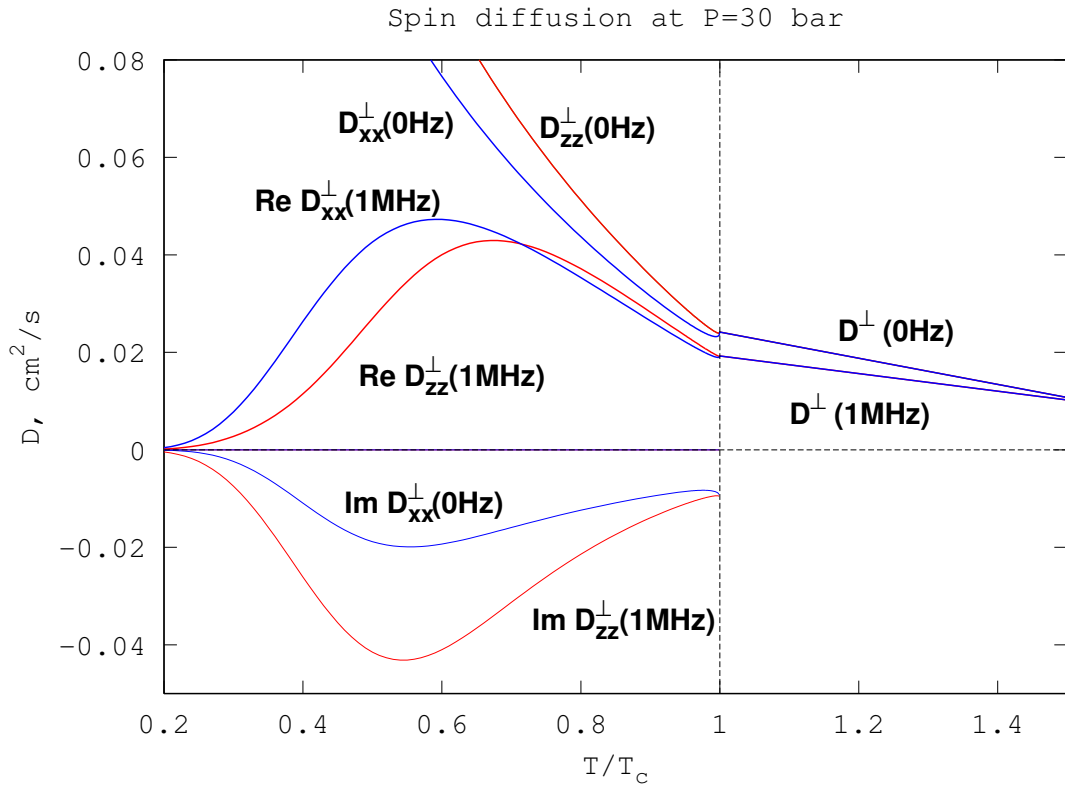
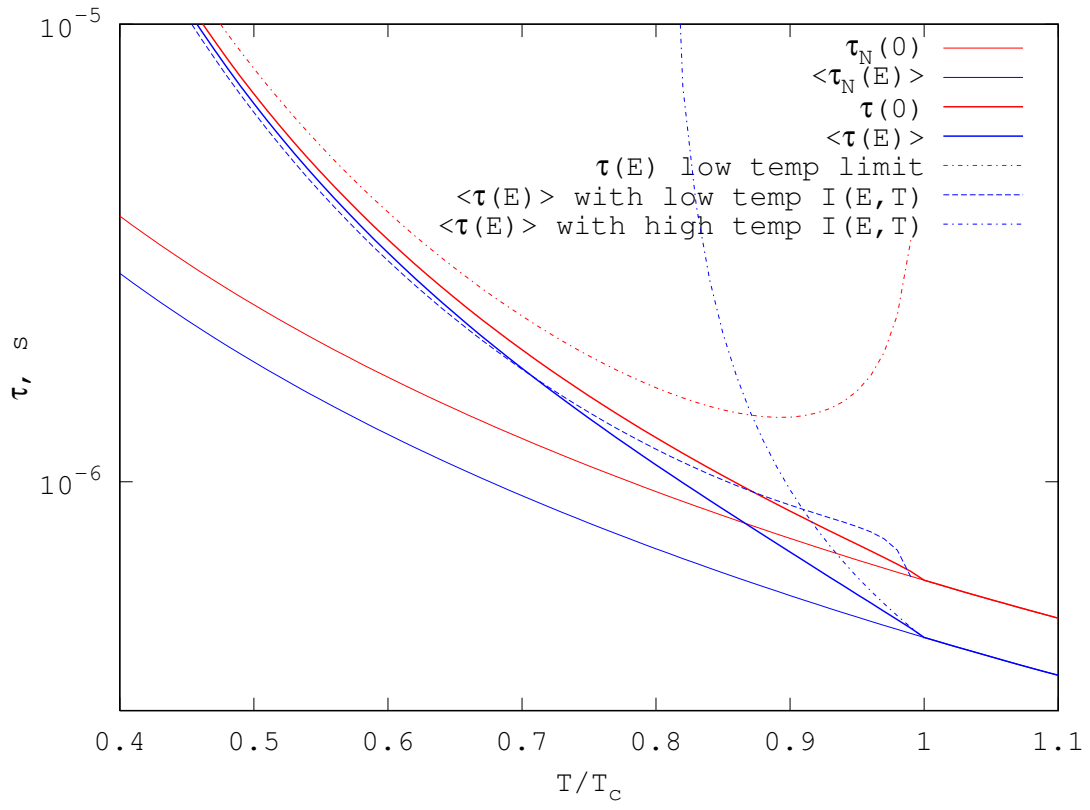
<code>he3_diff_hperp_zz(ttc, p)</code>	Spin diffusion in hydrodynamic limit ( $\omega_L \tau \ll 1$ ), $D_{zz}^{\perp, \parallel}(\omega_L = 0)$ , cm <sup>2</sup> /s. According to Einzel's paper (see f.105) nonhydrodynamic effects do not affect $D^{\parallel}$ . In Mukharsky paper they do. (Einzel JLTP84 (1991) f.102)
<code>he3_diff_hpar_zz(ttc, p)</code>	
<code>he3_diff_perp_xx(ttc, p, nu0)</code>	Components of spin diffusion tensor, cm <sup>2</sup> /s
<code>he3_diff_perp_zz(ttc, p, nu0)</code>	(Bunkov et al, 1990 f.3; Einzel, 1991, f.108;
<code>he3_diff_perp_xx_im(ttc, p, nu0)</code>	Markelov, Mukharsky, 1992, f.7,8)
<code>he3_diff_perp_zz_im(ttc, p, nu0)</code>	
<code>he3_diff_par_xx(ttc, p, nu0)</code>	
<code>he3_diff_par_zz(ttc, p, nu0)</code>	

Problem with  $D^{\parallel}$ . According to Einzel-1991 (see f.105) nonhydrodynamic effects do not affect  $D^{\parallel}$  and you should use `he3_diff_hpar_zz` for any frequency. In Markelov-Mukharsky paper the result for  $D^{\parallel}$  is completely different (it is used in `he3_diff_par_xx, zz`).  $D^{\perp}$  is the same in all papers.

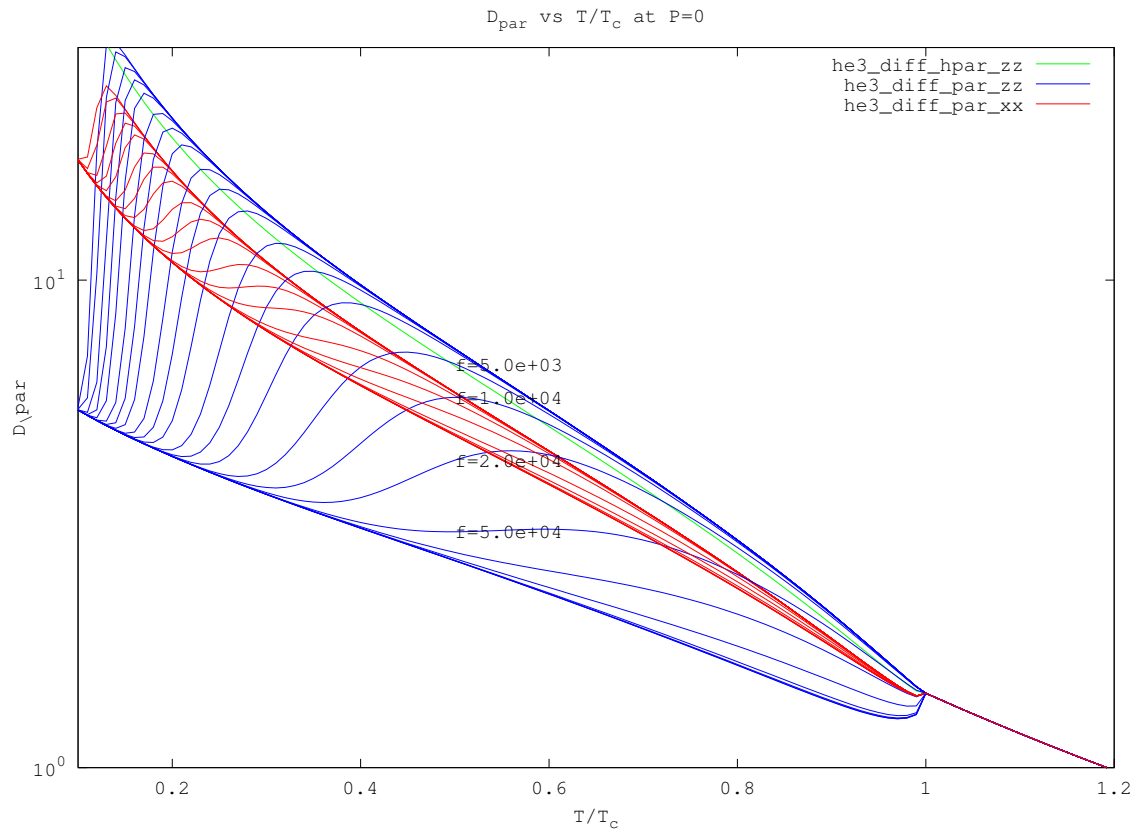
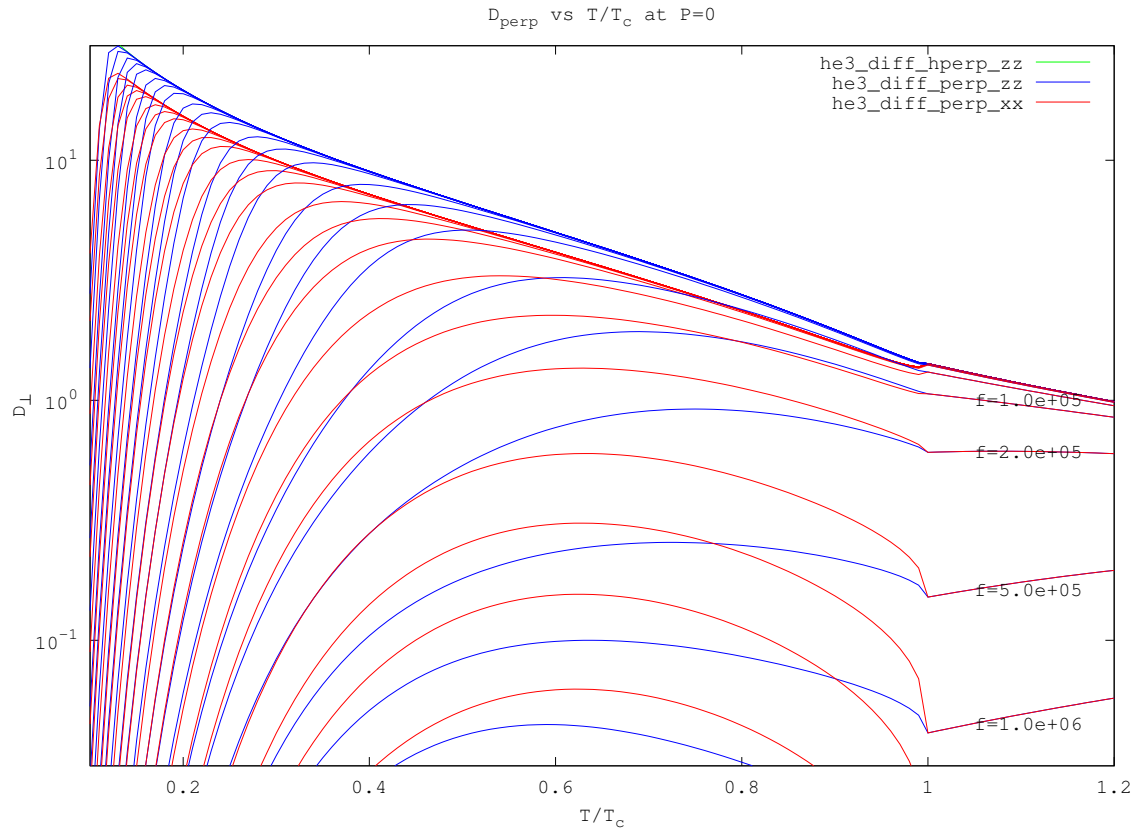
TODO:

Exchange coupling strength is in the  $F_1^a = 0$  limit. (small difference from normal phase values)

How does `he3_diff_perp_??_im` extends to normal phase?







## Other

See more information in the source file `he3_other.f`.

`he3_xigl(ttc, p)` Extrapolated GL coherence length, cm

`he3_vneq(ttc, p, omega, r)` Equilibrium vortex number

## Normal liquid beyond zero temperature limit

See more information in the source file `he3_normal.f`.

`he3_cv_n(t, p)` Normal phase heat capacity  $C_v$ , Greywall-1983

TODO:  $V_m$

## ROTA-specific functions and constants

See more information in the source files `he3_rota.f` and `he3_const.f`

`rota_c_ns(t, i)` Nuclear stage heat capacity [J/K] vs T[K] and I[A]  
 $C_{ns} = 9.66 \cdot 10^{-5} \text{ [J/T}^2\text{]} (0.113 \text{ [T/A]} I/T)^2$

`rota_fork_cal(w, p, n)` Calibration of fork  $n$ ,  $T/T_c$ , vs fork width  $w$  [Hz] and pressure  $P$  [bar]  
 $w = a_n \exp\left(-\frac{\Delta_{WC+}(P, T/T_c)}{T/T_c}\right),$   
 $a = \alpha_n p_F^4(P)$ , where  $\alpha_n$  is a geometrical factor  
 $N = 1$  : Fork K, calibration 30.4.2010, 29 bar,  $a = 11700$   
 $N = 2$  : Fork E, calibration 30.4.2010, 29 bar,  $a = 17543$

`rota_rcell` cell radius

`rota_nmra` field/current in nmrA solenoid [G/A]

`rota_nmrB` field/current in nmrB solenoid [G/A]

`rota_nmra_q(f0)` Q value of the nmrA spectrometer vs frequency

`rota_nmra_f(n)` frequencies of nmrA spectrometer, kHz for  $n=1..8$

`rota_hmina_r` effective radius of the HminA coil [cm]

`rota_hmina` field/current in the center of HminA coil [G/A]

`rota_hmina_mr` quadratic radial term of the HminA field, [G/A/cm<sup>2</sup>]

`rota_hmina_i0` effective HminA coil current caused by NMR field distortion, divided by NMR freq [G/Hz]

`rota_rrda` radiation damping constant  $R_{RD}$  for the nmrA spectrometer

## Q-balls in the zero temperature limit

See more information in the source file `he3_qball.f`

<code>qball_nu_b(P)</code>	Leggett frequency (measurements, same as <code>he3_nu_b(0,p)</code> ) [Hz]
<code>qball_cpar(P)</code> <code>qball_cper(P)</code>	Measured $c_{\parallel}$ , $c_{\perp}$ , [cm/s]
<code>qball_lg1(P)</code> <code>qball_lg2(P)</code>	$\lambda_{G1}$ , $\lambda_{G2}$ calculated using measured spin wave velocities.
<code>qball_text_a(P)</code>	measured textural parameter $a$ [erg/cm <sup>3</sup> 1/G <sup>2</sup> ]
<code>qball_text_d(P)</code>	measured textural parameter $d$ [erg/(cm <sup>2</sup> G <sup>2</sup> )]
<code>qball_text_lsg(P)</code>	measured textural parameter $\lambda_{SG}$
<code>qball_trd(P,f0,fr,fz)</code>	$\tau_{RD}$ for the magnon condensate with given radial and axial frequencies (rota-specific) [s]

A model of the zero-temperature, zero-rotation condensate, based on spectra measurements (rota-specific):

<code>qball_dbetan(P, f0)</code>	Derivative of the textural angle $\beta_N$ in the center of the cell, [rad/cm].
<code>qball_fz0(P,f0,Imin)</code> <code>qball_fr0(P,f0,Imin)</code>	1/2 of the distance between visible axial and radial levels, [Hz]
<code>qball_az0(P,f0,Imin)</code> <code>qball_ar0(P,f0,Imin)</code>	Axial and radial sizes of the magnon condensate, [cm]
<code>qball_trd0(P,f0,Imin)</code>	$\tau_{RD}$ for the magnon condensate, [s]

