Superfluid helium tutorial 1

Steady-state conduction in He II

Consider a 8-m long duct cooling a superconducting magnet by conduction in pressurized superfluid helium at 1 bar, from a cold source at 1.8 K.

1. Calculate the diameter of the duct to maintain the magnet at 1.9 K if its total heat load is 20 W
2. Calculate the diameter of the duct if its length is doubled to 16 m, same magnet heat load and temperature conditions
3. With the duct length and diameter of question 1, what will be the magnet temperature if its heat load is increased to 25 W?
4. Is there a maximum heat flux that the duct of question 1 can conduct to the cold source? Calculate this maximum heat flux and the corresponding heat flow with the duct diameter and length of question 1.

Superfluid helium tutorial 2

Cool-down of liquid helium duct to superfluid state

Consider a duct that cools a superconducting magnet by conduction in pressurized superfluid helium at 1 bar from a cold source at 1.8 K. The magnet and the duct are initially filled with saturated liquid helium at 4.2 K. At time zero, the end of the duct opposite the magnet is put in contact with the cold source.

1. Sketch the temperature profile along the duct and explain what happens
2. Calculate the velocity of the superfluid/normal fluid front (at T lambda) in the duct as a function of its distance x to the cold source
3. Calculate the time taken by the front at T lambda to reach the magnet, as a function of the distance L to the magnet. Calculate for L=8 m.

Superfluid helium tutorial 3

Adiabatic compression of low-pressure gaseous helium

One wishes to produce 120 W refrigeration at 1.8 K by compressing gaseous helium at the corresponding saturation pressure of 16.4 mbar, up to atmospheric pressure (1 bar), where it can then be recovered in a gas bag or enter the LP side of a helium liquefier.

1. Calculate the corresponding mass flow-rate.
2. Calculate the corresponding volume flow-rate:
   a. for a cold compressor handling the gas at 4 K, with a density 0.198 kg/m^3,
   b. for a conventional "warm" vacuum pump handling the gas at room temperature (290 K), with a density of 0.00272 kg/m^3.
3. Assuming reversible adiabatic compression and taking helium as an ideal gas, calculate the compression power in both cases.
4. Redo the same calculations using real thermodynamic properties of helium. Was the ideal gas approximation justified?

Superfluid helium tutorial 4

Production of saturated superfluid by J-T expansion

Consider Joule-Thomson expansion of saturated helium at 4.2 K through a valve, down to the pressure corresponding to a saturation temperature of 1.8 K.

1. What is the saturation pressure of helium at 1.8 K?
2. Which thermodynamic function of state remains constant in the expansion?
3. Calculate the fraction of vapour produced in the expansion, and the remaining fraction of liquid. What do you conclude about the efficiency of the process to produce saturated superfluid helium?
4. A heat exchanger is introduced before the expansion valve, to sub-cool the liquid by the returning cold vapour. What are the temperatures of the two streams at the cold end of the heat exchanger? What are the temperatures of the two streams at the warm end of the heat exchanger? Calculate the fraction of vapour produced in the expansion, and the remaining fraction of liquid. What do you conclude about the efficiency of the process?
5. What are the design and construction challenges of the heat exchanger?

SATURATED HELIUM

T [K]	P [Pa]	RhoL [kg/m3]	RhoV [kg/m3]	HL [J/kg]	HV [J/kg]	UL [J/kg]	UV [J/kg]
1.60	746.36	145.28	0.2301	392.3	23320.6	387.1	20076.5
1.61	779.35	145.28	0.2389	408.8	23365.6	403.4	20103.1
1.62	813.43	145.29	0.2479	425.9	23410.4	420.3	20129.6
1.63	848.62	145.29	0.2572	443.5	23455.2	437.6	20156.0
1.64	884.95	145.30	0.2668	461.7	23499.9	455.6	20182.4
1.65	922.43	145.31	0.2765	480.4	23544.5	474.1	20208.8
1.66	961.08	145.31	0.2866	499.8	23589.0	493.2	20235.1
1.67	1000.94	145.32	0.2968	519.8	23633.3	512.9	20261.3
1.68	1042.02	145.32	0.3074	540.4	23677.6	533.2	20287.5
1.69	1084.35	145.33	0.3182	561.6	23721.7	554.2	20313.6
1.70	1127.94	145.34	0.3292	583.6	23765.8	575.8	20339.7
1.71	1172.82	145.35	0.3405	606.1	23809.8	598.1	20365.7
1.72	1219.01	145.35	0.3521	629.4	23853.6	621.0	20391.7
1.73	1266.54	145.36	0.3640	653.3	23897.4	644.6	20417.6
1.74	1315.42	145.37	0.3761	678.0	23941.0	669.0	20443.4
1.75	1365.68	145.37	0.3885	703.4	23984.6	694.0	20469.2
1.76	1417.34	145.38	0.4012	729.6	24028.0	719.8	20494.9
1.77	1470.43	145.39	0.4141	756.5	24071.3	746.4	20520.6
1.78	1524.95	145.40	0.4274	784.3	24114.6	773.8	20546.3
1.79	1580.94	145.41	0.4409	812.8	24157.7	801.9	20571.8
1.80	1638.41	145.42	0.4547	842.2	24200.8	830.9	20597.4
1.81	1697.39	145.42	0.4688	872.4	24243.7	860.7	20622.9
1.82	1757.89	145.43	0.4832	903.4	24286.5	891.4	20648.3
1.83	1819.95	145.44	0.4979	935.4	24329.3	922.9	20673.7
1.84	1883.57	145.45	0.5128	968.3	24371.9	955.3	20699.0
1.85	1948.77	145.46	0.5281	1002.1	24414.4	988.7	20724.3
1.86	2015.59	145.47	0.5437	1036.9	24456.9	1023.0	20749.5
1.87	2084.02	145.48	0.5595	1072.7	24499.2	1058.3	20774.7
1.88	2154.10	145.49	0.5757	1109.4	24541.4	1094.6	20799.8
1.89	2225.85	145.51	0.5922	1147.3	24583.6	1132.0	20824.9
1.90	2299.27	145.52	0.6090	1186.2	24625.6	1170.4	20849.9
1.91	2374.39	145.53	0.6260	1226.2	24667.6	1209.9	20874.9
1.92	2451.22	145.54	0.6434	1267.3	24709.5	1250.5	20899.9
1.93	2529.78	145.55	0.6611	1309.6	24751.2	1292.3	20924.8
1.94	2610.08	145.57	0.6791	1353.2	24792.9	1335.2	20949.6
1.95	2692.14	145.58	0.6974	1398.0	24834.5	1379.5	20974.4
1.96	2775.98	145.59	0.7161	1444.0	24876.0	1425.0	20999.2
1.97	2861.59	145.61	0.7350	1491.4	24917.4	1471.8	21024.0
1.98	2949.01	145.62	0.7542	1540.2	24958.7	1520.0	21048.6
1.99	3038.23	145.64	0.7738	1590.5	24999.9	1569.6	21073.3
2.00	3129.26	145.65	0.7936	1642.2	25041.0	1620.8	21097.9
2.01	3222.12	145.67	0.8137	1695.5	25082.1	1673.4	21122.5
2.02	3316.82	145.69	0.8342	1750.5	25123.1	1727.7	21147.0
2.03	3413.35	145.71	0.8550	1807.2	25164.0	1783.7	21171.6
2.04	3511.73	145.72	0.8760	1865.6	25204.8	1841.5	21196.0
2.05	3611.96	145.74	0.8974	1926.0	25245.6	1901.2	21220.5
2.06	3714.03	145.76	0.9190	1988.3	25286.2	1962.8	21244.9
2.07	3817.96	145.79	0.9410	2052.8	25326.8	2026.6	21269.3
2.08	3923.74	145.81	0.9632	2119.5	25367.4	2092.6	21293.7

2.09	4031.36	145.83	0.9857	2188.7	25407.9	2161.1	21318.0
2.10	4140.83	145.86	1.0085	2260.6	25448.3	2232.2	21342.3
2.11	4252.13	145.89	1.0316	2335.3	25488.6	2306.1	21366.6
2.12	4365.26	145.91	1.0549	2413.2	25528.9	2383.3	21390.9
2.13	4480.20	145.95	1.0785	2494.7	25569.2	2464.0	21415.2
2.14	4596.95	145.98	1.1024	2580.3	25609.4	2548.8	21439.5
2.15	4715.48	146.02	1.1265	2671.0	25649.6	2638.7	21463.7
2.16	4835.78	146.06	1.1509	2768.1	25689.7	2735.0	21487.9
2.17	4957.83	146.11	1.1755	2874.9	25729.8	2840.9	21512.2
2.18	5081.62	146.16	1.2004	2987.5	25769.9	2952.8	21536.4
2.20	5335.15	146.15	1.2509	3090.1	25849.8	3053.6	21584.8
2.30	6730.35	145.89	1.5227	3417.9	26244.3	3371.8	21824.5
2.40	8354.10	145.49	1.8281	3678.4	26629.5	3620.9	22059.8
2.50	10227.77	145.01	2.1695	3922.0	27004.3	3851.5	22290.0
2.60	12372.07	144.43	2.5493	4160.9	27367.6	4075.2	22514.5
2.70	14806.95	143.77	2.9698	4408.1	27718.6	4305.1	22732.7
2.80	17551.76	143.03	3.4332	4661.8	28056.4	4539.1	22944.0
2.90	20625.50	142.23	3.9419	4923.2	28380.2	4778.2	23147.9
3.00	24047.07	141.35	4.4986	5195.2	28689.2	5025.1	23343.7
3.10	27835.49	140.43	5.1059	5482.8	28982.2	5284.6	23530.7
3.20	32009.97	139.44	5.7673	5786.8	29258.4	5557.3	23708.1
3.30	36589.89	138.39	6.4863	6108.4	29516.3	5844.0	23875.2
3.40	41594.70	137.27	7.2670	6448.0	29754.9	6144.9	24031.1
3.50	47043.78	136.08	8.1142	6806.2	29972.6	6460.4	24174.8
3.60	52956.31	134.81	9.0329	7183.5	30167.8	6790.6	24305.2
3.70	59351.24	133.47	10.0294	7580.5	30338.8	7135.8	24421.1
3.80	66247.39	132.05	11.1108	7998.0	30483.5	7496.3	24521.1
3.9	73663.73	130.54	12.2854	8437.2	30599.6	7872.9	24603.5
4.00	81619.69	128.93	13.5637	8899.3	30684.0	8266.3	24666.5
4.10	90135.69	127.21	14.9586	9386.4	30733.2	8677.9	24707.6
4.20	99233.46	125.37	16.4866	9900.7	30742.8	9109.2	24723.7

HELIUM AT 1638.41 Pa

T [K]	Rho [kg/m3]	H [J/kg]	U [J/kg]
1.60	145.29	398.4	387.2
1.61	145.30	414.7	403.5
1.62	145.30	431.6	420.3
1.63	145.31	448.9	437.7
1.64	145.31	466.9	455.6
1.65	145.32	485.4	474.1
1.66	145.32	504.5	493.2
1.67	145.33	524.2	512.9
1.68	145.34	544.5	533.3
1.69	145.34	565.5	554.2
1.70	145.35	587.1	575.8
1.71	145.35	609.3	598.1
1.72	145.36	632.3	621.0
1.73	145.37	655.9	644.6
1.74	145.37	680.3	669.0
1.75	145.38	705.3	694.1
1.76	145.39	731.1	719.9
1.77	145.39	757.7	746.4
1.78	145.40	785.0	773.8
1.79	145.41	813.2	801.9
1.80	145.42	24200.8	830.9
1.81	0.45	24258.9	20633.1
1.82	0.45	24316.9	20668.7
1.83	0.45	24374.7	20704.2
1.84	0.44	24432.4	20739.6
1.85	0.44	24489.9	20775.0
1.86	0.44	24547.3	20810.2
1.87	0.44	24604.6	20845.3
1.88	0.43	24661.8	20880.3
1.89	0.43	24718.8	20915.2
1.90	0.43	24775.8	20950.1
1.91	0.43	24832.6	20984.8
1.92	0.42	24889.3	21019.5
1.93	0.42	24945.9	21054.1
1.94	0.42	25002.4	21088.6
1.95	0.42	25058.9	21123.1
1.96	0.41	25115.2	21157.4
1.97	0.41	25171.4	21191.7
1.98	0.41	25227.5	21226.0
1.99	0.41	25283.6	21260.1
2.00	0.41	25339.5	21294.2
2.01	0.40	25395.4	21328.3
2.02	0.40	25451.2	21362.2
2.03	0.40	25506.9	21396.2
2.04	0.40	25562.5	21430.0
2.05	0.39	25618.1	21463.8
2.06	0.39	25673.5	21497.5

2.07	0.39	25729.0	21531.2
2.08	0.39	25784.3	21564.9
2.09	0.39	25839.6	21598.5
2.10	0.38	25894.8	21632.0
2.11	0.38	25949.9	21665.5
2.12	0.38	26005.0	21698.9
2.13	0.38	26060.0	21732.3
2.14	0.38	26115.0	21765.6
2.15	0.37	26169.9	21799.0
2.16	0.37	26224.7	21832.2
2.17	0.37	26279.5	21865.4
2.18	0.37	26334.2	21898.6
2.20	0.37	26443.6	21964.8
2.30	0.35	26987.3	22293.9
2.40	0.33	27527.1	22620.0
2.50	0.32	28063.7	22943.8
2.60	0.31	28597.8	23265.6
2.70	0.30	29129.8	23586.0
2.80	0.28	29660.1	23905.0
2.90	0.27	30189.1	24223.1
3.00	0.27	30716.8	24540.3
3.10	0.26	31243.6	24856.8
3.20	0.25	31769.6	25172.7
3.30	0.24	32294.9	25488.1
3.40	0.23	32819.6	25803.1
3.50	0.23	33343.7	26117.8
3.60	0.22	33867.4	26432.1
3.70	0.21	34390.8	26746.1
3.80	0.21	34913.8	27059.9
3.9	0.20	35436.5	27373.6
4.00	0.20	35958.9	27687.0
4.10	0.19	36481.1	28000.3
4.20	0.19	37003.1	28313.4

HELIUM AT 1 BAR

T [K]	Rho [kg/m3]	H [J/kg]	U [J/kg]
1.60	147.01	1075.5	395.2
1.61	147.02	1091.9	411.7
1.62	147.02	1108.8	428.7
1.63	147.03	1126.3	446.2
1.64	147.04	1144.4	464.3
1.65	147.05	1163.0	482.9
1.66	147.05	1182.2	502.2
1.67	147.06	1202.1	522.1
1.68	147.07	1222.5	542.6
1.69	147.08	1243.6	563.7
1.70	147.08	1265.4	585.5
1.71	147.09	1287.8	607.9
1.72	147.10	1310.9	631.1
1.73	147.11	1334.7	654.9
1.74	147.12	1359.2	679.5
1.75	147.13	1384.4	704.7
1.76	147.14	1410.4	730.8
1.77	147.15	1437.1	757.6
1.78	147.16	1464.7	785.1
1.79	147.17	1493.0	813.5
1.80	147.18	1522.2	842.8
1.81	147.19	1552.2	872.8
1.82	147.20	1583.1	903.8
1.83	147.22	1614.9	935.6
1.84	147.23	1647.5	968.3
1.85	147.24	1681.2	1002.0
1.86	147.25	1715.7	1036.6
1.87	147.27	1751.3	1072.3
1.88	147.28	1787.9	1108.9
1.89	147.30	1825.5	1146.6
1.90	147.31	1864.3	1185.4
1.91	147.33	1904.1	1225.3
1.92	147.34	1945.1	1266.4
1.93	147.36	1987.2	1308.6
1.94	147.38	2030.6	1352.0
1.95	147.39	2075.2	1396.8
1.96	147.41	2121.2	1442.8
1.97	147.43	2168.5	1490.2
1.98	147.45	2217.2	1539.0
1.99	147.47	2267.4	1589.2
2.00	147.49	2319.1	1641.0
2.01	147.51	2372.4	1694.4
2.02	147.53	2427.3	1749.5
2.03	147.55	2484.0	1806.3
2.04	147.58	2542.6	1865.0
2.05	147.60	2603.1	1925.6
2.06	147.63	2665.7	1988.3

2.07	147.66	2730.5	2053.2
2.08	147.69	2797.7	2120.5
2.09	147.72	2867.4	2190.4
2.10	147.75	2939.9	2263.1
2.11	147.78	3015.5	2338.8
2.12	147.82	3094.6	2418.0
2.13	147.85	3177.6	2501.3
2.14	147.89	3265.4	2589.3
2.15	147.94	3359.3	2683.4
2.16	147.99	3462.1	2786.4
2.17	148.06	3577.3	2901.9
2.18	148.06	3634.4	2959.0
2.20	148.04	3719.0	3043.6
2.30	147.77	4017.2	3340.5
2.40	147.38	4256.9	3578.4
2.50	146.90	4479.0	3798.3
2.60	146.35	4695.9	4012.6
2.70	145.72	4919.0	4232.7
2.80	145.00	5146.6	4456.9
2.90	144.20	5380.0	4686.5
3.00	143.33	5622.7	4925.0
3.10	142.39	5879.0	5176.7
3.20	141.38	6149.8	5442.5
3.30	140.30	6436.1	5723.3
3.40	139.13	6738.6	6019.8
3.50	137.87	7058.0	6332.6
3.60	136.51	7395.1	6662.6
3.70	135.05	7751.1	7010.7
3.80	133.47	8127.6	7378.4
3.9	131.75	8526.8	7767.8
4.00	129.86	8952.0	8181.9
4.10	127.77	9407.9	8625.3
4.20	125.42	9901.7	9104.4