ESS 5031 Physics of Earth and Planetary Interiors
Fall 2022

Homework Problem Set 2
(Due on 11/16/2022 in class)

1. Thermodynamics relations

a) The isothermal and adiabatic bulk moduli are defined as $K_T = -V\left(\frac{\partial P}{\partial V}\right)_T$ and $K_S = -V\left(\frac{\partial P}{\partial V}\right)_S$, respectively. Show that $K_S = K_T(1+\alpha\gamma T)$, where $\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$ is the coefficient of thermal expansion and $\gamma = \frac{\alpha K_T V}{C_V}$ is Grüneisen parameter, and $C_V = T\left(\frac{\partial S}{\partial T}\right)_V$ is the heat capacity at constant volume.

b) The pressure derivative of bulk modulus and the Anderson-Grüneisen parameter are defined as $K_T' = \left(\frac{\partial K_T}{\partial P}\right)_T$ and $\delta_T = \left(\frac{\partial \ln \alpha}{\partial \ln V}\right)_T$. Show that both K_T' and δ_T are related to the volume derivative of K_T as $K_T' = -\left(\frac{\partial \ln K_T}{\partial \ln V}\right)_T$ and $\delta_T = -\left(\frac{\partial \ln K_T}{\partial \ln V}\right)_P$. (Note: $\left(\frac{\partial \ln X}{\partial \ln Y}\right)_Z = \frac{Y}{X}\left(\frac{\partial X}{\partial Y}\right)_Z$).

2. Adiabatic temperature gradient of Earth's mantle

The Earth's mantle is convecting vigorously over the geological time scale. A consequence of that is the temperature of the majority of the mantle follows the adiabatic temperature gradient except for the top and bottom boundary layers. That is, the temperature of the mantle increases due to self-compression under adiabatic conditions (entropy is constant assuming the process is reversible).

a) Show that the temperature gradient in the mantle is given by $\frac{dT}{dz} = \frac{g\alpha T}{c_P}$, where z is depth, g is gravity, α is thermal expansion coefficient, and c_P is specific hear at constant pressure. Note that c_P has a dimension of J kg^{-1}K^{-1}, whereas $C_P = T\left(\frac{\partial S}{\partial T}\right)_P$ has a dimension of J mol^{-1}K^{-1}, assuming S is the molar entropy. Therefore they are related by $C_P = \rho V c_P$. (Hint: You will utilize the hydrostatic equilibrium equation $\frac{dP}{dz} = \rho g$, where P is pressure and ρ is density.)

b) Calculate $\frac{dT}{dz}$ in the Earth's mantle given g=10m/s^2 (assuming g is constant in the mantle), α=3×10^{-5}K^{-1}, c_P=1kJ kg^{-1}K^{-1}, and T=1600K.

3. Composition of the Earth's mantle

Density of the Earth's interior from seismological observations is often compared with densities of candidate Earth materials from laboratory measurements to infer the composition of Earth. In this homework, you will use the physical properties of typical mantle minerals given in the attached Table to calculate the density of olivine

($(Mg_{0.9}Fe_{0.1})_2SiO_4$) and wadsleyite (or β-phase, $(Mg_{0.9}Fe_{0.1})_2SiO_4$) at 355 km, 400 km, 450 km depths and compare these densities with the seismological model, the PREM (also attached). (1) Discuss which is the likely mantle mineral phase of $(Mg,Fe)_2SiO_4$ at depth of 355 km and 450 km, respectively. (2) Calculated the density contrast at the upper mantle and transition zone boundary (400 km depth) if the mantle is composed of $(Mg_{0.9}Fe_{0.1})_2SiO_4$.

To perform these calculations, you need to know the pressure (P) and temperature (T) at these depths. The values of pressure can be found in the PREM model. Assuming the temperature distribution in the mantle is adiabatic and assuming that the temperature at 660 km is 1900 K, estimate the temperatures at 355 km, 400 km, and 450 km using an adiabatic temperature gradient of 0.45 K/km.

The density can be calculated using the 3rd order Birch-Murnaghan equation of state (EoS), which is given as

$$P = \frac{3}{2}K_{T0}\left[\left(\frac{V_0}{V}\right)^{7/3} - \left(\frac{V_0}{V}\right)^{5/3}\right]\left\{1 + \frac{3}{4}\left(K_T' - 4\right)\left[\left(\frac{V_0}{V}\right)^{2/3} - 1\right]\right\} \quad (1)$$

where V is molar volume, V_0, K_{T0}, and K'_T are the molar volume, isothermal bulk modulus, and the pressure derivative of bulk modulus at ambient pressure. V_0, K_{T0}, and K'_T at T_0 = 298 K are given in the attached Table. To calculate the density at high pressure and high temperature conditions, you can first calculate V_0 and K_{T0} at high T (assuming K'_T is independent of T) and ambient P from

$$V_0(T) = V_0(T_0)\exp\left(\int_{T_0}^{T}\alpha(T')dT'\right) \quad (2)$$

and

$$K_{T0}(T) = K_{T0}(T_0) + \left(\frac{\partial K_T}{\partial T}\right)_P (T - T_0), \quad (3)$$

and then use the Birch-Murnaghan EoS to calculate the density at the desired P-T conditions. All required parameters are given in the attached Table. Be careful that the thermal expansion coefficient (α) is temperature dependent, so you should integrate equation (2) to get V_0 at T. Also pay attention to the units in the Table, especially those for thermal expansion coefficients (thermal expansion coefficients for mantle minerals should be on the order of 10^{-5} K^{-1}). To calculate the density from Birch-Murnaghan EoS, you need to solve a nonlinear equation. This can be accomplished by a nonlinear solver in *Excel*, *Matlab* or *Python*. To calculate densities for mineral compositions with an Fe_2SiO_4 mole fraction of Fe/(Fe+Mg)=0.1, you need first to calculate the densities for the Mg_2SiO_4 and Fe_2SiO_4 end members and then use the following ideal mixing model,

$$\rho = \frac{M}{V} = \frac{X_{Mg}M_{Mg} + X_{Fe}M_{Fe}}{X_{Mg}V_{Mg} + X_{Fe}V_{Fe}}$$

where X and M are the mole fraction and atomic weight for the Mg (Mg_2SiO_4) and Fe (Fe_2SiO_4) end members, respectively.

Table 3
Parameters used for density profile calculations

Phases	V^0_{298} (cm^3/mol)	$\alpha(T)=\alpha_0+\alpha_1 T+\alpha_2 T^{-2}$			K_0 (GPa)	K_T'	$(\partial K_T/\partial T)_P$ (GPa/K)
		α_0 (10^4)	α_1 (10^8)	α_2			
Olivine							
Mg_2SiO_4	43.60	0.3034	0.7422	−0.5381	129.0	5.37	−0.0224
Fe_2SiO_4	46.29	0.2386	1.1530	−0.0518	137.9	4.00	−0.0258
β-Phase							
Mg_2SiO_4	40.52	0.2893	0.5772	−0.8903	174.0	4.00	−0.0323
Fe_2SiO_4	43.15	0.2319	0.7117	−0.2430	166.0	4.00	−0.0215
Spinel							
Mg_2SiO_4	39.49	0.2497	0.3639	−0.6531	183.0	4.30	−0.0348
Fe_2SiO_4	42.03	0.2697	0.0000	−0.0000	197.0	4.00	−0.0375
Pyroxene							
$Mg_2Si_2O_6$ (ortho-)	62.67	0.2947	0.2694	−0.5588	107.0	4.20	−0.0200
$Fe_2Si_2O_6$ (ortho-)	65.94	0.3930	0.0000	−0.0000	101.0	4.20	−0.0200
$Mg_2Si_2O_6$ (clino-)	62.99	0.2947	0.2694	−0.5588	107.0	4.20	−0.0200
$Fe_2Si_2O_6$ (clino-)	65.89	0.3930	0.0000	−0.0000	101.0	4.20	−0.0200
$CaMgSi_2O_6$ (clino-)	66.04	0.3330	0.0000	−0.0000	113.0	4.80	−0.0200
$CaFeSi_2O_6$ (clino-)	67.87	0.2980	0.0000	−0.0000	119.0	4.00	−0.0200
Garnet–majorite							
$Mg_3Al_2Si_3O_{12}$	113.08	0.2311	0.5956	−0.4538	179.0	4.00	−0.0220
$Fe_3Al_2Si_3O_{12}$	115.43	0.1776	1.2140	−0.5071	175.0	4.00	−0.0220
$Ca_3Al_2Si_3O_{12}$	125.12	0.1951	0.8089	−0.4972	168.0	6.20	−0.0220
$Mg_4Si_4O_{12}$	114.32	0.2311	0.5956	−0.4538	161.0	4.00	−0.0220
Perovskite							
$MgSiO_3$	24.45	0.3156	0.9421	−0.3271	262.0	4.00	−0.0550
$FeSiO_3$	25.60	0.3156	0.9421	−0.3271	287.2	4.00	−0.0596
$CaSiO_3$	27.32	0.3156	0.9421	−0.3271	281.0	4.00	−0.0220
Magnesiowüstite							
MgO	11.25	0.3768	0.7404	−0.7446	160.3	4.13	−0.0272
FeO	12.25	0.3203	0.6293	0.0000	146.0	4.00	−0.0200
Iron–iron sulfide							
Fe (fcc)	7.09	0.7700	0.0000	−0.0000	170.0	4.00	−0.0200
FeS(IV) at 800 K	17.79	0.6852	0.0000	−0.0000	54.0	4.00	−0.0200

Data sources: Smyth and McCormick [33]; Fei et al. [34], Mao et al. [35], Boehler et al. [36], Fei et al. [37], Fei [38], and Knittle [39].

of γ-spinel at 13.5 GPa, is γ-spinel plus majorite. The lower mantle assemblage is Mg–Fe silicate perovskite, magnesiowüstite, and majorite. The mineral compositions and modal abundances of the MB high-pressure assemblages are given in Ref. [11]. These assemblages are used to calculate the density of the MB model mantle as a function of pressure and temperature with a Birch–Murnaghan equation of state. A detailed description of the calculations is given in Fei et al. [13]. The database for the end-member phases used in these calculations is given in Table 3. The calculated mantle density profile is shown in Fig. 1.

The mantle density profile shown in Fig. 1 assumes a crustal density of 3.0 g/cm^3 and a crust thickness of 50 km. Uncertainties in Martian crust density and thickness are discussed below. The density increase marking the beginning of the transition zone at 13.5 GPa is shown in Fig. 1, as is an increase in density at 17 GPa that is produced by the complete replacement of clinopyroxene by majorite and β-phase by γ-spinel. The density increase at 22.5

TABLE II

Earth model PREM and its functionals evaluated at a reference period of 1 s. Above 220 km the mantle is transversely isotropic; the parameters given are "equivalent" isotropic moduli and velocities. See Table IV for complete elastic constants in this region.

LEVEL	RACIUS KM	DEPTH KM	DENSITY G/CCM	VP KM/S	VS KM/S	QMU	QK	QAL	PHI KM2/S2	KAPPA KBAR	MU KBAR	SIGMA	PRESSURE KBAR	DK/DP	E.P.	GRAVITY CM/S2
1	0.	6371.0	13.08848	11.26220	3.66780	85	1328	431	108.90	14253	1761	0.4407	3638.524	2.3360	0.99	0.
2	100.0	6271.0	13.08630	11.26064	3.66670	85	1328	431	108.88	14248	1759	0.4407	3636.131	2.3363	0.99	36.56
3	200.0	6171.0	13.07977	11.25593	3.66342	85	1328	431	108.80	14231	1755	0.4408	3628.956	2.3365	0.99	73.11
4	300.0	6071.0	13.06888	11.24809	3.65794	85	1328	432	108.68	14203	1749	0.4409	3617.011	2.3369	0.99	109.61
5	400.0	5971.0	13.05364	11.23712	3.65027	85	1328	432	108.51	14164	1739	0.4410	3600.315	2.3375	0.99	146.04
6	500.0	5871.0	13.03404	11.22301	3.64041	85	1328	433	108.29	14114	1727	0.4412	3578.894	2.3382	0.99	182.39
7	600.0	5771.0	13.01009	11.20576	3.62835	85	1328	434	108.02	14053	1713	0.4414	3552.783	2.3391	0.99	218.62
8	700.0	5671.0	12.98178	11.18538	3.61411	85	1328	436	107.70	13981	1696	0.4417	3522.024	2.3402	0.99	254.73
9	800.0	5571.0	12.94912	11.16186	3.59767	85	1328	437	107.33	13898	1676	0.4420	3486.665	2.3414	0.99	290.68
10	900.0	5471.0	12.91211	11.13521	3.57905	85	1328	439	106.91	13805	1654	0.4424	3446.764	2.3428	0.99	326.45
11	1000.0	5371.0	12.87073	11.10542	3.55823	85	1328	440	106.45	13701	1630	0.4428	3402.383	2.3443	0.99	362.03
12	1100.0	5271.0	12.82501	11.07249	3.53522	85	1328	443	105.94	13586	1603	0.4432	3353.596	2.3460	1.00	397.39
13	1200.0	5171.0	12.77493	11.03643	3.51002	85	1328	445	105.38	13462	1574	0.4437	3300.480	2.3480	1.00	432.51
14	1221.5	5149.5	12.76360	11.02827	3.50432	85	1328	445	105.25	13434	1567	0.4438	3288.513	2.3486	1.00	440.02
15	1221.5	5149.5	12.16634	10.35568	0.	0	57822	57822	107.24	13047	0	0.5000	3288.502	3.7545	1.03	440.03
16	1300.0	5071.0	12.12500	10.30971	0.	0	57822	57822	106.29	12888	0	0.5000	3245.423	3.6539	1.02	463.68
17	1400.0	4971.0	12.06924	10.24959	0.	0	57822	57822	105.05	12679	0	0.5000	3187.493	3.5478	1.01	494.13
18	1500.0	4871.0	12.00989	10.18743	0.	0	57822	57822	103.78	12464	0	0.5000	3126.159	3.4649	1.01	524.77
19	1600.0	4771.0	11.94682	10.12291	0.	0	57822	57822	102.47	12242	0	0.5000	3061.461	3.4017	1.00	555.48
20	1700.0	4671.0	11.87990	10.05572	0.	0	57822	57822	101.12	12013	0	0.5000	2993.457	3.3552	1.00	586.14
21	1800.0	4571.0	11.80900	9.98554	0.	0	57822	57822	99.71	11775	0	0.5000	2922.221	3.3230	1.00	616.69
22	1900.0	4471.0	11.73401	9.91206	0.	0	57822	57822	98.25	11529	0	0.5000	2847.839	3.3028	1.00	647.04
23	2000.0	4371.0	11.65478	9.83496	0.	0	57822	57822	96.73	11273	0	0.5000	2770.407	3.2927	1.00	677.15
24	2100.0	4271.0	11.57119	9.75393	0.	0	57822	57822	95.14	11009	0	0.5000	2690.035	3.2911	1.00	706.57
25	2200.0	4171.0	11.48311	9.66865	0.	0	57822	57822	93.48	10735	0	0.5000	2606.838	3.2966	1.00	736.45
26	2300.0	4071.0	11.39042	9.57881	0.	0	57822	57822	91.75	10451	0	0.5000	2520.942	3.3080	1.00	765.56
27	2400.0	3971.0	11.29298	9.48409	0.	0	57822	57822	89.95	10158	0	0.5000	2432.484	3.3242	1.00	794.25
28	2500.0	3871.0	11.19067	9.38418	0.	0	57822	57822	88.06	9855	0	0.5000	2341.603	3.3441	1.00	822.48
29	2600.0	3771.0	11.08335	9.27876	0.	0	57822	57822	86.10	9542	0	0.5000	2248.453	3.3670	1.00	850.23
30	2700.0	3671.0	10.97091	9.16752	0.	0	57822	57822	84.04	9220	0	0.5000	2153.189	3.3919	1.00	877.46
31	2800.0	3571.0	10.85321	9.05015	0.	0	57822	57822	81.91	8889	0	0.5000	2055.978	3.4180	1.00	904.14
32	2900.0	3471.0	10.73012	8.92632	0.	0	57822	57822	79.68	8550	0	0.5000	1956.991	3.4448	1.00	930.23
33	3000.0	3371.0	10.60152	8.79573	0.	0	57822	57822	77.36	8202	0	0.5000	1856.409	3.4714	1.00	955.70
34	3100.0	3271.0	10.46727	8.65805	0.	0	57822	57822	74.96	7846	0	0.5000	1754.418	3.4972	1.00	980.51
35	3200.0	3171.0	10.32726	8.51298	0.	0	57822	57822	72.47	7484	0	0.5000	1651.209	3.5215	1.00	1004.64
36	3300.0	3071.0	10.18134	8.36019	0.	0	57822	57822	69.89	7116	0	0.5000	1546.982	3.5437	0.99	1028.04
37	3400.0	2971.0	10.02940	8.19939	0.	0	57822	57822	67.23	6743	0	0.5000	1441.941	3.5629	0.99	1050.65
38	3480.0	2891.0	9.90349	8.06482	0.	0	57822	57822	65.04	6441	0	0.5000	1357.510	3.5769	0.98	1068.23
39	3480.0	2891.0	5.56645	13.71660	7.26466	312	57822	826	117.78	6556	2938	0.3051	1357.509	1.6435	0.99	1068.23
40	3500.0	2871.0	5.55641	13.71168	7.26486	312	57822	826	117.64	6537	2933	0.3049	1345.619	1.6434	1.00	1065.32
41	3600.0	2771.0	5.50642	13.68753	7.26575	312	57822	823	116.96	6440	2907	0.3038	1287.067	1.6424	1.01	1052.04
42	3630.0	2741.0	5.49145	13.68041	7.26597	312	57822	822	116.76	6412	2899	0.3035	1269.742	1.6420	1.01	1048.44
43	3630.0	2741.0	5.49145	13.68041	7.26597	312	57822	822	116.76	6412	2899	0.3035	1269.741	3.3344	1.01	1048.44
44	3700.0	2671.0	5.45657	13.59597	7.23403	312	57822	819	115.08	6279	2855	0.3026	1229.719	3.2957	1.01	1040.66
45	3800.0	2571.0	5.40681	13.47742	7.18892	312	57822	815	112.73	6095	2794	0.3012	1173.465	3.2443	1.01	1030.95
46	3900.0	2471.0	5.35706	13.36074	7.14423	312	57822	811	110.46	5917	2734	0.2998	1118.207	3.2029	1.00	1022.72
47	4000.0	2371.0	5.30724	13.24532	7.09974	312	57822	807	108.23	5744	2675	0.2984	1063.864	3.1716	1.00	1015.80

LEVEL	RADIUS KM	DEPTH KM	DENSITY G/CCM	VP KM/S	VS KM/S	QMU	QK	QAL	PHI KM2/S2	KAPPA KBAR	MU KBAR	SIGMA	PRESSURE KBAR	DK/DP	E.P.	GRAVITY CM/S2
48	4100.0	2271.0	5.25729	13.13055	7.05525	312	57822	803	106.04	5575	2617	0.2971	1010.363	3.1503	1.00	1010.06
49	4200.0	2171.0	5.20713	13.01579	7.01053	312	57822	799	103.88	5409	2559	0.2957	957.641	3.1393	1.00	1005.35
50	4300.0	2071.0	5.15669	12.90045	6.96538	312	57822	795	101.73	5246	2502	0.2943	905.646	3.1383	1.00	1001.56
51	4400.0	1971.0	5.10590	12.78389	6.91957	312	57822	792	99.59	5085	2445	0.2928	854.332	3.1472	1.00	998.59
52	4500.0	1871.0	5.05469	12.66550	6.87289	312	57822	788	97.43	4925	2388	0.2913	803.660	3.1657	1.00	996.35
53	4600.0	1771.0	5.00299	12.54466	6.82512	312	57822	784	95.26	4766	2331	0.2898	753.598	3.1935	0.99	994.74
54	4700.0	1671.0	4.95073	12.42075	6.77606	312	57822	779	93.06	4607	2273	0.2881	704.119	3.2302	0.99	993.69
55	4800.0	1571.0	4.89783	12.29316	6.72548	312	57822	775	90.81	4448	2215	0.2864	655.202	3.2750	0.99	993.14
56	4900.0	1471.0	4.84422	12.16126	6.67317	312	57822	770	88.52	4288	2157	0.2846	606.830	3.3276	0.99	993.01
57	5000.0	1371.0	4.78983	12.02445	6.61891	312	57822	766	86.17	4128	2098	0.2826	558.991	3.3871	0.99	993.26
58	5100.0	1271.0	4.73460	11.88209	6.56250	312	57822	761	83.76	3966	2039	0.2805	511.676	3.4527	0.99	993.83
59	5200.0	1171.0	4.67844	11.73357	6.50370	312	57822	755	81.28	3803	1979	0.2783	464.882	3.5236	0.99	994.67
60	5300.0	1071.0	4.62129	11.57828	6.44232	312	57822	750	78.72	3638	1918	0.2758	418.606	3.5989	0.99	995.73
61	5400.0	971.0	4.56307	11.41560	6.37813	312	57822	743	76.08	3471	1856	0.2731	372.852	3.6775	0.98	996.98
62	5500.0	871.0	4.50372	11.24490	6.31091	312	57822	737	73.34	3303	1794	0.2701	327.623	3.7582	0.98	998.36
63	5600.0	771.0	4.44317	11.06557	6.24046	312	57822	730	70.52	3133	1730	0.2668	282.928	3.8403	0.97	999.85
64	5600.0	771.0	4.44316	11.06556	6.24046	312	57822	730	70.52	3133	1730	0.2668	282.927	2.9819	0.97	999.85
65	5650.0	721.0	4.41241	10.91005	6.09418	312	57822	744	69.51	3067	1639	0.2732	260.783	3.0086	0.97	1000.63
66	5701.0	670.0	4.38071	10.75131	5.94508	312	57822	759	68.47	2999	1548	0.2798	238.342	3.0358	0.98	1001.43
67	5701.0	670.0	3.99214	10.26622	5.57020	143	57822	362	64.03	2556	1239	0.2914	238.334	2.4000	0.37	1001.43
68	5736.0	635.0	3.98399	10.21203	5.54311	143	57822	362	63.32	2523	1224	0.2911	224.364	2.3868	0.37	1000.88
69	5771.0	600.0	3.97584	10.15782	5.51602	143	57822	362	62.61	2489	1210	0.2909	210.426	2.3734	0.37	1000.38
70	5771.0	600.0	3.97584	10.15782	5.51600	143	57822	362	62.61	2489	1210	0.2909	210.425	8.0910	1.98	1000.38
71	5821.0	550.0	3.91282	9.90185	5.37014	143	57822	363	59.60	2332	1128	0.2917	190.703	7.8833	1.92	999.65
72	5871.0	500.0	3.84980	9.64588	5.22428	143	57822	364	56.65	2181	1051	0.2924	171.311	7.6761	1.86	998.83
73	5921.0	450.0	3.78678	9.38990	5.07842	143	57822	365	53.78	2037	977	0.2933	152.251	7.4695	1.79	997.90
74	5971.0	400.0	3.72378	9.13397	4.93259	143	57822	366	50.99	1899	906	0.2942	133.527	7.2633	1.73	996.86
75	5971.0	400.0	3.54325	8.90522	4.76989	143	57822	372	48.97	1735	806	0.2988	133.520	3.3718	0.83	996.86
76	6016.0	355.0	3.51639	8.81867	4.73840	143	57822	370	47.83	1682	790	0.2971	117.702	3.3369	0.82	995.22
77	6061.0	310.0	3.48951	8.73209	4.70690	143	57822	367	46.71	1630	773	0.2952	102.027	3.3017	0.80	993.61
78	6106.0	265.0	3.46264	8.64552	4.67540	143	57822	365	45.60	1579	757	0.2933	86.497	3.2662	0.79	992.03
79	6151.0	220.0	3.43578	8.55896	4.64391	143	57822	362	44.50	1529	741	0.2914	71.115	3.2305	0.78	990.48
80	6151.0	220.0	3.35950	7.98970	4.41885	80	57822	195	37.80	1270	656	0.2797	71.108	-0.7364	-0.12	990.48
81	6186.0	185.0	3.36330	8.01180	4.43108	80	57822	195	38.01	1278	660	0.2797	59.466	-0.7200	-0.12	989.11
82	6221.0	150.0	3.36710	8.03370	4.44361	80	57822	195	38.21	1287	665	0.2796	47.824	-0.7035	-0.12	987.83
83	6256.0	115.0	3.37091	8.05540	4.45643	80	57822	195	38.41	1295	669	0.2795	36.183	-0.6868	-0.13	986.64
84	6291.0	80.0	3.37471	8.07688	4.46953	80	57822	195	38.60	1303	674	0.2793	24.546	-0.6700	-0.13	985.53
85	6291.0	80.0	3.37471	8.07689	4.46954	600	57822	1447	38.60	1303	674	0.2793	24.539	-0.6700	-0.13	985.53
86	6311.0	60.0	3.37688	8.08907	4.47715	600	57822	1447	38.71	1307	677	0.2792	17.891	-0.6603	-0.13	984.93
87	6331.0	40.0	3.37906	8.10119	4.48486	600	57822	1446	38.81	1311	680	0.2790	11.239	-0.6505	-0.13	984.37
88	6346.6	24.4	3.38076	8.11061	4.49094	600	57822	1446	38.89	1315	682	0.2789	6.043	-0.6428	-0.13	983.94
89	6346.6	24.4	2.90000	6.80000	3.90000	600	57822	1350	25.96	753	441	0.2549	6.040	-0.0000	-0.00	983.94
90	6356.0	15.0	2.90000	6.80000	3.90000	600	57822	1350	25.96	753	441	0.2549	3.370	0.0000	0.00	983.32
91	6356.0	15.0	2.60000	5.80000	3.20000	600	57822	1456	19.99	520	266	0.2812	3.364	0.0000	0.00	983.31
92	6368.0	3.0	2.60000	5.80000	3.20000	600	57822	1456	19.99	520	266	0.2812	0.303	-0.0000	-0.00	982.22
93	6368.0	3.0	1.02000	1.45000	0.	0	57822	57822	2.10	21	0	0.5000	0.299	-0.0000	-0.00	982.22
94	6371.0	0.	1.02000	1.45000	0.	0	57822	57822	2.10	21	0	0.5000	-0.000	0.0000	0.00	981.56