Física de Radiaciones 2
Primer Parcial
27/09/2022

Prueba 2 horas de duración

1. Calcule el número de interacciones Compton y estime el número de electrones liberados con energías entre 0,15 y 0,25 MeV cuando una lámina de hueso de 0,6 cm de espesor es bombardeada con 10^4 fotones de 0,5 MeV de energía.
2. Un haz colimado de 10^5 fotones de 6 MeV impacta en un gran bloque de carbono de 10 cm de espesor. Determine la energía absorbida en una capa de 1 mm de espesor a 5 cm de profundidad en el bloque.
3. En un acelerador lineal clínico, la fluencia de radiación de frenado, que se obtiene a partir de irradiar un blanco de tungsteno con electrones de alta energía, tiene una distribución angular dada por la siguiente expresión:

$$\Phi(\Theta) = \frac{\Phi(0)}{1 + \left(\frac{\mathrm{T}\Theta}{1{,}73}\right)^{1,4}}$$

donde T es la energía de los electrones y Θ es el ángulo en radianes.

Se quiere que el perfil de radiación que incide sobre los pacientes sea uniforme, de manera que es necesario "aplanarlo". Para ello se utiliza un filtro aplanador de espesor constante con plomo en el centro y aluminio en los bordes (véase Fig. 1).

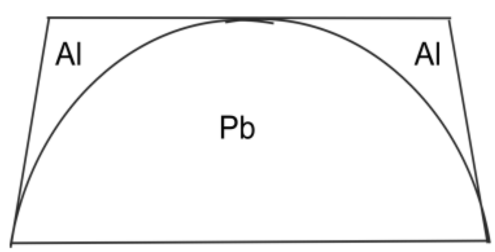

Fig. 1: Esquema de filtro aplanador formado por dos materiales.

Suponiendo para los fotones producidos una energía de 7 MeV en el eje central, 6 MeV en el borde de campo y una variación lineal en energía desde el eje hasta el borde:

a) Determine la fluencia de fotones en el borde de campo sabiendo que el tamaño del mismo es de 40x40 cm^2 en la superficie de un fantoma de agua, situado a una distancia de 100 cm, y que la energía de los electrones en el acelerador es de 21 MeV (véase Fig. 2).
b) Determine el espesor del filtro de forma que la fluencia de fotones en el eje central sea igual que la fluencia en los bordes.

c) Calcule la relación entre los espesores de plomo y aluminio que tiene que tener el filtro para que a una distancia de 10 cm desde el eje central el perfil de campo sea uniforme (véase Fig. 2).

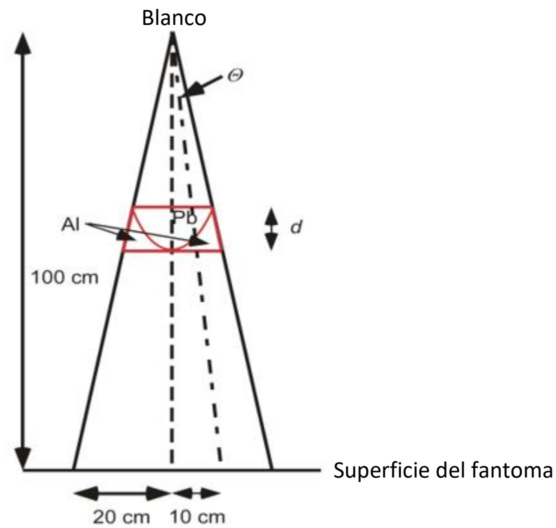

Fig. 2: Geometría de irradiación con filtro aplanador.

Appendix B.2. Data Table for Compounds and Mixtures[a]

Material	Density (g/cm^3)[c]	Electron density (10^{23} e/g)	I (eV)[d]
A-150 plastic[b]	1.127	3.306	65.1
Adipose tissue (Fat, ICRP)[b]	0.92	3.363	63.2
Air[b]	1.205×10^{-3}	3.006	85.7
Bone, cortical (ICRP)[b]	1.85	3.139	106.4
Calcium fluoride, CaF_2	3.18	2.931	166
Carbon dioxide, CO_2	1.842×10^{-3}	3.010	85.0
Cesium iodide, CsI	4.51	2.503	553
Lithium fluoride, LiF	2.64	2.786	94.0
Lucite, $(C_5H_8O_2)_n$	1.19	3.248	74.0
Muscle, skeletal (ICRP)[b]	1.04	3.308	75.3
Mylar, $(C_{10}H_8O_4)_n$	1.40	3.134	78.7
Nylon, type 6 $(C_6H_{11}NO)_n$	1.14	3.299	63.9
Polycarbonate $(C_{16}H_{14}O_3)_n$	1.20	3.173	73.1
Polyethylene $(C_2H_4)_n$	0.94	3.435	57.4
Polyimide $(C_{22}H_{10}N_2O_5)$	1.42	3.087	79.6
Polypropylene $(C_3H_5)_n$	0.90	3.372	59.2
Polystyrene $(C_8H_8)_n$	1.06	3.238	68.7
Polyvinyl Chloride $(C_2H_3Cl)_n$	1.30	3.083	108.2
Pyrex (borosilicate glass)[b]	2.23	2.993	134
Silicon dioxide, SiO_2	2.32	3.007	139.2
Silver bromide, AgBr	6.47	2.629	487
Sodium iodide, NaI	3.67	2.571	452
Teflon, $(C_2F_4)_n$	2.20	2.890	99.1
TE gas (methane-based)[b]	1.064×10^{-3}	3.312	61.2
TE gas (propane-based)[b]	1.826×10^{-3}	3.314	59.5
TE liquid (no sucrose)[b]	1.070	3.313	74.2
Water, H_2O	0.9982	3.343	75.0

[a] Data from Berger and Seltzer (1983)
[b] See compositions in Appendix B.3
[c] Assuming $T = 20°C.$, $P = 1$ atm., and Charles' Law for gases applies.
[d] I is the mean excitation potential for stopping power, see Chapter 8.

TABLE A-2a COMPTON COEFFICIENTS FOR FREE ELECTRONS

Photon energy $h\nu$	Compton coeff. in 10^{-28} m^2/electron by Klein-Nishina eq. (6-12) σ	(6-14) σ_s	(6-13) σ_{tr}	Average energy transf. (eq. 6-15) $_\sigma\bar{E}_{tr}$
(keV)				(keV)
1	.6627	.6614	.0013	.002
1.5	.6614	.6594	.0019	.004
2	.6601	.6575	.0026	.008
3	.6576	.6537	.0038	.017
4	.6550	.6500	.0050	.031
5	.6525	.6463	.0063	.048
6	.6501	.6426	.0074	.069
8	.6452	.6355	.0098	.121
10	.6405	.6285	.0120	.188
15	.6290	.6116	.0174	.414
20	.6180	.5957	.0223	.721
30	.5975	.5664	.0311	1.56
40	.5787	.5400	.0387	2.68
50	.5615	.5162	.0454	4.04
60	.5456	.4946	.0510	5.61
80	.5173	.4567	.0606	9.37
100	.4927	.4248	.0680	13.8
150	.4436	.3631	.0805	27.2
200	.4065	.3185	.0879	43.3
300	.3534	.2581	.0953	80.9
400	.3167	.2186	.0981	124.
500	.2892	.1905	.0987	171.
600	.2675	.1692	.0983	221.
662	.2561	.1584	.0978	253.
800	.2350	.1389	.0960	327.
(MeV)				(MeV)
1	.2112	.1183	.0929	.440
1.25	.1888	.1000	.0889	.588
1.5	.1716	.0867	.0849	.742
2	.1464	.0687	.0777	1.06
3	.1151	.0486	.0664	1.73
4	.0960	.0377	.0583	2.43
5	.0829	.0308	.0520	3.14
6	.0732	.0261	.0472	3.86
8	.0599	.0199	.0400	5.34
10	.0510	.0161	.0349	6.84
15	.0377	.0109	.0268	10.7
20	.0303	.0083	.0220	14.5
30	.0220	.0056	.0164	22.4
40	.0175	.0042	.0133	30.4
50	.0146	.0034	.0112	38.5
60	.0125	.0028	.0097	46.6
80	.0099	.0021	.0078	62.9
100	.0082	.0017	.0065	79.4

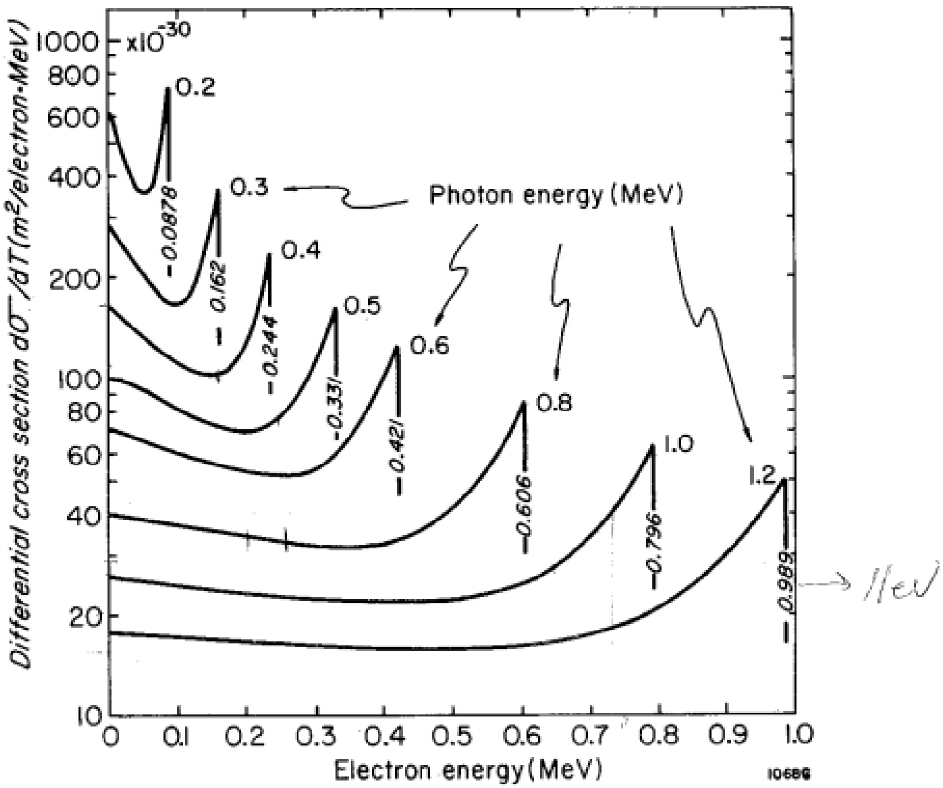

Figure 6-5. Differential cross section per unit kinetic energy interval, $d\sigma/dE$, as calculated by the Klein-Nishina coefficient for a free electron (N2). The areas under the curves give the total cross section for that photon energy. The curves give the distribution of electron energies produced by monoenergetic photons of energies 0.2 to 1.2 MeV. The numbers appearing along vertical lines at the ends of each curve are the maximum energy the recoil electron may acquire.

TABLE A-4b RADIOLOGICAL PROPERTIES OF CARBON

Z=6	ρ = 2250 kg/m^3	3.008×10^{26} elect./kg 5.014×10^{25} atom/kg	A=12.011

Photon energy $h\nu$	Basic Coefficients in $\left(10^{-24}\ \frac{cm^2}{atom}\right)$ or $\left(10^{-28}\ \frac{m^2}{atom}\right)$ σ_{coh} coh.	σ_{inc} incoh.	τ photo	κ pair	Interaction coef. in [cm^2/g] (To get [m^2/kg] divide by 10) $\left(\frac{\mu}{\rho}\right)$	$\left(\frac{\mu_{tr}}{\rho}\right)$	$\left(\frac{\mu_{ab}}{\rho}\right)$	Av. energy transferred or absorbed $\bar{E}_{tr}$	$\bar{E}_{ab}$	Stopping power $\bar{S}$ in $\frac{MeV\ cm^2}{g}$ $\bar{\bar{S}}$*
[keV]									[keV]	
1	21.57	.2525	43820.		2198.		2197.		1.00	
1.5	19.21	.5016	14130.		709.4		708.5		1.50	93.4
2	16.69	.7730	6107.		307.1		306.2		1.99	82.6
3	12.30	1.283	1793.		90.58		89.89		2.98	68.2
4	9.243	1.690	731.7		37.23		36.68		3.94	58.3
5	7.218	1.990	360.3		18.53		18.07		4.88	51.1
6	5.857	2.208	200.4		10.45		10.05		5.77	45.7
8	4.204	2.503	78.54		4.274		3.940		7.38	37.9
10	3.247	2.704	37.66		2.187		1.891		8.65	32.6
15	1.958	3.023	9.770		.7396		.4945		10.0	24.8
20	1.294	3.192	3.725		.4117		.1930		9.38	20.2
30	.6719	3.307	.9539		.2473		.0570		6.91	16.1
40	.4082	3.300	.3634		.2041		.0297		5.83	16.0
50	.2735	3.252	.1725		.1854		.0222		5.99	17.9
60	.1957	3.188	.0941		.1744		.0200		6.89	20.2
80	.1139	3.054	.0365		.1607		.0200		9.98	21.1
100	.0742	2.924	.0176		.1512		.0213		14.1	18.5
150	.0336	2.647	.0048		.1346		.0245		27.3	12.4
200	.0190	2.431	.0020		.1229		.0266		43.2	8.95
300	.0085	2.117	.0006		.1066		.0287		80.8	5.86
400	.0048	1.899	.0002		.0954		.0295		124.	4.53
500	.0031	1.734	.0001		.0871		.0297		171.	3.78
550	.0025	1.665	.0001		.0836		.0297		195.	3.53
662	.0018	1.535	.0001		.0771		.0294		253.	3.11
800	.0012	1.410			.0708		.0289		327.	2.78
[MeV]									[MeV]	
1	.0008	1.268			.0636		.0280		.440	2.49
1.25	.0005	1.134		.0001	.0569		.0268		.588	2.27
1.5	.0003	1.031		.0016	.0518		.0256	.742	.739	2.13
2	.0002	.8795		.0064	.0444		.0236	1.06	1.06	1.97
3	.0001	.6919		.0186	.0356		.0206	1.74	1.73	1.84
4		.5772		.0308	.0305	.0187	.0185	2.46	2.43	1.78
5		.4984		.0419	.0271	.0174	.0171	3.21	3.16	1.75
6		.4405		.0502	.0246	.0163	.0160	3.98	3.91	1.74
8		.3604		.0670	.0214	.0150	.0146	5.60	5.45	1.72
10		.3069		.0840	.0196	.0143	.0138	7.30	7.06	1.72
15		.2272		.1094	.0169	.0132	.0125	11.7	11.1	1.72
20		.1823		.1321	.0158	.0129	.0121	16.4	15.3	1.73
30		.1327		.1609	.0147	.0128	.0115	26.0	23.5	1.74
40		.1055		.1798	.0143	.0128	.0112	35.8	31.3	1.76
50		.0880		.1962	.0143	.0130	.0111	45.7	38.8	1.77
60		.0759		.2069	.0142	.0132	.0109	55.7	46.0	1.78
80		.0598		.2251	.0143	.0135	.0106	75.6	59.4	1.79
100		.0497		.2404	.0145	.0139	.0104	95.6	71.7	1.81

*Av. Stopping Power in [MeV cm^2 g^{-1}] for the spectrum of electrons produced in the medium by photons of energy $h\nu$

TABLE A-4e RADIOLOGICAL PROPERTIES OF ALUMINUM

Z=13 $\rho = 2699$ kg/m^3 2.902×10^{26} elect./kg 2.232×10^{25} atom/kg A=26.981

Photon energy	Basic Coefficients in $\left(10^{-24} \frac{cm^2}{atom}\right)$ or $\left(10^{-28} \frac{m^2}{atom}\right)$				Interaction coef. in [cm^2/g] (To get [m^2/kg] divide by 10)			Av. energy transferred or absorbed		Stopping power $\bar{S}$ in $\frac{MeV\ cm^2}{g}$
$h\nu$	σ_{coh} coh.	σ_{inc} incoh.	τ photo	κ pair	$\left(\frac{\mu}{\rho}\right)$	$\left(\frac{\mu_{tr}}{\rho}\right)$	$\left(\frac{\mu_{ab}}{\rho}\right)$	$\bar{E}_{tr}$	$\bar{E}_{ab}$	$\bar{\bar{S}}$*
[keV]								[keV]		
1.55	90.07	1.163	15870.		356.2	354.1		1.55		65.4
1.56	90.05	1.164	189900.		4241.	4105.		1.51		65.4
2	82.30	1.515	103200.		2305.	2247.		1.95		59.9
3	68.17	2.125	36080.		806.9	792.1		2.95		50.8
4	57.97	2.611	16490.		369.4	363.6		3.94		44.2
5	49.93	3.054	8814.		197.9	194.8		4.92		39.3
6	43.13	3.465	5224.		117.6	115.6		5.90		35.5
8	32.33	4.186	2246.		50.95	49.83		7.82		29.9
10	24.65	4.767	1151.		26.35	25.57		9.70		26.0
15	14.02	5.695	333.0		7.873	7.411		14.1		20.1
20	9.145	6.169	135.9		3.375	3.031		18.0		16.5
30	4.894	6.588	37.84		1.101	.8514	.8510	23.2		12.5
40	3.067	6.721	15.17		.5571	.3489	.3487	25.1		10.3
50	2.094	6.725	7.453		.3632	.1790	.1789	24.6		9.00
60	1.517	6.663	4.171		.2757	.1076	.1075	23.4		8.27
80	.8974	6.458	1.673		.2015	.0547	.0547	21.7		7.82
100	.5929	6.225	.8266		.1706	.0381	.0381	22.3		8.02
150	.2744	5.680	.2327		.1381	.0285	.0285	31.0		8.13
200	.1571	5.234	.0961		.1225	.0277	.0276	45.2		6.95
300	.0708	4.573	.0284		.1043	.0283	.0283	81.4		4.93
400	.0401	4.105	.0122		.0928	.0287	.0287	124.		3.88
500	.0257	3.752	.0065		.0845	.0288	.0287	171.		3.26
550	.0213	3.604	.0050		.0810	.0287	.0287	195.		3.05
662	.0147	3.324	.0030		.0746	.0284	.0283	252.		2.70
800	.0101	3.053	.0018		.0684	.0279	.0278	327.	325.	2.42
[MeV]								[MeV]		
1	.0064	2.746	.0010		.0615	.0270	.0269	.440	.437	2.18
1.25	.0041	2.456	.0007	.0003	.0549	.0258	.0257	.588	.584	1.99
1.5	.0029	2.232	.0005	.0075	.0501	.0247	.0245	.741	.735	1.88
2	.0016	1.905	.0003	.0306	.0433	.0229	.0227	1.06	1.05	1.75
3	.0007	1.499	.0002	.0872	.0354	.0206	.0203	1.75	1.72	1.64
4	.0004	1.250	.0001	.1420	.0311	.0193	.0189	2.48	2.43	1.60
5	.0003	1.080	.0001	.1918	.0284	.0185	.0180	3.27	3.17	1.58
6	.0002	.9545	.0001	.2283	.0264	.0179	.0173	4.08	3.93	1.57
8	.0001	.7808		.3010	.0242	.0175	.0166	5.79	5.51	1.56
10	.0001	.6650		.3734	.0232	.0176	.0166	7.61	7.14	1.56
15		.4922		.4811	.0217	.0178	.0162	12.3	11.2	1.57
20		.3950		.5761	.0217	.0186	.0165	17.2	15.2	1.59
30		.2876		.6961	.0220	.0198	.0167	27.1	22.8	1.61
40		.2285		.7752	.0224	.0207	.0166	37.0	29.7	1.62
50		.1908		.8428	.0231	.0217	.0167	47.0	36.1	1.64
60		.1644		.8858	.0234	.0223	.0164	57.0	42.0	1.65
80		.1296		.9581	.0243	.0234	.0160	77.1	52.8	1.67
100		.1076		1.018	.0251	.0244	.0156	97.1	62.3	1.69

TABLE A-4i RADIOLOGICAL PROPERTIES OF LEAD

Z=82	ρ = 11360 kg/m^3	2.383×10^{26} elect./kg 2.907×10^{24} atom/kg	A=207.20

Photon energy	Basic Coefficients in $\left(10^{-24}\ \frac{cm^2}{atom}\right)$ or $\left(10^{-28}\ \frac{m^2}{atom}\right)$				Interaction coef. in [cm^2/g] (To get [m^2/kg] divide by 10)			Av. energy transferred or absorbed		Stopping power $\bar{S}$ in $\frac{MeV\ cm^2}{g}$
$h\nu$	σ_{coh} coh.	σ_{inc} incoh.	τ photo	κ pair	$\left(\frac{\mu}{\rho}\right)$	$\left(\frac{\mu_{tr}}{\rho}\right)$	$\left(\frac{\mu_{ab}}{\rho}\right)$	$\bar{E}_{tr}$	$\bar{E}_{ab}$	$\bar{\bar{S}}$*
[keV]								[keV]		
2.48	3686.	4.278	276000.		812.9	802.1		2.45		14.9
2.48	3686.	4.280	736200.		2151.	2073.		2.39		14.9
2.58	3647.	4.477	663300.		1939.	1870.		2.49		15.0
2.58	3646.	4.479	921300.		2688.	2597.		2.50		15.0
3.06	3475.	5.385	590700.		1727.	1673.		2.97		15.0
3.06	3475.	5.386	793400.		2316.	2247.		2.98		15.0
3.55	3280.	6.262	539600.		1578.	1534.		3.45		15.0
3.55	3280.	6.263	609000.		1780.	1731.		3.46		15.0
3.84	3179.	6.780	494399.		1446.	1408.		3.75		14.9
3.85	3179.	6.782	533600.		1560.	1519.		3.75		14.9
6	2504.	10.28	167200.		493.3	479.7		5.83		13.7
8	2035.	13.20	78790.		235.0	226.8		7.72		12.6
10	1686.	15.75	43960.		132.7	126.8		9.55		11.5
13	1285.	18.87	21980.		67.68	63.52	63.48	12.2		10.3
15.2	1095.	20.72	36270.		108.7	80.52	80.43	11.3		9.60
15.2	1095.	20.72	51139.		151.9	113.5	113.4	11.4		9.60
15.8	1040.	21.23	45730.		136.0	102.8	102.7	12.0		9.39
15.8	1039.	21.23	53030.		157.2	119.2	119.1	12.0		9.39
20	781.5	24.00	28750.		85.91	68.56	68.43	16.0		8.33
30	455.7	28.69	9745.		29.73	24.93	24.85	25.2		6.64
50	213.3	33.03	2441.		7.811	6.594	6.556	42.2	42.0	4.87
60	159.2	33.90	1480.		4.863	4.054	4.026	50.0	49.7	4.35
88	83.99	34.49	512.7		1.835	1.444	1.429	69.2	68.5	3.44
88	83.99	34.49	2456.		7.483	2.118	2.096	24.9	24.7	3.42
100	67.57	34.41	1777.		5.461	1.974	1.952	36.2	35.7	3.17
150	32.81	32.90	620.3		1.994	1.075	1.058	80.9	79.6	2.52
200	19.51	31.03	290.5		.9913	.6027	.5902	122.	119.	2.17
300	9.230	27.77	100.5		.3996	.2540	.2469	191.	185.	1.81
400	5.366	25.22	48.33		.2294	.1419	.1371	247.	239.	1.64
500	3.502	23.21	27.93		.1588	.0945	.0909	298.	286.	1.54
662	2.038	20.68	14.59		.1084	.0616	.0589	376.	360.	1.44
800	1.410	19.06	9.549		.0872	.0485	.0461	444.	423.	1.38
[MeV]								[MeV]		
1	.9111	17.19	6.028		.0701	.0386	.0364	.550	.520	1.32
1.25	.5875	15.40	3.987	.0055	.0581	.0322	.0302	.693	.649	1.26
2	.2317	11.98	1.669	1.701	.0453	.0257	.0235	1.13	1.04	1.18
3	.1034	9.437	.8630	3.944	.0417	.0259	.0231	1.86	1.66	1.14
4	.0583	7.878	.5672	5.782	.0415	.0281	.0244	2.70	2.35	1.12
5	.0373	6.805	.4096	7.288	.0423	.0305	.0258	3.60	3.06	1.11
6	.0259	6.016	.3241	8.380	.0429	.0324	.0268	4.54	3.76	1.11
8	.0146	4.922	.2239	10.45	.0454	.0367	.0291	6.47	5.12	1.11
10	.0093	4.193	.1681	12.40	.0488	.0412	.0313	8.45	6.42	1.12
15	.0042	3.103	.1075	15.66	.0549	.0491	.0342	13.4	9.37	1.13
20	.0023	2.491	.0783	18.48	.0612	.0564	.0366	18.5	12.0	1.15
30	.0010	1.814	.0501	22.23	.0700	.0665	.0378	28.5	16.2	1.17
40	.0006	1.441	.0365	24.56	.0757	.0728	.0371	38.5	19.6	1.19
50	.0004	1.203	.0285	26.54	.0807	.0783	.0363	48.5	22.5	1.20
60	.0003	1.037	.0233	27.77	.0838	.0817	.0348	58.5	24.9	1.21
80	.0001	.8176	.0170	29.83	.0891	.0875	.0324	78.6	29.1	1.23
100	.0001	.6786	.0133	31.53	.0937	.0923	.0304	98.6	32.4	1.24