Georgia Institute of Technology

The George W. Woodruff School of Mechanical Engineering
Nuclear & Radiological Engineering/Medical Physics Program

Ph.D. Qualifier Exam

Fall Semester 2005

_______________ Your ID Code

Radiation Physics (Day 1)

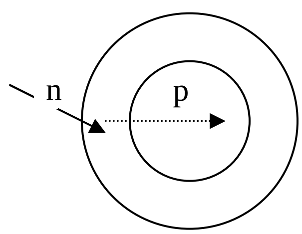
Instructions

1. Use a separate page for each answer sheet (no front to back answers).
2. The question number should be shown on each answer sheet.
3. ANSWER 4 OF 6 QUESTIONS ONLY.
4. Staple your question sheet to your answer sheets and turn in.

RADIATION PHYSICS

Answer 4 of the following questions.

1. A tissue-equivalent ionization chamber has A-150 tissue-equivalent plastic walls and is filled with methane-based tissue equivalent gas (10^{-3} g/cm^3). The density of A-150 is 1.12 g/cm3. The chamber is a sphere with a gas filling volume that is 1 cm in diameter and the A-150 is 5-mm thick. A 4-MeV proton is produced by a high-energy neutron interaction in the A-150 at a distance of 100 microns from the gas chamber. The proton enters the gas chamber on the diameter of the cylinder (we don't want to worry about chord lengths). Answer the following questions using the attached data.
   a) What energy is the proton when it enters the gas?
   b) Does it travel through the gas before coming to rest? Or does it come to rest in the gas?
   c) How much energy is dumped in the gas?



PROTONS IN A-150 TISSUE-EQUIVALENT PLASTIC

ENERGY MeV	STOPPING POWER ELECTRONIC MeV cm2/g	STOPPING POWER NUCLEAR MeV cm2/g	STOPPING POWER TOTAL MeV cm2/g	CSDA RANGE g/cm2	DETOUR FACTOR
0.001	1.768E+02	4.471E+01	2.215E+02	5.313E-06	0.4926
0.0015	2.166E+02	3.577E+01	2.523E+02	7.411E-06	0.5328
0.002	2.501E+02	3.020E+01	2.803E+02	9.290E-06	0.5644
0.0025	2.796E+02	2.633E+01	3.059E+02	1.100E-05	0.5901
0.003	3.063E+02	2.345E+01	3.297E+02	1.257E-05	0.6114
0.004	3.511E+02	1.941E+01	3.705E+02	1.543E-05	0.6455
0.005	3.909E+02	1.668E+01	4.075E+02	1.800E-05	0.6719
0.006	4.268E+02	1.469E+01	4.415E+02	2.035E-05	0.6930
0.007	4.598E+02	1.316E+01	4.729E+02	2.254E-05	0.7105
0.008	4.899E+02	1.196E+01	5.018E+02	2.459E-05	0.7253
0.009	5.178E+02	1.097E+01	5.288E+02	2.653E-05	0.7380
0.010	5.440E+02	1.015E+01	5.542E+02	2.838E-05	0.7491
0.0125	5.964E+02	8.594E+00	6.050E+02	3.269E-05	0.7719
0.015	6.413E+02	7.482E+00	6.488E+02	3.667E-05	0.7897
0.0175	6.806E+02	6.645E+00	6.873E+02	4.041E-05	0.8042
0.020	7.157E+02	5.991E+00	7.217E+02	4.396E-05	0.8162
0.0225	7.470E+02	5.463E+00	7.525E+02	4.735E-05	0.8263
0.025	7.750E+02	5.027E+00	7.800E+02	5.061E-05	0.8351
0.0275	8.000E+02	4.661E+00	8.047E+02	5.377E-05	0.8429
0.030	8.226E+02	4.349E+00	8.269E+02	5.683E-05	0.8497
0.035	8.617E+02	3.843E+00	8.655E+02	6.274E-05	0.8613
0.040	8.942E+02	3.450E+00	8.976E+02	6.841E-05	0.8709
0.045	9.207E+02	3.135E+00	9.238E+02	7.390E-05	0.8790
0.050	9.415E+02	2.877E+00	9.444E+02	7.925E-05	0.8859
0.055	9.573E+02	2.660E+00	9.600E+02	8.449E-05	0.8920
0.060	9.686E+02	2.476E+00	9.711E+02	8.967E-05	0.8974
0.065	9.762E+02	2.318E+00	9.785E+02	9.480E-05	0.9022
0.070	9.805E+02	2.180E+00	9.827E+02	9.990E-05	0.9066
0.075	9.820E+02	2.058E+00	9.840E+02	1.050E-04	0.9106
0.080	9.810E+02	1.950E+00	9.830E+02	1.101E-04	0.9142
0.085	9.780E+02	1.854E+00	9.799E+02	1.152E-04	0.9175
0.090	9.732E+02	1.768E+00	9.750E+02	1.203E-04	0.9206
0.095	9.670E+02	1.689E+00	9.686E+02	1.254E-04	0.9235
0.100	9.595E+02	1.618E+00	9.611E+02	1.306E-04	0.9262
0.125	9.104E+02	1.341E+00	9.117E+02	1.573E-04	0.9375
0.150	8.536E+02	1.148E+00	8.548E+02	1.856E-04	0.9461
0.175	7.979E+02	1.007E+00	7.989E+02	2.158E-04	0.9529
0.200	7.469E+02	8.982E-01	7.478E+02	2.482E-04	0.9584
0.225	7.015E+02	8.117E-01	7.023E+02	2.827E-04	0.9629
0.250	6.615E+02	7.413E-01	6.622E+02	3.194E-04	0.9667
0.275	6.264E+02	6.823E-01	6.271E+02	3.582E-04	0.9699
0.30	5.956E+02	6.320E-01	5.962E+02	3.991E-04	0.9726
0.35	5.448E+02	5.516E-01	5.454E+02	4.869E-04	0.9770
0.40	5.044E+02	4.901E-01	5.049E+02	5.823E-04	0.9802
0.45	4.711E+02	4.415E-01	4.715E+02	6.849E-04	0.9827
0.50	4.428E+02	4.020E-01	4.432E+02	7.943E-04	0.9847
0.55	4.164E+02	3.693E-01	4.168E+02	9.106E-04	0.9863
0.60	3.920E+02	3.416E-01	3.924E+02	1.034E-03	0.9877
0.65	3.699E+02	3.179E-01	3.702E+02	1.166E-03	0.9888
0.70	3.500E+02	2.974E-01	3.503E+02	1.304E-03	0.9897
0.75	3.322E+02	2.794E-01	3.325E+02	1.451E-03	0.9905
0.80	3.164E+02	2.636E-01	3.166E+02	1.605E-03	0.9912
0.85	3.022E+02	2.495E-01	3.024E+02	1.767E-03	0.9918
0.90	2.895E+02	2.369E-01	2.897E+02	1.936E-03	0.9923
0.95	2.781E+02	2.256E-01	2.783E+02	2.112E-03	0.9928
1.00	2.679E+02	2.154E-01	2.681E+02	2.295E-03	0.9932
1.25	2.289E+02	1.758E-01	2.290E+02	3.308E-03	0.9946
1.50	2.008E+02	1.488E-01	2.009E+02	4.476E-03	0.9955
1.75	1.795E+02	1.292E-01	1.796E+02	5.795E-03	0.9961
2.00	1.626E+02	1.143E-01	1.627E+02	7.259E-03	0.9965
2.25	1.490E+02	1.026E-01	1.491E+02	8.866E-03	0.9968
2.50	1.376E+02	9.308E-02	1.377E+02	1.061E-02	0.9970
2.75	1.281E+02	8.523E-02	1.282E+02	1.250E-02	0.9972
3.0	1.199E+02	7.864E-02	1.200E+02	1.451E-02	0.9974
3.5	1.065E+02	6.817E-02	1.066E+02	1.894E-02	0.9976
4.0	9.604E+01	6.022E-02	9.610E+01	2.389E-02	0.9977

ENERGY MeV	STOPPING POWER ELECTRONIC MeV cm2/g	STOPPING POWER NUCLEAR MeV cm2/g	STOPPING POWER TOTAL MeV cm2/g	CSDA RANGE g/cm2	DETOUR FACTOR
4.5	8.761E+01	5.397E-02	8.766E+01	2.935E-02	0.9979
5.0	8.065E+01	4.892E-02	8.070E+01	3.530E-02	0.9980
5.5	7.480E+01	4.475E-02	7.485E+01	4.173E-02	0.9980
6.0	6.982E+01	4.126E-02	6.986E+01	4.865E-02	0.9981
6.5	6.551E+01	3.828E-02	6.555E+01	5.605E-02	0.9982
7.0	6.175E+01	3.571E-02	6.178E+01	6.391E-02	0.9982
7.5	5.843E+01	3.348E-02	5.846E+01	7.223E-02	0.9982
8.0	5.548E+01	3.151E-02	5.551E+01	8.101E-02	0.9983
8.5	5.284E+01	2.977E-02	5.287E+01	9.024E-02	0.9983
9.0	5.047E+01	2.821E-02	5.049E+01	9.992E-02	0.9983
9.5	4.831E+01	2.681E-02	4.834E+01	1.100E-01	0.9984
10.0	4.635E+01	2.555E-02	4.637E+01	1.206E-01	0.9984
12.5	3.868E+01	2.071E-02	3.870E+01	1.799E-01	0.9985
15.0	3.334E+01	1.743E-02	3.336E+01	2.497E-01	0.9985
17.5	2.940E+01	1.507E-02	2.942E+01	3.297E-01	0.9986
20.0	2.637E+01	1.328E-02	2.638E+01	4.196E-01	0.9986
22.5	2.395E+01	1.188E-02	2.396E+01	5.192E-01	0.9986
25.0	2.198E+01	1.075E-02	2.199E+01	6.282E-01	0.9986
27.5	2.033E+01	9.823E-03	2.034E+01	7.465E-01	0.9987
30.0	1.895E+01	9.045E-03	1.895E+01	8.739E-01	0.9987
35.0	1.672E+01	7.814E-03	1.673E+01	1.155E+00	0.9987
40.0	1.501E+01	6.883E-03	1.502E+01	1.471E+00	0.9987
45.0	1.365E+01	6.155E-03	1.366E+01	1.821E+00	0.9988
50.0	1.255E+01	5.568E-03	1.256E+01	2.203E+00	0.9988
55.0	1.164E+01	5.086E-03	1.164E+01	2.617E+00	0.9988
60.0	1.086E+01	4.682E-03	1.087E+01	3.062E+00	0.9988
65.0	1.020E+01	4.338E-03	1.021E+01	3.537E+00	0.9988
70.0	9.630E+00	4.043E-03	9.634E+00	4.041E+00	0.9988
75.0	9.129E+00	3.786E-03	9.133E+00	4.575E+00	0.9989
80.0	8.687E+00	3.560E-03	8.691E+00	5.136E+00	0.9989
85.0	8.294E+00	3.361E-03	8.297E+00	5.725E+00	0.9989
90.0	7.942E+00	3.183E-03	7.945E+00	6.341E+00	0.9989
95.0	7.625E+00	3.023E-03	7.628E+00	6.983E+00	0.9989
100.0	7.338E+00	2.879E-03	7.341E+00	7.652E+00	0.9989
125.0	6.230E+00	2.328E-03	6.233E+00	1.137E+01	0.9989
150.0	5.477E+00	1.957E-03	5.479E+00	1.566E+01	0.9990
175.0	4.931E+00	1.690E-03	4.932E+00	2.048E+01	0.9990
200.0	4.516E+00	1.488E-03	4.518E+00	2.578E+01	0.9990
225.0	4.192E+00	1.330E-03	4.193E+00	3.153E+01	0.9990
250.0	3.931E+00	1.203E-03	3.932E+00	3.769E+01	0.9991
275.0	3.716E+00	1.099E-03	3.717E+00	4.424E+01	0.9991
300.0	3.537E+00	1.011E-03	3.538E+00	5.114E+01	0.9991
350.0	3.256E+00	8.733E-04	3.257E+00	6.589E+01	0.9991
400.0	3.045E+00	7.692E-04	3.046E+00	8.179E+01	0.9992
450.0	2.883E+00	6.877E-04	2.884E+00	9.868E+01	0.9992
500.0	2.754E+00	6.222E-04	2.755E+00	1.164E+02	0.9992
550.0	2.651E+00	5.683E-04	2.651E+00	1.349E+02	0.9992
600.0	2.565E+00	5.233E-04	2.566E+00	1.541E+02	0.9992
650.0	2.494E+00	4.850E-04	2.495E+00	1.739E+02	0.9993
700.0	2.432E+00	4.521E-04	2.433E+00	1.942E+02	0.9993
750.0	2.380E+00	4.234E-04	2.380E+00	2.150E+02	0.9993
800.0	2.335E+00	3.983E-04	2.335E+00	2.362E+02	0.9993
850.0	2.295E+00	3.761E-04	2.296E+00	2.578E+02	0.9993
900.0	2.261E+00	3.562E-04	2.261E+00	2.797E+02	0.9993
950.0	2.231E+00	3.385E-04	2.231E+00	3.020E+02	0.9993
1000.0	2.205E+00	3.224E-04	2.205E+00	3.245E+02	0.9994
1500.0	2.056E+00	2.198E-04	2.056E+00	5.608E+02	0.9994
2000.0	2.003E+00	1.676E-04	2.003E+00	8.077E+02	0.9995
2500.0	1.984E+00	1.358E-04	1.984E+00	1.059E+03	0.9996
3000.0	1.980E+00	1.144E-04	1.980E+00	1.311E+03	0.9996
4000.0	1.991E+00	8.733E-05	1.991E+00	1.815E+03	0.9997
5000.0	2.010E+00	7.083E-05	2.010E+00	2.315E+03	0.9997
6000.0	2.031E+00	5.971E-05	2.031E+00	2.810E+03	0.9997
7000.0	2.051E+00	5.168E-05	2.051E+00	3.300E+03	0.9997
8000.0	2.071E+00	4.560E-05	2.071E+00	3.785E+03	0.9998
9000.0	2.089E+00	4.084E-05	2.089E+00	4.266E+03	0.9998
10000.0	2.106E+00	3.700E-05	2.106E+00	4.743E+03	0.9998

PROTONS IN TISSUE-EQUIVALENT GAS (methane-based)

ENERGY	STOPPING POWER			CSDA	DETOUR
	ELECTRONIC	NUCLEAR	TOTAL	RANGE	FACTOR
MeV	MeV cm2/g	MeV cm2/g	MeV cm2/g	g/cm2	
0.001	1.745E+02	4.348E+01	2.180E+02	5.418E-06	0.4856
0.0015	2.138E+02	3.486E+01	2.486E+02	7.548E-06	0.5249
0.002	2.468E+02	2.947E+01	2.763E+02	9.454E-06	0.5561
0.0025	2.760E+02	2.573E+01	3.017E+02	1.118E-05	0.5815
0.003	3.023E+02	2.294E+01	3.253E+02	1.278E-05	0.6028
0.004	3.491E+02	1.902E+01	3.681E+02	1.566E-05	0.6368
0.005	3.903E+02	1.636E+01	4.067E+02	1.825E-05	0.6631
0.006	4.276E+02	1.442E+01	4.420E+02	2.060E-05	0.6843
0.007	4.618E+02	1.294E+01	4.748E+02	2.278E-05	0.7019
0.008	4.937E+02	1.176E+01	5.055E+02	2.482E-05	0.7167
0.009	5.236E+02	1.080E+01	5.344E+02	2.675E-05	0.7296
0.010	5.520E+02	9.997E+00	5.620E+02	2.857E-05	0.7408
0.0125	6.078E+02	8.470E+00	6.162E+02	3.281E-05	0.7638
0.015	6.562E+02	7.380E+00	6.636E+02	3.672E-05	0.7818
0.0175	6.991E+02	6.559E+00	7.057E+02	4.037E-05	0.7964
0.020	7.374E+02	5.916E+00	7.433E+02	4.382E-05	0.8086
0.0225	7.719E+02	5.397E+00	7.773E+02	4.710E-05	0.8189
0.025	8.030E+02	4.969E+00	8.080E+02	5.026E-05	0.8279
0.0275	8.311E+02	4.608E+00	8.357E+02	5.330E-05	0.8357
0.030	8.565E+02	4.301E+00	8.608E+02	5.625E-05	0.8427
0.035	9.002E+02	3.802E+00	9.040E+02	6.191E-05	0.8545
0.040	9.356E+02	3.415E+00	9.390E+02	6.733E-05	0.8643
0.045	9.638E+02	3.104E+00	9.669E+02	7.258E-05	0.8726
0.050	9.859E+02	2.849E+00	9.887E+02	7.769E-05	0.8798
0.055	1.003E+03	2.635E+00	1.005E+03	8.270E-05	0.8861
0.060	1.015E+03	2.453E+00	1.017E+03	8.764E-05	0.8917
0.065	1.022E+03	2.297E+00	1.025E+03	9.254E-05	0.8967
0.070	1.027E+03	2.160E+00	1.029E+03	9.741E-05	0.9012
0.075	1.028E+03	2.040E+00	1.030E+03	1.023E-04	0.9053
0.080	1.027E+03	1.934E+00	1.029E+03	1.071E-04	0.9091
0.085	1.023E+03	1.839E+00	1.025E+03	1.120E-04	0.9126
0.090	1.018E+03	1.753E+00	1.019E+03	1.169E-04	0.9159
0.095	1.011E+03	1.675E+00	1.012E+03	1.218E-04	0.9189
0.100	1.002E+03	1.605E+00	1.004E+03	1.268E-04	0.9217
0.125	9.478E+02	1.330E+00	9.491E+02	1.523E-04	0.9336
0.150	8.855E+02	1.140E+00	8.867E+02	1.796E-04	0.9427
0.175	8.249E+02	9.997E-01	8.259E+02	2.088E-04	0.9500
0.200	7.697E+02	8.919E-01	7.706E+02	2.402E-04	0.9558
0.225	7.209E+02	8.062E-01	7.217E+02	2.737E-04	0.9607
0.250	6.782E+02	7.364E-01	6.789E+02	3.094E-04	0.9648
0.275	6.410E+02	6.778E-01	6.417E+02	3.473E-04	0.9682
0.30	6.086E+02	6.279E-01	6.092E+02	3.873E-04	0.9711
0.35	5.532E+02	5.482E-01	5.538E+02	4.735E-04	0.9757
0.40	5.079E+02	4.872E-01	5.084E+02	5.678E-04	0.9792
0.45	4.705E+02	4.389E-01	4.709E+02	6.701E-04	0.9819
0.50	4.391E+02	3.997E-01	4.395E+02	7.801E-04	0.9841
0.55	4.124E+02	3.672E-01	4.127E+02	8.976E-04	0.9858
0.60	3.890E+02	3.397E-01	3.894E+02	1.022E-03	0.9872
0.65	3.686E+02	3.162E-01	3.690E+02	1.154E-03	0.9883
0.70	3.505E+02	2.959E-01	3.508E+02	1.293E-03	0.9893
0.75	3.344E+02	2.781E-01	3.346E+02	1.439E-03	0.9902
0.80	3.198E+02	2.624E-01	3.200E+02	1.592E-03	0.9909
0.85	3.066E+02	2.484E-01	3.069E+02	1.752E-03	0.9915
0.90	2.946E+02	2.359E-01	2.949E+02	1.918E-03	0.9920
0.95	2.836E+02	2.247E-01	2.839E+02	2.091E-03	0.9925
1.00	2.735E+02	2.145E-01	2.737E+02	2.270E-03	0.9929
1.25	2.332E+02	1.751E-01	2.334E+02	3.263E-03	0.9944
1.50	2.044E+02	1.483E-01	2.045E+02	4.410E-03	0.9953
1.75	1.825E+02	1.288E-01	1.826E+02	5.706E-03	0.9959
2.00	1.652E+02	1.140E-01	1.653E+02	7.147E-03	0.9963
2.25	1.512E+02	1.023E-01	1.514E+02	8.730E-03	0.9967
2.50	1.397E+02	9.285E-02	1.398E+02	1.045E-02	0.9969
2.75	1.299E+02	8.505E-02	1.300E+02	1.231E-02	0.9971
3.0	1.216E+02	7.848E-02	1.217E+02	1.429E-02	0.9972
3.5	1.080E+02	6.805E-02	1.080E+02	1.867E-02	0.9975
4.0	9.732E+01	6.013E-02	9.738E+01	2.355E-02	0.9976
4.5	8.875E+01	5.390E-02	8.880E+01	2.893E-02	0.9978
5.0	8.169E+01	4.887E-02	8.174E+01	3.481E-02	0.9979
5.5	7.576E+01	4.471E-02	7.580E+01	4.116E-02	0.9979
6.0	7.070E+01	4.123E-02	7.074E+01	4.800E-02	0.9980
6.5	6.633E+01	3.826E-02	6.637E+01	5.530E-02	0.9981
7.0	6.251E+01	3.570E-02	6.255E+01	6.306E-02	0.9981
7.5	5.914E+01	3.346E-02	5.918E+01	7.128E-02	0.9982
8.0	5.615E+01	3.150E-02	5.619E+01	7.996E-02	0.9982
8.5	5.348E+01	2.976E-02	5.351E+01	8.908E-02	0.9982
9.0	5.107E+01	2.821E-02	5.110E+01	9.864E-02	0.9982
9.5	4.888E+01	2.681E-02	4.891E+01	1.086E-01	0.9983
10.0	4.690E+01	2.555E-02	4.692E+01	1.191E-01	0.9983
12.5	3.912E+01	2.071E-02	3.914E+01	1.777E-01	0.9984
15.0	3.372E+01	1.744E-02	3.373E+01	2.467E-01	0.9984
17.5	2.973E+01	1.508E-02	2.974E+01	3.258E-01	0.9985
20.0	2.665E+01	1.329E-02	2.667E+01	4.147E-01	0.9985
22.5	2.421E+01	1.189E-02	2.422E+01	5.132E-01	0.9985
25.0	2.221E+01	1.076E-02	2.222E+01	6.211E-01	0.9986
27.5	2.055E+01	9.832E-03	2.056E+01	7.382E-01	0.9986
30.0	1.914E+01	9.054E-03	1.915E+01	8.642E-01	0.9986
35.0	1.689E+01	7.822E-03	1.690E+01	1.143E+00	0.9986
40.0	1.516E+01	6.891E-03	1.517E+01	1.456E+00	0.9987
45.0	1.379E+01	6.162E-03	1.380E+01	1.802E+00	0.9987
50.0	1.268E+01	5.575E-03	1.268E+01	2.180E+00	0.9987
55.0	1.175E+01	5.092E-03	1.176E+01	2.590E+00	0.9987
60.0	1.097E+01	4.688E-03	1.098E+01	3.030E+00	0.9987
65.0	1.030E+01	4.344E-03	1.031E+01	3.501E+00	0.9988
70.0	9.723E+00	4.048E-03	9.727E+00	4.000E+00	0.9988
75.0	9.217E+00	3.791E-03	9.221E+00	4.529E+00	0.9988
80.0	8.770E+00	3.565E-03	8.774E+00	5.085E+00	0.9988
85.0	8.373E+00	3.365E-03	8.376E+00	5.668E+00	0.9988
90.0	8.017E+00	3.187E-03	8.020E+00	6.278E+00	0.9988
95.0	7.696E+00	3.027E-03	7.699E+00	6.915E+00	0.9988
100.0	7.406E+00	2.883E-03	7.409E+00	7.577E+00	0.9988
125.0	6.288E+00	2.331E-03	6.290E+00	1.126E+01	0.9989
150.0	5.526E+00	1.960E-03	5.528E+00	1.551E+01	0.9989
175.0	4.975E+00	1.692E-03	4.976E+00	2.029E+01	0.9989
200.0	4.556E+00	1.490E-03	4.558E+00	2.554E+01	0.9990
225.0	4.228E+00	1.332E-03	4.230E+00	3.124E+01	0.9990
250.0	3.965E+00	1.205E-03	3.966E+00	3.735E+01	0.9990
275.0	3.748E+00	1.100E-03	3.749E+00	4.384E+01	0.9990
300.0	3.567E+00	1.013E-03	3.568E+00	5.068E+01	0.9990
350.0	3.283E+00	8.747E-04	3.284E+00	6.531E+01	0.9991
400.0	3.071E+00	7.704E-04	3.072E+00	8.108E+01	0.9991
450.0	2.907E+00	6.888E-04	2.908E+00	9.783E+01	0.9991
500.0	2.777E+00	6.232E-04	2.778E+00	1.154E+02	0.9992
550.0	2.672E+00	5.692E-04	2.673E+00	1.338E+02	0.9992
600.0	2.586E+00	5.241E-04	2.587E+00	1.528E+02	0.9992
650.0	2.514E+00	4.858E-04	2.515E+00	1.724E+02	0.9992
700.0	2.454E+00	4.528E-04	2.455E+00	1.926E+02	0.9992
750.0	2.403E+00	4.241E-04	2.404E+00	2.132E+02	0.9992
800.0	2.359E+00	3.990E-04	2.360E+00	2.342E+02	0.9993
850.0	2.322E+00	3.767E-04	2.322E+00	2.555E+02	0.9993
900.0	2.289E+00	3.568E-04	2.290E+00	2.772E+02	0.9993
950.0	2.261E+00	3.390E-04	2.261E+00	2.992E+02	0.9993
1000.0	2.236E+00	3.230E-04	2.237E+00	3.214E+02	0.9993
1500.0	2.105E+00	2.201E-04	2.105E+00	5.532E+02	0.9994
2000.0	2.068E+00	1.678E-04	2.068E+00	7.933E+02	0.9995
2500.0	2.064E+00	1.360E-04	2.065E+00	1.036E+03	0.9995
3000.0	2.074E+00	1.146E-04	2.075E+00	1.277E+03	0.9996
4000.0	2.109E+00	8.748E-05	2.109E+00	1.755E+03	0.9996
5000.0	2.149E+00	7.096E-05	2.149E+00	2.225E+03	0.9997
6000.0	2.188E+00	5.981E-05	2.188E+00	2.686E+03	0.9997
7000.0	2.224E+00	5.177E-05	2.224E+00	3.139E+03	0.9997
8000.0	2.258E+00	4.568E-05	2.258E+00	3.586E+03	0.9998
9000.0	2.289E+00	4.091E-05	2.289E+00	4.025E+03	0.9998
10000.0	2.318E+00	3.707E-05	2.318E+00	4.459E+03	0.9998

2. A radionuclide decays both by spontaneous fission and by alpha decay. The half-life for alpha decay is T_α and the half-life for spontaneous fission is T_f. What is the mathematical relationship for the effective half-life, T_{eff}, of the nuclide in terms of T_α and T_f?

3. Consider the semi-empirical mass formula (SEMF) below. Explain the significance of each term.

$$B_e = a_1 A - a_2 A^{2/3} - a_3 \frac{Z(Z-1)}{A^{1/3}} - a_4 \frac{(A-2Z)^2}{A} (\pm, 0) \frac{a_5}{A^{3/4}}$$

Using this equation, derive a formula for the atomic number of the most stable isobar of a given A and use it to find the most stable isobar of A = 25. Use a_1 = 14.1 MeV, a_2 = 13.0 MeV, a_3 = 0.595 MeV, a_4 = 19.0 MeV and a_5 = 33.5 MeV.

4. Given that the ordering of the nuclear levels is

$1s_{1/2}$; $1p_{3/2}$; $1p_{1/2}$; $1d_{5/2}$; $1d_{3/2}$; $2s_{1/2}$; $1f_{7/2}$; $2p_{3/2}$; $1f_{5/2}$

justify the following ground state spin and parity assignments

$${}^{3}_{2}\mathrm{He}(\frac{1}{2}^{+});\ {}^{20}_{10}\mathrm{Ne}(0^{+});\ {}^{27}_{13}\mathrm{Al}(\frac{5}{2}^{+});\ {}^{41}_{21}\mathrm{Sc}(\frac{7}{2}^{-});\ {}^{69}_{31}\mathrm{Ga}(\frac{3}{2}^{-});$$

In this model the first excited states can be produced either

a. by excitation of the unpaired nucleon into the next higher subshell, or
b. by pairing this nucleon with another excited from the next lower subshell.

Determine the spin and parity for these two types of excited state for each of the four given nuclides.

5. (a) What is "the Doppler broadening effect (DBE)" in neutron interactions with matter?

(b) What type of neutron interaction, e.g. (n, γ), (n, elastic), (n, inelastic) etc, to which the DBE is most important? Why?

6. Choose the proper neutron interaction type for each of the following scenarios and provide your rationale.

Scenarios:
(a) 10-MeV neutrons interacting with lead.
(b) Thermal neutrons interacting with gold.
(c) 1-MeV neutrons interacting with hydrogen in water.
(d) Thermal neutrons interacting with boron-10.
(e) 6- MeV neutrons interacting with beryllium.

Interaction types: elastic scattering, inelastic scattering, (n, γ), $(n, 2n)$, and (n, α)