In [1]:
```
import pandas as pd
import numpy as np
```

Number 1: Anderson 9.3

Consider the case of a 1 MeV neutron incident on a nucleus of mass number $A = 100$. Using $R = R_0 A^{1/3} = (1.1)10^{-15} A^{1/3}$m, calculate the time required for a single transversal of the nuclear diameter by the neutron. Assume a square well nuclear potential with depth of 10 MeV. Compare this time with an estimate of the compound nucleus lifetime from the uncertainty principle for a resonance with level width $\Delta E = 0.1$eV

In [2]:
```
R = 1.1 * 1e-15 * 100.**(1./3.)
R
```

Out[2]: 5.105747716974057e-15

Using the relativistic relationship $\beta^2 = \frac{T(T+2mc^2)}{(T+mc^2)^2}, v = \beta c$

In [3]:
```
def beta_2(T, m):
    numerator = T * (T + 2 * m)
    denominator = (T + m) ** 2
    return numerator / denominator
```

In [4]:
```
beta = beta_2(11., 939.57) ** 0.5
beta
```

Out[4]: 0.15169079422109602

To calculate the time interval, use the Heisenberg relationship $\Delta E \times \Delta t \geq \hbar/2 = \frac{h}{4\pi}$

In [22]:
```
planck = 4.135e-15 * 1e-6 # convert from eV*s to MeV*s
```

In [23]:
```
t = planck / (4. * np.pi * 11.)
t
```

Out[23]: 2.9913894985681243e-23

This is the estimated compound nucleus lifetime (in seconds). Now we compare this to the transit time for the nuclear diameter

In [24]:
```
d = 2. * R

c = 3e8 # m/s
v = beta * c

t_transit = d / v
```

In [25]:
```
t_transit
```

Out[25]:
```
2.2439277405026986e-22
```

Number 2

Look up the thermal neutron cross sections for each stable isotope of Cd, and then using those values determine the thermal neutron cross section for natural Cd (please include the natural abundances of each isotope that you use in this calculation)

List of stable isotopes obtained from [ENDF (https://www.nndc.bnl.gov/sigma/index.jsp?as=116&lib=endfb7.1&nsub=10)](https://www.nndc.bnl.gov/sigma/index.jsp?as=116&lib=endfb7.1&nsub=10)

Natural abundance fractions obtained from [NC State (https://www.ncsu.edu/chemistry/msf/pdf/IsotopicMass_NaturalAbundance.pdf)](https://www.ncsu.edu/chemistry/msf/pdf/IsotopicMass_NaturalAbundance.pdf)

In [9]:
```
cadmium = pd.DataFrame(
    {
        "Isotope": [106, 108, 110, 111, 112, 113, 114, 116],
        "Abundance": [1.25, 0.89, 12.49, 12.80, 24.13, 12.22, 28.73, 7.49],
        "Cross Section": [1., 1.1, 11, 24, 2.2, 20600, 0.34, 0.075]
    }
)
```

In [10]:
```
cadmium["Fractional Cross Section Contribution"] = cadmium["Abundance"] * 1e-2
 * cadmium["Cross Section"]
```

In [11]:
```
cadmium
```

Out[11]:

	Abundance	Cross Section	Isotope	Fractional Cross Section Contribution
0	1.25	1.000	106	0.012500
1	0.89	1.100	108	0.009790
2	12.49	11.000	110	1.373900
3	12.80	24.000	111	3.072000
4	24.13	2.200	112	0.530860
5	12.22	20600.000	113	2517.320000
6	28.73	0.340	114	0.097682
7	7.49	0.075	116	0.005618

In [12]:
```
sum(cadmium["Fractional Cross Section Contribution"])
```

Out[12]:
```
2522.4223495000001
```

In [26]:
```
cadmium.to_latex()
```

Out[26]:
```
u'\\begin{tabular}{lrrrrrr}\n\\toprule\n{} &  Abundance &  Cross Section &  I
sotope &  Fractional Cross Section Contribution &  Macroscopic Cross Section
 &  Number Fraction \\\\\n\\midrule\n0 &       1.25 &          1.000 &      1
06 &                                0.012500 &               4.914179e+22 &
  5.787400e+20 \\\\\n1 &       0.89 &          1.100 &      108 &
                 0.009790 &               5.305494e+22 &     4.120628e+20
 \\\\\n2 &      12.49 &         11.000 &      110 &
    1.373900 &               5.209030e+23 &     5.782770e+21 \\\\\n3 &
 12.80 &         24.000 &      111 &                                3.072000 &
              1.126277e+24 &     5.926297e+21 \\\\\n4 &      24.13 &
  2.200 &      112 &                                0.530860 &
 1.023202e+23 &     1.117200e+22 \\\\\n5 &      12.22 &      20600.000 &
 113 &                             2517.320000 &               9.496108e+26 &
    5.657762e+21 \\\\\n6 &      28.73 &          0.340 &      114 &
                   0.097682 &               1.553570e+22 &     1.330176e+22
 \\\\\n7 &       7.49 &          0.075 &      116 &
    0.005618 &               3.367907e+21 &     3.467810e+21 \\\\\n\\bottomr
ule\n\\end{tabular}\n'
```

Problem 3

Anderson 9.9, change the material to natural Cd. Use the cross section you determined in #3.

What thickness of Cd will remove 95% of a beam of 100 eV neutrons?

Convert to macroscopic cross sections, using the A-number of each isotope as an approximation for the isotopic mass

In [13]:
```
def macroscopic_cross_section(A, microscopic):
    na = 6.022e23
    density = 8.65 # g/cm^3, from wikipedia for solid Cd

    macroscopic = microscopic * na * density / A

    return macroscopic
```

In [14]:
```
cadmium["Macroscopic Cross Section"] = macroscopic_cross_section(cadmium["Isotope"], cadmium["Cross Section"])
```

In [15]:
```
cadmium_mass_average = sum(cadmium["Abundance"] * 1e-2 * cadmium["Isotope"])
cadmium_mass_average
```

Out[15]:
```
112.50800000000001
```

In [16]:
```
cadmium["Number Fraction"] = 6.022e23 * 8.65 / cadmium_mass_average *
cadmium["Abundance"] * 1e-2
```

In [17]:
```
cadmium
```

Out[17]:

	Abundance	Cross Section	Isotope	Fractional Cross Section Contribution	Macroscopic Cross Section	Number Fraction
0	1.25	1.000	106	0.012500	4.914179e+22	5.787400e+20
1	0.89	1.100	108	0.009790	5.305494e+22	4.120628e+20
2	12.49	11.000	110	1.373900	5.209030e+23	5.782770e+21
3	12.80	24.000	111	3.072000	1.126277e+24	5.926297e+21
4	24.13	2.200	112	0.530860	1.023202e+23	1.117200e+22
5	12.22	20600.000	113	2517.320000	9.496108e+26	5.657762e+21
6	28.73	0.340	114	0.097682	1.553570e+22	1.330176e+22
7	7.49	0.075	116	0.005618	3.367907e+21	3.467810e+21

$$\phi = \phi_0 \exp\left(-\Sigma_i * t\right)$$
$$t = \frac{-\log(\phi/\phi_0)}{\Sigma}$$

In [18]:
```
Sigma = sum(cadmium['Number Fraction'] * cadmium['Cross Section'] * 1e-24)
```

In [19]:
```
t = -np.log(0.05) / Sigma
```

In [20]:
```
t
```

Out[20]: 0.025651439296405364

To reduce the beam by 95%, you must have 2.57×10^{-2} cm of Cd

Problem 4

What is the relative probability of production of I-131 with respect to production of Cs-137 in thermal neutron fission of U-235? Use the double-hump curve on Figure 9.18. What is the relative probability of production of Mo-99 with respect to production of Cs-137?

From Wikipedia (https://en.wikipedia.org/wiki/Fission_product_yield#Ordered_by_yield_.28thermal_neutron_fission_of_U-235.29), Cs-137 has a yield of 6.0899% while I-131 has a yield of 2.8336%. Mo-99 has a yield of 6.1%. Mo-99 is therefore about as likely to be produced as Cs-137, while I-131 is about half (46.6%) as likely to be produced as Cs-137.

In [21]:
```
2.8366 / 6.0899
```

Out[21]: 0.46578761556018977

In [ ]:
```

```