NUEN 301
Homework 2

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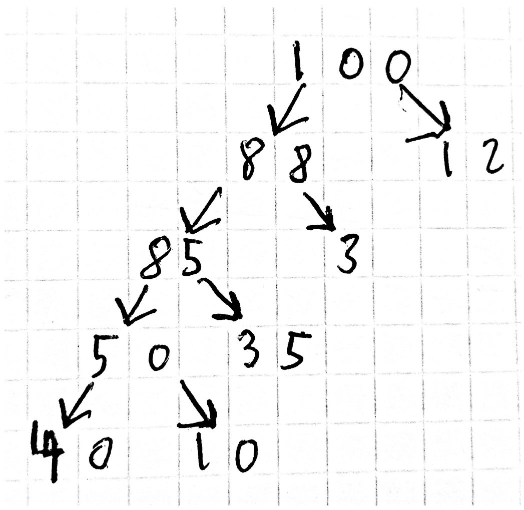
Exercise 1 [30 pts]: [chain reaction] In a certain thermal reactor, for every 100 neutrons emitted in fission, 12 escape while fast, and 3 escape after slowing down to thermal energies. No neutrons are absorbed while slowing down. The values of η_T and ν_T in the fissile material are 2 and 2.5, respectively. The reactor is critical.
a. [5 pts]Fill the neutron tree of life, below.

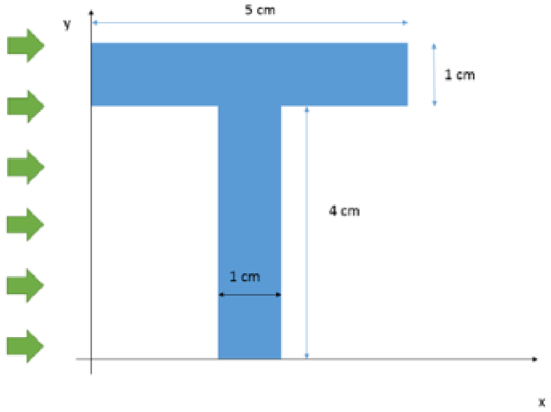


b.[5 pts]Calculate the fast non-leakage probability (P_{FNL}).
$P_{FNL} = \frac{88}{100} = 0.88$
c.[5 pts]What is the resonance-escape probability (p)?
$p = \frac{88}{88} = 1$
d.[5 pts]Calculate the thermal non-leakage probability (P_{TNL}).
$P_{TNL} = \frac{85}{88} = 0.966$
e.[5 pts]Calculate the thermal utilization (f also known as u_T). $u_T = \frac{50}{85} = 0.588$

f.[5 pts]Calculate P_{TAF}.
$P_{TAF} = \frac{\eta_F}{\nu_F} = \frac{2}{2.5} = 0.8$

Exercise 2 [30 pts]: [RRD] Ni-62 is a beta- emitter, produced when a thermal neutron is captured in Ni-62 (molar mass 62 g/mol, density 8.9 g/cc). The radiative microscopic cross section of Ni-62 is 15 b when the neutron energy is E=1/40 eV (the cross section has been averaged of the nucleus velocities). Assume no other types of interactions occur. A thin 0.05-gram target of pure Ni-62 is placed in a beam of thermal neutrons that has intensity $6x10^8$ n/(cm2-s).
a.[5 pts]What is the density of the neutrons in the incident beam?
$E = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2(2.5*10^{-8}[Mev])}{939.6[Mev/c^2]}} = 7.29 * 10^-4[cm/s]$
$I = nv \Rightarrow n = \frac{I}{n} = \frac{6x10^8}{7.29*10^{-6}} = 8.23 * 10^{11}[n/cm^3]$
b.[5 pts]What is the capture rate (captures/second) in the target?
$Rate = (15 * 10^{-24}[\frac{cm^2}{nucleus}])(6 * 10^8[n/cm^2 - s])(\frac{(8.9)(6.022*10^{23})}{62}[\frac{atoms}{cm^3}])(\frac{8.9}{0.05}[cm^3]) = 1.38 * 10^{11}[captures/s]$
c.[5 pts]At what rate is Ni-63 produced (atoms/second)?
1 capture = 1 production so $(8.9) = 4.01 * 10^{-15}[atoms/s]$
d.[5 pts]What is the maximum activity that this experiment can produce (the maximum decays of Ni-63 per second)? (Assume that the Ni-63 does not interact with the neutrons, but is lost only via decay.)
The maximum decay rate would be equal to the production rate assuming all the Ni-63s decay immediately so $(8.9) = 4.01 * 10^{-15}[decays/s]$
e.[10 pts]Suppose another Ni-62 target is now employed. It is thick enough that beam attenuation cannot be neglected. The exit intensity is 25% lower than the incident bean intensity.
i.What is the target thickness?
$I = I_0e^{-\Sigma_t x} \Rightarrow x = -\Sigma_t ln(\frac{I}{I_0}) = -(15 * 10^{-24})(\frac{(8.9)(6.022*10^{23})}{62})ln(\frac{75}{100}) = 0.373[cm]$
ii.What is the capture rate in this thick target (assume a beam-target interaction area of 3 cm^2)?
$Rate = (15*10^{-24}[\frac{cm^2}{nucleus}])(6*10^8[n/cm^2-s])(\frac{(8.9)(6.022*10^{23})}{62}[\frac{atoms}{cm^3}])(3[cm^2])(0.373[cm]) = 8.71 * 10^8[captures/s]$

Exercise 3 [20 pts]: [RRD] The letter T of the A & M logo is made of texasanmium. Its total cross section for thermal neutrons is 2 cm-1. A beam of thermal neutrons (intensity 105 n/(cm2-s)) is normally incident at x=0.



a.[10 pts]Plot the exiting uncollided intensity as a function of y for x=5cm

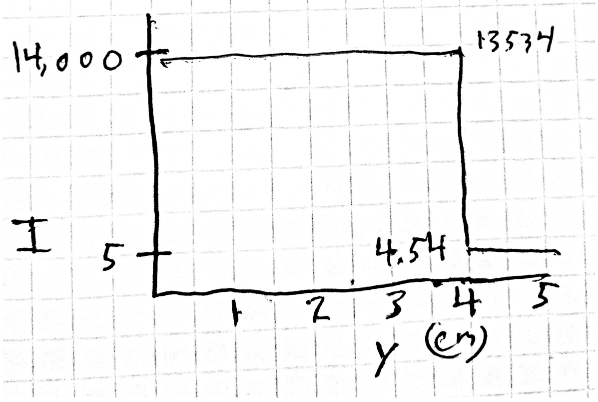
$$I = I_0 e^{-\Sigma_t(x)}$$

$$I_0 = 10^5 \qquad \Sigma_t = 2$$

$$I(x) = 10^5 e^{-2(x)}$$

$$I(1) = 13534 \ \frac{n}{cm^2-s}$$

$$I(5) = 4.54 \ \frac{n}{cm^2-s}$$



b.[10 pts]Assume that the letter T is 1-cm tall along the z-axis and that the beam fully covers the lateral faces, what is the reaction rate (reactions/s) in the letter T.
$Rate = (10^5[\frac{n}{cm^2-s}])(2[cm^{-1}])((5[cm])(1[cm])+(4[cm])(1[cm]))(1[cm]) = 1.80*10^6[reactions/s]$

Exercise 4 [20 pts]: [Monte Carlo]Reproduce in python the Monte Carlo code shown in class. Requirements:
1. Slab thickness = 20 cm. Macroscopic total XS = 0.2 cm-1.
2. Number of bins = 12
a.[5 pts]When running, the code you interactively request the user for the number of neutron histories.
b.[5 pts]Provide 3 plots for the flux in the slab using (1) 100 histories, (2) 1,000 histories, (3) 10,000 histories.

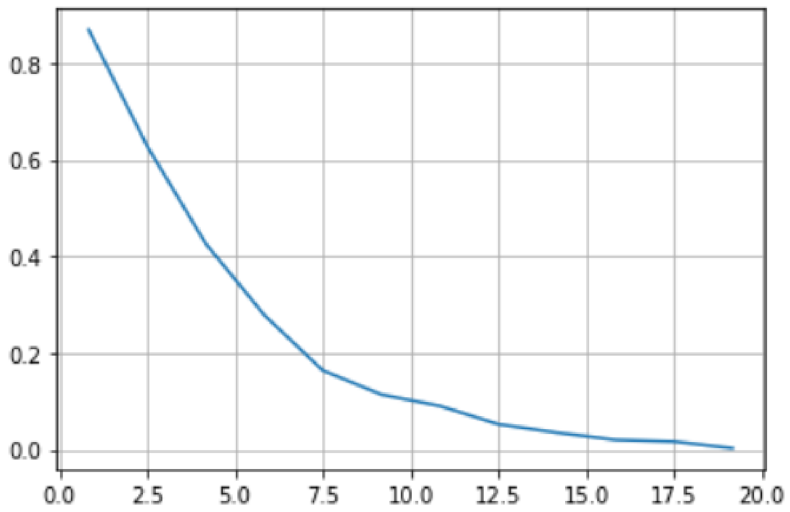


Figure 1: 100 histories

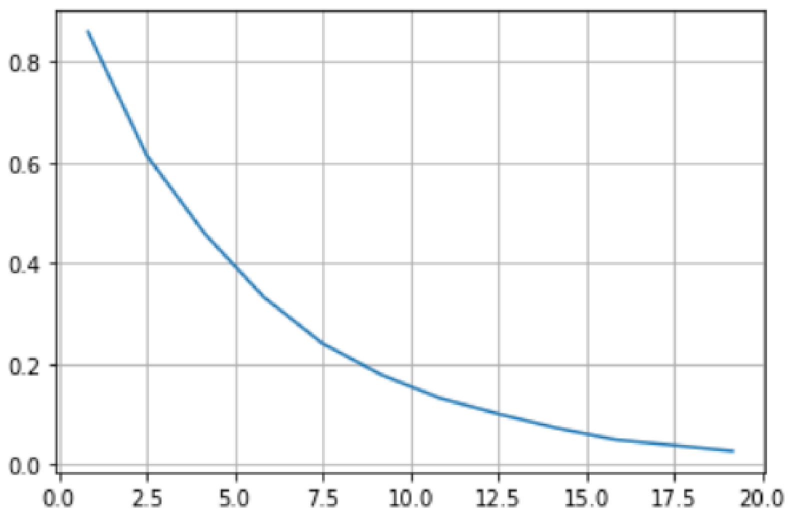


Figure 2: 1,000 histories

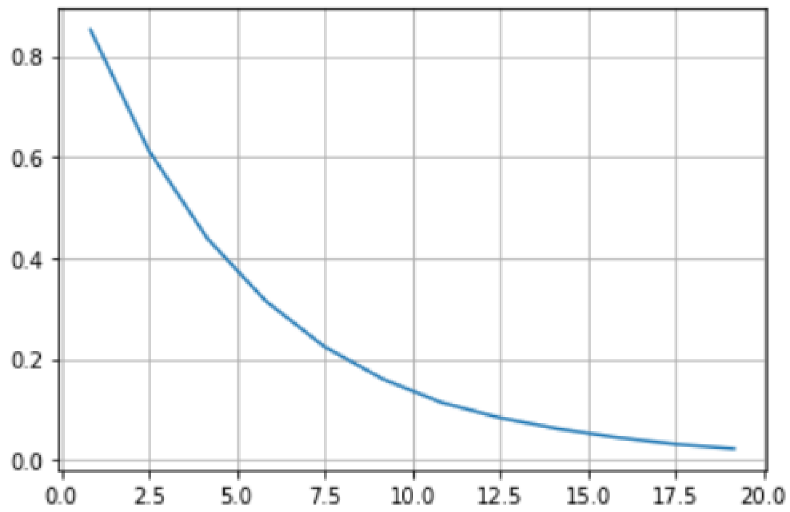


Figure 3: 10,000 histories

c.[5 pts]Provide your code in the HW submission (copy/paste). Code must be clean (meaningful variable names, no superfluous/unused lines of code, adequate comments/documentation)

```python
import numpy as np

# slab description: width and total sigma (macroscopic cross section)
width = 20
sigt_t = 0.2
# numerical parameters
n_bins = 12
bin_width = width/n_bins

# number of histories to follow
neutron_histories = int(input("Input numebr of neutron histories to run: "))
# array to record track length left by neutrons
flux = np.zeros(n_bins)
# create value to count how many neutrons leak out
n_leak = 0

for i in range(neutron_histories):
    absorbed = 0

    # assume random number given
    x = np.random.uniform(0,1,1)
    # distance to be traveld
    distance = -1/sigt_t * np.log(x)

    if distance > width:
        # if the neutron gets out of material
        flux[:] += bin_width
        n_leak += 1
    else:
        n_bins_traversed = int(np.floor(distance/bin_width))
        flux[0:n_bins_traversed] += bin_width
        # remainder of distance
        distance_remainder = distance - bin_width * n_bins_traversed
        flux[n_bins_traversed] += distance_remainder

# compute fraction of leaked neutons
frac = n_leak/neutron_histories
print('Fraction of neutrons that leked out of slab: ')
print(frac)
# transform track length tally ito a flux
flux /= bin_width
# normalize statistics this is now I(x)/I(0)
# Recall that I(x)/I(0) should be equal to: exp(-sigt*x)
flux /= neutron_histories

# plots
import matplotlib.pyplot as plt
x = np.linspace(0,width,n_bins+1)
xx = x[0:-1] + bin_width/2
plt.plot(xx, flux)
plt.grid()

```

d.[5 pts]Provide your python code (.py file to be submitted, we will be running the file)

Exercise 5 [10 EXTRA pts, MADATORY for Honors]: [Monte Carlo]Compute the fraction of neutrons that leak out of the slab. Provide a table that shows your Monte Carlo code results for 100, 1,000, and 10,000 histories. Compare it against the exact analytical answer.

For analytical solution $I = I_0 e^{(.2)(20)}$ for the fraction $\frac{I}{I_0}$

From Code	Analytical
0.0	0.018
0.024	0.018
0.0193	0.018

As expected the Monte Carlo approaches the analytical solution as the number of histories increases.