Exercise 1 – From E. E. Lewis Book

- A reactor is to be built with fuel rods of 1.2cm in diameter and a liquid moderator with a 2:1 volume ratio of moderator to fuel. What will the distance between nearest fuel centerlines be

  - a. For a square lattice?
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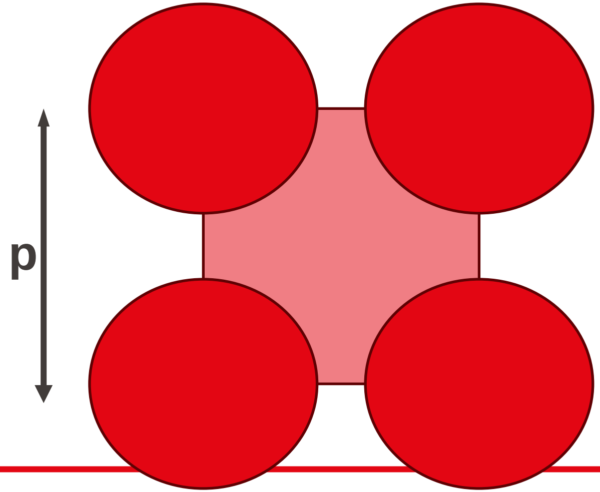
$$A_{tot} = p^2$$

$$A_{fuel} = 4 * \frac{1}{4} * \left(\frac{\pi}{4} * d^2\right)$$



$$\frac{A_M}{A_F} = 2 = \frac{p^2 - \left(\frac{\pi}{4} * d^2\right)}{\frac{\pi}{4} * d^2} \Rightarrow p = 1.842 \text{ cm}$$

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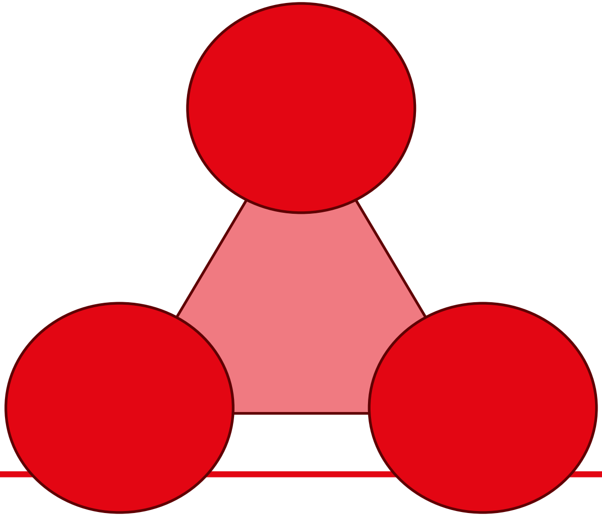
$$A_{tot} = \frac{\sqrt{3}}{4} p^2$$

$$A_{fuel} = 3 * \frac{1}{6} * (\frac{\pi}{4} * d^2)$$



$$\frac{A_M}{A_F} = 2 \Rightarrow p = \left(\frac{\sqrt{3}}{4} p^2 - \frac{\pi}{8} d^2\right)^{\frac{1}{2}}$$ =1.98 cm

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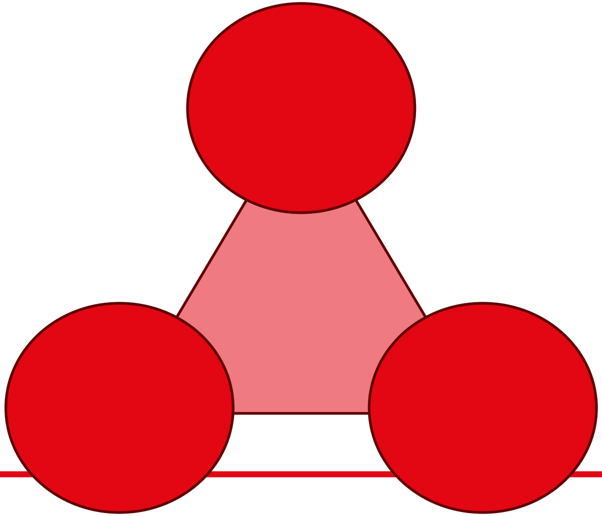

- One can achieve the same volume ratio of moderator to fuel with a larger pitch in a hexagonal lattice.
- Alternatively, with the same pitch one has a smaller volume ratio in a hexagonal lattice.
- → most fast reactors use hexagonal lattices also for this reason

Exercise 2 – From E. E. Lewis Book

- In a fast reactor designers often want to minimize the coolant to fuel volume ratio to minimize the amount of neutron slowing down. From a geometric point of view what is the theoretical limit on the smallest ratio of coolant to fuel volume that can be obtained
  - a. With a square lattice?
  - b. With a hexagonal lattice?

Exercise 2 – From E. E. Lewis Book (solved)

- Theoretical limit is achieved when the pins are touching (i.e. the pitch is equal to the fuel diameter)

- Square

$$\frac{V_M}{V_F} = \frac{p^2}{d^2} \cdot \frac{4}{\pi} - 1 = 0.273$$

- Hexagon

$$\frac{V_M}{V_F} = \frac{\sqrt{3}}{4} \frac{p^2}{d^2} \cdot \frac{8}{\pi} - 1 = 0.103$$

Exercise 3 – From E. E. Lewis Book

- A sodium-cooled fast reactor is fueled with PuO2, mixed with depleted UO2. The structural material is iron. Averaged over the spectrum of fast neutrons, the microscopic cross sections and densities are as follows:

	σ_f b	σ_a b	σ_t b	ρ g/cm^3
PuO_2	1.95	2.40	8.6	11.0
UO_2	0.05	0.404	8.2	11.0
Na	–	0.0018	3.7	0.97
Fe	–	0.0087	3.6	7.87

- The fuel is 15% PuO2 and 85% UO2 by volume. The volumetric composition of the core is 30% fuel, 50% coolant, and 20% structural material. **Calculate k_∞** assuming that the values of ν for plutonium and uranium in the fast spectrum are 2.98 and 2.47, respectively, and that the cross sections of oxygen can be neglected.

Exercise 3 – From E. E. Lewis Book

- Remembering

$$k_\infty = \frac{\nu\Sigma_f}{\Sigma_A} = \frac{F\%\ \nu\Sigma_f}{F\%\ \Sigma_A^F + M\%\Sigma_A^M + S\%\Sigma_A^S}$$

$$\nu\Sigma_f = \frac{V_{PUO_2}}{V_F} \cdot \nu_{Pu}\Sigma_f^{Pu} + \frac{V_{UO_2}}{V_F} \cdot \nu_U\Sigma_f^U$$

$$\Sigma = \bar{N}\sigma = \frac{\rho}{N} N_A \sigma$$

$$k_\infty = \frac{0.045\,\frac{\rho_{PuO_2}}{N_{PuO_2}} N_A \nu_{Pu} \sigma_f^{PuO_2} + 0.255\,\frac{\rho_{UO_2}}{N_{UO_2}} N_A \nu_U \sigma_f^{UO_2}}{0.045\,\frac{\rho_{PuO_2}}{N_{PuO_2}} N_A \sigma_A^{PuO_2} + 0.255\,\frac{\rho_{UO_2}}{N_{UO_2}} N_A \sigma_A^{UO_2} + 0.5\,\frac{\rho_{Na}}{N_{Na}} N_A \sigma_A^{Na} + 0.2\,\frac{\rho_{Fe}}{N_{Fe}} N_A \sigma_A^{Fe}} = \mathbf{1.342}$$

Exercise 4 – From E. E. Lewis Book

- A reactor lattice consists of uranium rods in a heavy water moderator. The heavy water is replaced by light water.
  - a. Would the resonance escape probability increase or decrease? Why?
  - b. Would the thermal utilization increase or decrease? Why?
  - c. What would you expect the net effect on k_∞ to be? Why?

- Suppose the volume ratio of coolant to fuel is increased in a pressurized water reactor:
  - a. Will the fast fission factor increase, decrease, or remain unchanged? Why?
  - b. Will the resonance escape probability increase, decrease, or remain unchanged? Why?

Exercise 4 – From E. E. Lewis Book (solved)

a) p will increase because H2O has a higher slowing down power
b) f will decrease because H2O absorbs more neutrons than D2O
c) k_∞ would probably decrease because of large absorption in H2O, unless one increases the enrichment. This is the reason why heavy water reactors do not need to enrich fuel. However, heavy water reactors need to be bigger because there are more leakage losses (which are not considered in k_∞)

a) (relatively small effect) If there is more moderator, there is faster thermalization, hence less fast fissions
b) If there is more moderator, there are less absorptions in the U238 resonances, hence p will increase

Exercise 5 – From E. E. Lewis Book

- What is the minimum number of elastic scattering collisions required to slow a neutron down from 1.0MeV to 1.0 eV in the following?

  - a. Deuterium.
  - b. Carbon-12.
  - c. Iron-56.
  - d. Uranium-238.

Exercise 5 – From E. E. Lewis Book (solved)

- One needs to remember the meaning of the slow down decrement ξ which is the average logarithmic energy decrease per collision.
- Therefore → $\ln(\frac{E_0}{E_N}) = \xi N$. In our case E_0 is 1E6 eV, while E_N is 1 eV
- To estimate ξ one can use the formula → $\xi \approx \frac{2}{A+\frac{2}{3}}$

Isotope	A	$\xi \approx \frac{2}{A+\frac{2}{3}}$	N
Deuterium	2	0.75	18.42068
Carbon-12	12	0.157895	87.49823
Iron-56	56	0.035294	391.4395
Uranium-238	238	0.00838	1648.651

Exercise 6 – From E. E. Lewis Book

- A power reactor is cooled by heavy water (D2O) but a leak causes a 1.0 atom % contamination of the coolant with light water (H2O). Determine the resulting percentage increase or decrease in the following characteristics of the coolant:

  - a. Slowing down decrement.
  - b. Slowing down power.
  - c. Slowing down ratio.

Exercise 6 – From E. E. Lewis Book (solved)

- Online, one can lookup typical values of slowing down decrement, power and ratio of different moderators

Moderator	ξ	$\Sigma_s \xi$	$\Sigma_s/\Sigma_A \xi$
H20	0.93	1.28	58
D20	0.51	0.18	21000
Graphite	0.158	0.056	200

Exercise 6 – From E. E. Lewis Book (solved)

- From this, remembering

$$\bar{\xi} = \frac{1}{\Sigma_s} \sum_i \xi_i \Sigma_{s,i}$$

$$\bar{\xi} = \frac{0.99\,\xi_{D_2O} + 0.01\xi_{H_2O}}{0.99\Sigma^s_{D_2O} + 0.01\Sigma^s_{H_2O}} = 0.53$$

$$\bar{\xi}\Sigma_s = \bar{\xi}(0.99\Sigma^s_{D_2O} + 0.01\Sigma^s_{H_2O}) = 0.193$$

$$\bar{\xi}\Sigma_s/\Sigma_A = \bar{\xi}(0.99\Sigma^s_{D_2O} + 0.01\Sigma^s_{H_2O})/\,(0.99\Sigma^A_{D_2O}+0.01\Sigma^A_{H_2O}) = 833$$