Week 7 Lecture 2 – Nuclear Reactions Overview

MICHIGAN STATE UNIVERSITY

Nuclear Reactions

-- Nuclear Reactions & Waste

-- Transmutation

-- Nuclear Reactions overview

--- neutron induced reactions

--- charged particle induced reactions

-- Conservation of Momentum

No Homework this week,
Practice Exam on Monday

Neutron induced reactions -1

MICHIGAN STATE UNIVERSITY

There are essentially no free neutrons around with the exception of a few produced by cosmic ray interactions (that produce ^{14}C, for example).

All neutron induced reactions have some general features:

1. The neutrons have to be created in some reaction, thus, the number is low enough that we only have to consider the reactions with one neutron at a time.
2. The binding energy of an additional neutron to ALL stable nuclei is about the same and the reaction is ALWAYS exoergic.
3. Neutrons do not have any barrier to reaction and given (item 2) the neutrons will eventually be absorbed by a nucleus no matter how low their energy gets.

$$^{1}n+{}^{A}_{Z}Z_{N} \rightarrow \left({}^{A+1}_{Z}Z_{N+1}\right)^{*} \rightarrow {}^{A+1}_{Z}Z_{N+1} + \gamma' s$$

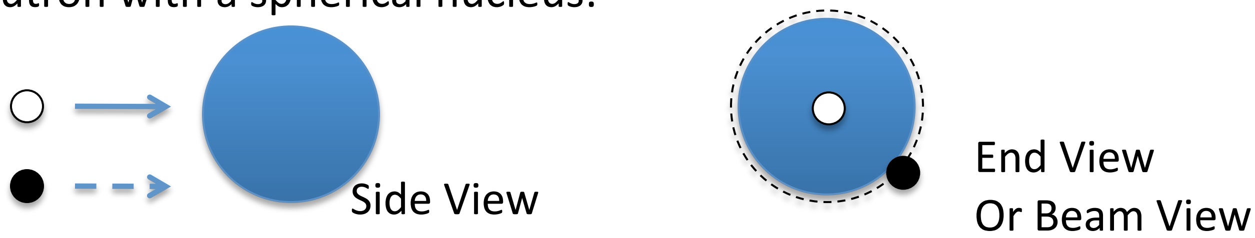
These reactions are called (n,γ) reactions because a neutron goes in, creates an intermediate and very excited *compound nucleus* that almost always de-excites by emitting gamma rays. For reasons already discussed, the total excitation energy is about the same and generally many more than one gamma ray is emitted.

Make an estimate of the lifetime of the excited compound nucleus:

Neutron induced reactions -2

MICHIGAN STATE UNIVERSITY

The probability of a nuclear reaction is given by the nuclear cross section. We encountered the idea of a cross section in the very first lecture of the course. As a reminder, for a neutron with a spherical nucleus:



The probability or cross section to strike dead center is small but the neutron induced reactions produce essentially the same results if the neutron hits off-center, all the way up to the point that the neutron misses … thus, we can consider the geometrical cross section. The normal unit of cross section would be fm^2 but a historical unit of 100 fm^2 = 1 barn is used.

$$\sigma_{Geometrical} = \pi\left(R_{nucleus} + r_{neutron}\right)^2$$

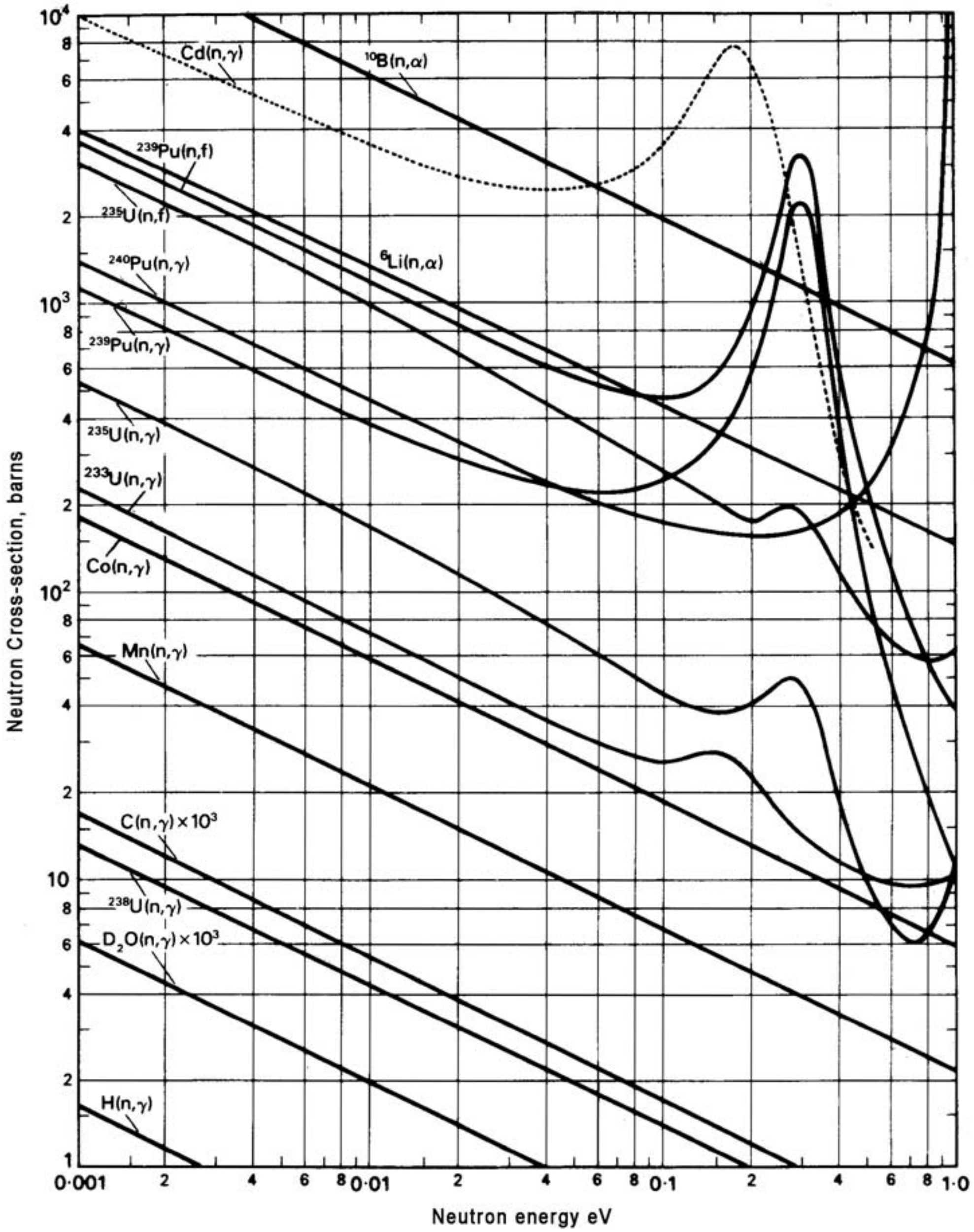
$$\lambda_{deB} = \frac{h}{mv} = \frac{h}{\sqrt{2mT}}$$

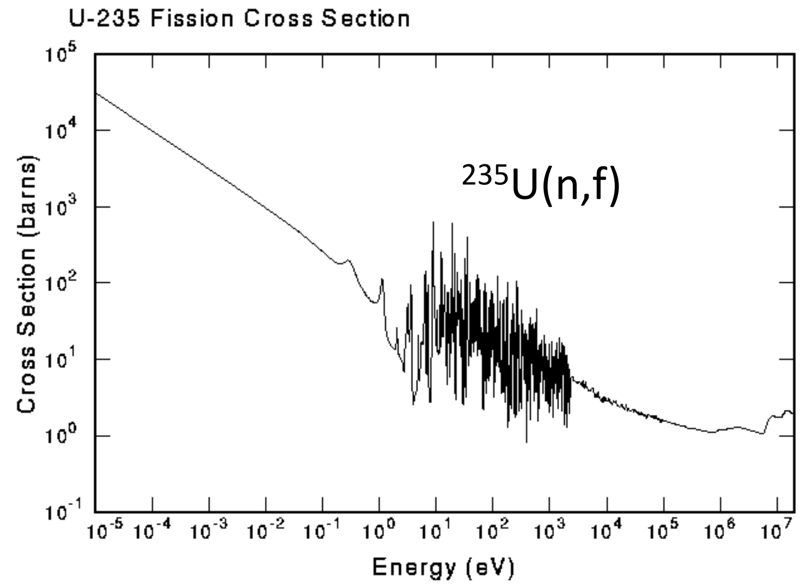
$$\sigma_{\text{Reaction}} = \pi\left(1.2A^{1/3} + r_{neutron}\right)^2\ fm^2$$

$$\sigma_{\text{Reaction}} = \frac{\pi}{100}\left(1.2A^{1/3} + r_{neutron}\right)^2\ barns$$

Neutron induced reactions -3

MICHIGAN STATE UNIVERSITY





Resonances – available energy exactly matches excitation energy of a state in the compound nucleus.

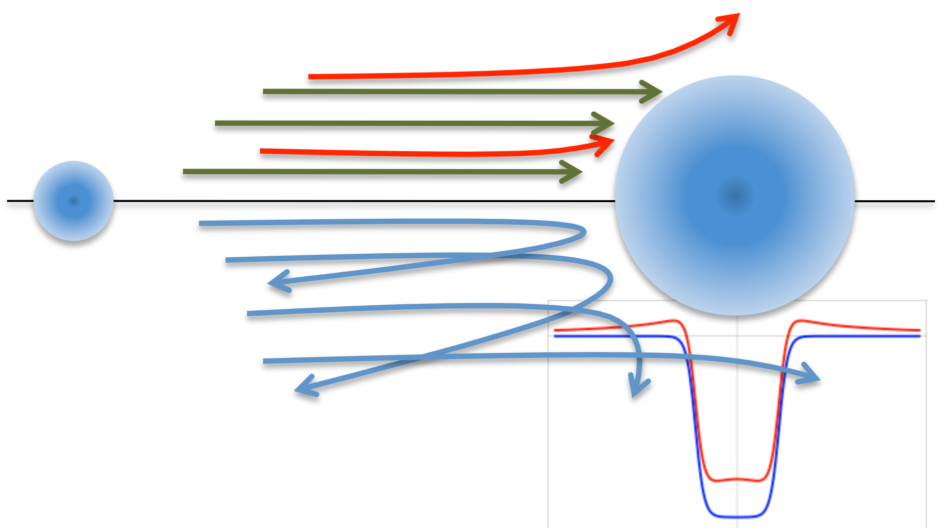
Common slope for all reactions !

Charged Particle Induced Reactions -1

MICHIGAN STATE UNIVERSITY

As opposed to neutrons, all of the matter that we have at hand is made up of charged nuclei and since sometime in the 1970's we have been able to induce nuclear reactions using isotopic beams of all stable elements with targets of all stable elements.

All nuclei repel another due to the Coulomb force acting between like-charges.



The repulsion is large enough that there are essentially no nuclear reactions taking place anywhere near room temperature.
The geometric cross section is only attained when the incident energy >> coulomb barrier.

Summarizing: $\sigma(E) \to 0$ when $E \to 0$, $\sigma(E) \to \sigma_{Geo}$ when $E >> V_{coul}$

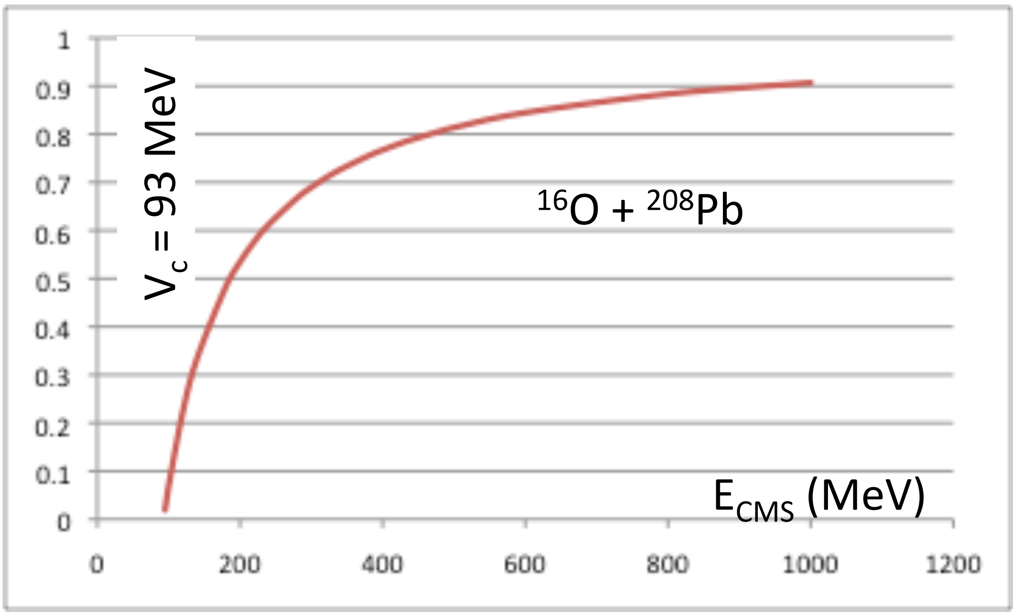
Charged Particle Induced Reactions -2

MICHIGAN STATE UNIVERSITY

The textbook gives a derivation of the algegraic effect of the coulomb barrier on the reaction cross section for charged particle induced reactions. The reaction cross section goes to zero below the barrier... Note that $V_c(R_1+R_2)$ is the Coulomb potential at R_1+R_2 and is a constant for a given reaction.

$$\sigma_{\text{Reaction}}(E) = \pi\left(R_1 + R_2\right)^2\left[1 - \frac{V_C(R_1 + R_2)}{E}\right]$$

$$\frac{\sigma_{\text{Reaction}}(E)}{\pi(R_1 + R_2)^2} = \frac{\sigma_{\text{Reaction}}(E)}{\sigma_{\text{Geometrical}}}$$



Overview of Nuclear Reactions

MICHIGAN STATE UNIVERSITY

The summary of the expected (classical) behavior of nuclear reactions is given in a qualitative figure from the text. This picture presents the total reaction cross section, regardless of the outcome of the reaction itself. “something happens”
The details of what actually happens are still to be considered.

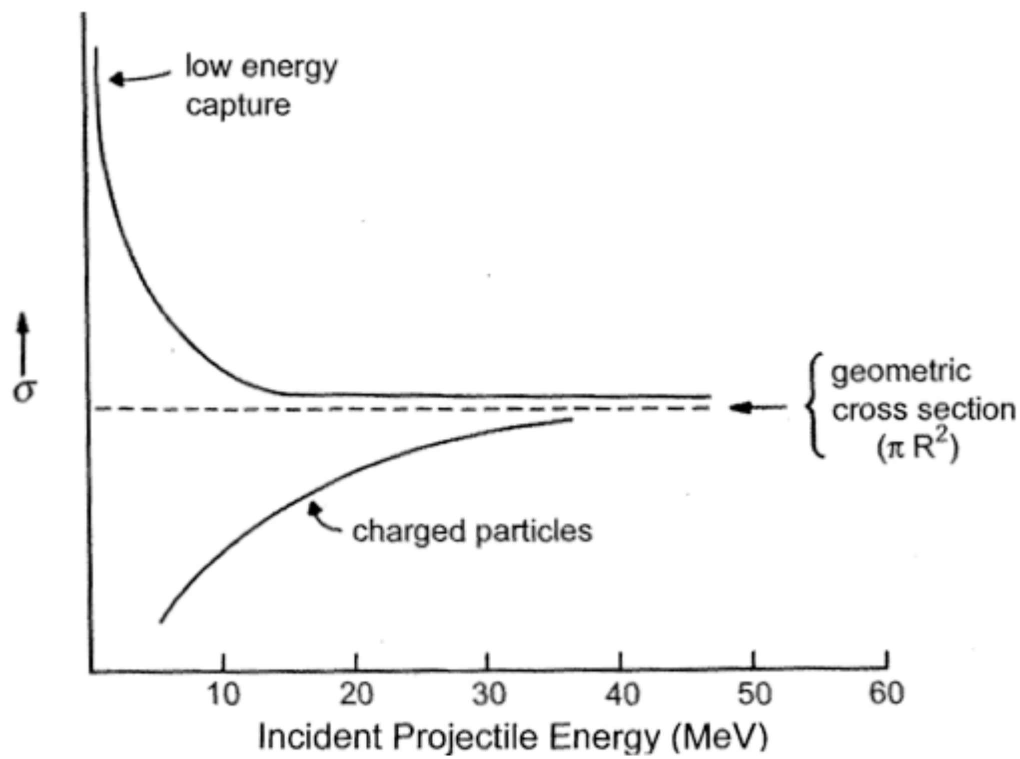


Fig. 10-xyz in the text