Nuclear Process & Radio-Analytical Chemistry

Class Notes – Part 1.3.1

Nuclear Fission

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Nuclear Fission

- *Spontaneous fission* – Nuclei of some heavy elements such as U-238 undergo spontaneous fission at a very slow rate. The nucleus splits into two parts with a release of energy.

- *Neutron-induced fission* – Some heavy elements will fission when struck by neutrons. U-235 and a few others will undergo fission when struck by very low energy (thermal) neutrons.

- The fission process also releases 2 to 3 neutrons which allows the process of fission to repeat and produce a **self-sustaining** chain reaction.

- Each fission releases energy equivalent to **200 MeV**, which is thousands of times more than is released by chemical reactions involving material of similar mass.

S-1.3.1

Nuclear Fission

Fission

In the fission reaction the incident neutron enters the heavy target nucleus, forming a compound nucleus that is excited to such a high energy level ($E_{exe} > E_{crit}$) that the nucleus "splits“ (fissions) into two large fragments plus some neutrons.

An example of a typical fission reaction is shown below.

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow \left({}^{236}_{92}U\right)^{*} \rightarrow {}^{140}_{55}Cs + {}^{93}_{37}Rb + 3\left({}^{1}_{0}n\right) $$

A large amount of energy is released in the form of radiation and fragment kinetic energy.

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Nuclear Fission

Liquid Drop Model of a Nucleus

The nucleus is held together by the attractive nuclear force between nucleons. The characteristics of the nuclear force are listed below.

(a) very short range, with essentially no effect beyond nuclear dimensions (10-13 cm)

(b) stronger than the repulsive electrostatic forces within the nucleus

(c) independent of nucleon pairing, in that the attractive forces between pairs of neutrons are no different than those between pairs of protons or a neutron and a proton

(d) saturable, that is, a nucleon can attract only a few of its nearest neighbors

Nuclear Fission

Liquid Drop Model of a Nucleus

The fission process can be explained using the liquid drop model of a nucleus.

In the ground state the nucleus is nearly spherical in shape.

After the absorption of a neutron, the nucleus will be in an excited state and start to oscillate and become distorted.

If the oscillations cause the nucleus to become shaped like a dumbbell, the repulsive electrostatic forces will overcome the short-range attractive nuclear forces, and the nucleus will split in two.

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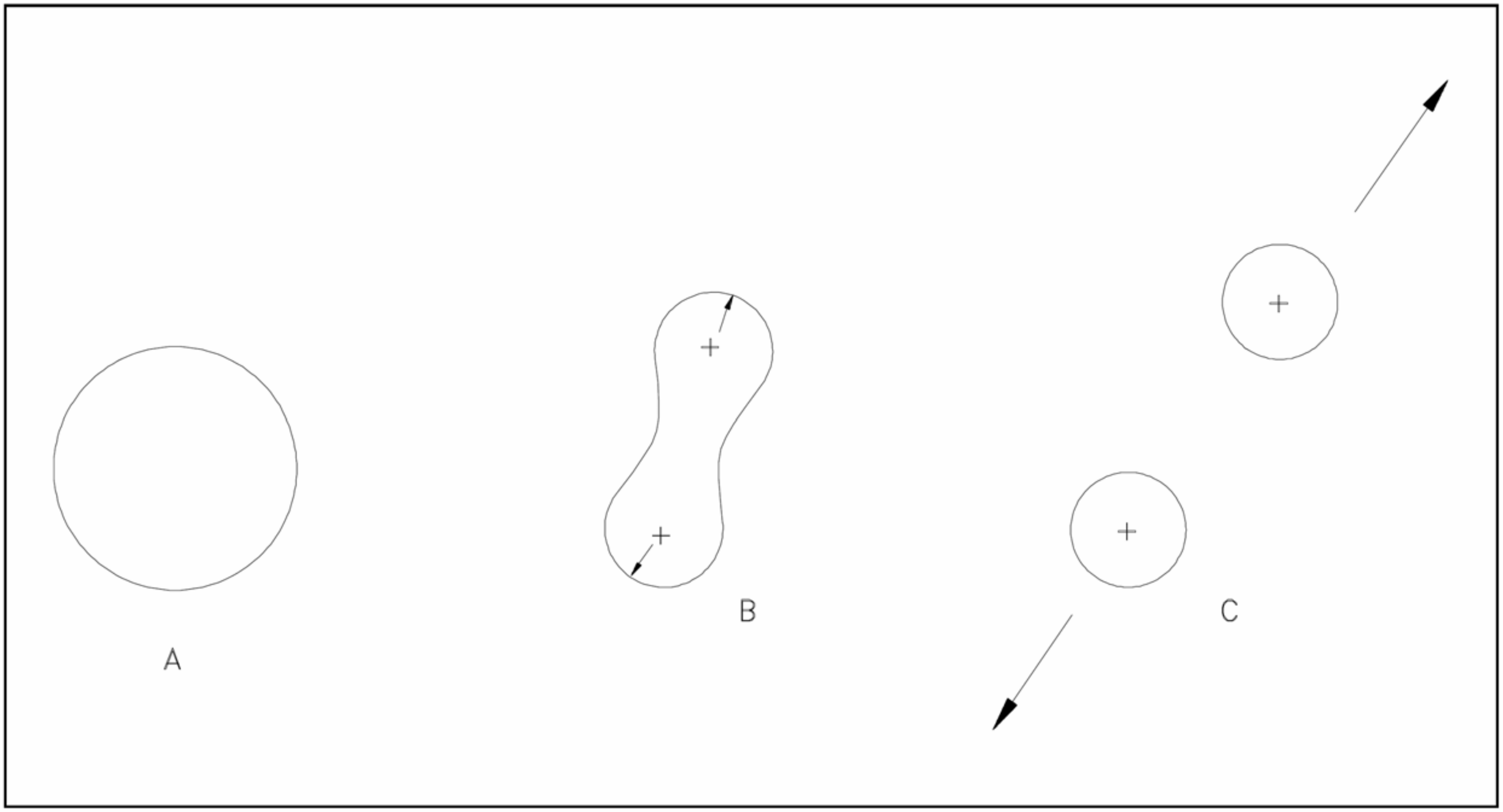
Nuclear Fission

Liquid Drop Model of a Nucleus



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Nuclear Fission

Fission

Excitation energy is the amount of energy a nucleus has above its ground state.

Critical energy is the minimum excitation energy that a nucleus must have before it can fission.

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Nuclear Fission

Fissile Material

A fissile material is composed of nuclides for which fission is possible with neutrons of any energy level. What is especially significant about these nuclides is their ability to be fissioned with zero kinetic energy neutrons (thermal neutrons).

Thermal neutrons have very low kinetic energy levels (essentially zero) because they are roughly in equilibrium with the thermal motion of surrounding materials.

Therefore, in order to be classified as fissile, a material must be capable of fissioning after absorbing a thermal neutron.

Some examples of fissile nuclides are uranium-235, uranium-233, and plutonium-239.

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Nuclear Fission

Fissionable Material

A fissionable material is composed of nuclides for which fission with neutrons is possible.

All fissile nuclides fall into this category.

However, also included are those nuclides that can be fissioned only with high energy neutrons.

The change in binding energy that occurs as the result of neutron absorption results in a nuclear excitation energy level that is less than the required critical energy.

Therefore, the additional excitation energy must be supplied by the kinetic energy of the incident neutron.

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Nuclear Fission

Odd-even Effect

TABLE 4
Critical Energies Compared to Binding Energy of Last Neutron

Target Nucleus	Critical Energy E_{crit}	Binding Energy of Last Neutron BE_n	$BE_n - E_{crit}$
$^{232}_{90}Th$	7.5 MeV	5.4 MeV	-2.1 MeV
$^{238}_{92}U$	7.0 MeV	5.5 MeV	-1.5 MeV
$^{235}_{92}U$	6.5 MeV	6.8 MeV	+0.3 MeV
$^{233}_{92}U$	6.0 MeV	7.0 MeV	+1.0 MeV
$^{239}_{94}Pu$	5.0 MeV	6.6 MeV	+1.6 MeV

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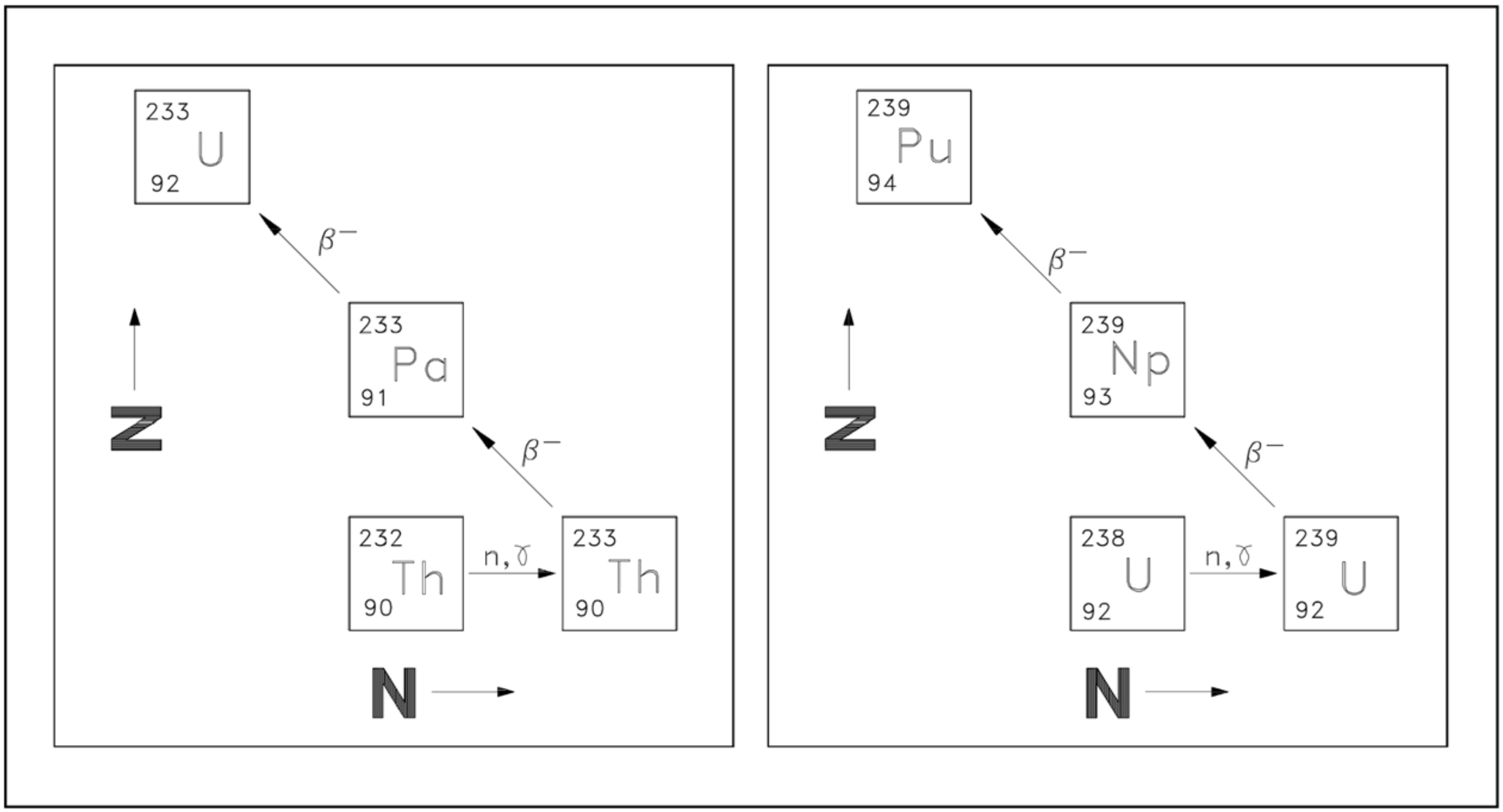
Nuclear Fission

Fertile Material

Fertile materials are materials that can undergo transmutation to become fissile materials



Nuclear Fission

Fission Products

Fission products have some general characteristics in common.

> *They generally decay by ϑ- emission.*
> *The most common mass numbers are grouped near 95 and 140.*

The energy released by fission can be calculated based on the difference in mass between the masses of the reactants before fission and the fission fragments and fission neutrons after fission.

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Nuclear Fission

Typical Fission Reaction

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow \left({}^{236}_{92}U\right)^{*} \rightarrow {}^{140}_{55}Cs + {}^{93}_{37}Rb + 3\left({}^{1}_{0}n\right) $$

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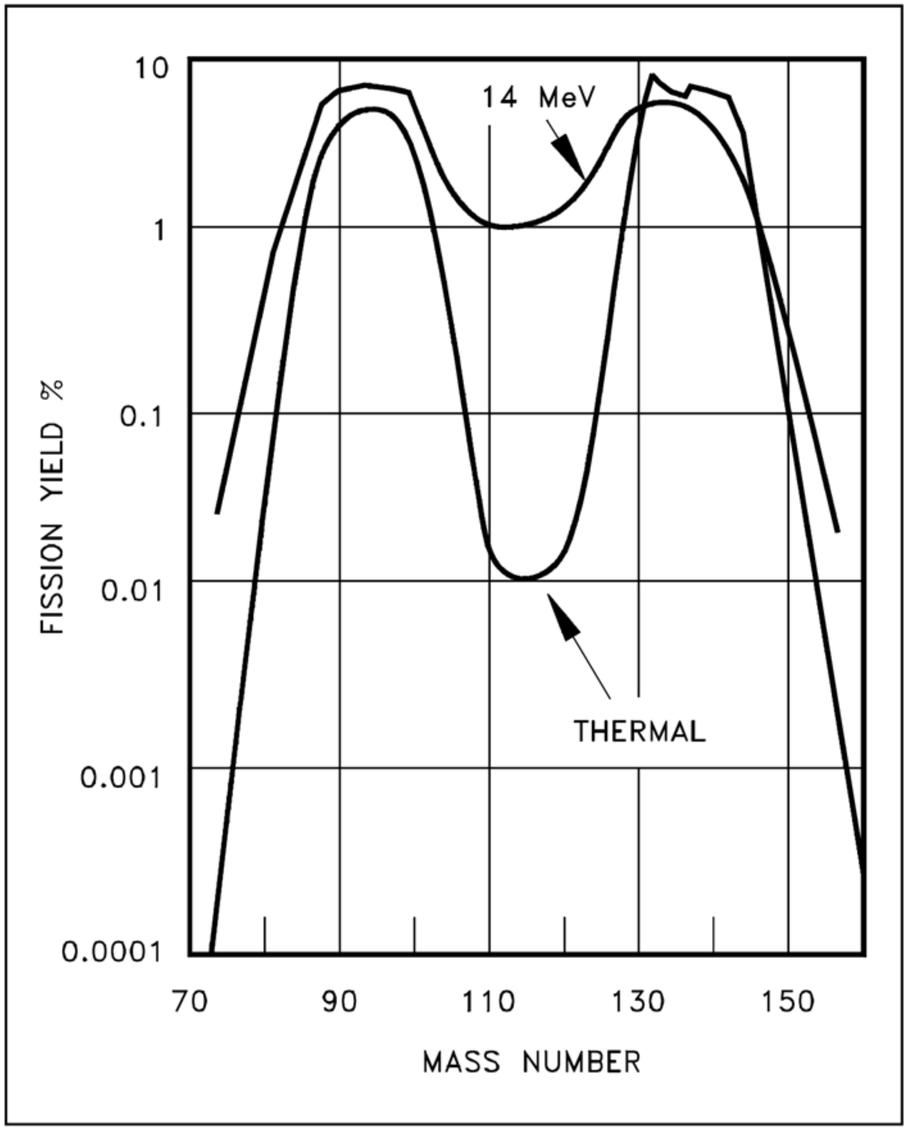
Nuclear Fission

Uranium-235 Fission Yield vs. Mass Number



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U-238 and Th-232 Fission Yield vs. Mass Number

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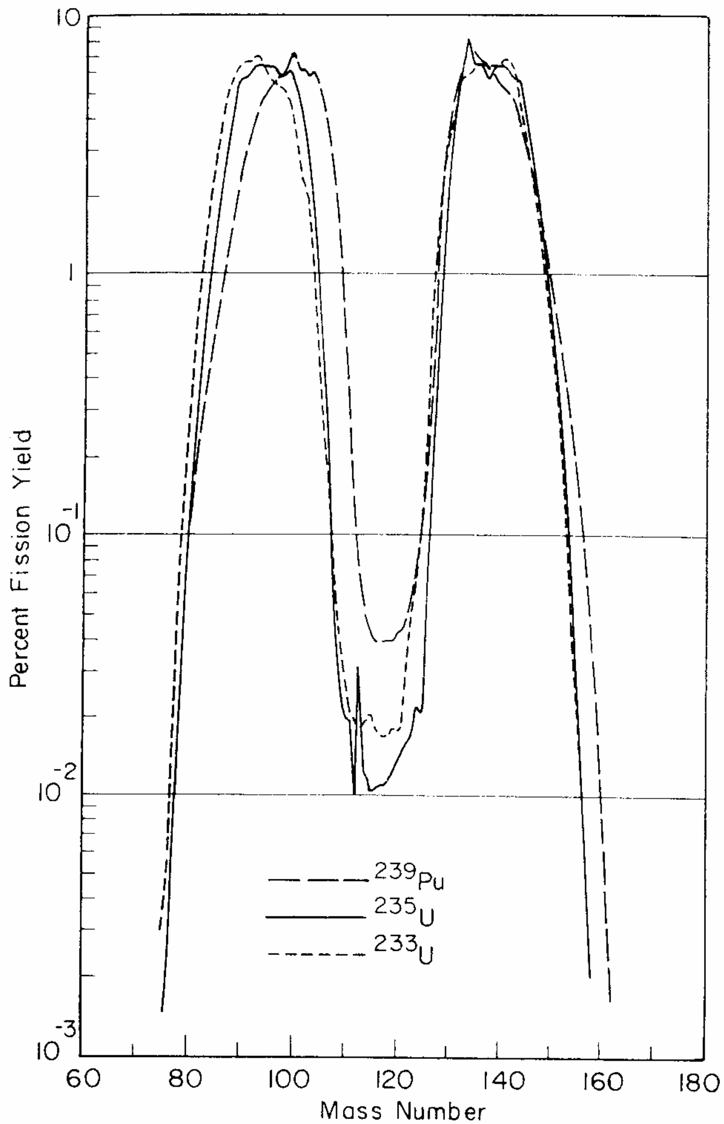
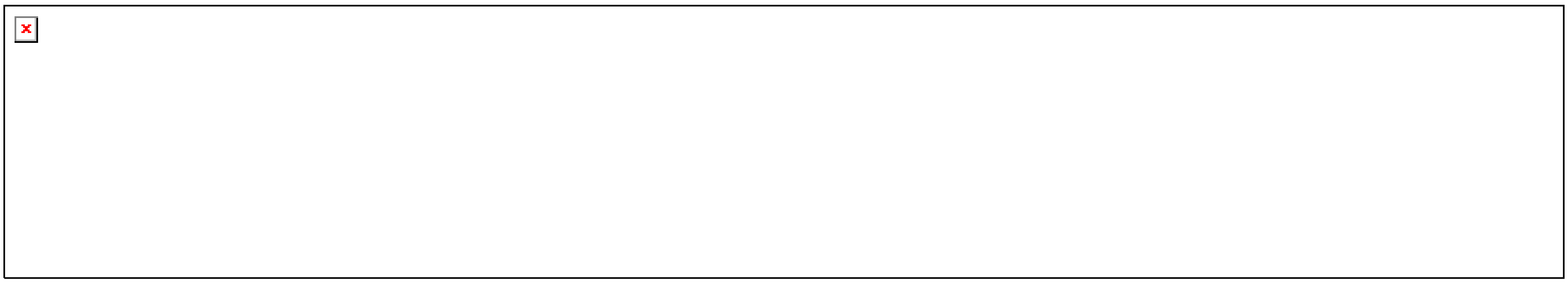
Nuclear Fission

Fission yields for slow-neutron fission of U-233, U-235, and Pu-239



Nuclear Fission

The Decay Chains for Kr-91 and Ba-143



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Modes of Radioactive Decay