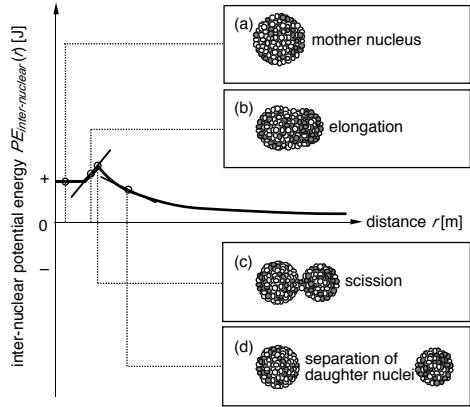


Inter-Nuclear PE Graphs: Beyond Balancing Reaction Equations and Calculating Mass Defects in Analyzing Fusion, Fission, and α Decay



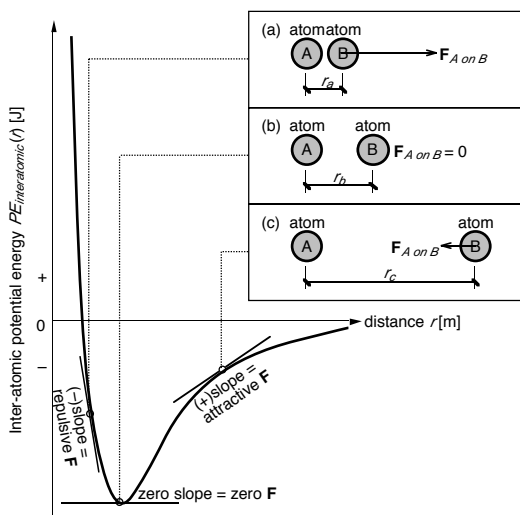
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03.04.02

Motivation for internuclear PE graphs

Connection with interatomic PE graphs

- Interatomic PE graphs
- A.k.a. "Lennard-Jones" plots
 - Characterizes atom-atom interactions
 - PE gradient (slope) = force



- Similarly, an internuclear PE graph can be constructed to characterize nuclear-nuclear interactions

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Outline

- Motivation for internuclear PE graphs
Connection with interatomic PE graphs
Characterizing certain nuclear processes
- Construction of internuclear PE graphs
General features
Exothermic fission example
Exothermic fusion example
- Analysis of nuclear processes
Fusion/fission initiation energy paradox
 α decay versus "symmetric fission" paradox
- Conclusions
So what can internuclear PE graphs do?

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Motivation for internuclear PE graphs

Characterizing certain nuclear processes

Usual textbook coverage of various nuclear processes:

- | | | |
|----------------------------------|---|---|
| Fusion | } | <ul style="list-style-type: none"> • Balancing reaction equations • Exo/endo- energetics from mass decrements • Exponential decay of unstable nuclei |
| Fission | | |
| α decay | | |
| β^\pm (ϵ) decay | | |
| γ decay | | |

Emphasis on describing "what happens," not explaining "why!"

Two "toy" models can motivate the "why" of nuclear processes!

- | | | |
|----------------------------------|---|---|
| Fusion | } | "Internuclear PE graphs" (discussed here) N. Bohr and J. A. Wheeler, <i>Phys. Rev.</i> 56 , 426 (1939) |
| Fission | | |
| α decay | | |
| β^\pm (ϵ) decay | } | "Fermi-gas model" ("box model") T. A. Moore, <i>Six Ideas of Physics, Unit Q</i> |
| γ decay | | |

"Different model approaches try to accentuate various aspects of nuclear structure in a simple and schematic way. No single model, as yet, is detailed enough to encompass all aspects of the nucleus..."

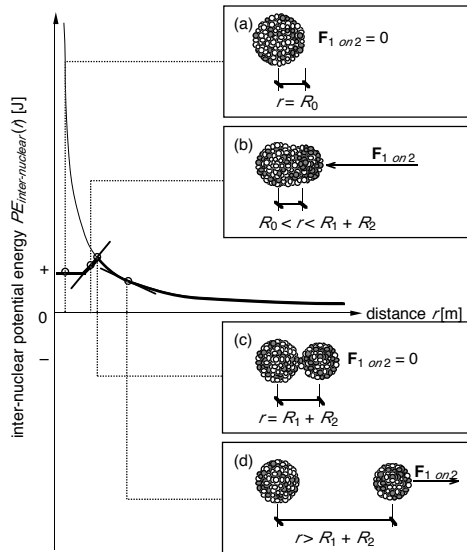
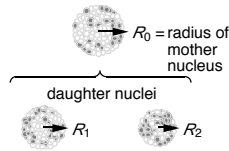
—K. Heyde,
Basic Ideas and Concepts in Nuclear Physics, 1994

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Construction of internuclear PE graphs
General features

Internuclear PE graphs

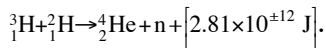
- Characterizes nuclear-nuclear interactions
- PE gradient (slope) = force
Electric repulsion when separated
Combination of strong nuclear attraction and electric repulsion when touching (net force attractive)



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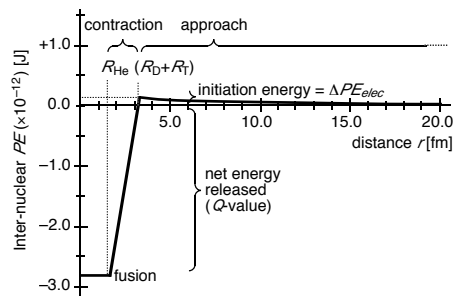
Construction of internuclear PE graphs
Exothermic fusion example

Exothermic fusion reaction:



Construction of internuclear PE graph:

- Radii calculated from $R \approx (1.2 \text{ fm}) A^{1/3}$.
- Energy at fusion point calculated from PE_{elec} of D and T nuclei
- Assume straight-line segment during contraction



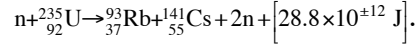
What can this graph tell us?

- PE gradient (slope) = net force between daughter nuclei during elongation or separation
- Required initiation energy (comparison with fission later)
- Relative initiation energies for various nucleosynthesis processes can be compared
- In general:
exothermic fusion = endothermic fission
exothermic fission = endothermic fusion

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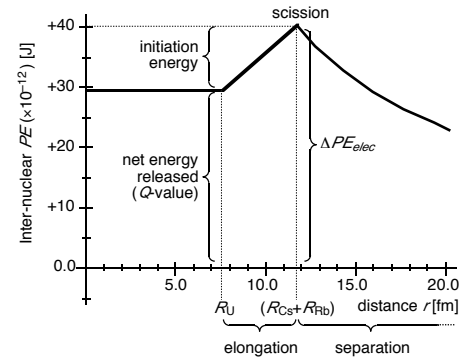
Construction of internuclear PE graphs
Exothermic fission example

Induced exothermic fission reaction:



Construction of internuclear PE graph:

- Radii calculated from $R \approx (1.3 \text{ fm}) A^{1/3}$.
- Energy at scission point calculated from PE_{elec} of daughter nuclei
- Assume straight-line segment during elongation



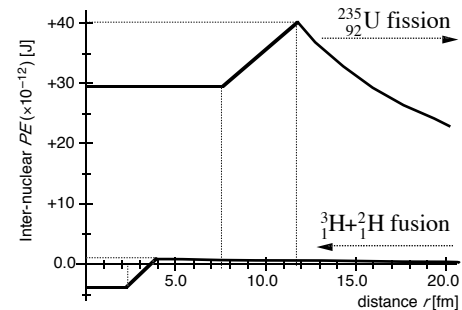
What can this graph tell us?

- PE gradient (slope) = net force between daughter nuclei during elongation or separation
- Required initiation energy from neutron (overestimated, if tunneling effects are not included, and graph not smoothed at scission point)

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Analysis of nuclear processes

Fusion/fission initiation energy paradox



What can these graphs tell us?

- Both graphs constructed in the same manner
- Appreciation of relative distance and energy scales involved

Common question asked by students:

- Initiation energy for tritium-deuterium fusion is two orders of magnitude smaller than initiation energy for induced U-238 fission!
- Yet why is fusion so much more difficult to initiate than fission?**

Fusion—two nuclei must come into contact

- Both nuclei repel each other
- Both nuclei move independent of each other in plasma phase

Induced fission—neutron penetrates U-238 nucleus

- No neutron-uranium repulsion
- Neutron will eventually hit a U-238 nucleus in a solid phase critical mass sample

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• Analysis of nuclear processes

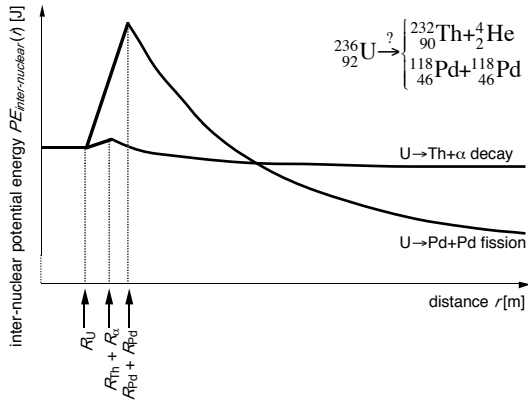
α decay versus "symmetric fission" paradox

Common question asked by students:

- α decay can be thought of as "asymmetric" fission, where less net energy released than fission into symmetric daughter nuclei
- Yet why is α decay observed rather than energetically favorable symmetric fission?

Compare internuclear PE graphs of both processes:

- Symmetric fission: more exothermic, but higher initiation energy (KE from external neutron required)
- α decay: less exothermic, but much lower initiation energy ("self-initiating" with tunneling)



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• Conclusions

So what can internuclear PE graphs do?

Visualization of relative distance and energy scales involved in different nuclear processes

- Uses already available information:
 - Nuclear radius, calculated from nucleon number
 - Q -values, calculated from mass decrements
- Emphasizes reversibility of exo/endo-thermic fission/fusion processes
- Quantifies net internuclear forces during elongation/contraction phases of fission/fusion
- Graphical comparison of initiation energies for:
 - Induced versus spontaneous fission
 - Stellar nucleosynthesis processes
 - α decay versus "symmetric" fission
- More complex effects can be introduced and incorporated (such as tunneling, smoother increase in internuclear PE due to increase in surface area during elongation)

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