Week 9, Lecture 1 – Reactions in the Lab

MICHIGAN STATE UNIVERSITY

Nuclear Reactions

-- Nuclear Reactions overview

--- neutron induced reactions

--- charged particle induced reactions

-- Cross Section, Target attenuation

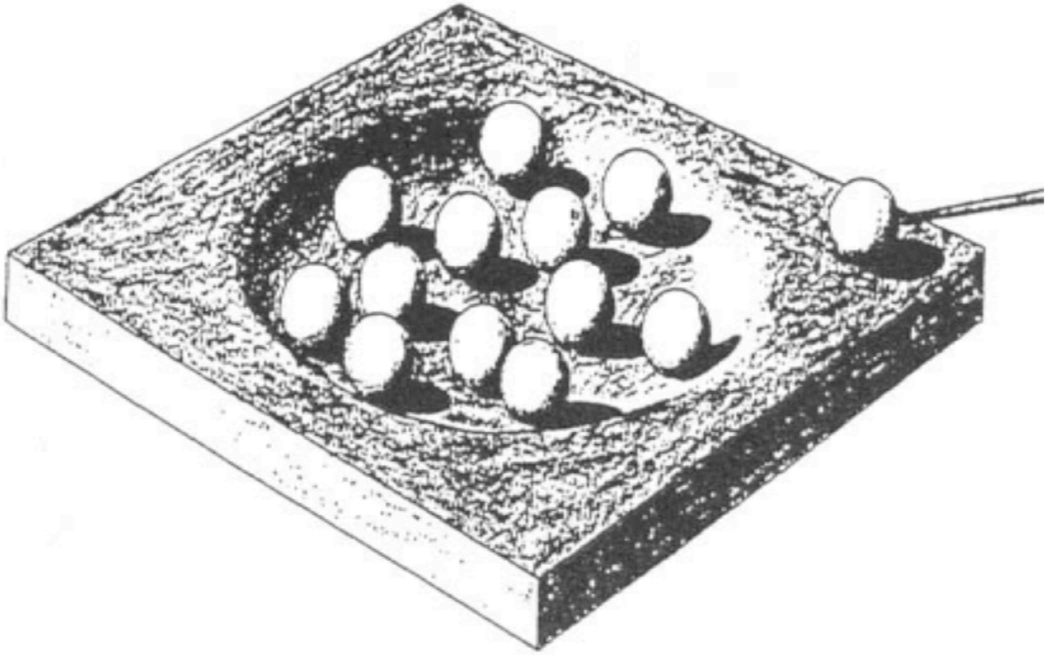
-- Energetics, Q-values, thresholds

-- Conservation of Momentum, Center of Mass

-- Reactions between complex nuclei

--- Low energy reactions, fusion

--- "High" energy reactions



N. Bohr, Nature **137** (1936) 351

Low vs. High Energy?

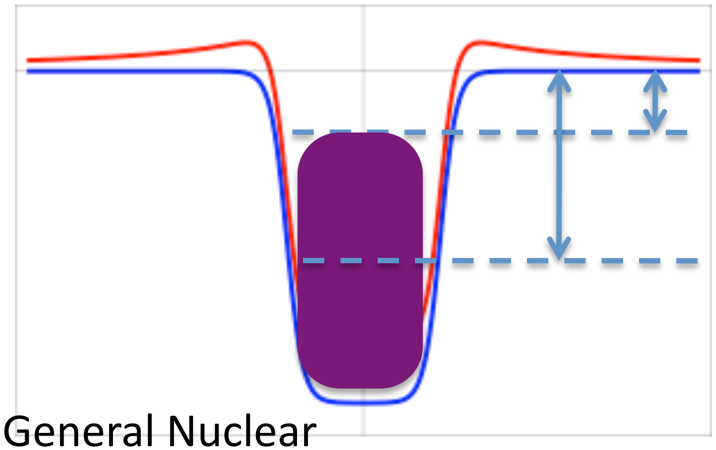
Recall that we are considering reactions between charged particles so:

The Coulomb barrier represents a threshold energy in the Center of Mass system …

$V_{coul} = [Z_1 Z_2 e^2 / (R_1 + R_2)]$ in CMS $V_{coul} = [(M_1+M_2)/M_{target}] [Z_1 Z_2 e^2 / (R_1 + R_2)]$ in LAB

A qualitative dividing line between “low” and “high” energy reactions might be when the projectile moves past (or perhaps through) the target so fast that the nucleons inside don’t have time to react.

So how fast are the nucleons moving inside a nucleus?



General Nuclear Potential Energy

Example of CMS to LAB System

The Coulomb barrier in the Center of Mass system converted to LAB system …

$V_{coul} = [Z_1\ Z_2\ e^2 / (R_1 + R_2)]$ in CMS $\quad V_{coul} = [(M_1+M_2)/M_{target}]\ [Z_1\ Z_2\ e^2 / (R_1 + R_2)]$ in LAB

Pick a target Z_2/A_2

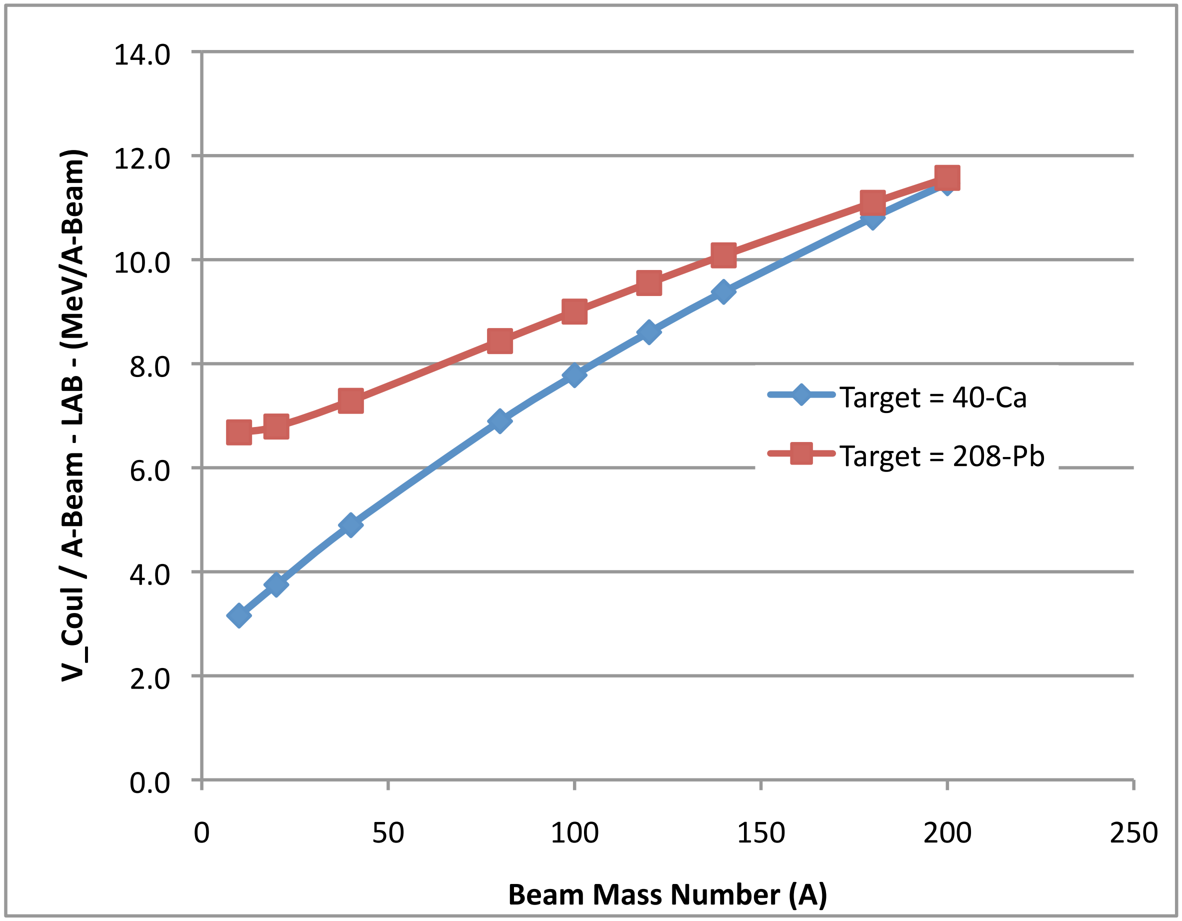
Scan beam A_1 10, 20 .. 200

Calculate Z_p for stable beam

Calculate Radii

Calculate V_{coul} (CMS)

Calculate V_{coul} (LAB)



Low Energy Reactions - 1

Imagine the sequence of events that might occur in a collision between two charged particles:

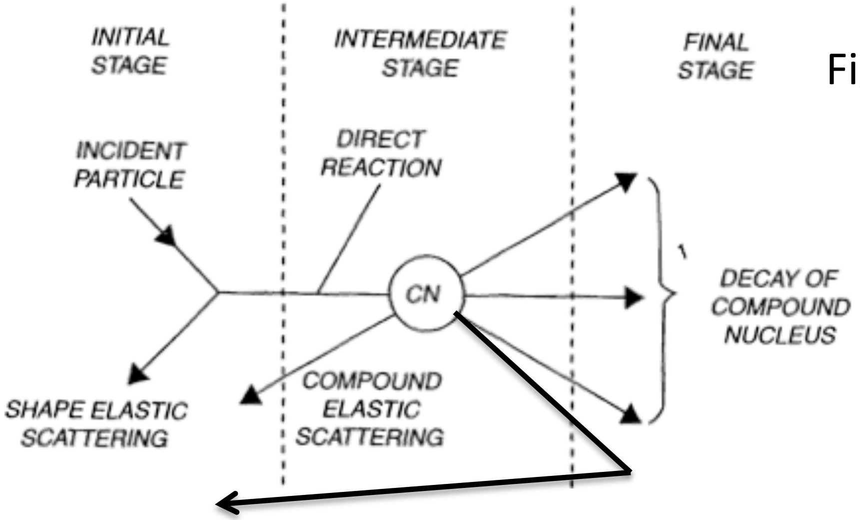
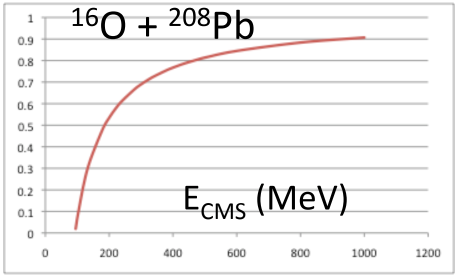


Fig. 10-3 in the text



Same kind of
particle exits …
Zero Degrees,
Same Energy??

Different angle,
kinetic energy?

E.g.,

$^{16}O + ^{208}Pb \to (^{224}Th)^*$

$E^* = Q + [M_{beam}/(M_1+M_2)] * E_{beam}(LAB)$

$E_{CMS} = [M_{target}/(M_1+M_2)] * E_{beam}(LAB)$
is not available to excite the CN

Low Energy Reactions -2

$^{16}O + ^{208}Pb \rightarrow (^{224}Th)^*$ Q = -46.481 MeV

$E^* = Q + [M_{beam}/(M_1+M_2)] * E_{beam}(LAB)$

E_Lab	E* = E_cms+Q	
96.9		43.5
102.3		48.5
105.5		51.5
107.7		53.5
129.2		73.5
150.8		93.5
193.8		133.5
215.4		153.5
236.9		173.5
258.5		193.5
301.5		233.5

~5 n

~10 n

~20 n

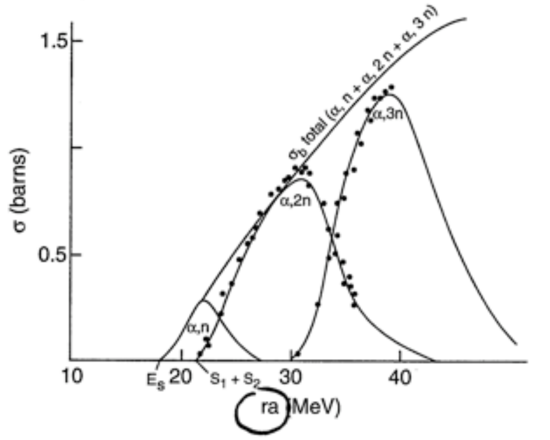
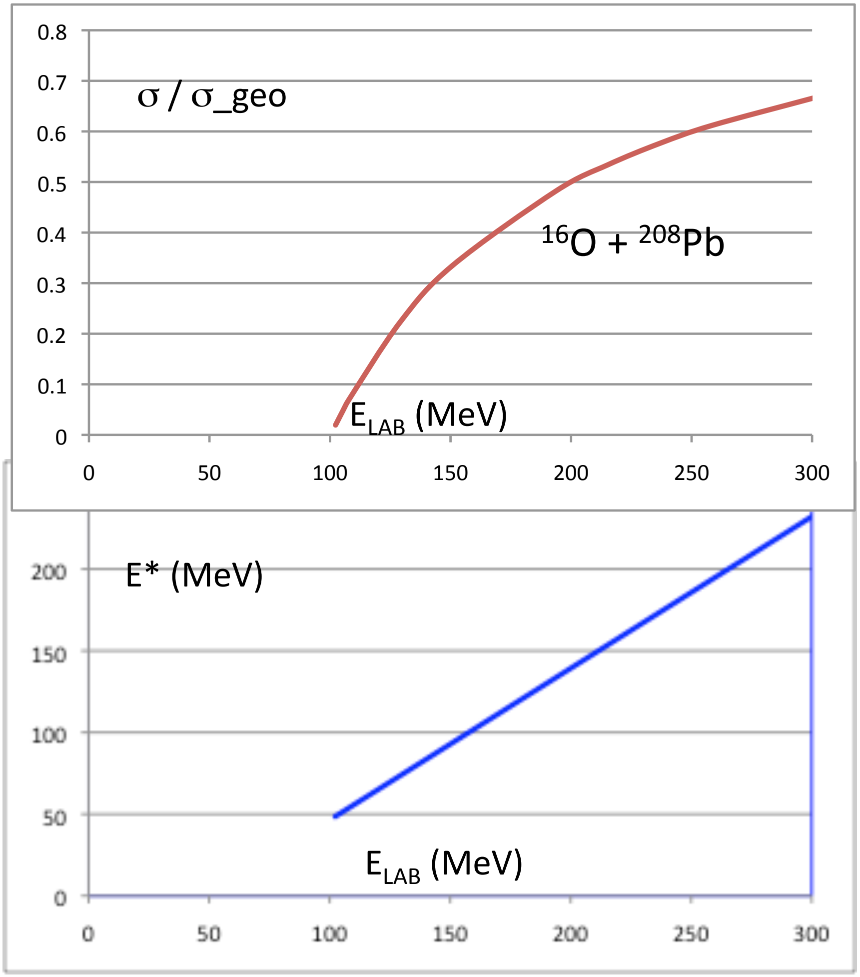
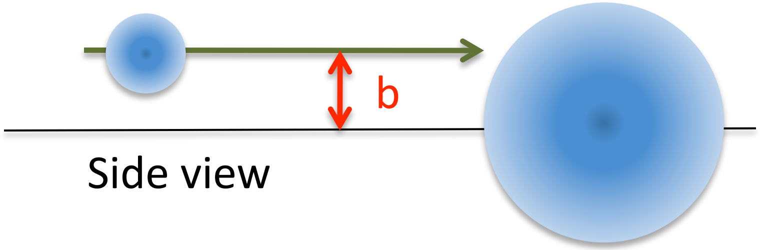


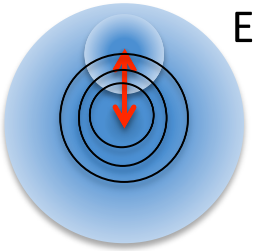
Figure 10.20 Excitation function for the ^{209}Bi(α, xn) reaction.



Reactions & Angular Momentum



Side view



End view

The distance off-center is called the *Impact Parameter, b,* and determines the amount of angular momentum before reaction … a quantity that must be conserved …

The Impact parameter is also linked to the cross section, or probability, of a collision:

$$L = r \otimes mv \qquad l\hbar = b \otimes mv \qquad \lambda_{deB} = \frac{h}{mv} \leftrightarrow mv = \frac{h}{\lambda_{deB}}$$

One ring:

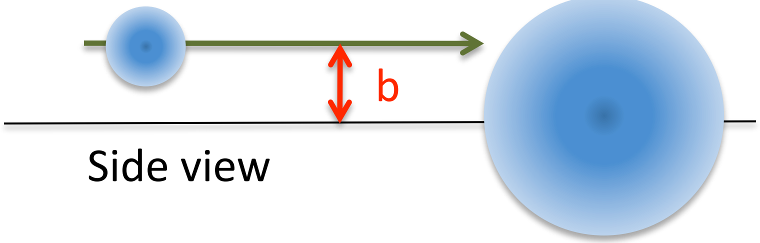
$$\sigma_l = \pi\left(\frac{(l+1)\lambda_{deB}}{2\pi}\right)^2 - \pi\left(\frac{l\lambda_{deB}}{2\pi}\right)^2 = \pi\left(\frac{\lambda_{deB}}{2\pi}\right)^2(2l+1)$$

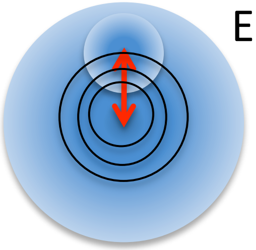
The maximum angular momentum, when b = $(R_1 + R_2)$, and the affect of the coulomb potential:

$$\sigma_{l-\max} = \pi\left(\frac{(l_{\max}+1)\lambda_{deB}}{2\pi}\right)^2 = \sigma_{reaction} = \pi(R_1+R_2)^2\left(1-\frac{V_{coul}}{E_{CMS}}\right)$$

$$l_{\max} = \left[\frac{(R_1+R_2)}{\lambda_{deB}/2\pi}\left(1-\frac{V_{coul}}{E_{CMS}}\right)^{1/2}\right] - 1$$

Reactions & Angular Momentum





$^{16}O + ^{208}Pb \rightarrow (^{224}Th)^*$ Q = -46.481 MeV

$E_{CMS} = [M_{target}/(M_1+M_2)] * E_{beam}(LAB)$

$$\lambda_{deB} = h/mv \qquad l_{\max} = \left[\frac{(R_1+R_2)}{\lambda/2\pi} \left(1 - \frac{V_{coul}}{E_{CMS}}\right)^{1/2} \right] - 1$$

E_cms (MeV)	E_Lab	lambda = h/mv (fm)	L-max (h-bar)
95	102.3	0.113	0.74
98	105.5	0.111	3.51
100	107.7	0.110	5.30
120	129.2	0.101	21.55
140	150.8	0.093	35.44
180	193.8	0.082	58.57
200	215.4	0.078	68.53
220	236.9	0.074	77.70
240	258.5	0.071	86.23
280	301.5	0.066	101.76