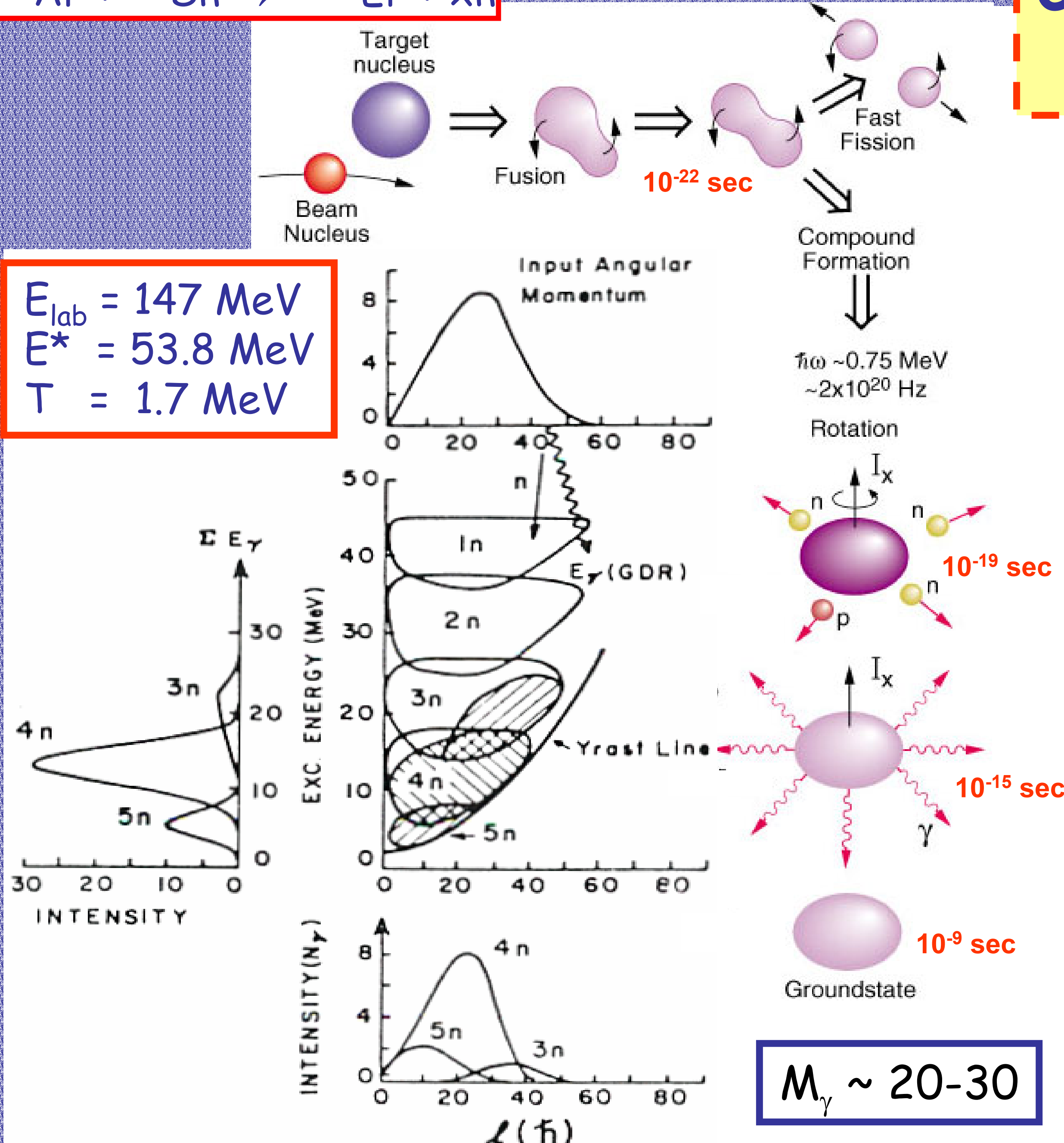
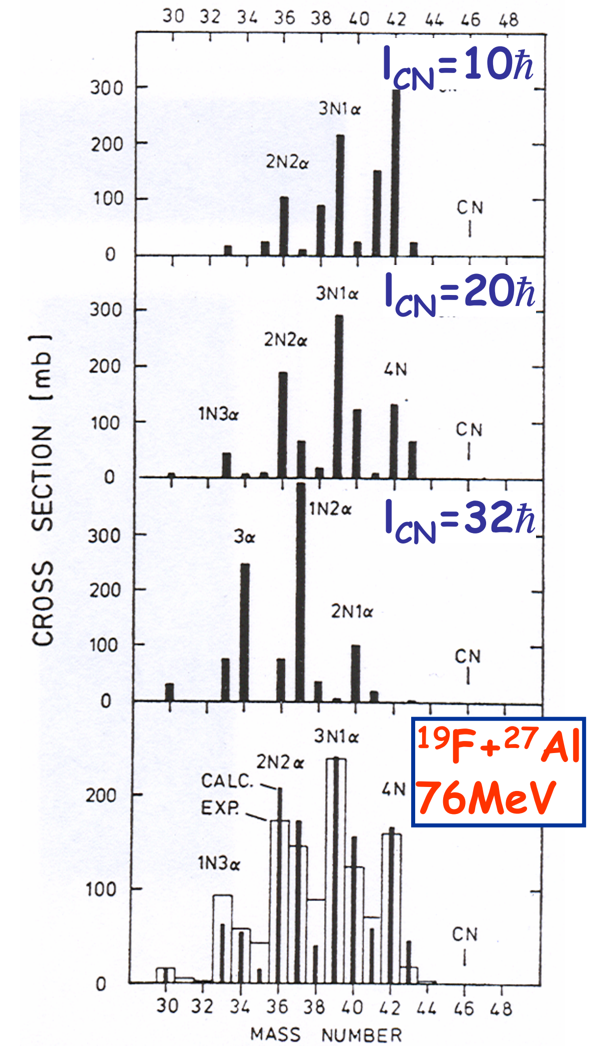
Compound Nucleus Decay

$^{40}Ar + ^{124}Sn \rightarrow ^{164-x}Er + xn$

E_{lab} = 147 MeV
E^* = 53.8 MeV
T = 1.7 MeV



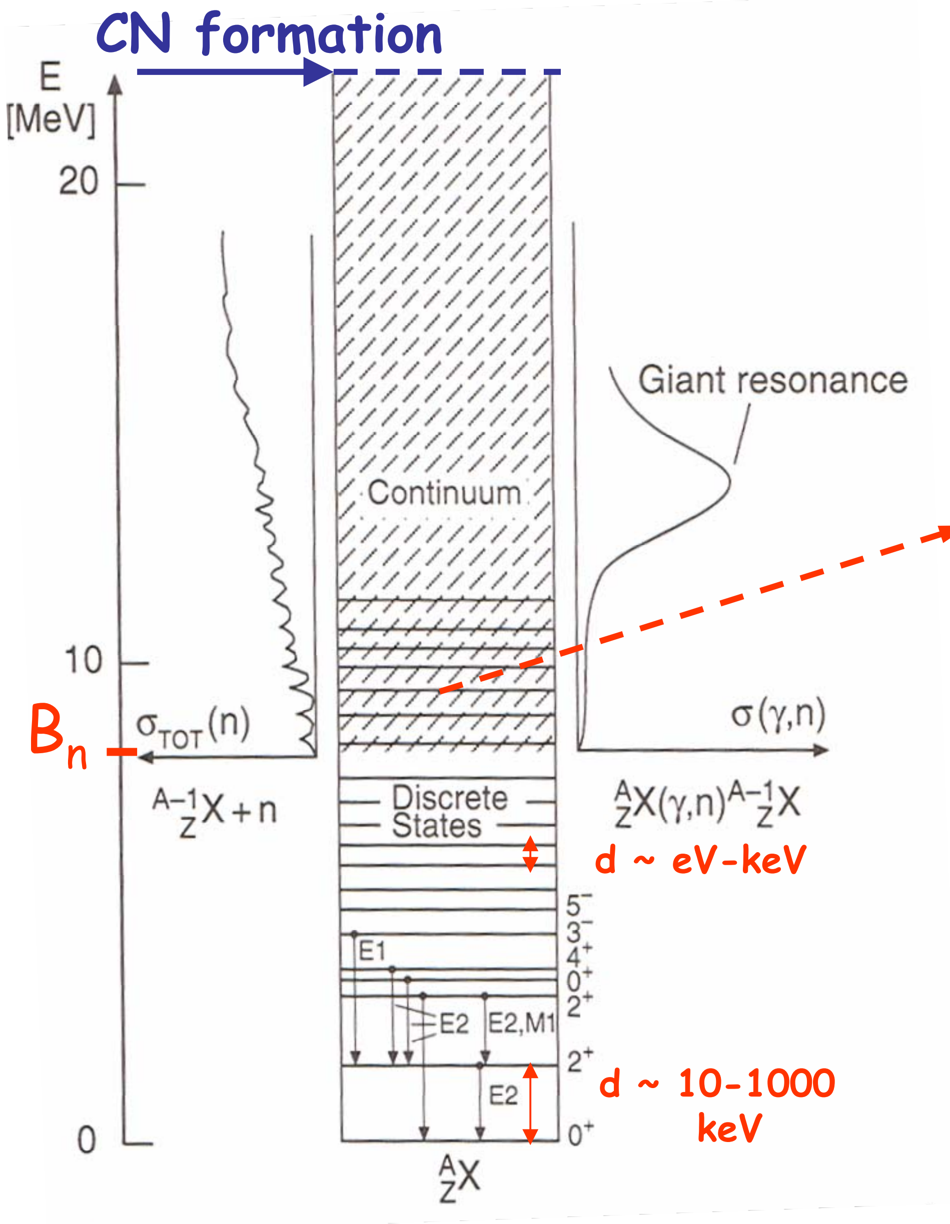
M_γ ~ 20-30



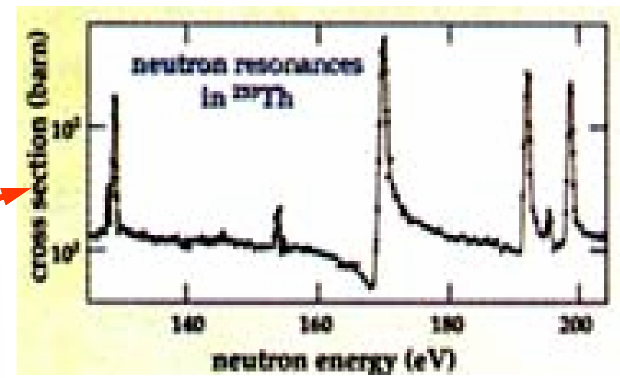
Cascade Code

Pulhöfer et al., NPA280(1977)267

Level density of Nuclear States



- Compound nucleus reactions populate excitation energy region of **high level density** (high number of states per MeV)



$\Delta E \approx eV$

$\tau = \hbar / \Delta E \approx 10^{-16}\text{-}10^{-18} s$

- impossibility of counting individual nuclear levels

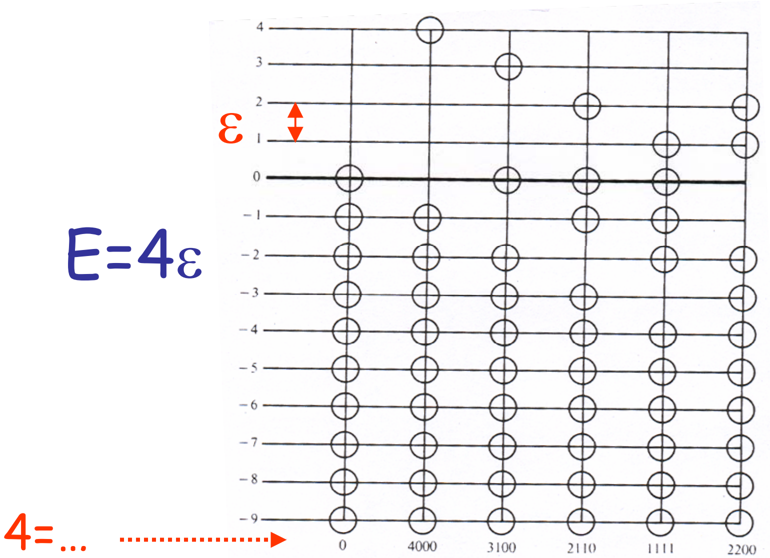
- need of statistical concepts:
  level density ρ
  excitation energy **E^***
  temperature **T**

Equidistant spacing model for level density evaluation

being E the total energy of the system
how can one distribute A nucleons
in equidistant single particle levels
(respecting Pauli's principle) ?

level density $\rho(E) = \frac{\Delta n}{\Delta E}$

equivalent problem:
decomposition of $n=E/\varepsilon$ in n_1+n_2+ …



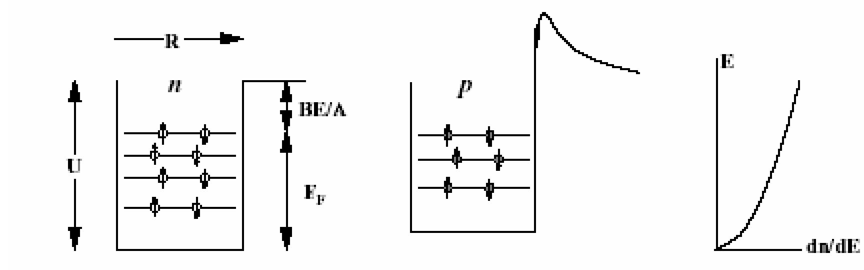
$$p(n) = (4\sqrt{3n})^{-1}\exp\left[\pi(2n/3)^{1/2}\right]$$

Ramanujan & Hardy

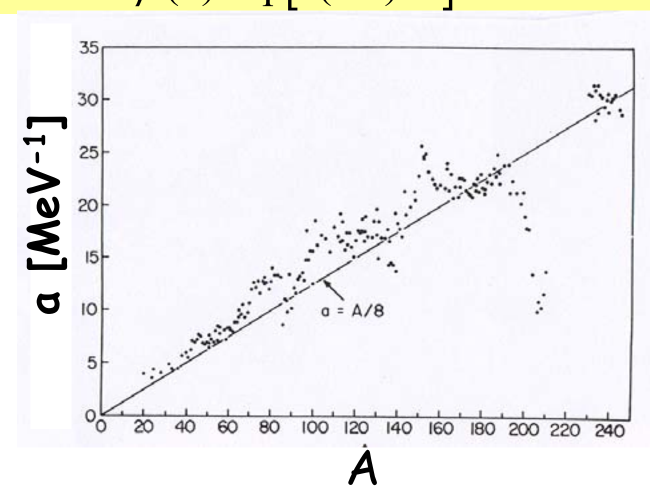
Nuclear System:

Z protons
N neutrons
2 particles per state (spin up & down)

Fermi Gas



$$\rho(E) = (\sqrt{\pi}/12)a^{-1/4}E^{-5/4}\exp\left[2(aE)^{1/2}\right]$$
$$= \rho(0)\exp\left[2(aE)^{1/2}\right]$$



example: A=100, E=50MeV ⇒ ρ = 10^{20}MeV^{-1} !!

Thermodynamics in Nuclear Physics

With some care: the nucleus contains few particles compared to macroscopic systems described by statistical models

entropy

$$S(E) \underset{def}{=} k_B \ln \rho(E) = \ln \rho(E)$$

temperature

$$T \underset{def}{=} \left(\frac{\partial S(E)}{\partial E} \right)^{-1}$$

$$\rho(E) = (\sqrt{\pi}/12) a^{-1/4} E^{-5/4} \exp\left[2(aE)^{1/2}\right]$$

$$\frac{1}{T} = \frac{\partial \ln \rho(E)}{\partial E} = -\frac{5}{4}\frac{1}{E} + \sqrt{\frac{a}{E}} \approx \sqrt{\frac{a}{E}}$$ leading term

$$E = aT^2$$

Examples:

a=A/8=160/8=20

CN formation (5MeV/A): E=50MeV, T=1.6MeV

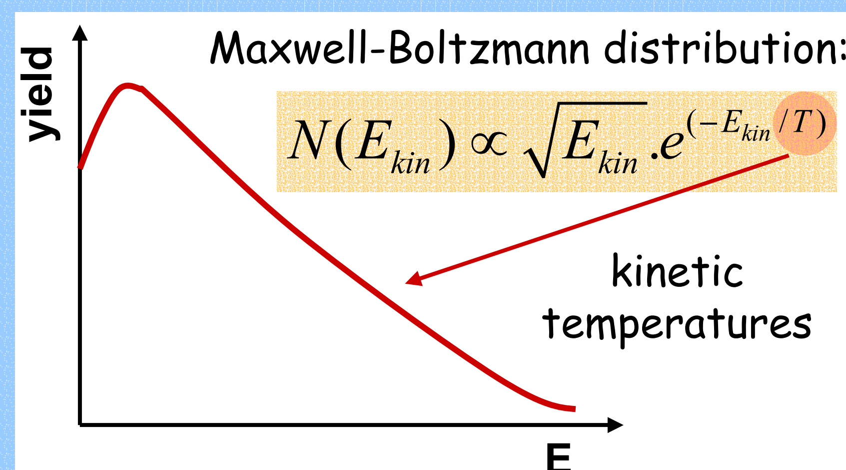
Binding Energy: E=8 MeV, T=0.6 MeV

Limit of discrete spectroscopy: E=1 MeV, T=0.2 MeV

Requirement

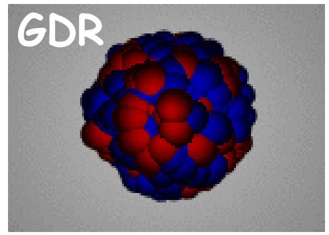
full statistical equilibrium

Experimental Thermometers: particles and γ energy distribution

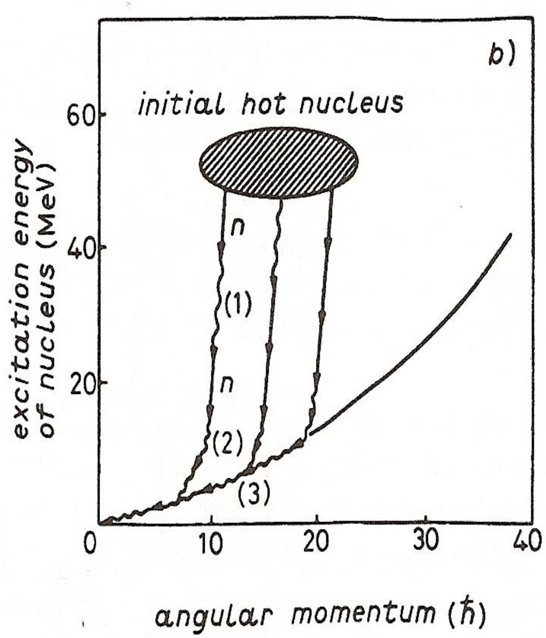


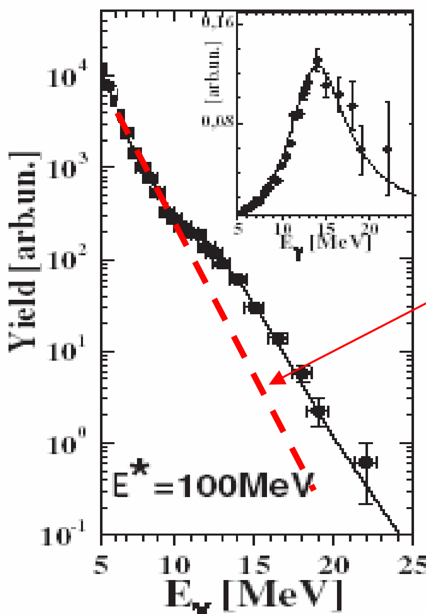
HOT Giant Dipole Resonance

- $E_\gamma \sim 15$ MeV
- FWHM ~ 5-7 MeV
- $P_\gamma / P_{part} \approx 10^{-3}$



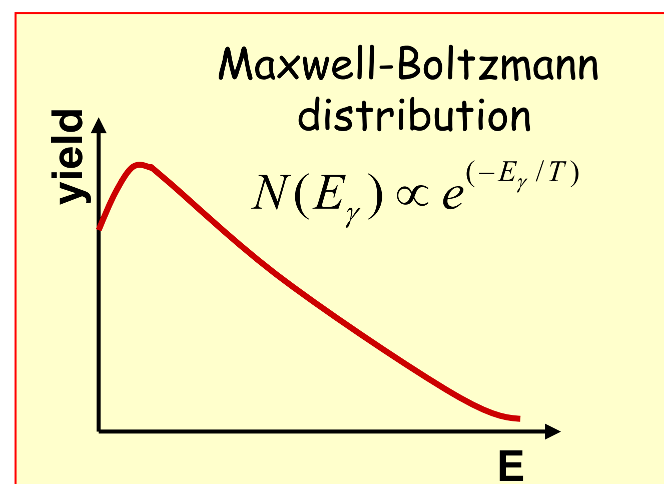
^{64}Ni (@300MeV) + ^{68}Zn → ^{132}Ce





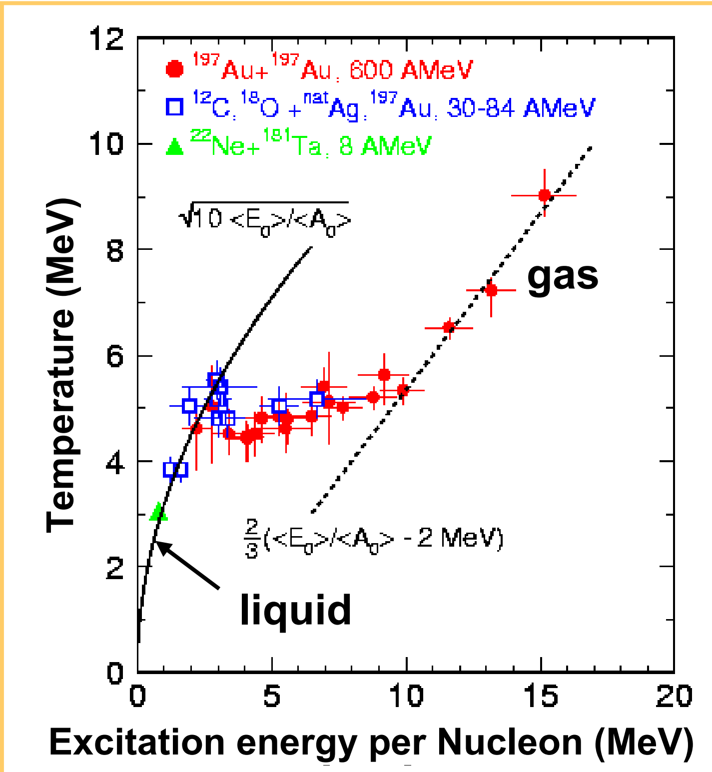
statistical decay of compound nucleus

by γ**-ray emission**

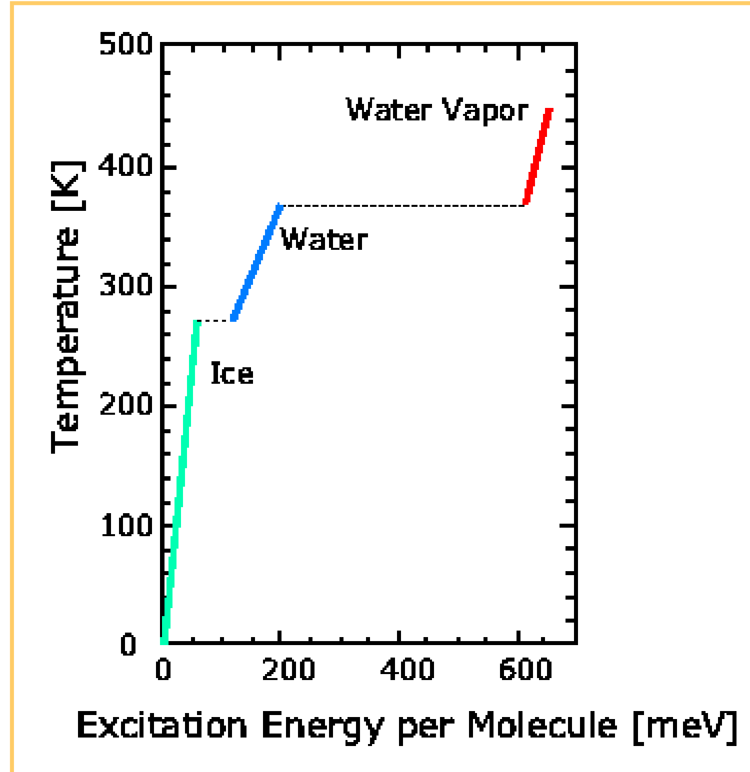


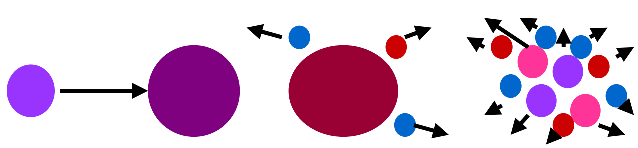
Caloric curve of nuclear matter

Caloric curve of nucleus

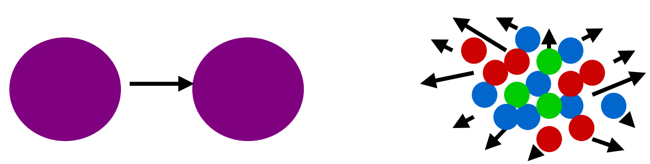


Caloric curve of water





Multifragmentation: T≈5 MeV, E*≈4-5/A MeV



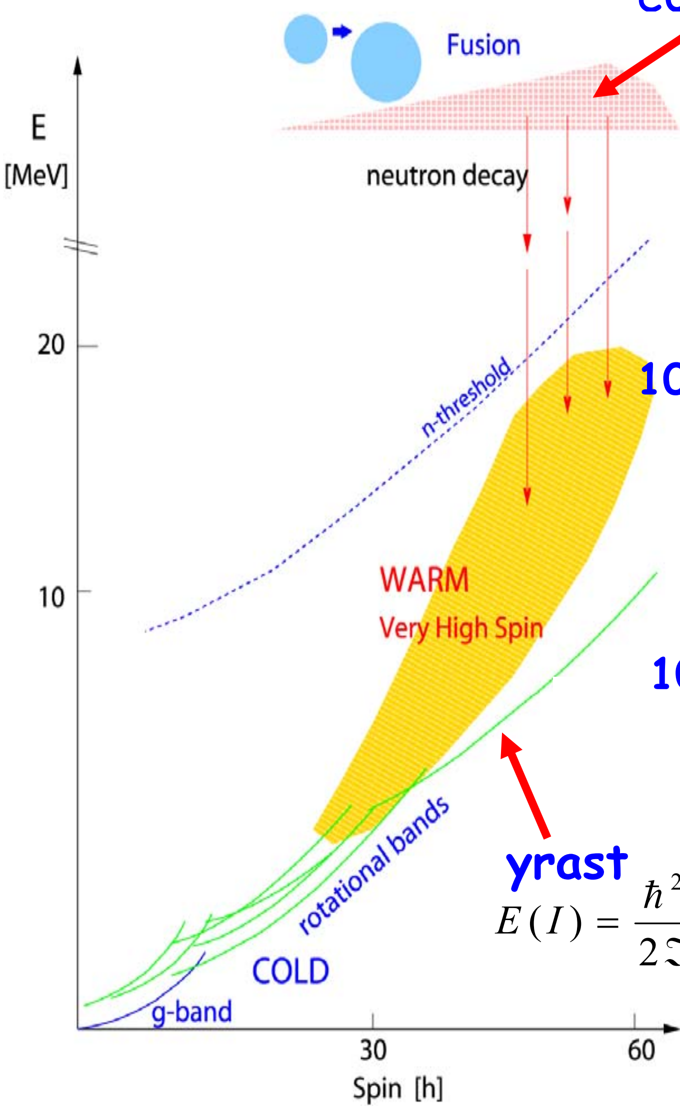
Vaporization: T>6 MeV, E*>10/A MeV

J. Pochodzalla et al., Phys. Rev. Lett. 75(1995)1040

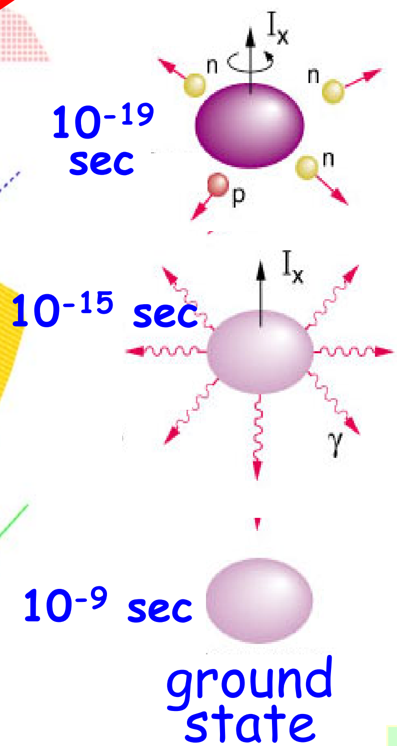
Heavy Ions Fusion Reactions:

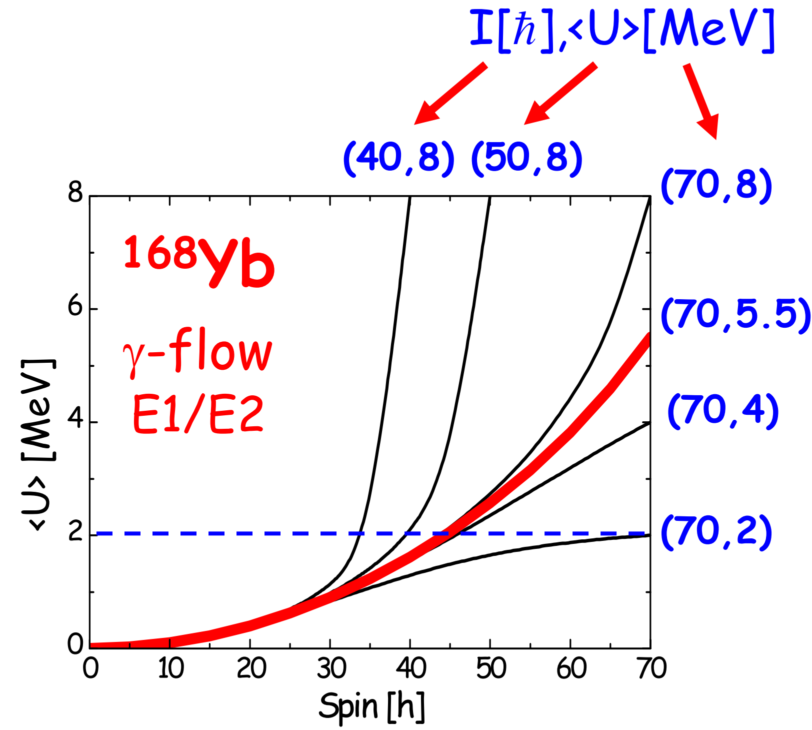
population of excited (0<E<8 MeV), high spins states (>40 $\hbar$)

compound nucleus formation



$$E(I) = \frac{\hbar^2}{2\Im} I(I+1)$$





Most of the experimental works on γ spectroscopy focus on high spins and low excitation energies $(E-E_{yrast})=U \leq 2$ MeV, $T \leq 0.3$ MeV

Døssing, Vigezzi, NPA587(1995)13.