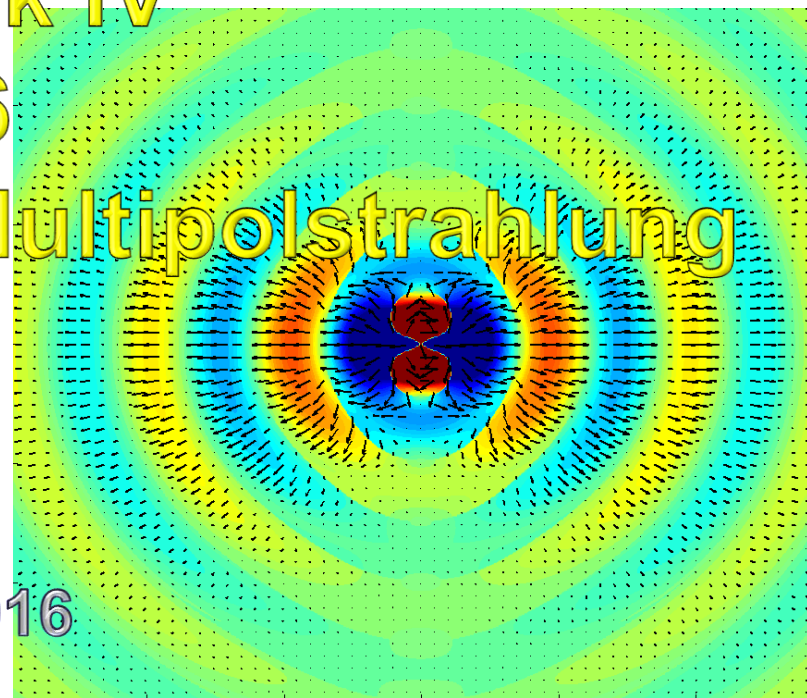
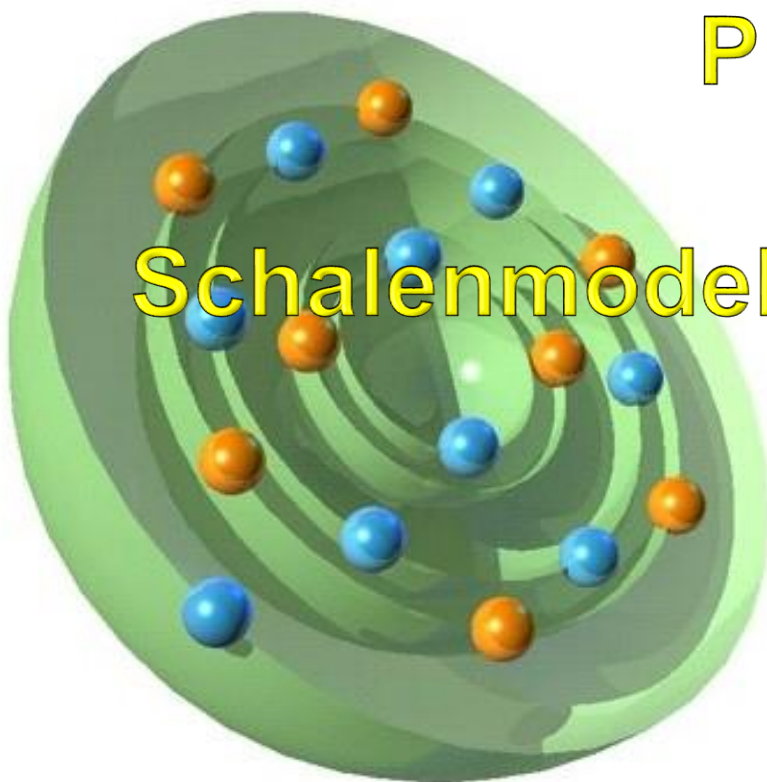


# Physik IV

06

## Schalenmodell / Multipolstrahlung



SS2016

05.04.2016	Aufbau der Kerne	CW
07.04.2016	keine Veranstaltung	
12.04.2016	Tröpfchenmodell	CW
14.04.2016	alpha Zerfall	CW
19.04.2016	beta Zerfall	CW
21.04.2016	gamma Zerfall	CW
26.04.2016	Schalenmodell	CW
28.04.2016	Neutronen und Kernreaktionen	CW
03.05.2016	fällt aus	CW
05.05.2016	Himmelfahrt	
10.05.2016	Molekülphysik 1	SO
12.05.2016	Molekülphysik 2	SO
17.05.2016	Pfingsten	
19.05.2016	Pfingsten	



- A. liegt typischerweise im Energiebereich  $< 50\text{keV}$
- B. wird in Materie exponentiell geschwächt
- C. ist eine Folge der schwachen Wechselwirkung
- D. trägt halbzahligen Drehimpuls



## SMART Response Question

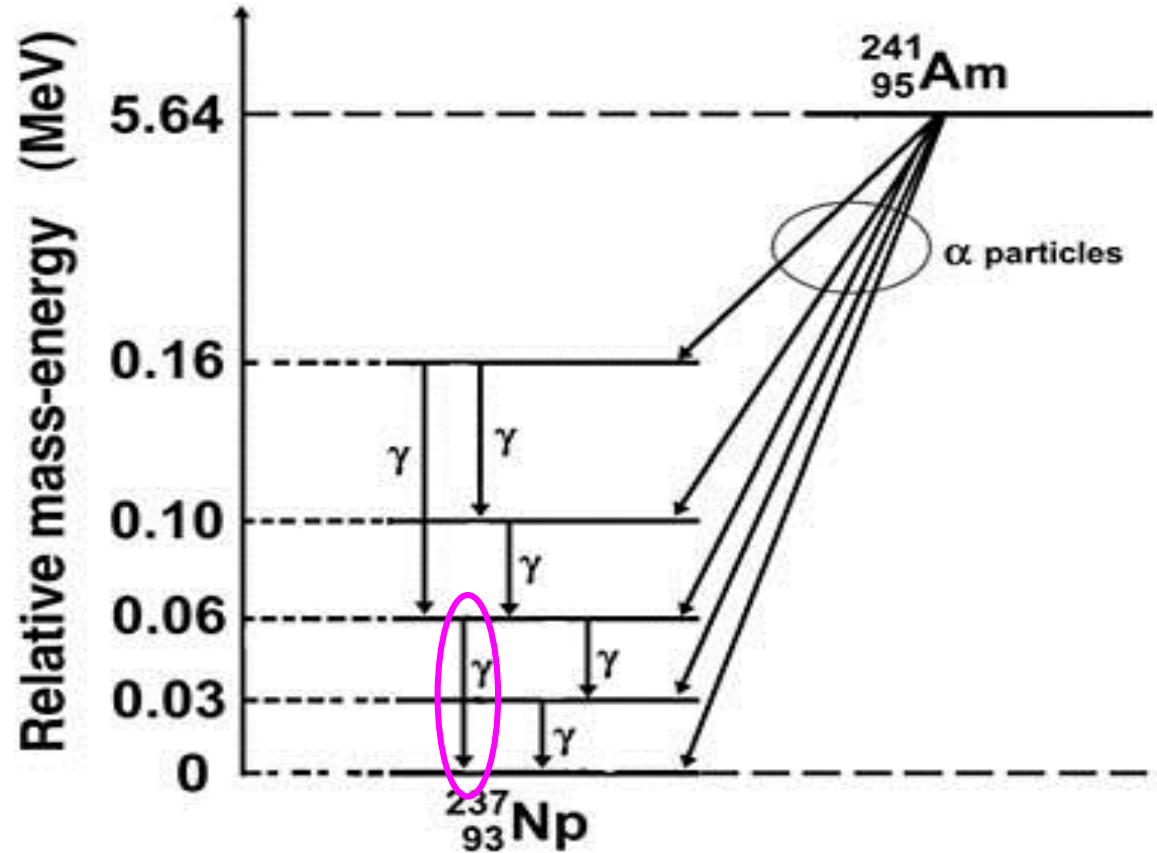
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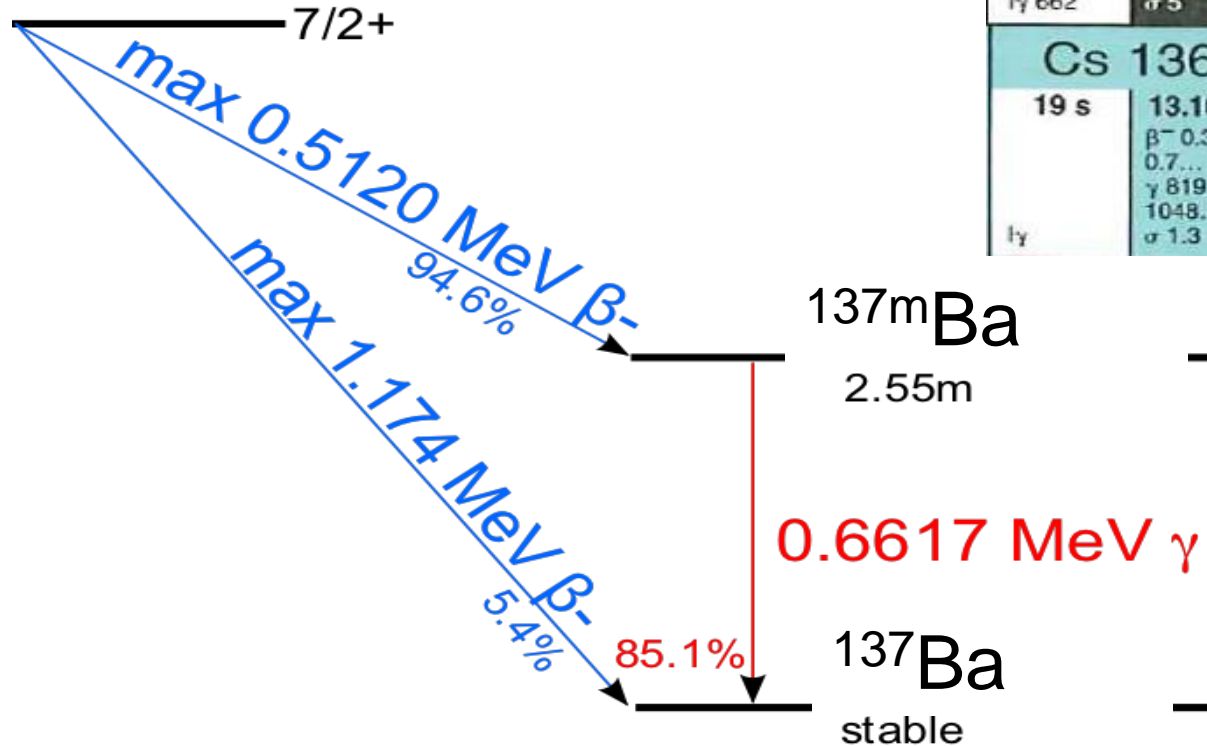
- Dringt sehr weit ein (Reichweite im Prinzip unendlich)
  - Exponentielle Schwächung in Materie
  - Sehr stark abhängig von Energie und Material
- Lässt sich mit Blei abschirmen (Energieabhängig!)
- Durchdringt den Körper
- Gefahr sowohl bei äußerer Einwirkung als auch bei Inkorporation



	g	g	$\alpha_f \sim 5$	
	<b>Am 239</b> 11.9 h	<b>Am 240</b> 50.8 h	<b>Am 241</b> 432.2 a	
	sf $\epsilon$ 5.774... $\gamma$ 278; 228... $e^-$ g	sf $\epsilon$ 5.378... $\gamma$ 988; 889... g	sf $\alpha$ 5.486; 5.443... sf; $\gamma$ 60; 26... $e^-$ ; g; $\sigma$ 60 + 640 $\sigma_f$ 3.15	
	<b>Pu 238</b> 87.74 a	<b>Pu 239</b> $2.411 \cdot 10^4$ a	<b>Pu 240</b> 6563 a	
	sf $\alpha$ 5.499; 5.456... sf; Si; Mg $\gamma$ (43; 100...); $e^-$ $\sigma$ 510; $\sigma_f$ 17	sf $\alpha$ 5.157; 5.144... sf; $\gamma$ (52...) $e^-$ ; m $\sigma$ 270; $\sigma_f$ 752	sf $\alpha$ 5.168; 5.124... sf; $\gamma$ (45...) $e^-$ ; g $\sigma$ 290; $\sigma_f \sim 0.059$	
	<b>Np 237</b> $2.144 \cdot 10^6$ a	<b>Np 238</b> 2.117 d	<b>Np 239</b> 2.355 d	
	sf $\alpha$ 4.790; 4.774... $\gamma$ 29; 87...; $e^-$ $\sigma$ 170; $\sigma_f$ 0.020	$\beta^-$ 1.2... $\gamma$ 984; 1029; 1026; 924...; $e^-$ g; $\sigma_f$ 2600	$\beta^-$ 0.4; 0.7... $\gamma$ 106; 278; 228...; $e^-$ ; g $\sigma$ 32 + 19; $\sigma_f < 1$	
	<b>U 236</b> $2.342 \cdot 10^7$ a	<b>U 237</b> 6.75 d	<b>U 238</b> 99.2742 a	



$^{137}\text{Cs}$   
30.17 a



Ba 137		Ba 138	
2.55 m	11.232	71.698	
I <sub>γ</sub> 662	σ 5	σ 0.41	
Cs 136		Cs 137	
19 s	13.16 d	30.17 a	
I <sub>γ</sub>		β <sup>-</sup> 0.5; 1.2 m; g σ 0.20 + 0.07	
		β <sup>-</sup> 0.3; 0.7... γ 819; 1048... σ 1.3	

wanda

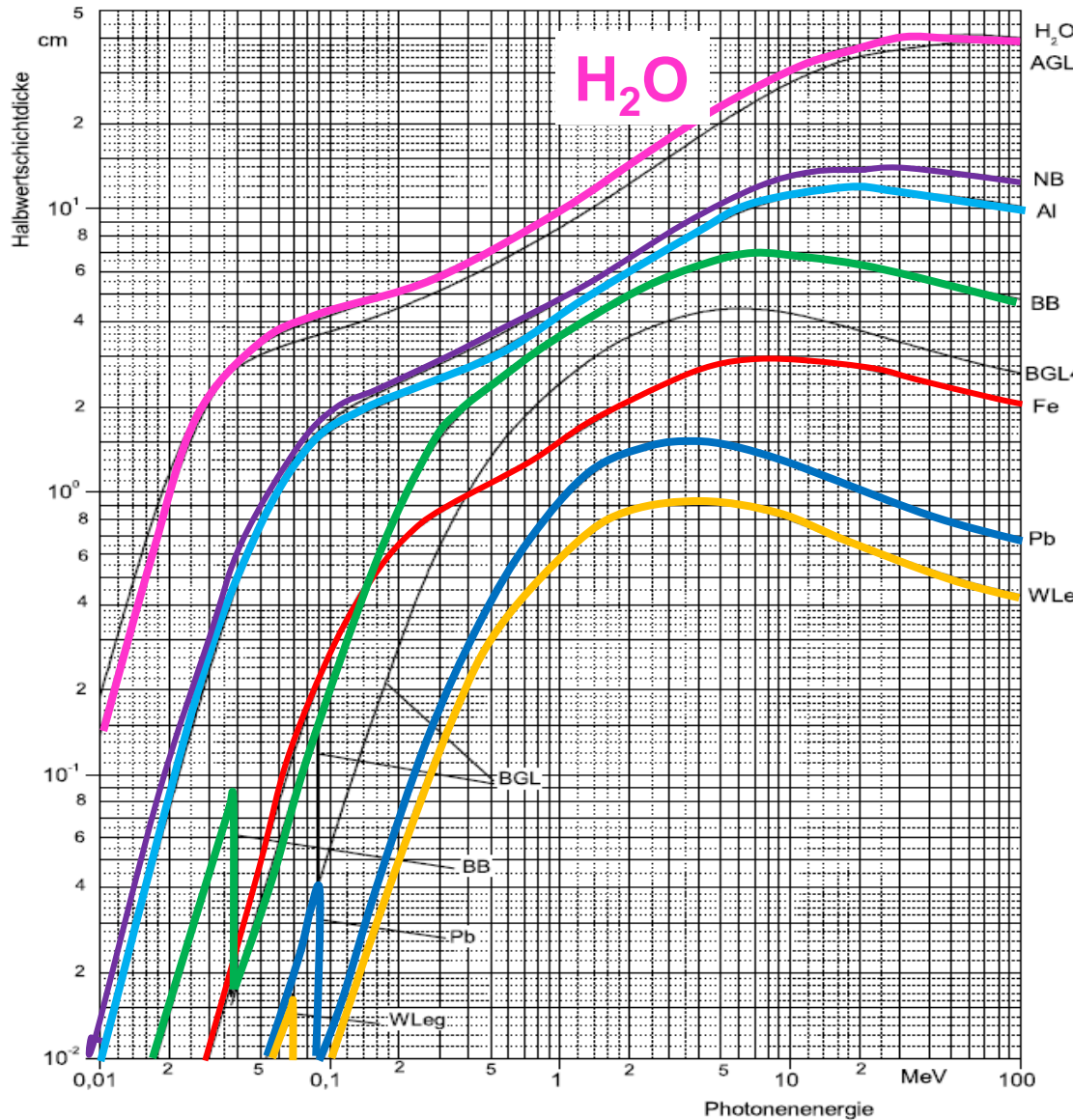


- A. Wasserstoffgas
- B. Wasser
- C. Aluminium
- D. Eisen
- E. Blei
- F. Wolfram-Legierung

## SMART Response Question

To set the properties right click and select  
SMART Response Question Object->Properties...





Normalbeton

Al

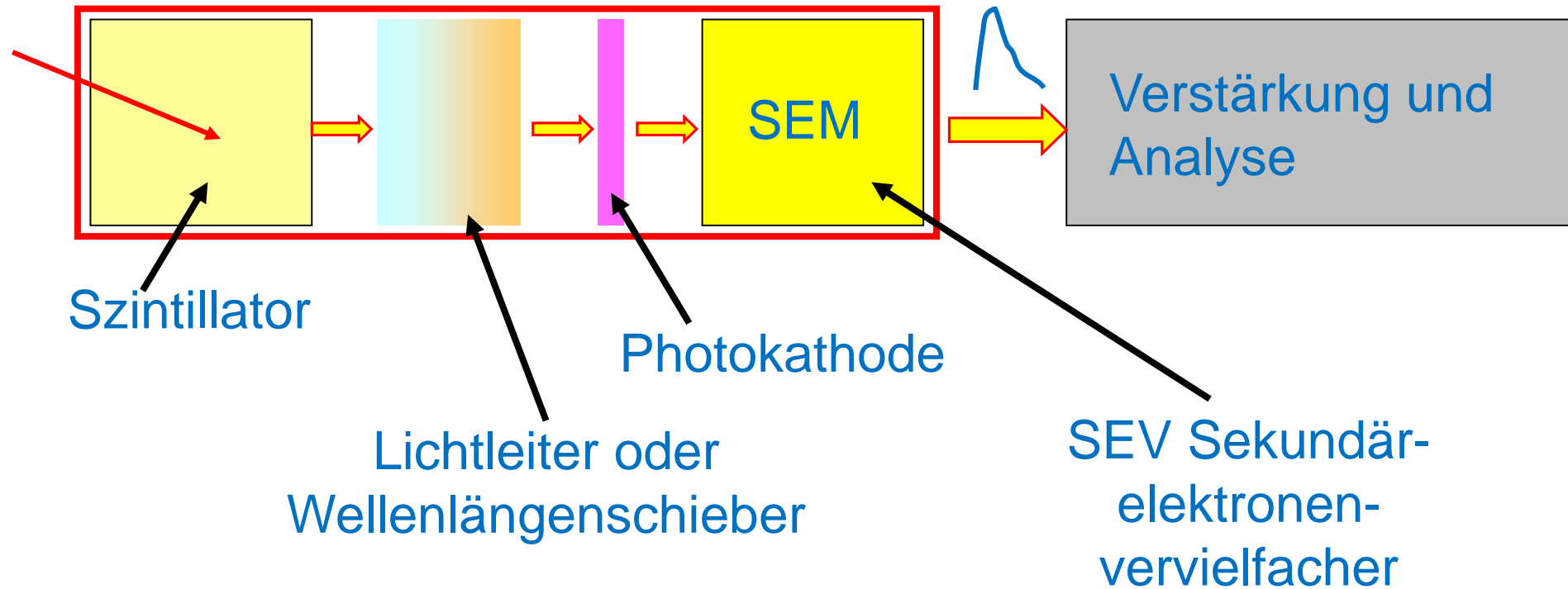
Barytbeton

Fe

Pb

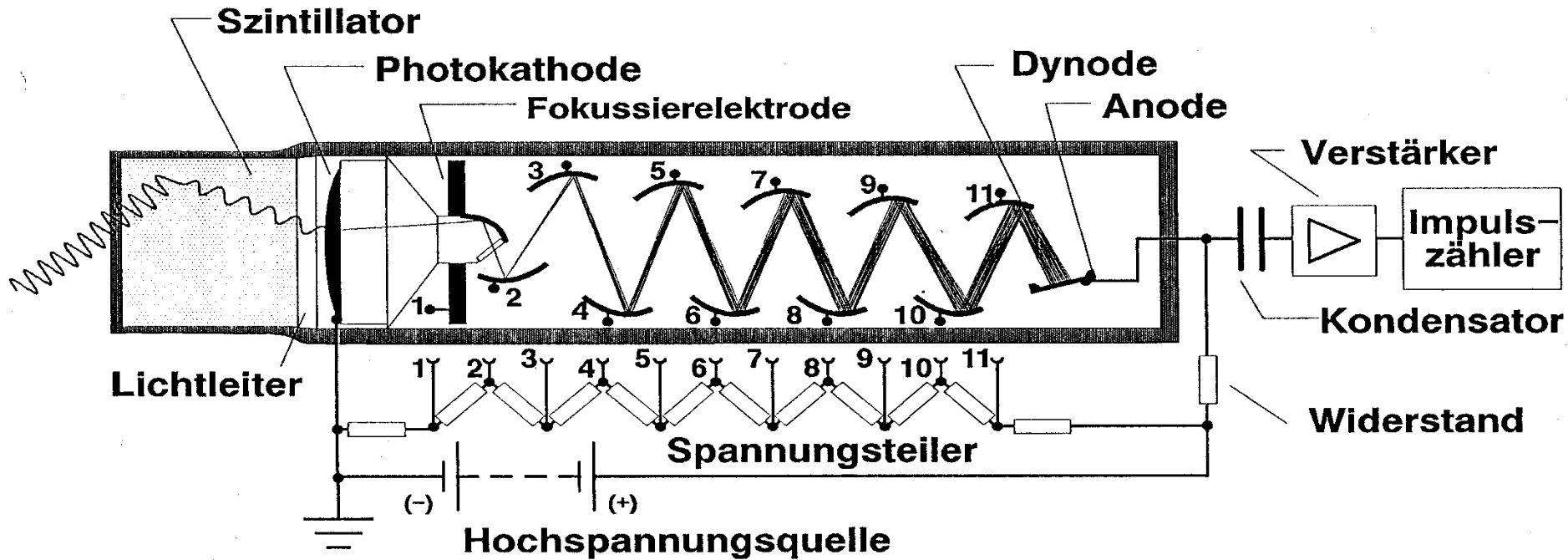
W-Leg

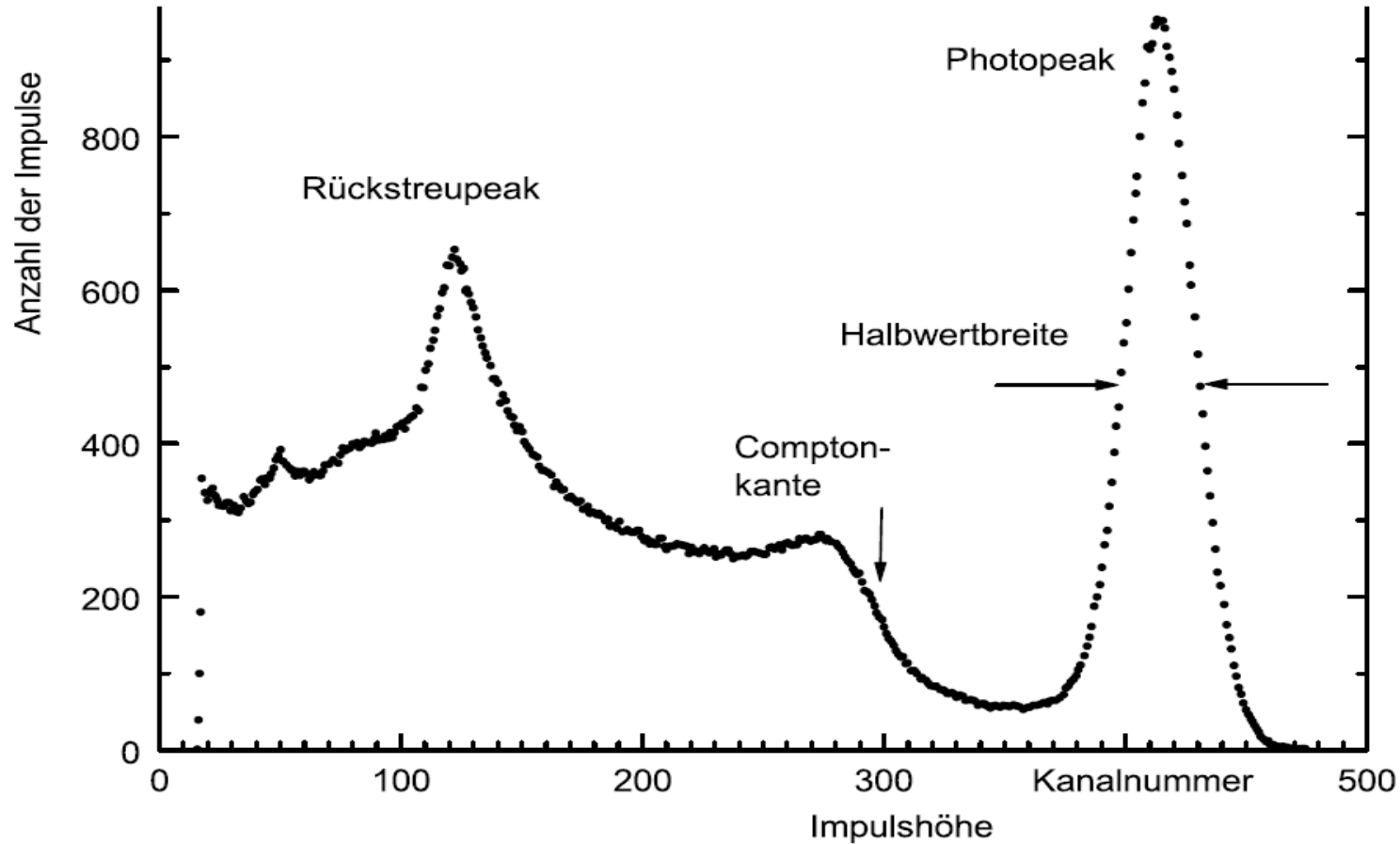
Halbwertsdicke



Material	Emission band Maximum (Å)	Decay time (ns)	Relative pulse height versus anthracene (=100)	Application
<b>anthracene</b>	4470	30	100	<b>beta</b> , alpha, gamma
<b>stilbene</b>	4110	6	60	<b>beta</b> , alpha, gamma
<b>"plastic"</b>	4300	4	40-70	<b>beta</b> , <b>alpha</b> , gamma
<b>Nal(Tl)</b>	4130	250	230	<b>gamma</b>
<b>ZnS(Ag)</b>	4500	200	300	<b>alpha</b> , <b>beta</b>

# Funktionsprinzip eines NaI(Tl)-Szintillationszählers

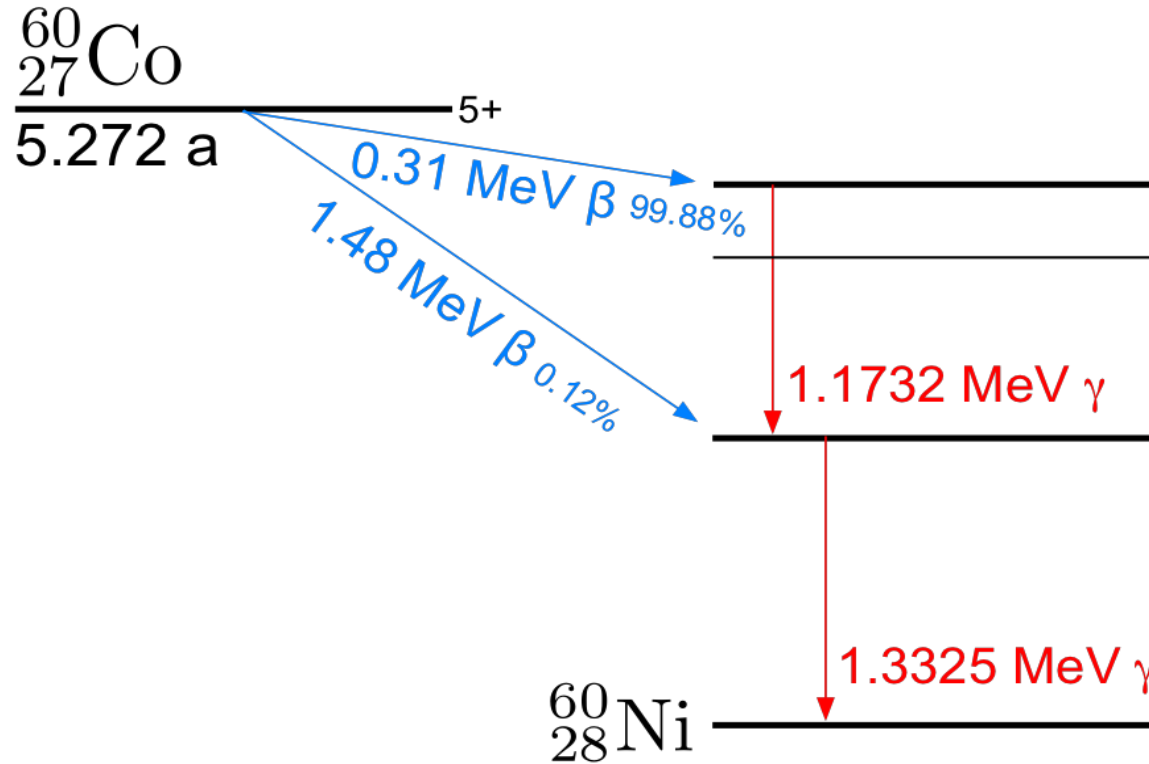






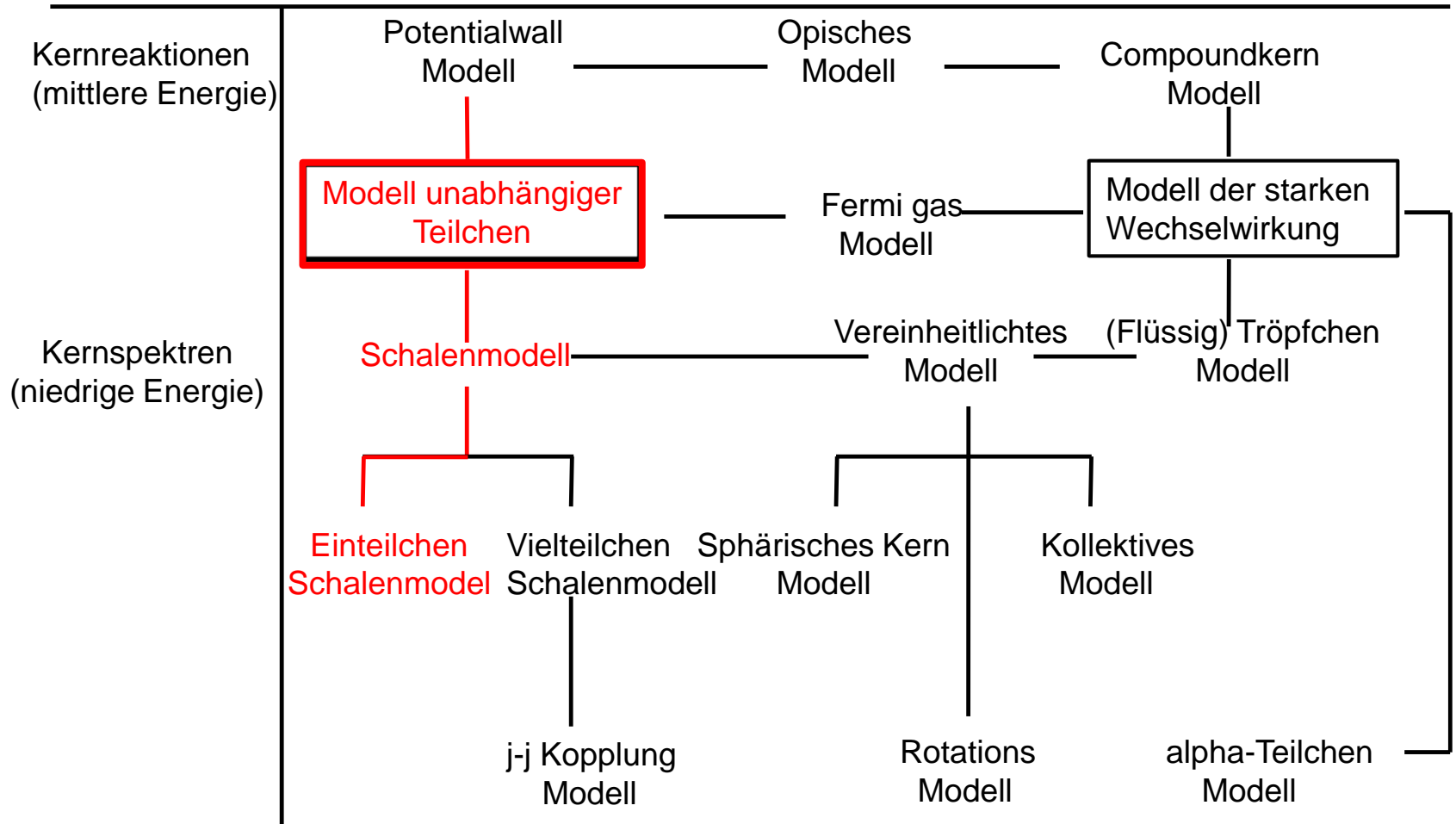


<b>Ni 60</b> 26.2231  $\sigma$ 2.9	<b>Ni 61</b> 1.1399  $\sigma$ 2.5 $\sigma_n, \alpha$ 0.00003
<b>Co 59</b> 100  $\sigma$ 20.7 + 16.5	<b>Co 60</b> 10.5 m 5.272 a $t_{1/2}$ 59 $e^-$ $\beta^-$ ... $\gamma$ (1332...) 1173... $\sigma$ 58 $\sigma$ 2.0



wanda

# Kernmodelle



- |       |                   |
|-------|-------------------|
| A. 2  | E. 40             |
| B. 8  | F. 50             |
| C. 20 | G. 82             |
| D. 28 | H. 0xDEAD<br>BEEF |

## SMART Response Question

To set the properties right click and select  
SMART Response Question Object->Properties...

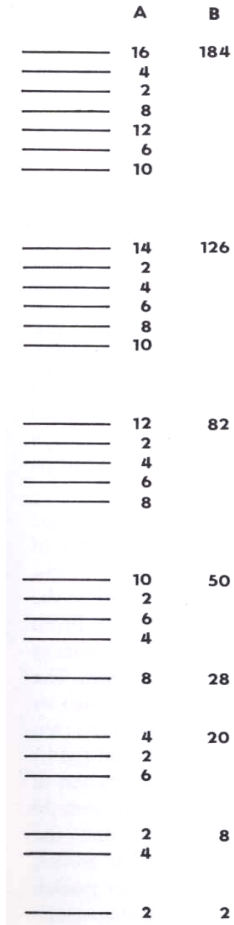


## Magische Zahlen als Markierung in der Programmierung [\[Bearbeiten\]](#)

Hexadezimalzahlen werden oft dazu benutzt, Werte auf [Datenträgern](#) bzw. anderem [Speicher](#) darzustellen. Die meisten Zahlen sehen dabei nicht sofort auffallenden Wert zu haben (beispielsweise bei der Fehlersuche).

`0xDEADBEEF` (dezimal: 3.735.928.559) ist eine Zahl in [hexadezimaler](#) Notation, die als „dead beef“ (engl. Totes Rindfleisch) gelesen wird.

Normalerweise tritt ein Wert wie `0xDEADBEEF` eher selten auf und wird somit dazu verwendet, besondere Werte anzuzeigen. Die Zahl an sich „lesbare“ Werte wie `0xABABABAB`, `0x00C0FFEE` oder `0xBAADF00D` (engl. „bad food“, etwa „schlechtes Essen“) ersetzt werden.



**Z** 114, 126, 164, 228, ...  
**N** 2, 8, 20, 28, 50, 82, 126, 164, 178, 184, 228

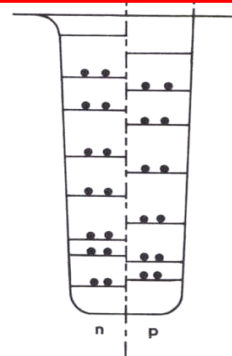
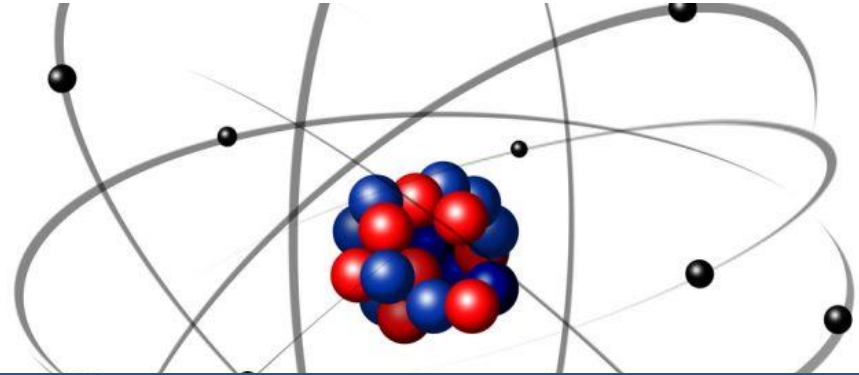


Fig. 1.8  
Arrangement of nucleons in  
the  $^{26}_{12}\text{Mg}$  nucleus

1. **Anzahl stabiler Isotope** und Isotone
2. Maxima der **Elementhäufigkeit** im **Sonnensystem**
3. Lokale Maxima der **Bindungsenergie pro Nukleon**
4. Strukturen in der Systematik der **Zerfallsenergien**
5. Strukturen in der Systematic der **Wirkungsquerschnitte**
6. Energien der 1<sup>en</sup> **angeregten Zustände** von **gg-Kernen**
7. **Insel der Isomere**
8. Bei **magischen Zahlen** sind Kerne **sphärisch**



- A. Kernmodell hat Zentralpotential
- B. Kernmodell hat selbstkonsistentes Potential
- C. Kernpotential ist nie sphärisch
- D. Kernpotential beruht auf der schwachen WW



## SMART Response Question

To set the properties right click and select  
SMART Response Question Object->Properties...



$$H = \sum_{i=1}^Z T_i + \sum_{i=1}^Z V_C(r_i) + \sum_{\substack{i,j=1 \\ i \neq j}}^Z V_{ij}(|\vec{r}_i - \vec{r}_j|)$$

$$T_i = -\frac{\hbar^2}{2m_i} \Delta_i \quad \text{kinetische Energie}$$

$V_C$  Zentralpotential, Coulombpotential

$V_{i,j}$  Wechselwirkungspotential

ist ein Modell **unabhängiger Teilchen** analog dem Modell des Atoms

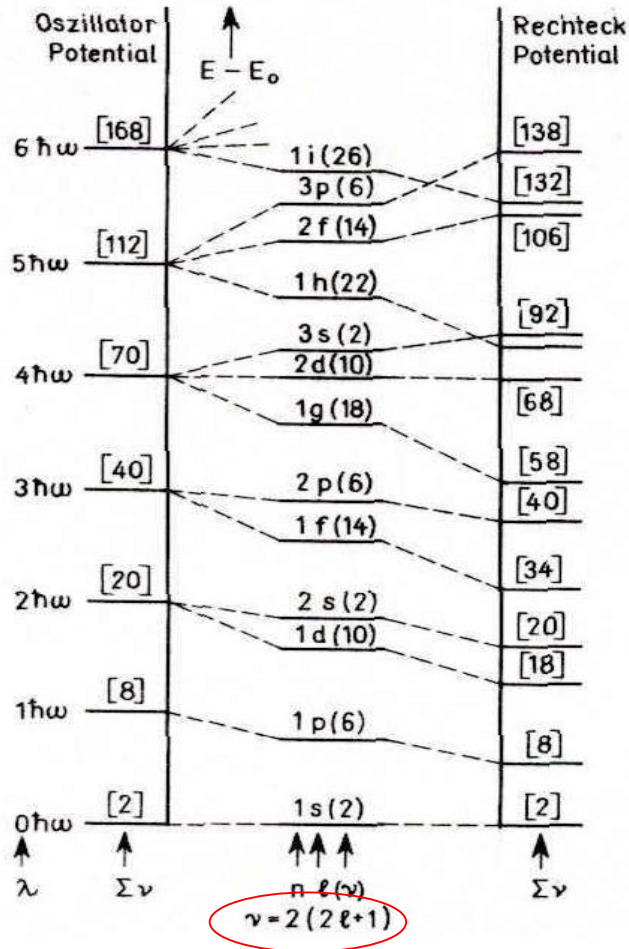
$$H = \sum_{i=1}^A T_i + \sum_{i,j=1}^A V_{ij}$$

mit  $T_i = -\frac{h^2}{2m_i} \Delta_i$  kinetische Energie

$V_{i,j}$  Wechselwirkungspotential

Ansatz:  $H = H_0 + V_R$  mit Restwechselwirkung  $V_R$

$$H_0 = \sum_{i=1}^A (T_i + V_i) = \sum_{i=1}^A h_i \quad \text{and} \quad V_R = \sum_{i,j=1}^A V_{i,j} - \sum_{i=1}^A V_i$$

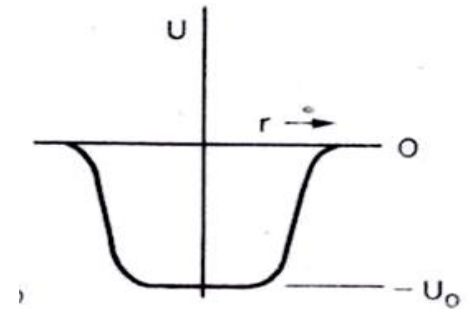
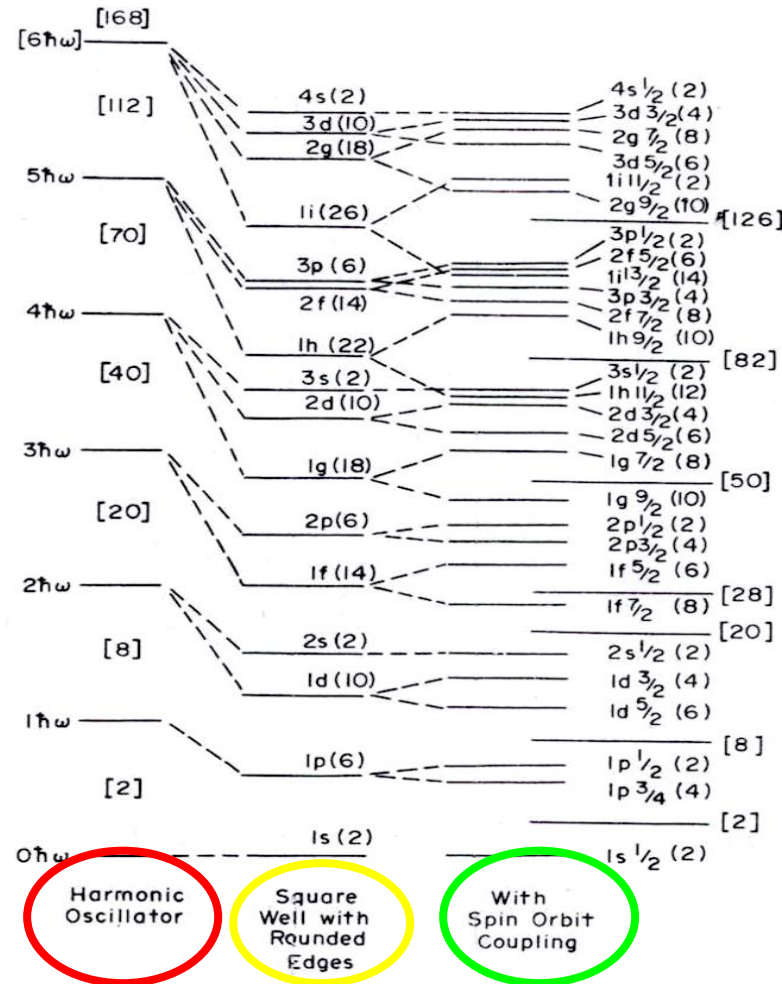
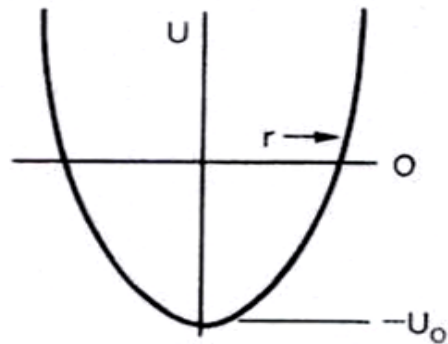


$$E_{n,\ell} = E_\lambda = \left( \lambda + \frac{3}{2} \right) \hbar\omega$$

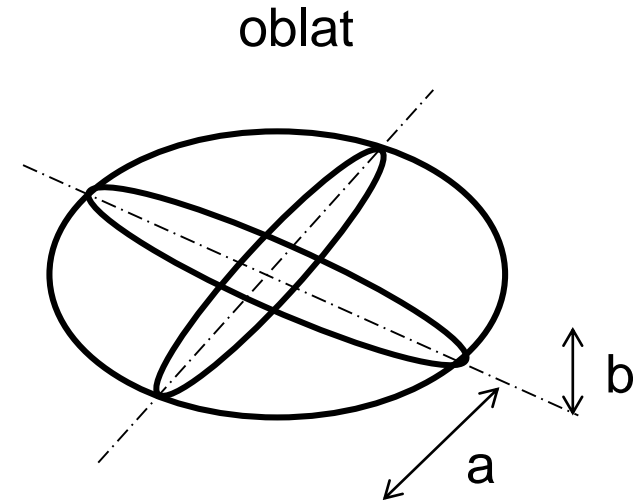
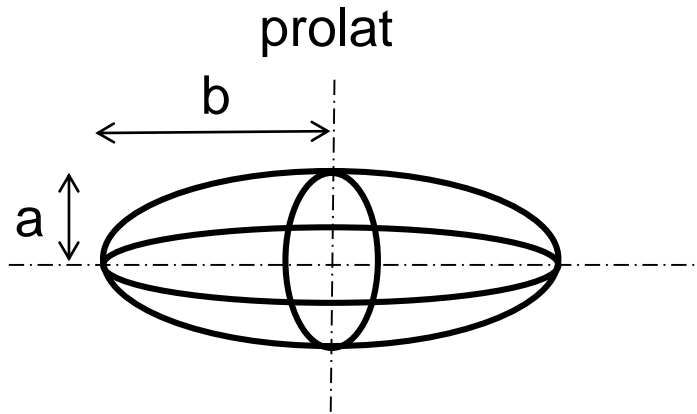
mit  $\lambda = 2(n-1) + \ell = 0, 1, 2, \dots$

$(n = 1, 2, 3, \dots; \ell = 0, 1, 2, \dots)$

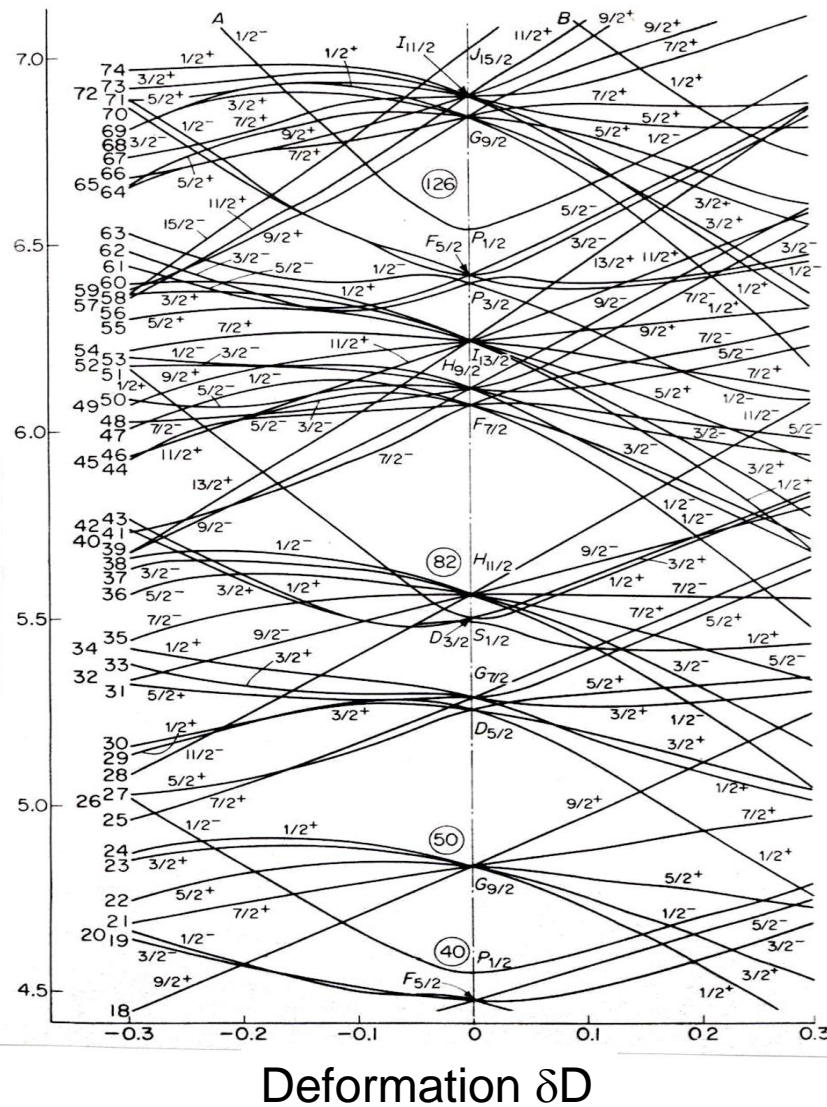
**Fig.72 Energieniveaus im Oszillator- und im Rechteckpotential, in der Mitte interpolierte Werte; nach [May 55]**



$$\delta = \frac{b - a}{(a + b) / 2}$$



Oftmals auch  $R = (a + b)/2$  und  $\Delta R = b - a$  ;  $\delta = (\Delta R/R)$



# Anregungsschema deformierter Kerne nach dem Nilsson Modell



- A. 0,1,2,3,4,...
- B.  $\frac{1}{2}, 1, \frac{3}{2}, 2, \dots$
- C. immer 1 (weil Bosonen)
- D. ganzzahlig echt positiv

## SMART Response Question

To set the properties right click and select  
 SMART Response Question Object->Properties...



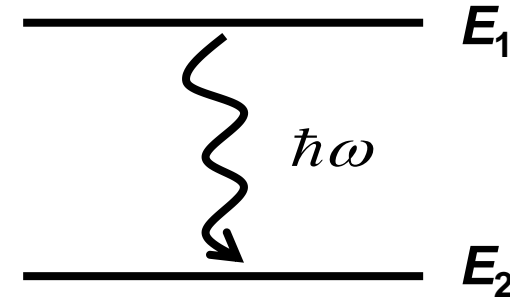
$A = \text{konstant}$   $Z = \text{konstant}$

Abregung durch

- Emission elektronischer Strahlung
- Innere Konversion
- Innere Paar Produktion

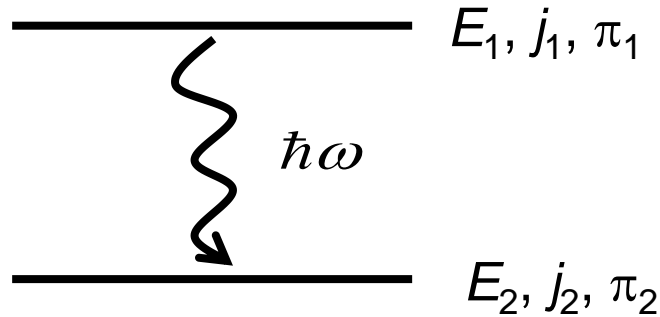
Lebensdauer?

$$E_{\text{kin,e}} = E^* - E_{\text{B,e}}$$



$$\begin{aligned} E^* &= E_1 - E_2 \\ &= \hbar\omega + \frac{(\hbar\omega)^2}{2m_A c^2} \end{aligned}$$

Rückstoß Energie  
(später)



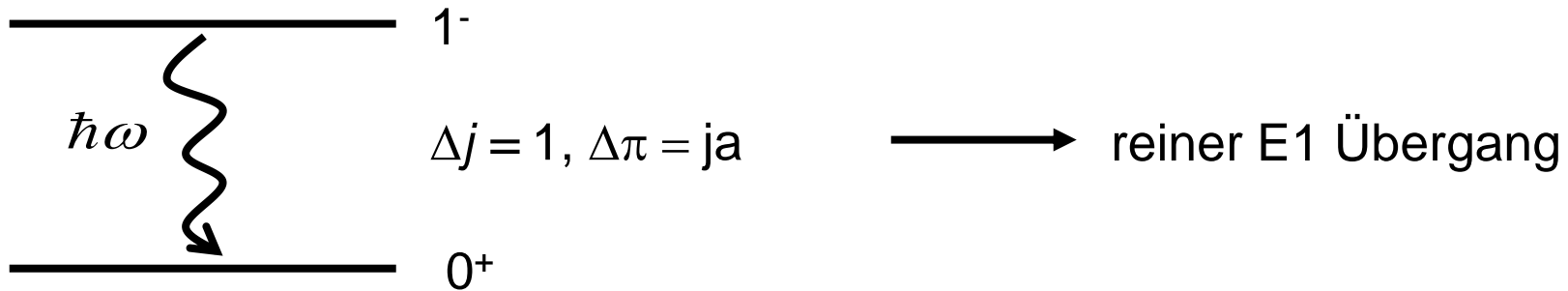
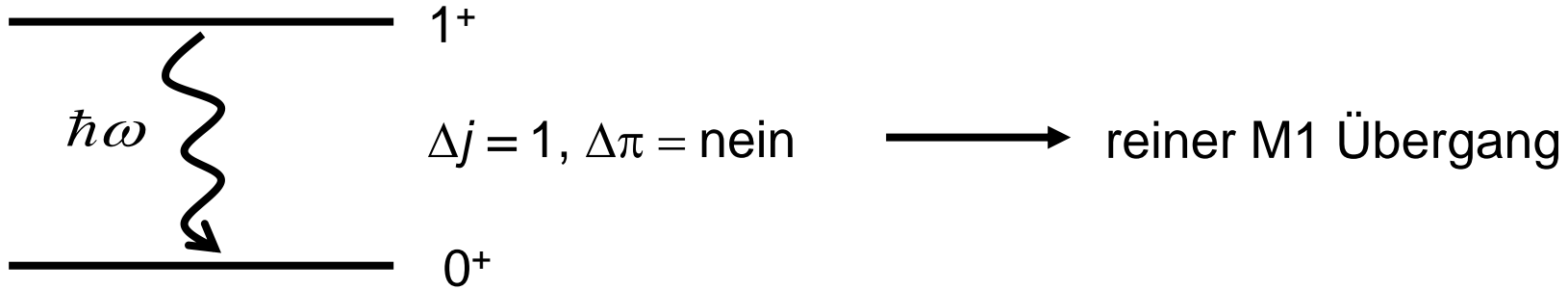
Elektromagnetische Multipol  
Strahlung:  $L = 1, 2, 3, \dots, L \neq 0$

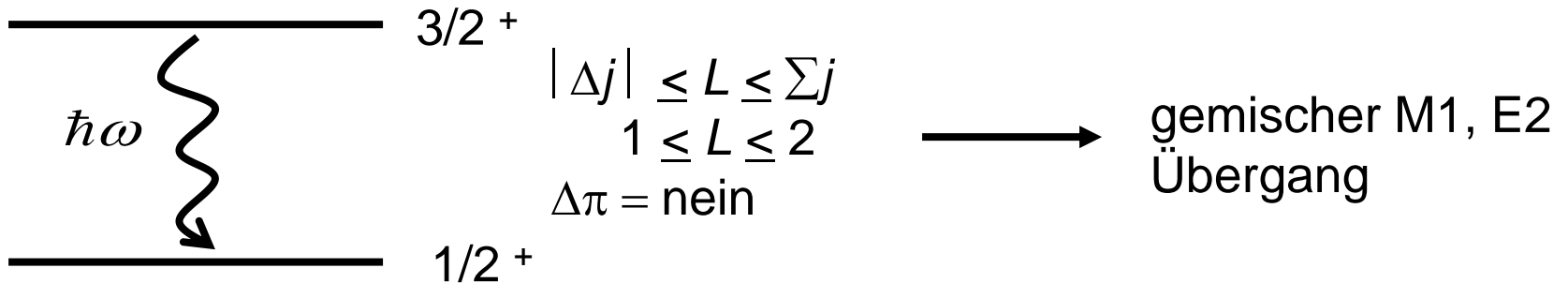
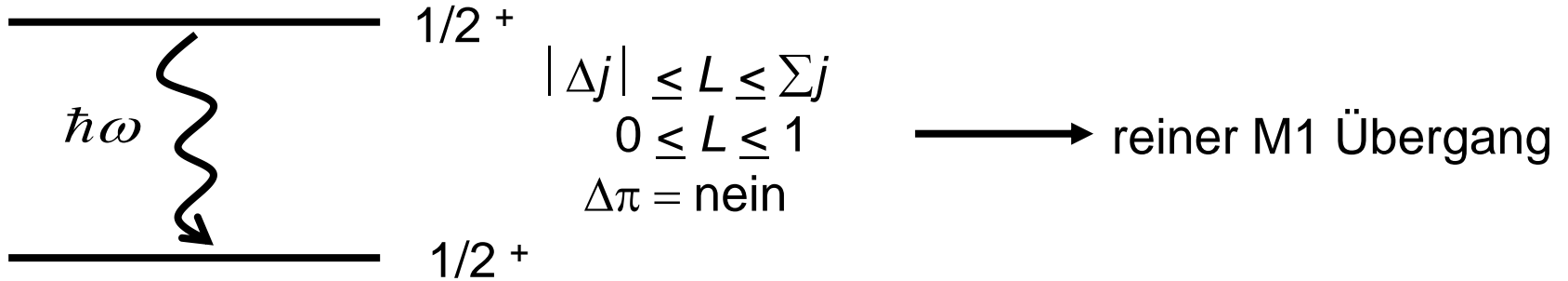
elektrisch	magnetisch	Paritätswechsel
$L$ gerade	$L$ ungerade	nein
$L$ ungerade	$L$ gerade	ja

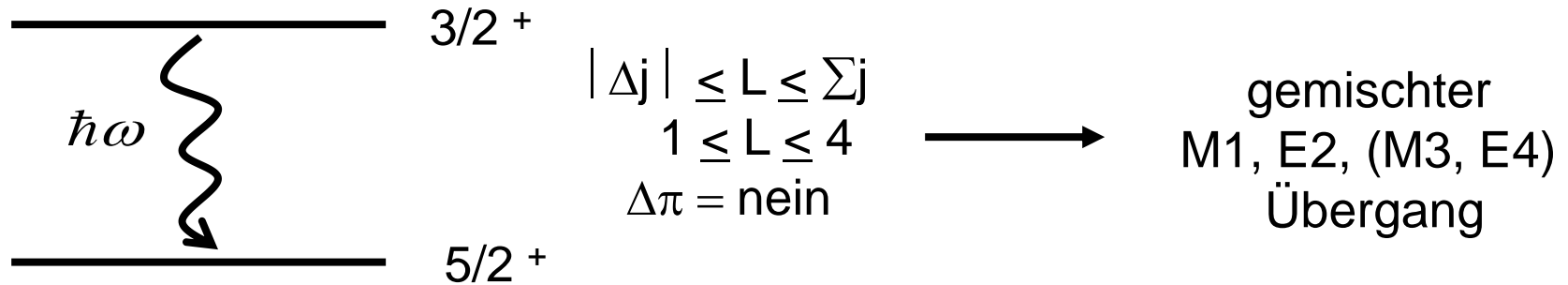
Parität  $\pi_E = (-1)^L$   
 $\pi_M = (-1)^{L+1}$

$$|j_1 - j_2| \leq L \leq j_1 + j_2$$

AO







$$\lambda_E = 2,4 \cdot S \cdot (r_0 \cdot A^{1/3})^{2L} \cdot \left( \frac{E}{197 \text{ MeV}} \right)^{2L+1} \cdot 10^{21} \text{ s}^{-1}$$

$$\lambda_M = 0,55 \cdot S \cdot A^{-2/3} \cdot (r_0 \cdot A^{1/3})^{2L} \cdot \left( \frac{E}{197 \text{ MeV}} \right)^{2L+1} \cdot 10^{21} \text{ s}^{-1}$$

mit  $r_0 = 1,28 \text{ fm}$  und

$$S = \frac{2(L+1)}{L \cdot [1 \cdot 3 \cdot 5 \cdot \dots (2L+1)]^2} \left( \frac{3}{L+3} \right)^2 \text{ spektroskopischer Faktor}$$

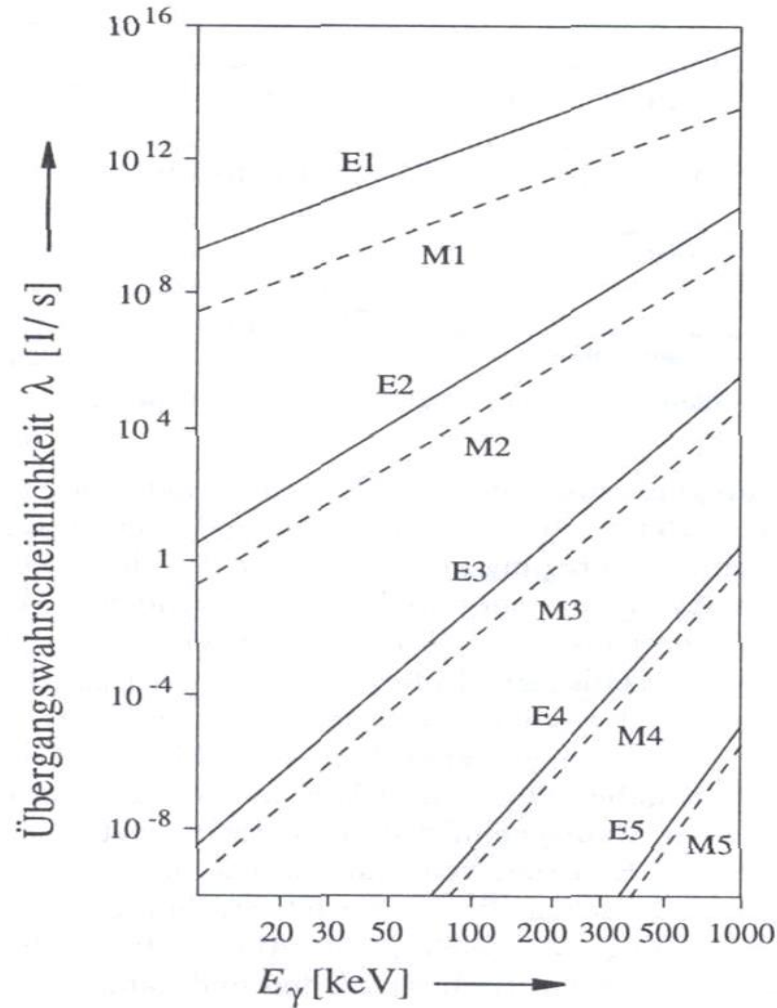
$$L = 1 \rightarrow S = 0,25$$

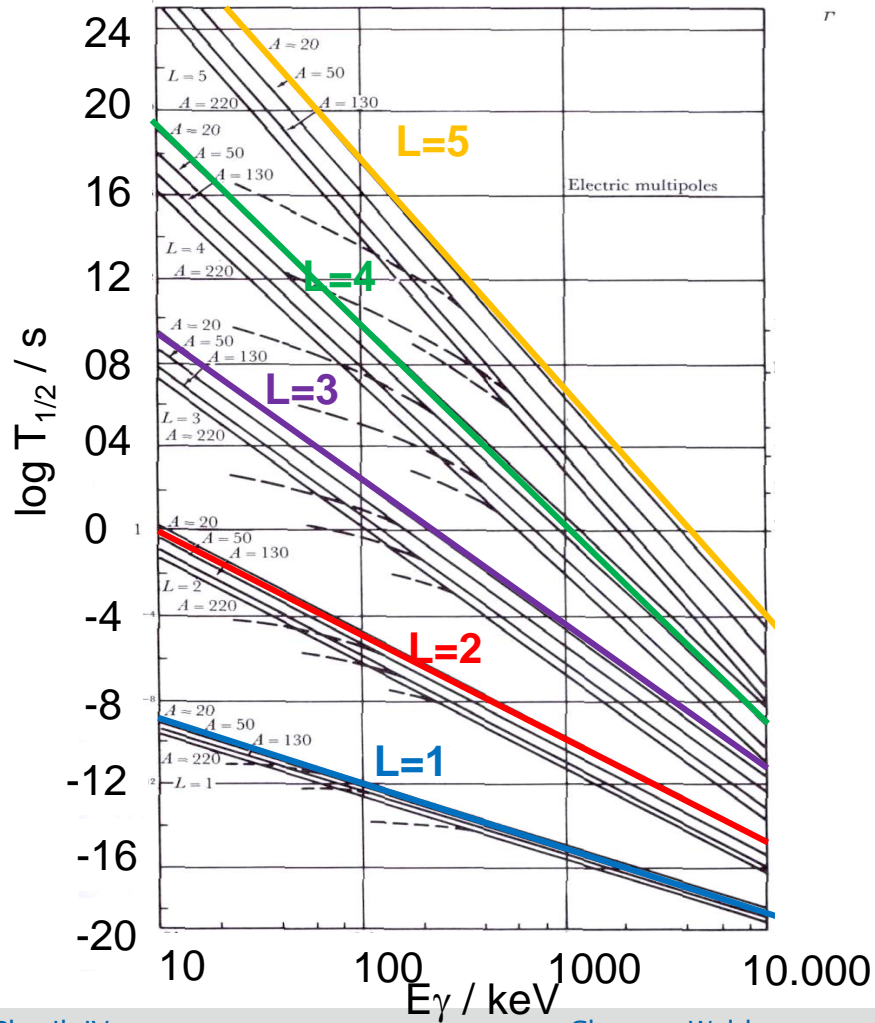
$$L = 2 \rightarrow S = 4,8 \cdot 10^{-3}$$

$$L = 3 \rightarrow S = 6,25 \cdot 10^{-5}$$

$$L = 4 \rightarrow S = 5,3 \cdot 10^{-7}$$



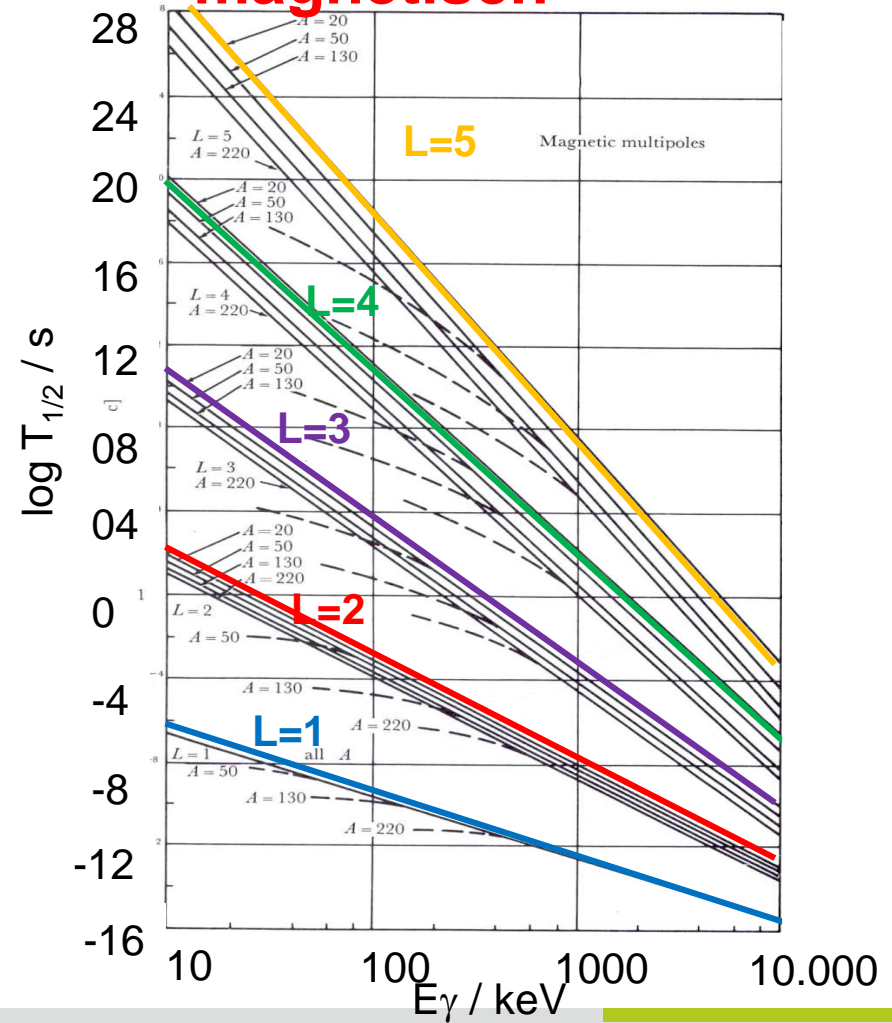
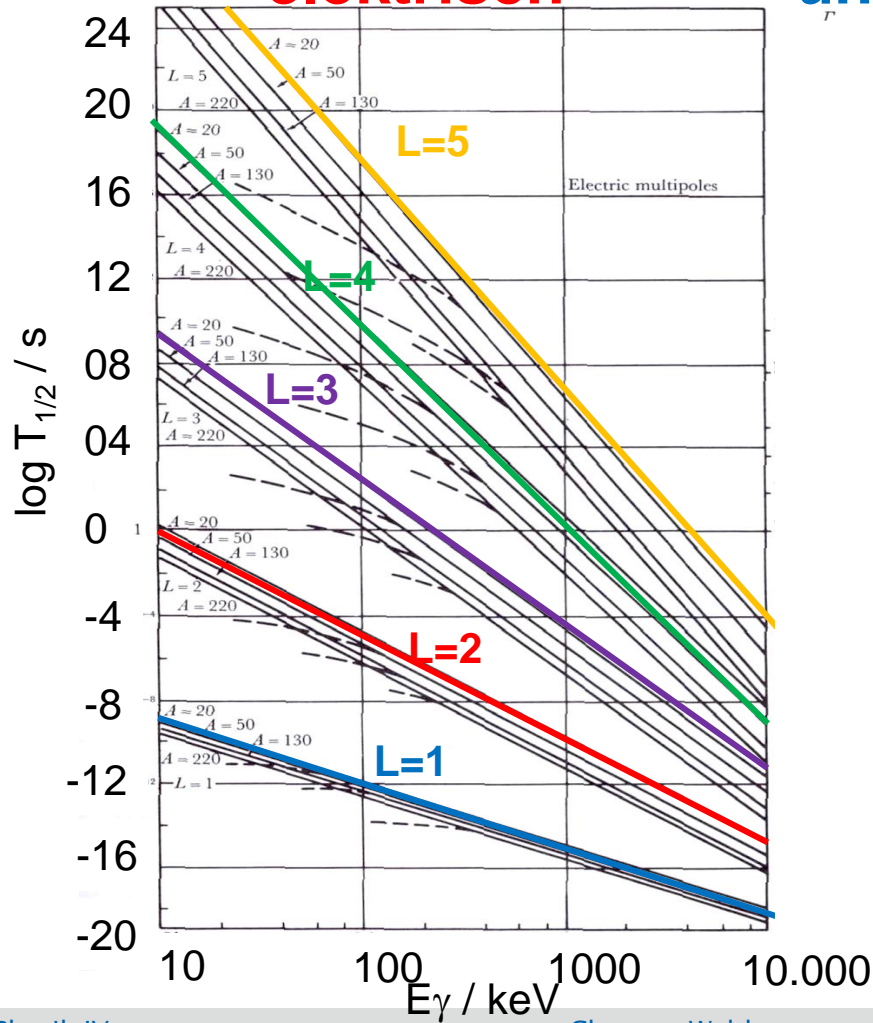




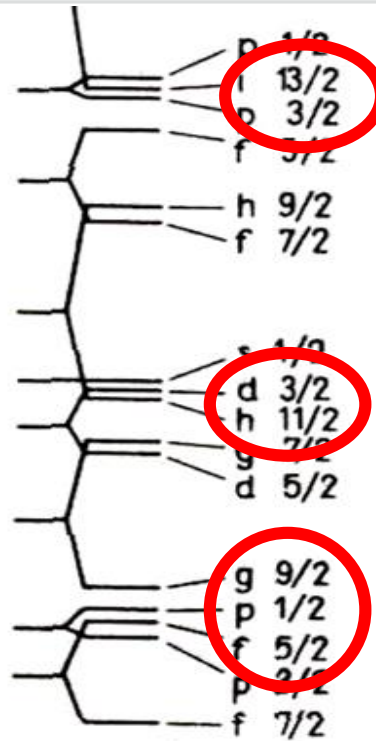
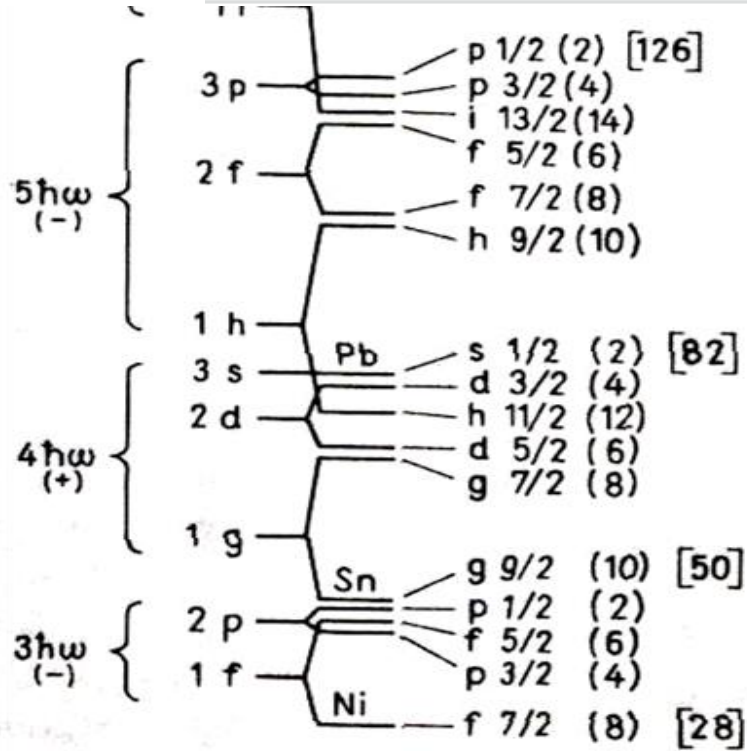
elektrisch

und

magnetisch



Typ	$L \Delta\pi$		Halbwertszeiten in s bei Energie		
			1 MeV	0,2 MeV	0,05 MeV
E1	1	ja	$2 \cdot 10^{-16}$	$3 \cdot 10^{-14}$	$2 \cdot 10^{-12}$
M1	1	nein	$2 \cdot 10^{-14}$	$2 \cdot 10^{-12}$	$2 \cdot 10^{-10}$
E2	2	nein	$1 \cdot 10^{-11}$	$3 \cdot 10^{-8}$	$3 \cdot 10^{-5}$
M2	2	ja	$9 \cdot 10^{-10}$	$3 \cdot 10^{-6}$	$3 \cdot 10^{-3}$
E3	3	ja	$7 \cdot 10^{-7}$	$6 \cdot 10^{-2}$	$9 \cdot 10^2$
M3	3	nein	$7 \cdot 10^{-5}$	5	$8 \cdot 10^4$
E4	4	nein	$8 \cdot 10^{-2}$	$2 \cdot 10^5$	$4 \cdot 10^{10}$
M4	4	ja	7	$1 \cdot 10^7$	$4 \cdot 10^{12}$



$$|j_1 - j_2| \leq L \leq j_1 + j_2$$

große  $\Delta j$   
verursachen  
lange  
Halbwertszeiten



**$^{180}\text{Ta}$ ,  
Das langlebigste Isomer**

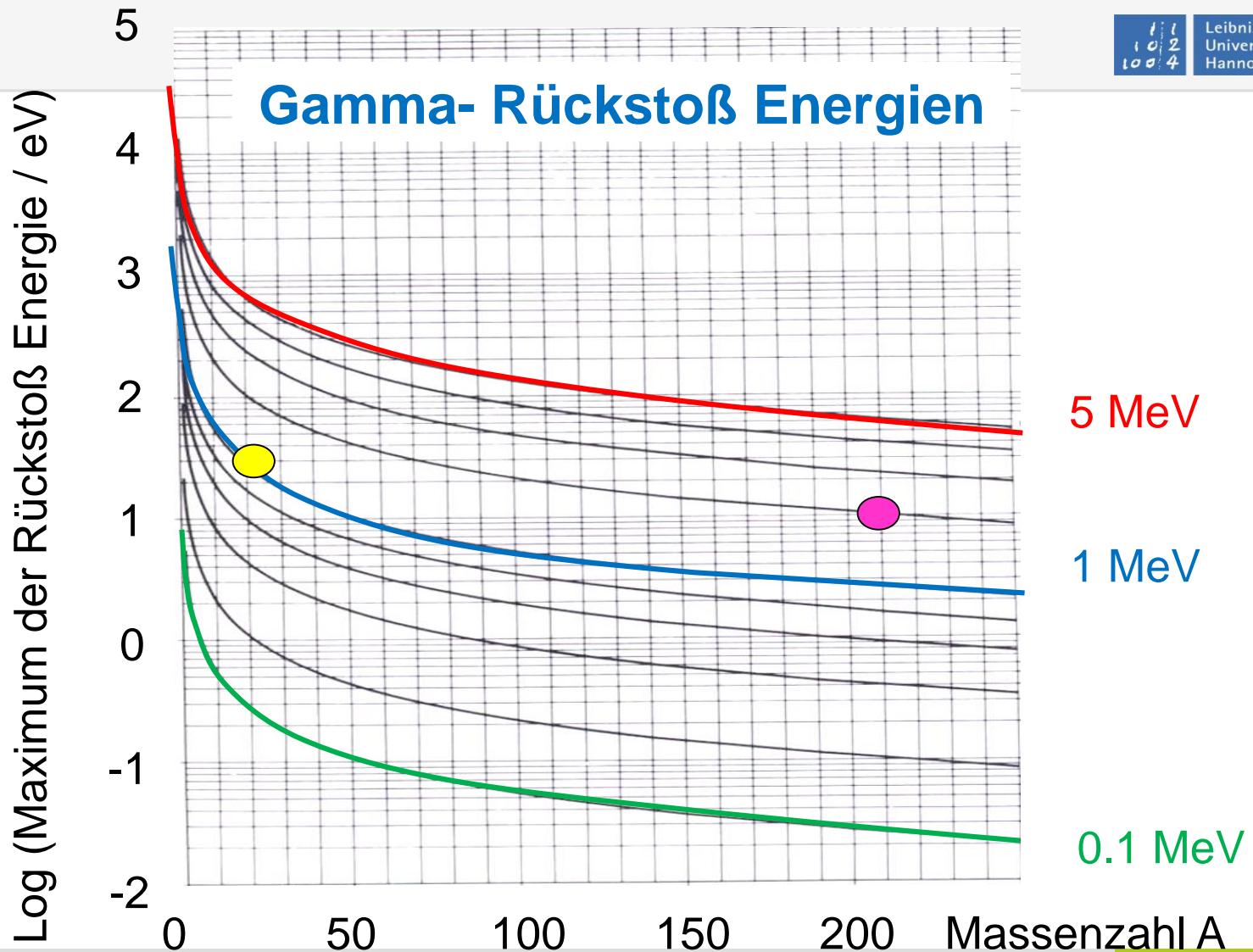
$$E_{\gamma} = h\nu \quad p_{\gamma} = \frac{h\nu}{c} \quad E_{\text{recoil nucleus}} = \frac{p_{\gamma}^2}{2m_A}$$

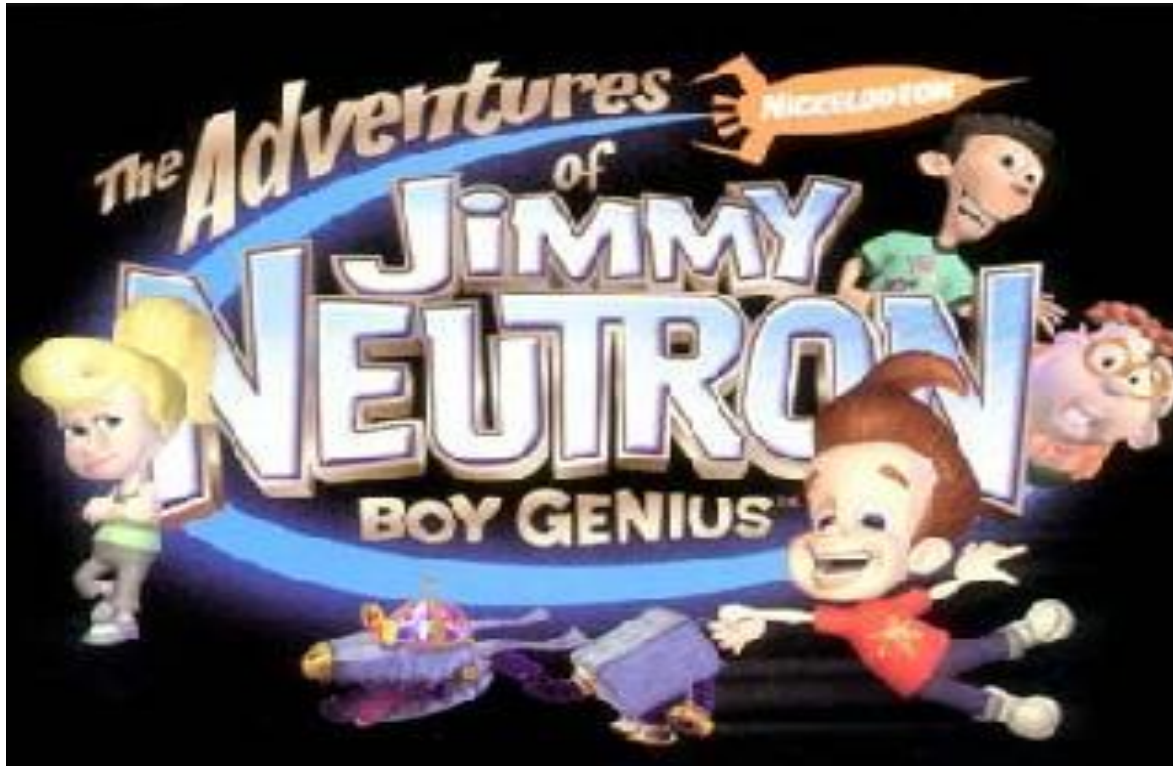
$$E_{\text{recoil nucleus}} = \frac{(h\nu)^2}{2m_A c^2} = \frac{1}{2m_A c^2} E_{\gamma}^2 \approx \frac{E_{\gamma}^2}{2000 \text{ MeV} \cdot A}$$

Bei  $A = 20$  und  $E_{\gamma} = 1 \text{ MeV}$  ergibt sich

$$E_{\text{recoil nucleus}} = 25 \text{ eV.}$$









- Bethe & Becker (1930) beobachteten eine **durchdringende nicht-ionisierende Strahlung** wenn Be mit  $^{210}\text{Po}$   $\alpha$ -Teilchen beschossen wurde ( $E_{\alpha} = 5,3 \text{ MeV}$ ).  $\gamma$ -Strahlung ?
- Curie und Joliot: Wechselwirkung dieser Strahlung mit Wasserstoffhaltigem Paraffin produziert Protonen mit  $E_p = 5,7 \text{ MeV}$ .

- Bethe & Becker (1930) beobachteten eine **durchdringende nicht-ionisierende Strahlung** wenn Be mit  $^{210}\text{Po}$   $\alpha$ -Teilchen beschossen wurde ( $E_\alpha = 5,3 \text{ MeV}$ ).  $\gamma$ -Strahlung ?
- Curie und Joliot: Wechselwirkung dieser Strahlung mit Wasserstoffhaltigem Paraffin produziert Protonen mit  $E_p = 5,7 \text{ MeV}$ .

Erklärungsversuch:

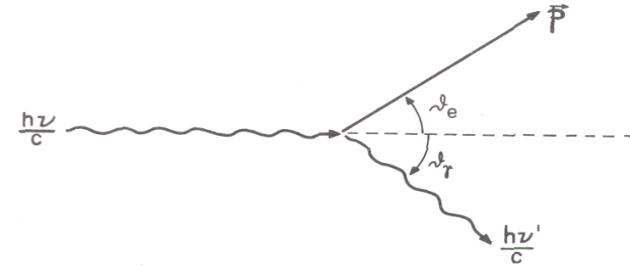
**Rückstoß Protonen mittels  
Compton Effekt**

A.  $E_e = h\nu - \frac{h\nu}{1+2\varepsilon}$  mit  $\varepsilon = \frac{h\nu}{m_e c^2}$

B.  $E_e = \frac{h\nu}{1+2\varepsilon}$  mit  $\varepsilon = \frac{h\nu}{m_e c^2}$

C.  $E_e = h\nu - \frac{2h\nu}{1+\varepsilon}$  mit  $\varepsilon = \frac{h\nu}{m_e c^2}$

D.  $E_e = 2h\nu - \frac{h\nu}{1+\varepsilon}$  mit  $\varepsilon = \frac{h\nu}{m_e c^2}$



## SMART Response Question

To set the properties right click and select  
SMART Response Question Object->Properties...

$$E_e = h\nu - \frac{h\nu}{1 + 2\varepsilon} \quad \text{mit} \quad \varepsilon = \frac{h\nu}{m_e c^2}$$

$$E_e = \frac{2h\nu}{2 - \frac{1}{\varepsilon}}$$

$$E_p = \frac{2E_\gamma}{2 + \frac{M_p \cdot c^2}{E_\gamma}}$$

$$E_p = 5,7 \text{ MeV} \longrightarrow E_\gamma = 55 \text{ MeV}$$

- Bethe & Becker (1930) beobachteten eine **durchdringende nicht-ionisierende Strahlung** wenn Be mit  $^{210}\text{Po}$   $\alpha$ -Teilchen beschossen wurde ( $E_\alpha = 5,3 \text{ MeV}$ ).  $\gamma$ -Strahlung ?
- Curie und Joliot: Wechselwirkung dieser Strahlung mit Wasserstoffhaltigem Paraffin produziert Protonen mit  $E_p = 5,7 \text{ MeV}$ .

Um so hoch energetische **Rückstoß Protonen mittels Compton Effekt** zu produzieren, müßten Photonen mit  $E_\gamma = 55 \text{ MeV}$  (!) vorhanden sein

- **Chadwick (1932): Das NEUTRON, Protonen sind Rückstoß Protonen**
- Heisenberg (1932): Der Kern besteht aus Protonen und Neutronen

- Bethe & Becker (1930) beobachteten eine **durchdringende nicht-ionisierende Strahlung** wenn Be mit  $^{210}\text{Po}$   $\alpha$ -Teilchen beschossen wurde ( $E_\alpha = 5,3 \text{ MeV}$ ).  $\gamma$ -Strahlung ?
  - Curie und Joliot: Wechselwirkung dieser Strahlung mit Wasserstoffhaltigem Paraffin produziert Protonen mit  $E_p = 5,7 \text{ MeV}$ .
- Um so hoch energetische **Rückstoß Protonen mittels Compton Effekt** zu produzieren, müßten Photonen mit  **$E_\gamma = 55 \text{ MeV}$  (!)** vorhanden sein



$$Q = 5,7 \text{ MeV}$$

## Letters to the Editor

*[The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, nor to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. No notice is taken of anonymous communications.]*

### Possible Existence of a Neutron

It has been shown by Bothe and others that beryllium when bombarded by  $\alpha$ -particles of polonium emits a radiation of great penetrating power, which has an absorption coefficient in lead of about  $0.3 \text{ (cm.)}^{-1}$ . Recently Mme. Curie-Joliot and M. Joliot found, when measuring the ionisation produced by this beryllium radiation in a vessel with a thin window, that the ionisation increased when matter containing hydrogen was placed in front of the window. The effect appeared to be due to the ejection of protons with velocities up to a maximum of nearly  $3 \times 10^9 \text{ cm. per sec.}$  They suggested that the transference of energy to the proton was by a process similar to the Compton effect, and estimated that the beryllium radiation had a quantum energy of  $50 \times 10^6 \text{ electron volts.}$

I have made some experiments using the valve counter to examine the properties of this radiation excited in beryllium. The valve counter consists of a small ionisation chamber connected to an amplifier, and the sudden production of ions by the entry of a particle, such as a proton or  $\alpha$ -particle, is recorded by the deflection of an oscillograph. These experi-

This again receives a simple explanation on the neutron hypothesis.

If it be supposed that the radiation consists of quanta, then the capture of the  $\alpha$ -particle by the  $\text{Be}^9$  nucleus will form a  $\text{C}^{13}$  nucleus. The mass defect of  $\text{C}^{13}$  is known with sufficient accuracy to show that the energy of the quantum emitted in this process cannot be greater than about  $14 \times 10^6 \text{ volts.}$  It is difficult to make such a quantum responsible for the effects observed.

It is to be expected that many of the effects of a neutron in passing through matter should resemble those of a quantum of high energy, and it is not easy to reach the final decision between the two hypotheses. Up to the present, all the evidence is in favour of the neutron, while the quantum hypothesis can only be upheld if the conservation of energy and momentum be relinquished at some point.

J. CHADWICK.

Cavendish Laboratory,  
Cambridge, Feb. 17.

### The Oldoway Human Skeleton

A LETTER appeared in NATURE of Oct. 24, 1931, signed by Messrs. Leakey, Hopwood, and Reck, in which, among other conclusions, it is stated that "there is no possible doubt that the human skeleton came from Bed No. 2 and not from Bed No. 4". This must be taken to mean that the skeleton is to be considered as a natural deposit in Bed No. 2, which is overlaid by the later beds Nos. 3 and 4, and that all consideration of human interment is ruled out.

ments have shown that the radiation ejects particles from hydrogen, helium, lithium, beryllium, carbon, air, and argon. The particles ejected from hydrogen behave, as regards range and ionising power, like protons with speeds up to about  $3.2 \times 10^9$  cm. per sec. The particles from the other elements have a large ionising power, and appear to be in each case recoil atoms of the elements.

If we ascribe the ejection of the proton to a Compton recoil from a quantum of  $52 \times 10^6$  electron volts, then the nitrogen recoil atom arising by a similar process should have an energy not greater than about 400,000 volts, should produce not more than about 10,000 ions, and have a range in air at N.T.P. of about 1.3 mm. Actually, some of the recoil atoms in nitrogen produce at least 30,000 ions. In collaboration with Dr. Feather, I have observed the recoil atoms in an expansion chamber, and their range, estimated visually, was sometimes as much as 3 mm. at N.T.P.

These results, and others I have obtained in the course of the work, are very difficult to explain on the assumption that the radiation from beryllium is a quantum radiation, if energy and momentum are to be conserved in the collisions. The difficulties disappear, however, if it be assumed that the radiation consists of particles of mass 1 and charge 0, or neutrons. The capture of the  $\alpha$ -particle by the  $\text{Be}^9$  nucleus may be supposed to result in the formation of a  $\text{C}^{12}$  nucleus and the emission of the neutron. From the energy relations of this process the velocity of the neutron emitted in the forward direction may well be about  $3 \times 10^9$  cm. per sec. The collisions of this neutron with the atoms through which it passes give rise to the recoil atoms, and the observed energies of the recoil atoms are in fair agreement with this view. Moreover, I have observed that the protons ejected from hydrogen by the radiation emitted in the opposite direction to that of the exciting  $\alpha$ -particle appear to have a much smaller range than those ejected by the forward radiation.

If this be true, it is a most unusual occurrence. The skeleton, which is of modern type, with filed teeth, was found completely articulated down even to the phalanges, and in a position of extraordinary contraction. Complete mammalian skeletons of any age are, as field palaeontologists know, of great rarity. When they occur, their perfection can usually be explained as the result of sudden death and immediate covering by volcanic dust. Many of the more or less perfect skeletons which may be seen in museums have been rearticulated from bones found somewhat scattered as the result of death from floods, or in the neighbourhood of drying water-holes. We know of no case of a perfect articulated skeleton being found in company with such broken and scattered remains as appear to be abundant at Oldoway. Either the skeletons are all complete, as in the *Stenomylus* quarry at Sioux City, Nebraska, or are all scattered and broken in various degrees, as in ordinary bone beds. The probability, therefore, that the Oldoway skeleton represents an artificial burial is thus one that will occur to palaeontologists.

The skeleton was exhumed in 1913, and published photographs show that the excavation made for its disinterment was extensive. It is, therefore, very difficult to believe that in 1931 there can be reliable evidence left at the site as to the conditions under which it was deposited. If naturally deposited in Bed No. 2, the skeleton is of the highest possible importance, because it would be of pre-Mousterian age, and would be in the company of *Pithecanthropus* and the Piltown, Heidelberg, and Peking men, all of whose remains are fragmentary to the last degree. Of the few other human remains for which such antiquity is claimed, the Galley Hill skeleton and the Ipswich skeleton are, or apparently were, complete. The first of these was never seen *in situ* by any trained observer, and the latter has, we believe, been withdrawn by its discoverer. The other fragments, found long ago, are entirely without satisfactory evidence as to their mode of occurrence.



- hat **keine Ladung**
- hat eine Masse von  **$939,5 \text{ MeV}/c^2$**
- ist nicht stabil,  **$T_{1/2} = 10,6 \text{ min}$**
- wechselwirkt hauptsächlich durch die **starke Kernkraft**
- ist ein **Fermion ( $S=1/2$ )**
- wechselwirkt (wenig) über sein **magnetisches Moment.**



Reaktion:

$$X(x,y)Y \Leftrightarrow (\alpha,\beta)$$

Eingangskanal:

$$\alpha = X(x,$$

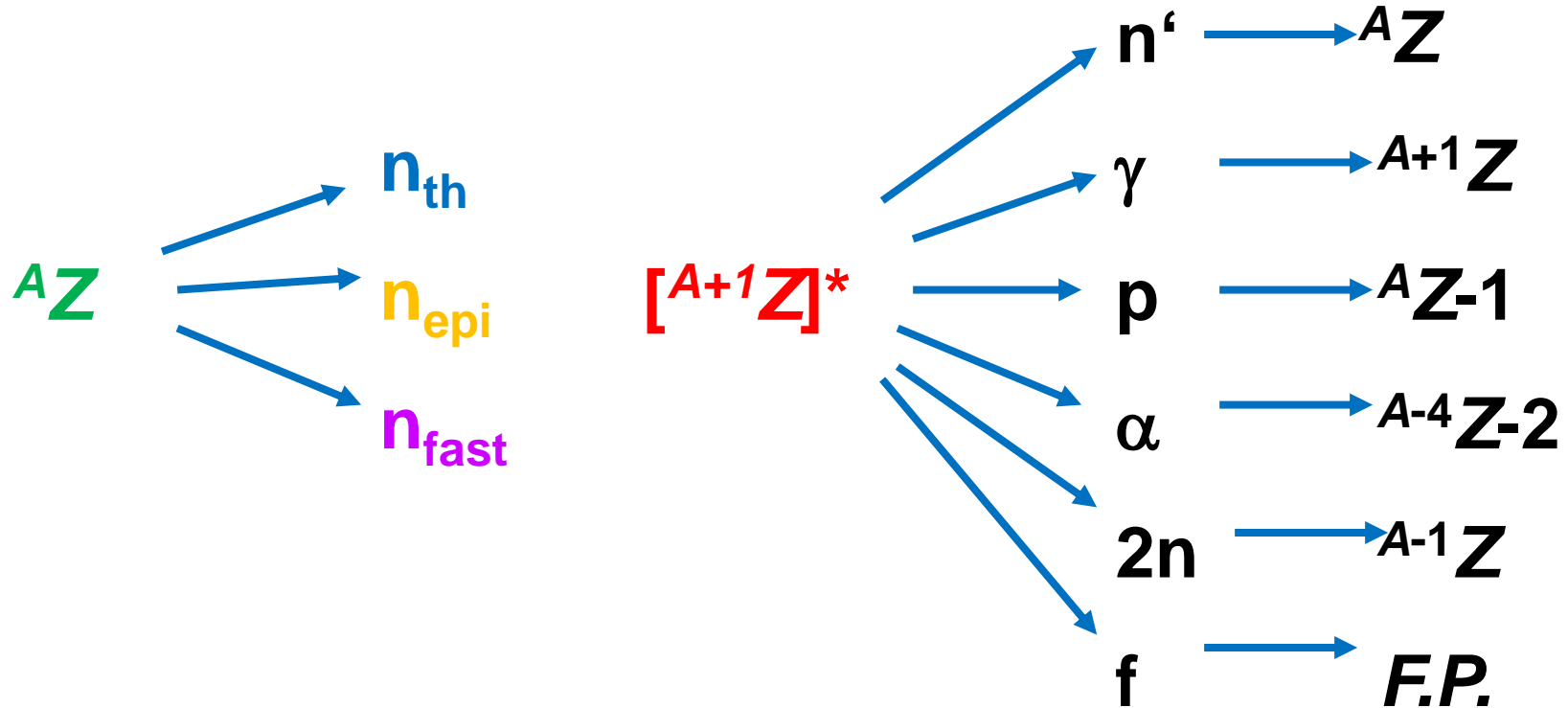
Ausgangskanal:

$$y)Y = \beta$$

Kinetische Energie (CMS):

$$\varepsilon_\alpha, \varepsilon_\beta$$

<u><math>{}^9\text{Be}(\alpha, n){}^{12}\text{C}</math></u>	<u><math>Q = 5,7 \text{ MeV}</math></u>	70 Neutronen pro 1Mio ${}^{241}\text{Am}$ $\alpha$ -Partikel
${}^7\text{Li}(\alpha, n){}^{10}\text{B}$	$Q = - 2,79 \text{ MeV}$	
${}^{10}\text{B}(\alpha, n){}^{13}\text{N}$	$Q = 1,07 \text{ MeV}$	
${}^{11}\text{B}(\alpha, n){}^{14}\text{N}$	$Q = 0,158 \text{ MeV}$	
${}^{210}\text{Po-Be}$	$T_{1/2} = 140 \text{ d}$	$E_n = 5,7 \text{ MeV}$ (Chadwick)
${}^{226}\text{Ra-Be}$	$T_{1/2} = 1600 \text{ a}$	$1,35 \cdot 10^7 \text{ s}^{-1} (\text{g Ra})^{-1}$ starker; $\gamma$ -Untergrund
${}^{239}\text{Pu-Be}$	$T_{1/2} = 24\,110 \text{ a}$	
${}^{241}\text{Am-Be}$	$T_{1/2} = 433 \text{ a}$	
${}^{252}\text{Cf(sf)}$	$T_{1/2} = 2,645 \text{ a}$	3,5 Neutronen pro Spaltung $2,7 \cdot 10^9 \text{ s}^{-1} (\text{g Cf})^{-1}$



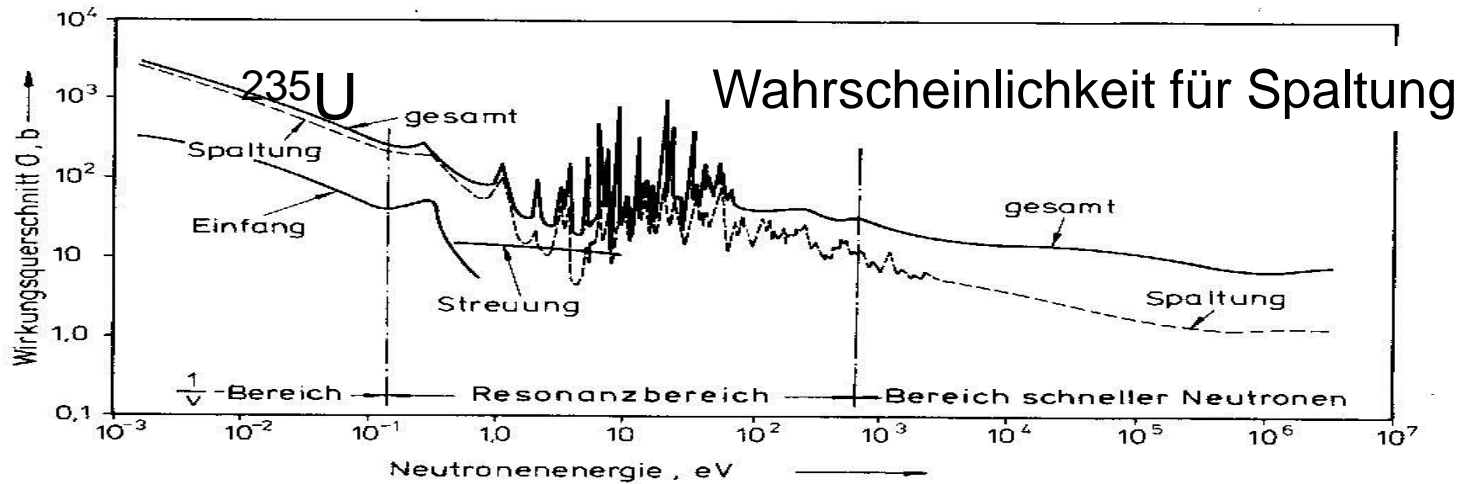
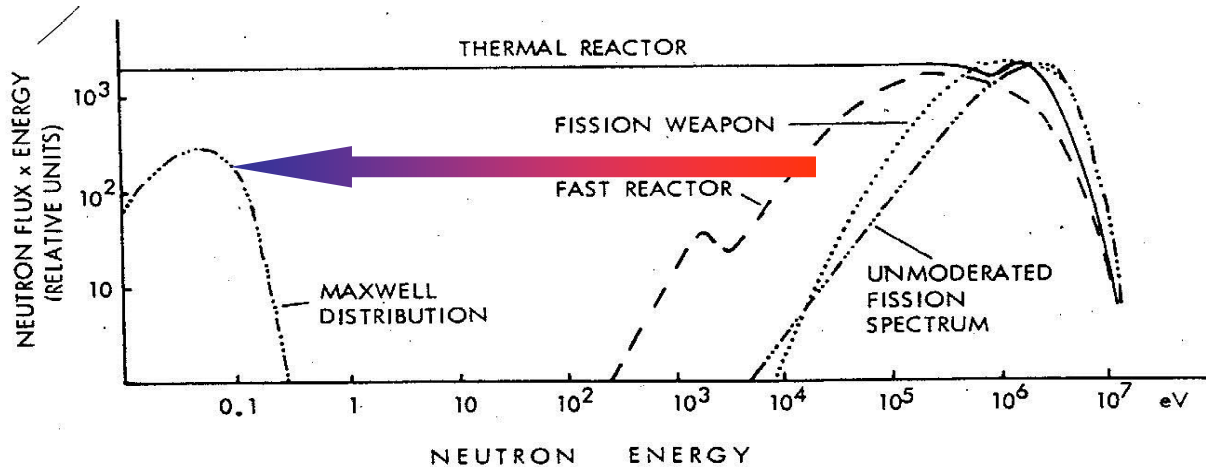


Langsame Neutronen	$E_n < 1 \text{ keV}$
Mittlere Neutronen	$1 \text{ keV} < E_n < 500 \text{ keV}$
Schnelle Neutronen	$500 \text{ keV} < E_n < 10 \text{ MeV}$
Sehr schnelle Neutronen	$10 \text{ MeV} < E_n < 50 \text{ MeV}$
Mittelschnelle Neutronen	$50 \text{ MeV} < E_n < 10 \text{ GeV}$
Relativistische Neutronen	$10 \text{ GeV} < E_n$

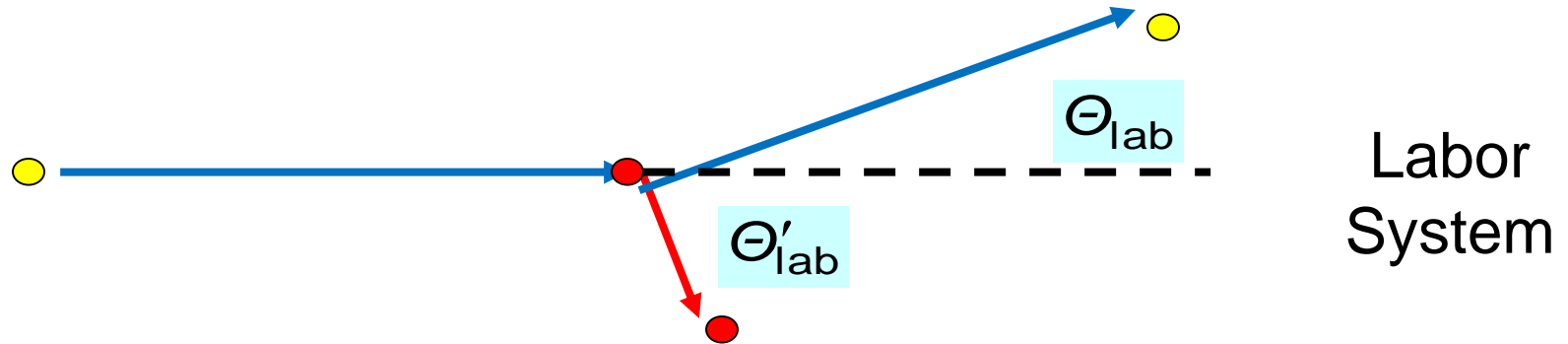
## Reaktorphysik:

Kalte Neutronen	$0 \text{ MeV} < E_n < 2 \text{ meV}$
Thermische Neutronen	$2 \text{ meV} < E_n < 0,6 \text{ eV}$
Epithermische Neutronen	$0,6 \text{ eV} < E_n < 1 \text{ keV}$
Schnelle Neutronen	$1 \text{ keV} < E_n$

$20 \text{ }^{\circ}\text{C} \cong kT = 1/40 \text{ eV} \cong v = 2500 \text{ m s}^{-1}$



## Abbremsen von Neutronen durch elastische Stöße mit Atomkernen



- Neutron mit Masse  $m = 1$ ;  $v_0$  vor;  $v$  nach Stoß
- Kern mit Masse  $M = A$ ;  $V_0 = 0$  vor;  $V$  nach Stoß



wir lassen jetzt  
ca 50 Folien weg



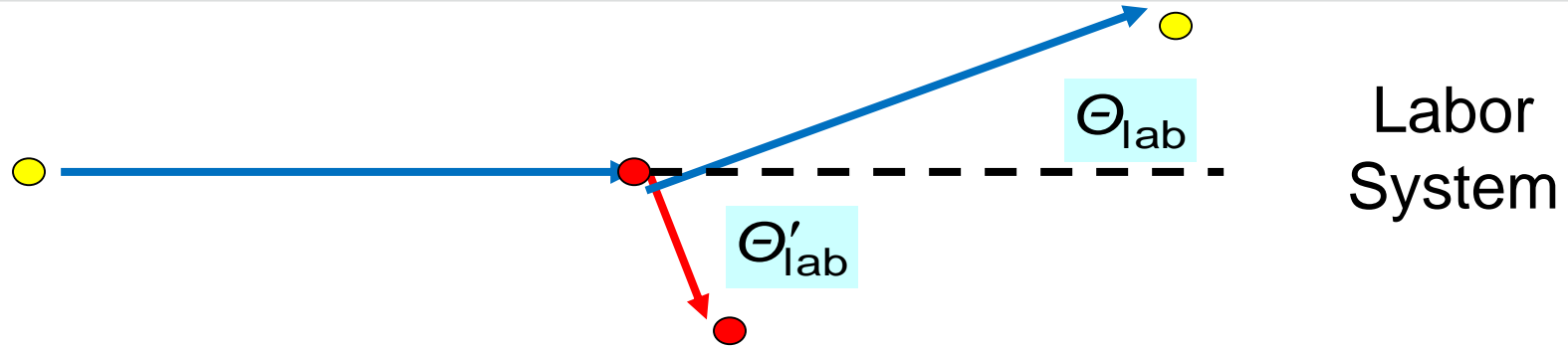
	H	D	He	C	O	U
<b>A</b>	<b>1</b>	<b>2</b>	<b>4</b>	<b>12</b>	<b>16</b>	<b>238</b>
<b><math>\alpha</math></b>	<b>0</b>	<b>0,111</b>	<b>0,360</b>	<b>0,716</b>	<b>0,778</b>	<b>0,983</b>
<b><math>\xi</math></b>	<b>1,0</b>	<b>0,725</b>	<b>0,425</b>	<b>0,158</b>	<b>0,120</b>	<b>0,00838</b>
<b><math>\xi \cdot \Sigma_s / \Sigma_a</math></b>	<b>75</b>	<b>9300</b>	<b>-</b>	<b>142</b>	<b>265</b>	
<b><math>n</math> (2 MeV <math>\rightarrow</math> 0,025 eV)</b>	<b>18</b>	<b>25</b>	<b>43</b>	<b>114</b>	<b>150</b>	<b>2172</b>

$$n \cdot \xi = \ln \frac{E_0}{E} \quad n = \frac{\ln(E_0 / E)}{\xi}$$

$\xi \cdot \Sigma_s / \Sigma_a$  Moderatorverhältnis / Abbremsverhältnis  
 $\xi \cdot \Sigma_s$  Abbremsstärke

# Wer versteht das alles?

# Na, dann eben doch die restlichen Folien



- Neutron mit Masse  $m = 1$ ; vor Stoß  $v_0$  nach Stoß  $v$
- Kern mit Masse  $M = A$ ; vor Stoß  $V_0 = 0$  nach Stoß  $V$

Energie  $m \cdot v_0^2 = M \cdot V^2 + m \cdot v^2$

Impuls  $m \cdot v_0 = M \cdot V \cdot \cos \Theta'_{\text{lab}} + m \cdot v \cdot \cos \Theta_{\text{lab}}$

$$0 = M \cdot V \cdot \sin \Theta'_{\text{lab}} + m \cdot v \cdot \sin \Theta_{\text{lab}}$$

Energie

Impuls

$$m \cdot v_0^2 = M \cdot V^2 + m \cdot v^2$$

$$m \cdot v_0 = M \cdot V \cdot \cos \Theta'_{\text{lab}} + m \cdot v \cdot \cos \Theta$$

$$0 = M \cdot V \cdot \sin \Theta'_{\text{lab}} + m \cdot v \cdot \sin \Theta$$

Neutron mit  $M$

Kern mit  $M$

Stoß  $v$

Stoß  $V$

Mit  $\mu = \cos \Theta_{\text{lab}}$   $M = A$   $m = 1$

Energie  $E$  nach dem Stoß:

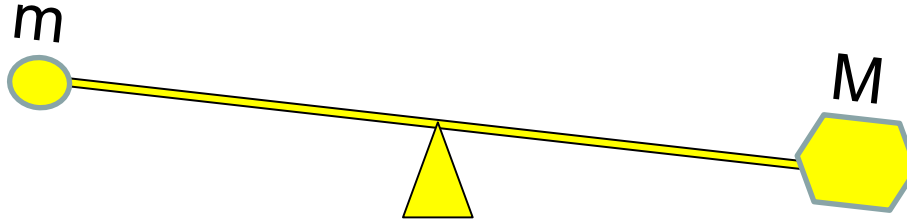
$$\frac{E}{E_0} = \frac{\left[ (A^2 - 1 + \mu^2)^{1/2} + \mu \right]^2}{(A + 1)^2}$$

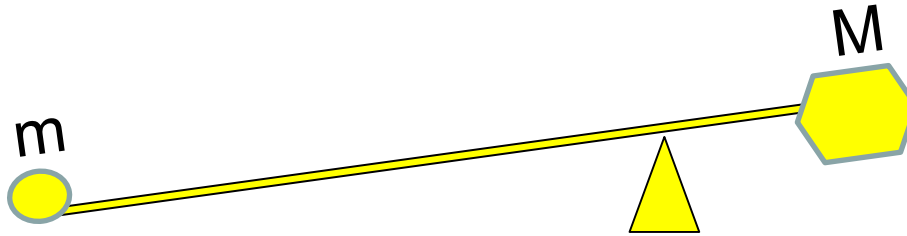
$$\frac{E}{E_0} = \frac{\left[ A^2 + 1 + 2A \cdot \cos \Theta_{\text{CMS}} \right]}{(A + 1)^2}$$

Häh?



$$\Rightarrow \frac{(A - 1)^2}{(A + 1)^2} \leq \frac{E}{E_0} \leq 1$$





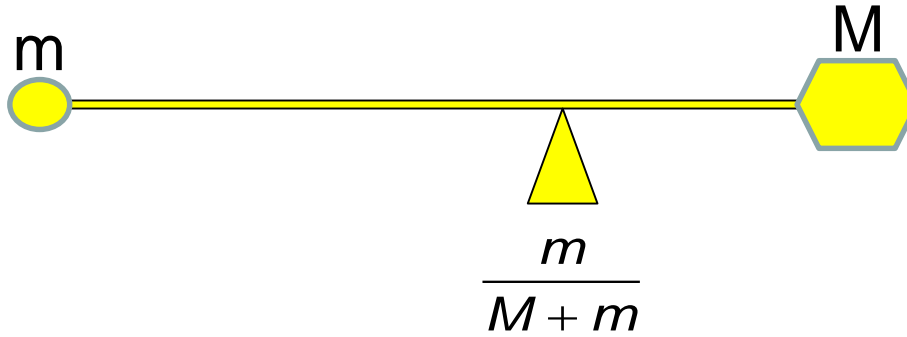


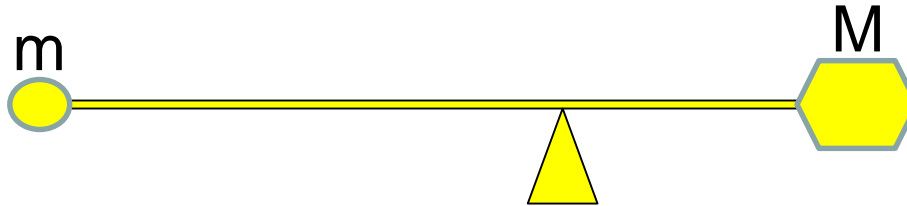
- A.  $m/(m+M)$
- B.  $(m-M)/(m+M)$
- C.  $M/(m-M)$
- D.  $m^2/(m-M)^2$

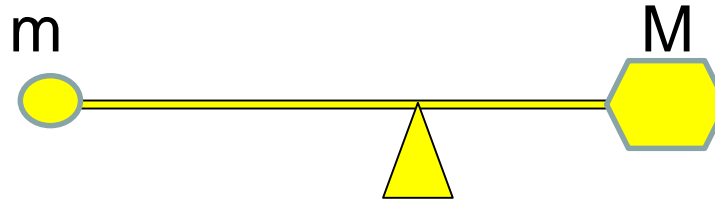
## SMART Response Question

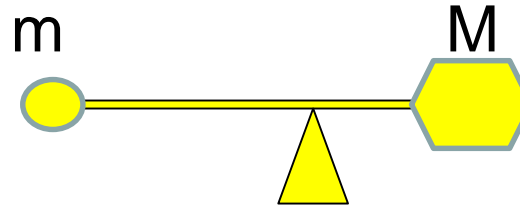
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SMART Response Question Object->Properties...

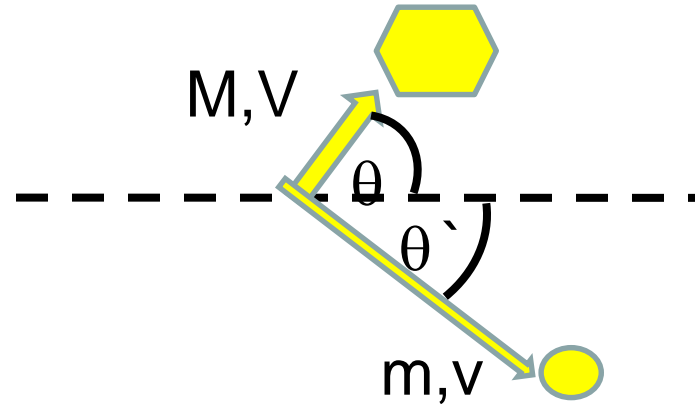
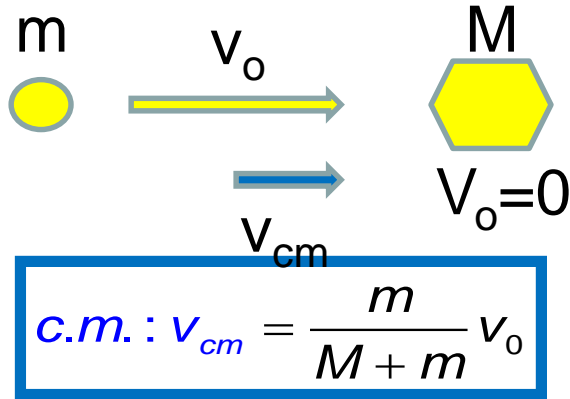


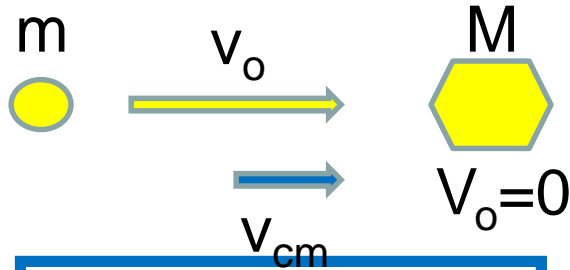




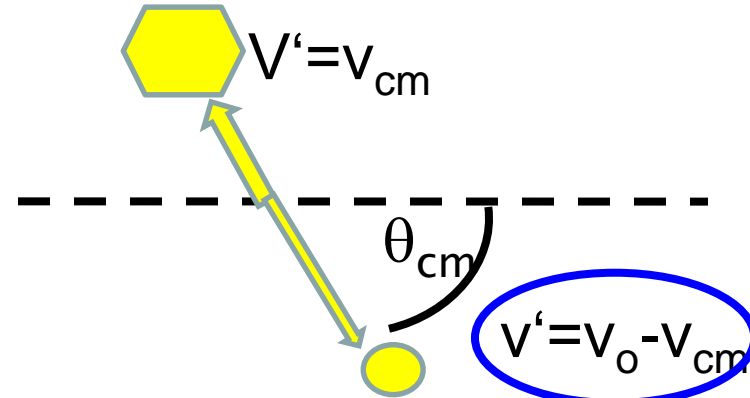
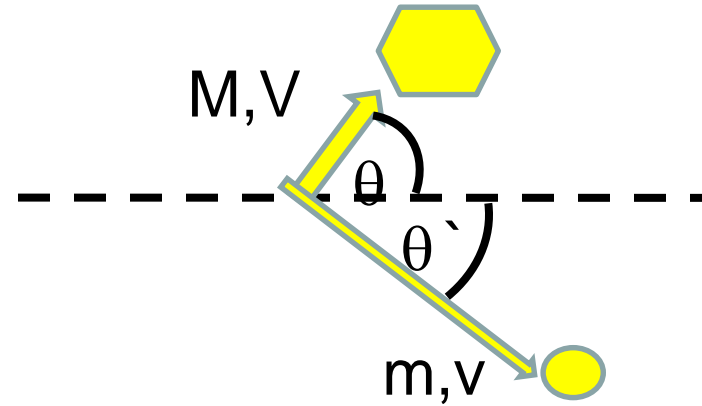
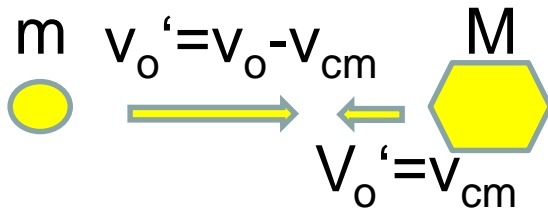








$$\text{c.m.: } v_{cm} = \frac{m}{M+m} v_0$$



$$E_{kin} = \frac{1}{2} m v^2 = \frac{1}{2} m (v' + v_{cm})^2 = \frac{1}{2} m (v'^2 + v_{cm}^2 + 2v'v_{cm} \cos \theta_{cm})$$



$$E_{kin} = \frac{1}{2} m v^2 = \frac{1}{2} m (v' + v_{cm})^2 = \frac{1}{2} m (v'^2 + v_{cm}^2 + 2v'v_{cm} \cos \theta_{cm})$$

$$E_{kin}(\max) = \frac{1}{2} m (v'^2 + v_{cm}^2 + 2v'v_{cm}) = \frac{1}{2} m v_0^2 \quad \text{Wegen: } v' = v_0 - v_{cm}$$

$$\begin{aligned} E_{kin}(\min) &= \frac{1}{2} m (v'^2 + v_{cm}^2 - 2v'v_{cm}) = \frac{1}{2} m (v' - v_{cm})^2 \\ &= \frac{1}{2} m (v_0 - 2v_{cm})^2 \\ &= \frac{1}{2} m v_0^2 \left( \frac{M - m}{M + m} \right)^2 \end{aligned}$$

$$\text{c.m.: } v_{cm} = \frac{m}{M + m} v_0$$

$$\begin{aligned} M &= A \\ m &= 1 \end{aligned} \quad \Rightarrow \quad \left( \frac{A - 1}{A + 1} \right)^2$$

# AO

Energie

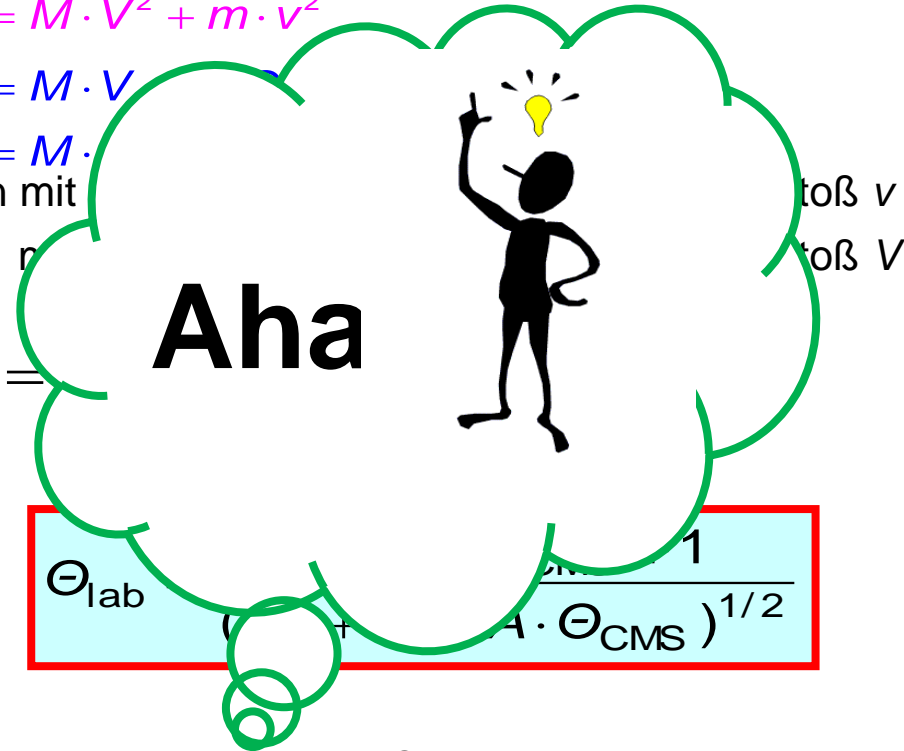
Impuls

$$m \cdot v_0^2 = M \cdot V^2 + m \cdot v^2$$

$$m \cdot v_0 = M \cdot V$$

$$0 = M \cdot$$

Neutron mit  
Kern



Mit  $\mu = \cos \Theta_{lab}$   $M = A$   $m =$

Energie  $E$  nach dem Stoß:

$$\frac{E}{E_0} = \frac{\left[ (A^2 - 1 + \mu^2)^{1/2} + \mu \right]^2}{(A + 1)^2}$$

$$\frac{E}{E_0} = \frac{\left[ A^2 + 1 + 2A \cdot \cos \Theta_{CMS} \right]}{(A + 1)^2}$$

$$\Rightarrow \frac{(A - 1)^2}{(A + 1)^2} \leq \frac{E}{E_0} \leq 1$$

- Wissen Sie was eine s-Welle ist?

Ja 

 Nein



## SMART Response Question

To set the properties right click and select  
SMART Response Question Object->Properties...



Für **s-Wellen**, ist elastische Streuung im **Schwerpunktsystem (CMS) isotrop**. Höhere Drehimpulse werden bei hoher Neutronenenergie wichtig.

$$\lambda = \frac{h}{m \cdot v} = \frac{h}{\sqrt{2mE}}$$

$$\lambda = \frac{4,05 \cdot 10^{-9}}{\sqrt{2mE}} \text{ cm}$$

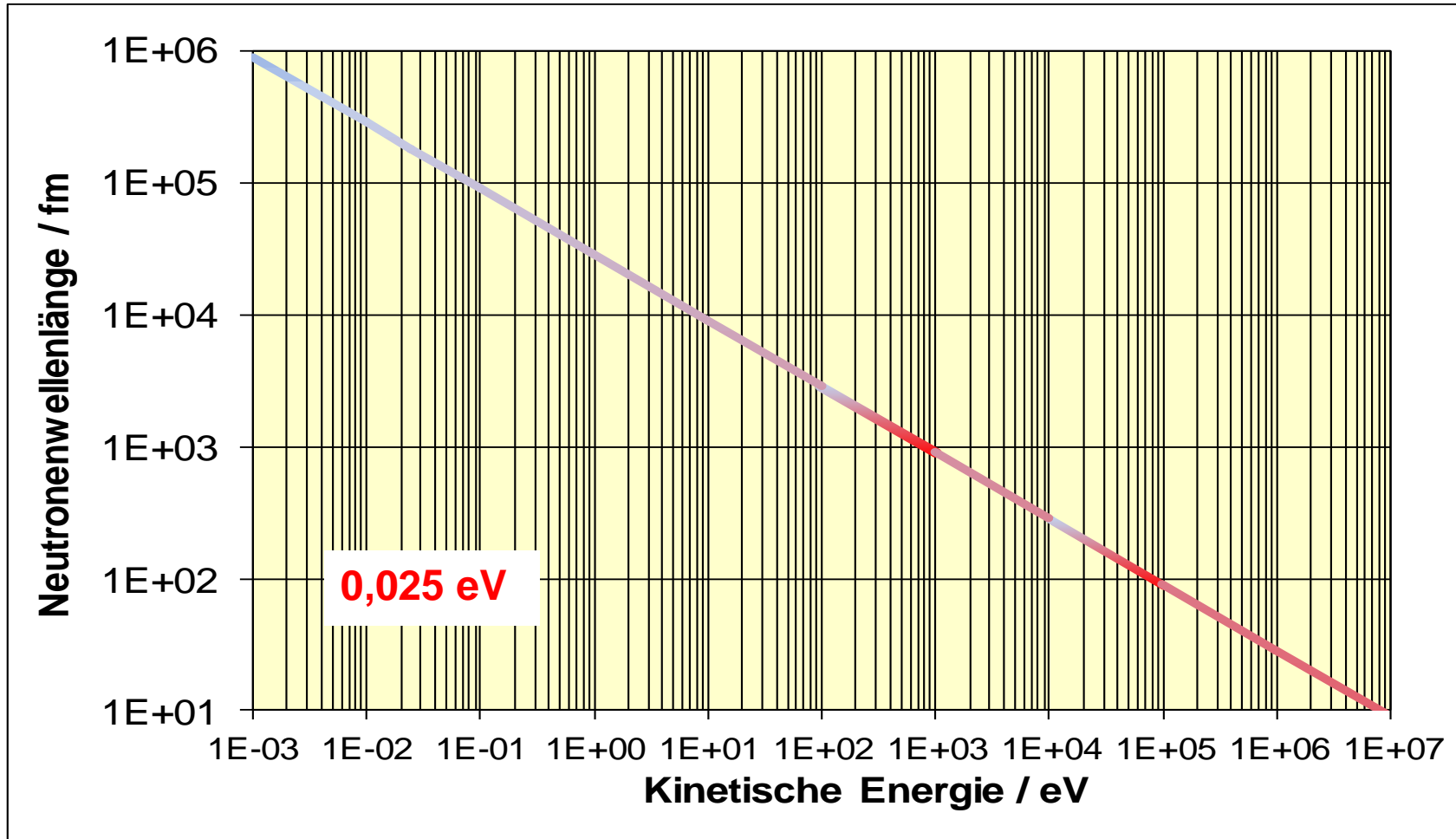
$m$  in amu

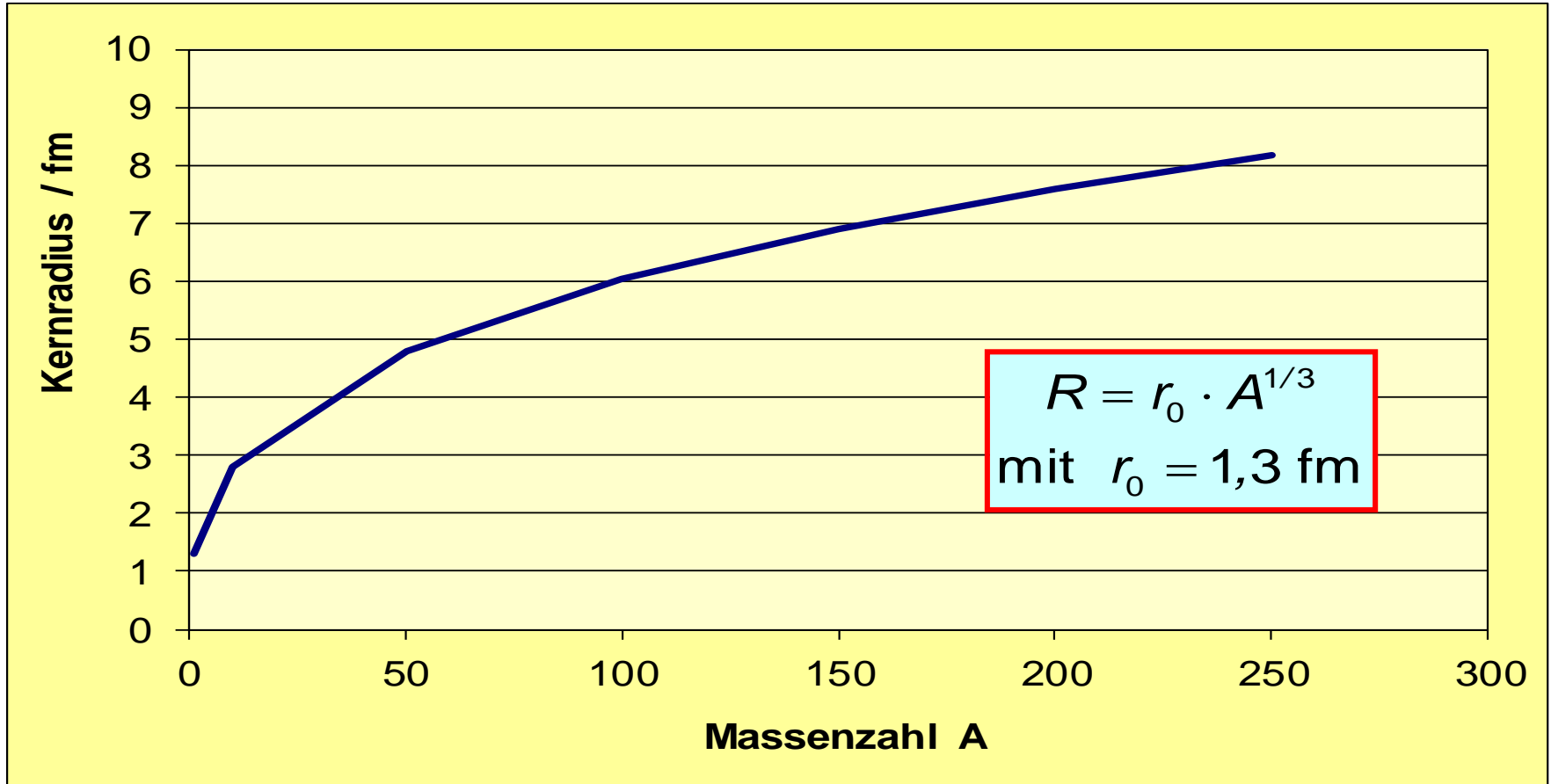
$E$  in eV

Im Falle von Neutronen:

$$\lambda = \frac{2,86 \cdot 10^{-9}}{\sqrt{E}} \text{ cm für } E_n \text{ in eV}$$

$$E_n = 0,025 \text{ eV: } \lambda = 1,7 \cdot 10^{-8} \text{ cm}$$







Für **s-Wellen**, ist elastische Streuung im **Schwerpunktsystem (CMS)** **isotrop**. Höhere Drehimpulse werden bei hoher Neutronenenergie wichtig.

Für s-Wellen ist die Wahrscheinlichkeit  $dW$  im CMS in den Winkel  $d\omega$  gestreut zu werden:

$$\frac{dW}{4\pi} = \frac{\sin\Theta_{\text{CMS}}}{2} \frac{d\Theta_{\text{CMS}}}{2} = -\frac{d(\cos\Theta_{\text{CMS}})}{2}$$

$$\begin{aligned} dx dy dz &= r^2 dr d\phi \sin\theta d\theta \\ \rightarrow d\omega &= 2\pi \sin\theta d\theta \end{aligned}$$

Für **s-Wellen**, ist elastische Streuung im **Schwerpunktsystem (CMS)** **isotrop**. Höhere Drehimpulse werden bei hoher Neutronenenergie wichtig. AO

Für s-Wellen ist die Wahrscheinlichkeit  $dW$  im CMS in den Winkel  $d\omega$  gestreut zu werden:

$$\frac{dW}{4\pi} = \frac{\sin \Theta_{\text{CMS}} d\Theta_{\text{CMS}}}{2} = -\frac{d(\cos \Theta_{\text{CMS}})}{2}$$

Die Wahrscheinlichkeit, nach dem Stoß ein bestimmtes Intervall  $\cos \Theta_{\text{CMS}}$  zu erreichen hängt nicht von  $\Theta_{\text{CMS}}$  ab..

$$\frac{E}{E_0} = \frac{[A^2 + 1 + 2A \cdot \cos \Theta_{\text{CMS}}]}{(A + 1)^2} \Rightarrow \frac{dE}{E_0} = \frac{2A}{(A + 1)^2} d\cos \Theta_{\text{CMS}}$$

Beim zentralen Stoß ist der maximale Energieverlust:

$$\left[ \frac{E}{E_0} \right]_{\max} = \frac{(A-1)^2}{(A+1)^2} = \alpha$$

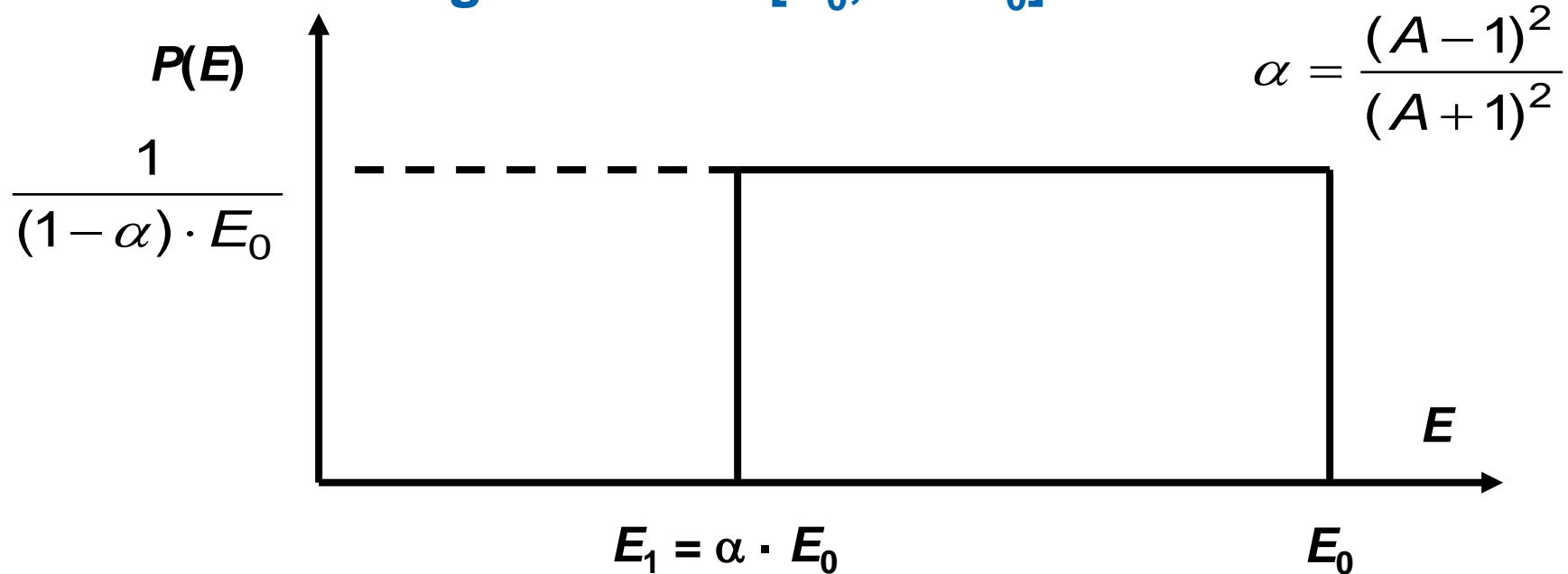
$\Theta$  und  $\mu = \cos \theta$  folgen den Gesetzen für Streuung: isotrop im CMS System



Dann ist das **mittlere logarithmische Energie Dekrement** gegeben durch:

$$\bar{\xi} = \ln \frac{E_0}{E_1} = 1 + \frac{(A-1)^2}{2A} \cdot \ln \frac{A-1}{A+1}$$

# Konstante Wahrscheinlichkeit, nach einem Stoß die Energie $E$ zu erreichen im Energieintervall $[E_0, \alpha \cdot E_0]$



Für  $^1\text{H}$  wird jede Energie zwischen  $E_0$  und 0 mit gleicher Wahrscheinlichkeit erreicht:

$$\Rightarrow \langle E_n \rangle = \frac{1}{2^n} \cdot E_0$$