Prof. Dr. C. von Borczyskowski

# Aspekte der modernen Optik

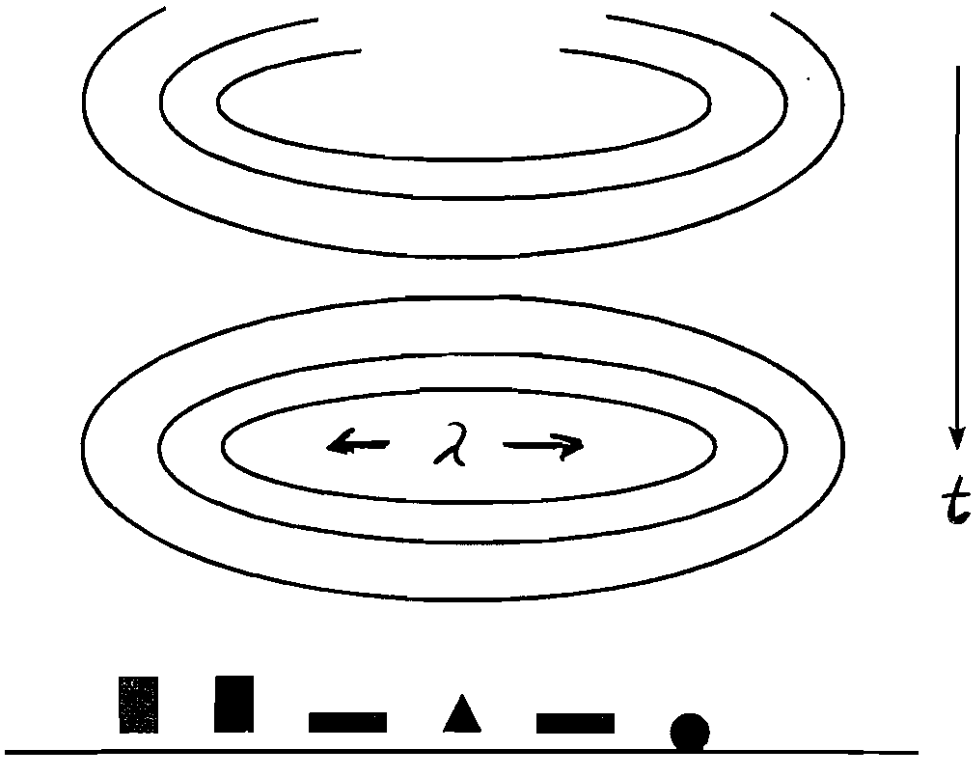
Vorlesung vom 03.06.2010

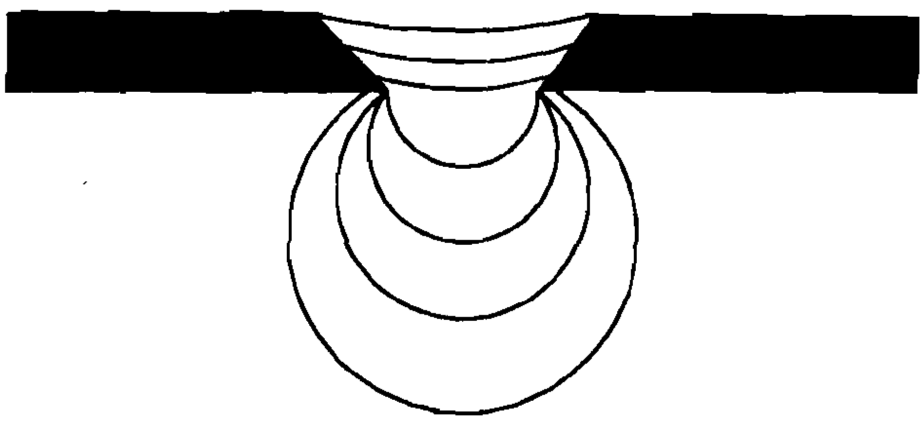
**Spektrale Auflösung ...**

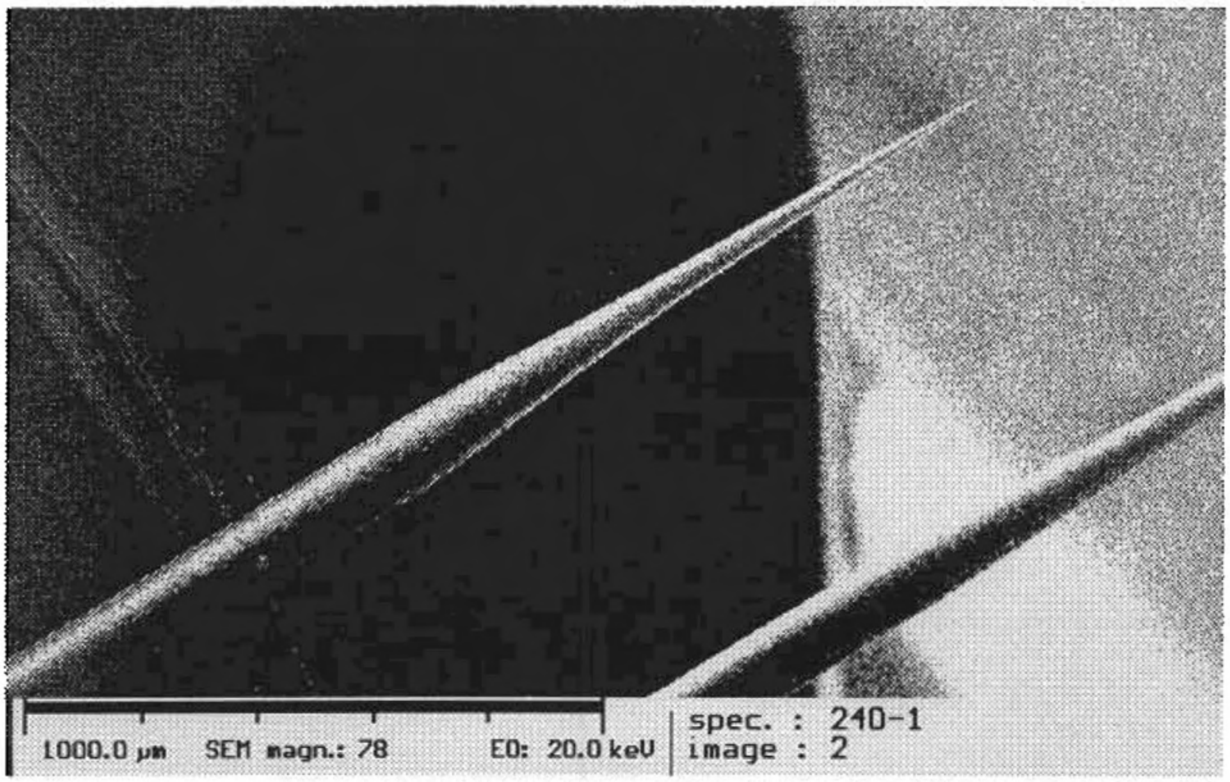
# *Spektrale Auflösung*

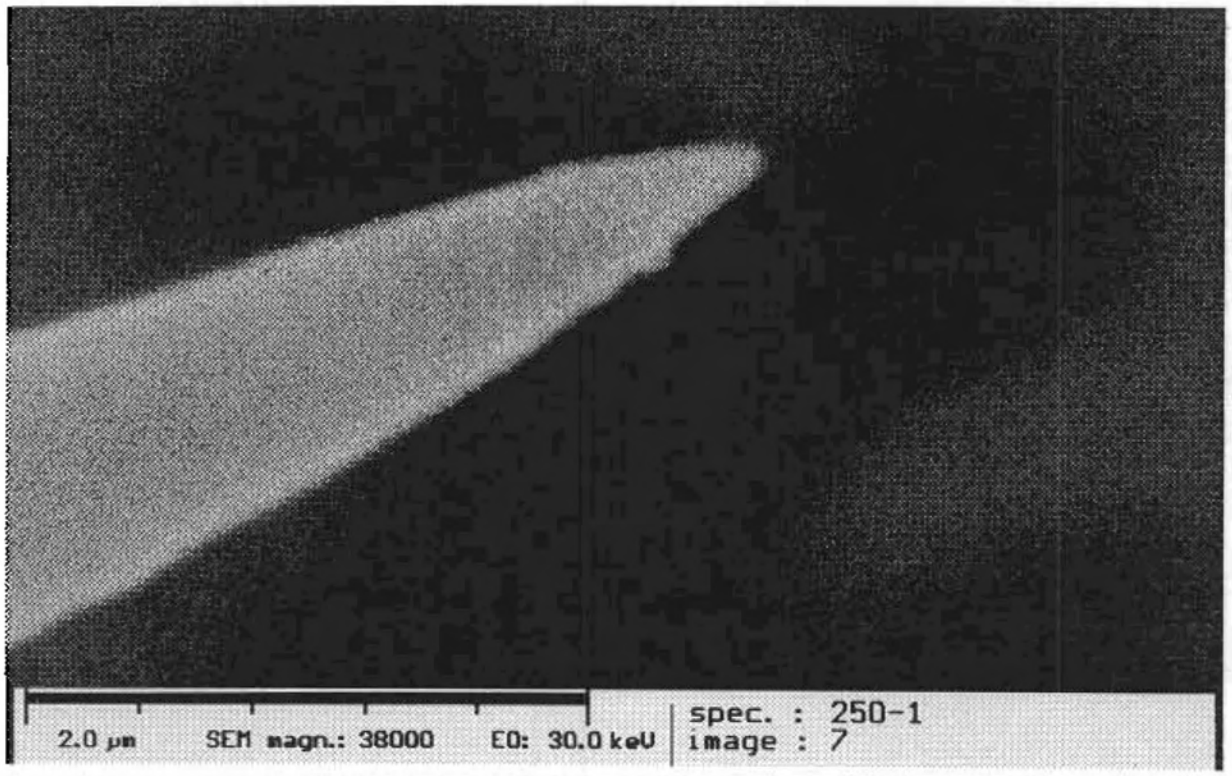
- Heisenbergsche Unschärferelation
- Homogene Verbreiterung durch dynamische Prozesse
- Inhomogene Verbreiterung durch statische „Unordnung“
- Ensemble- Zeitmittelung

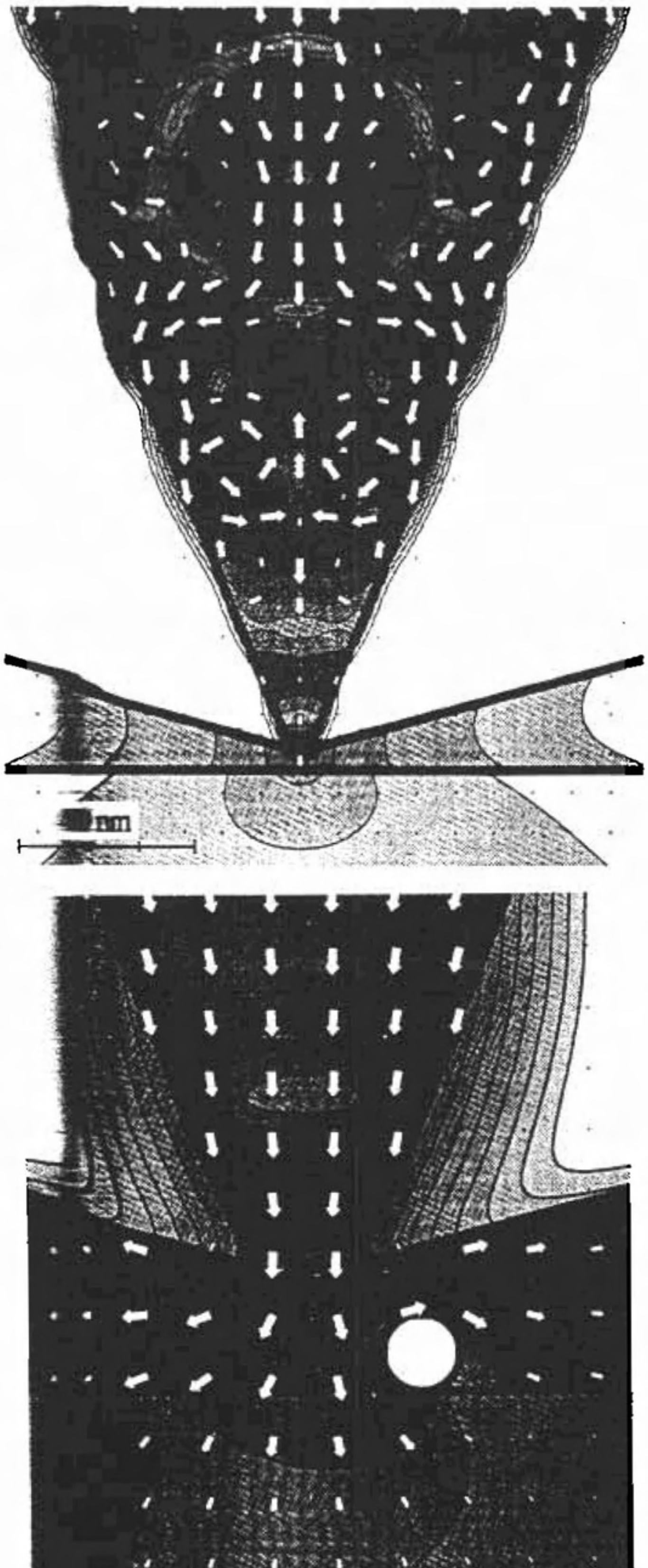
- ***Kohärente Verfahren, Doppel-“Resonanz“verfahren***
- ***Spektrale Selektion Lochbrennen), Einzelmolekültechniken***


λ
t

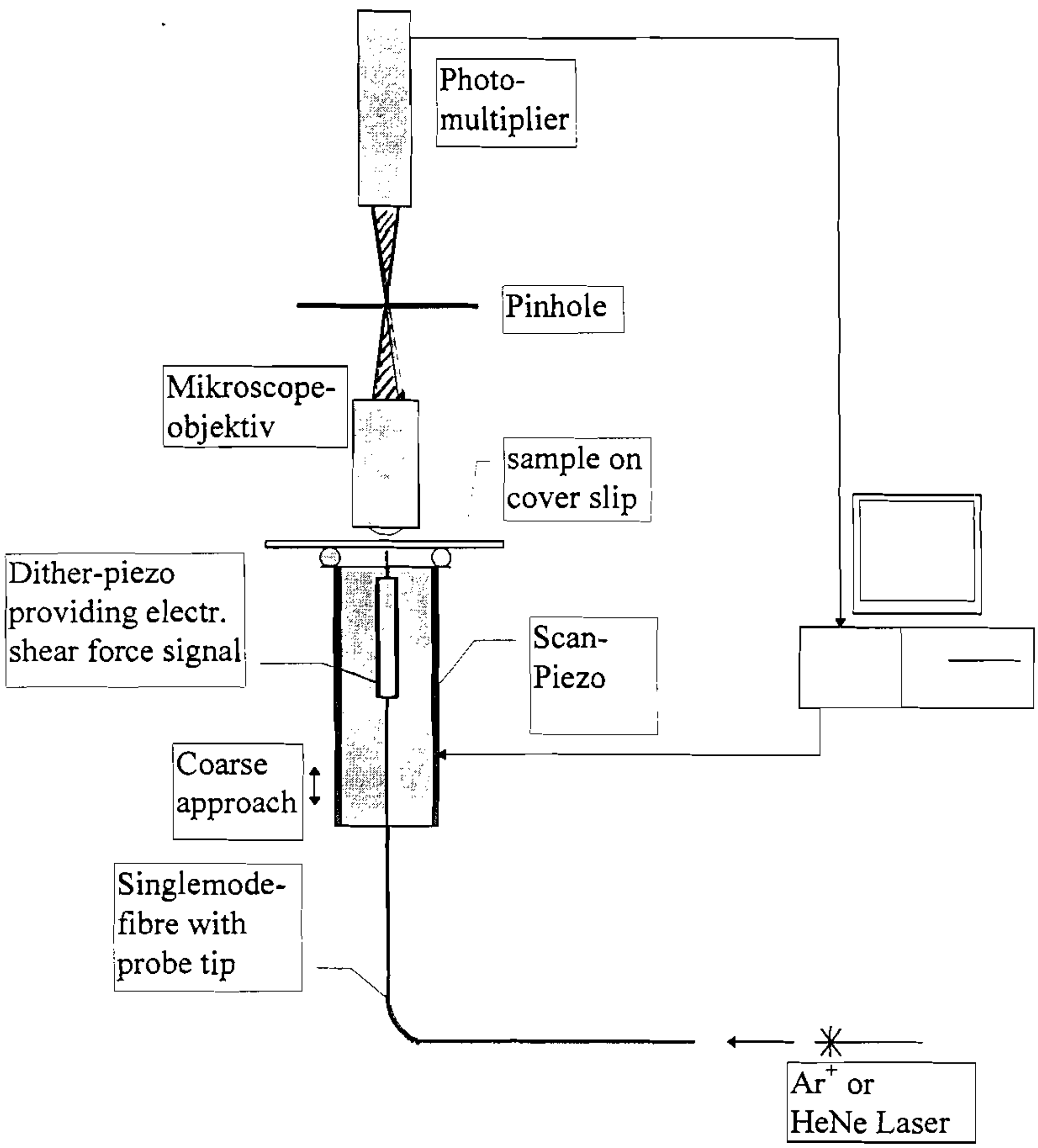



1000.0 µm SEM magn.: 78 E0: 20.0 keV
spec. : 240-1
image : 2

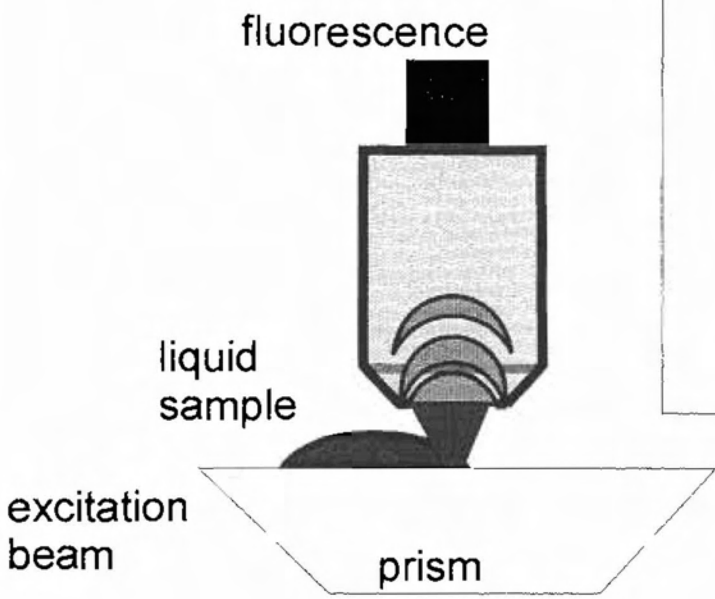

2.0 µm SEM magn.: 38000 E0: 30.0 keV
spec. : 250-1
image : 7

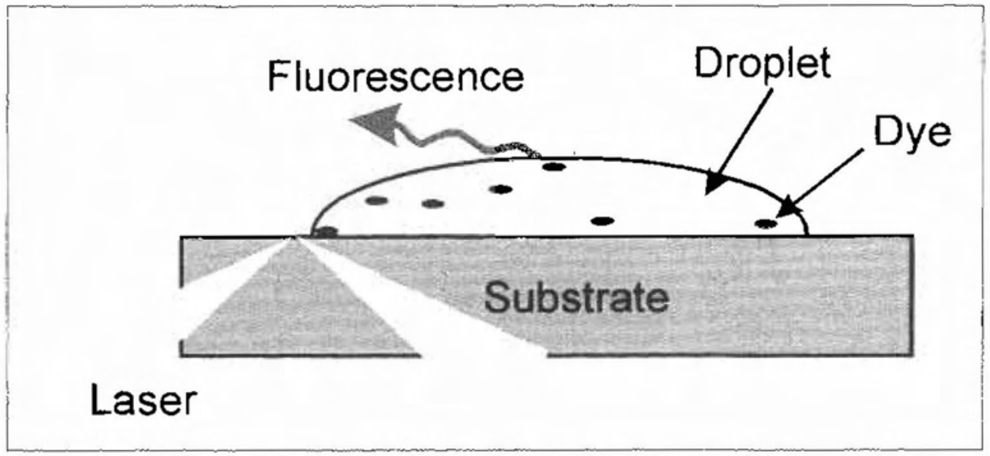

50 nm

# Room temperature SNOM-setup



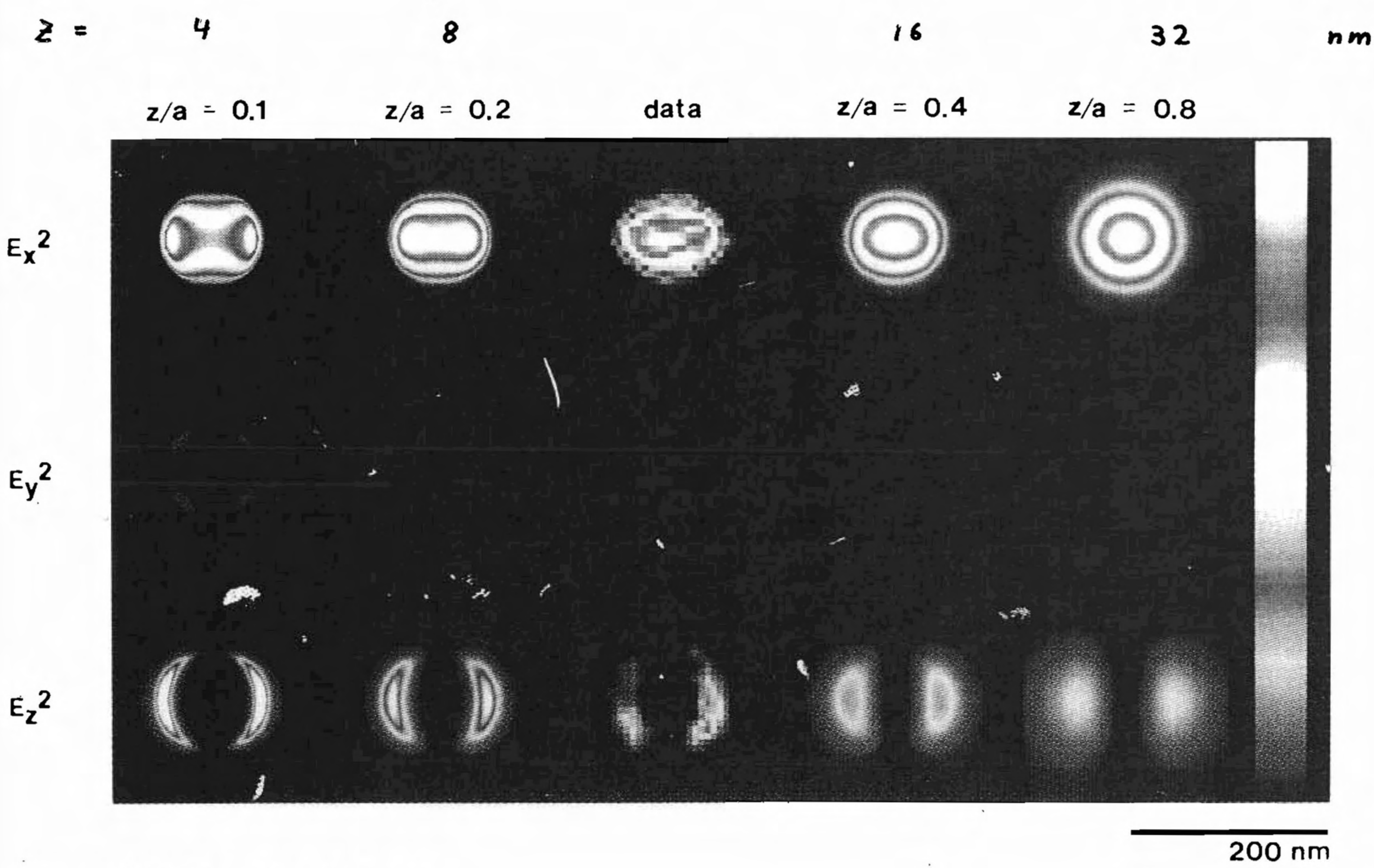
# Total internal reflection setup




Droplet:
$10^{-7}$ mol/l solution of rhodamine 6G in tetrakis(2-ethylhexoxy)-silane

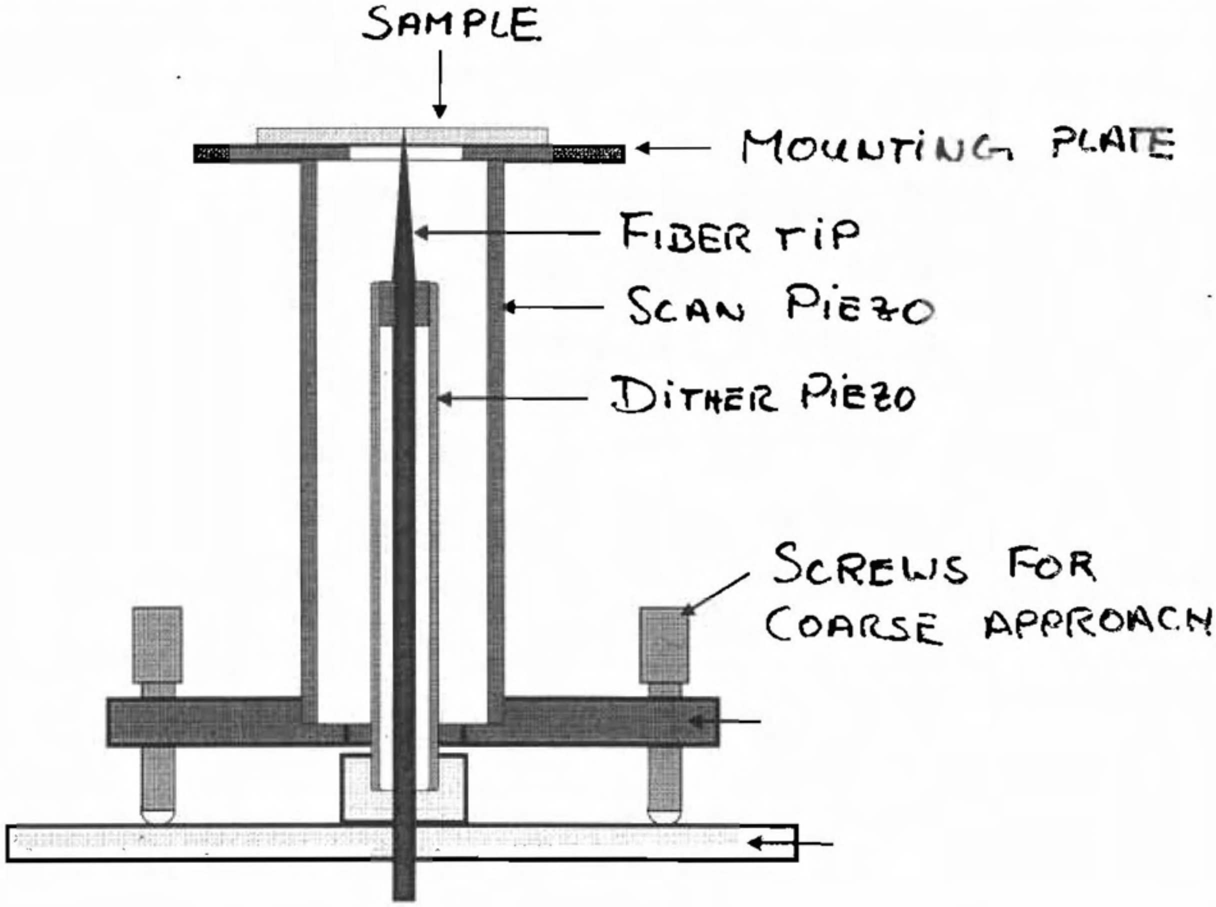
Substrate:
quartz cover slip

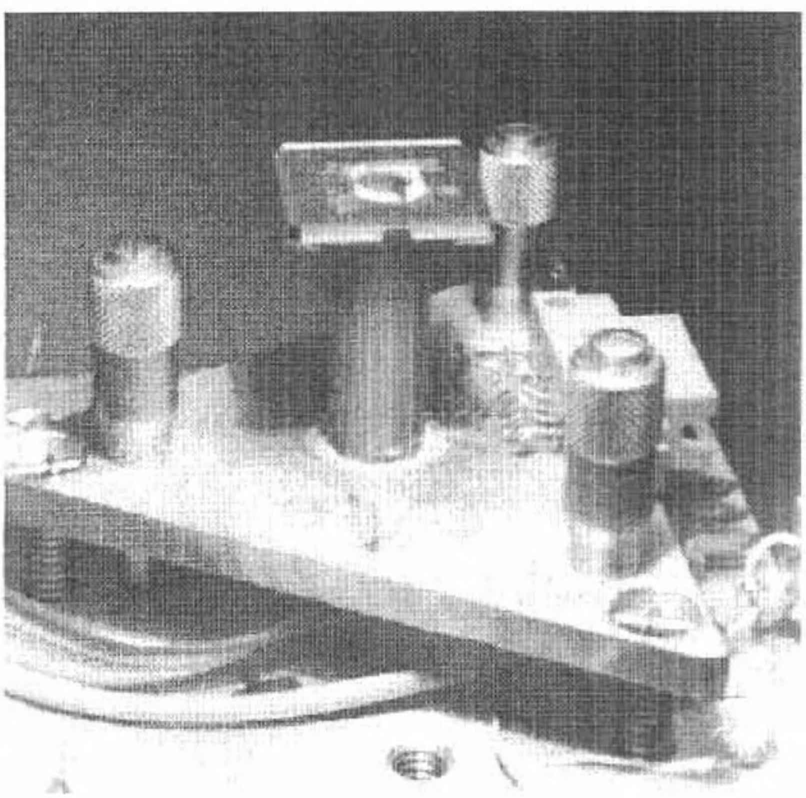


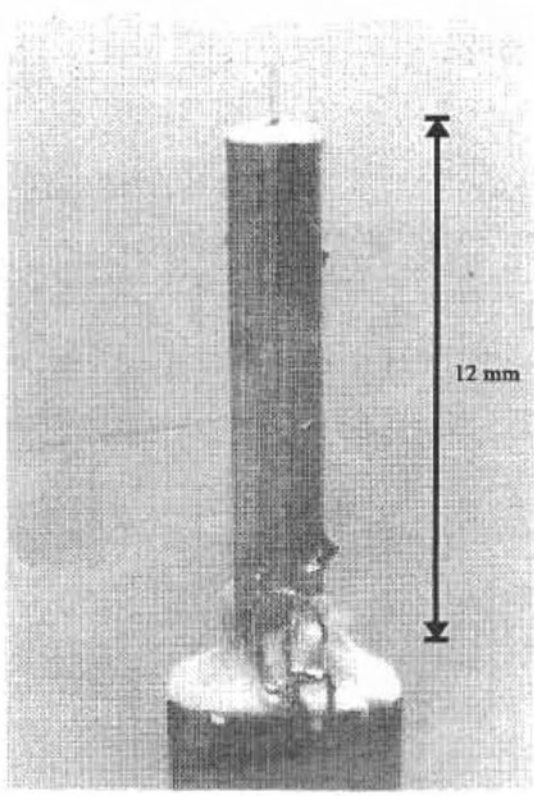

Betzig et al 1993

# Set-up

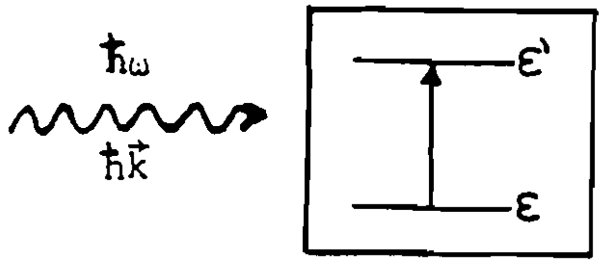
- Scanner and sample mounting





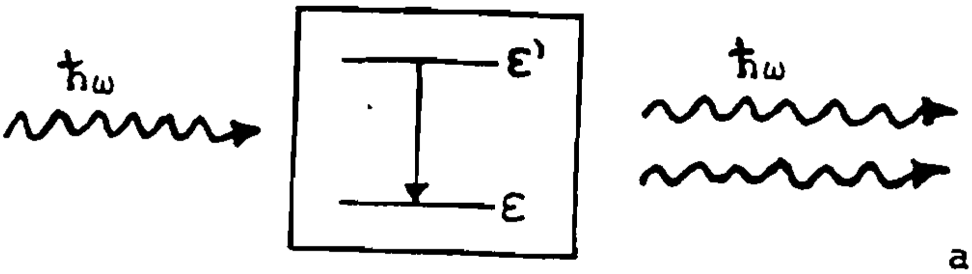
## Absorption




$\varepsilon \rightarrow \varepsilon'$

$p \rightarrow p'$

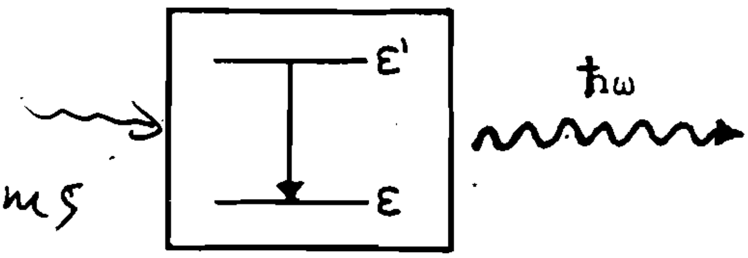
## Stimulierte Emission




kohärent
gleiche Phase
anisotrope Abstra

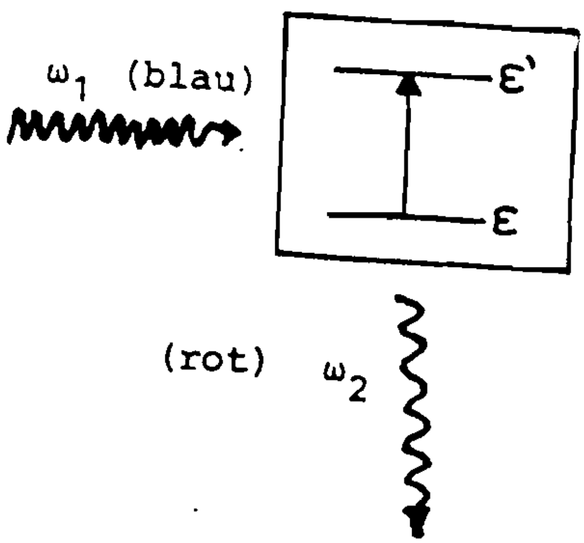
## Spontane Emission

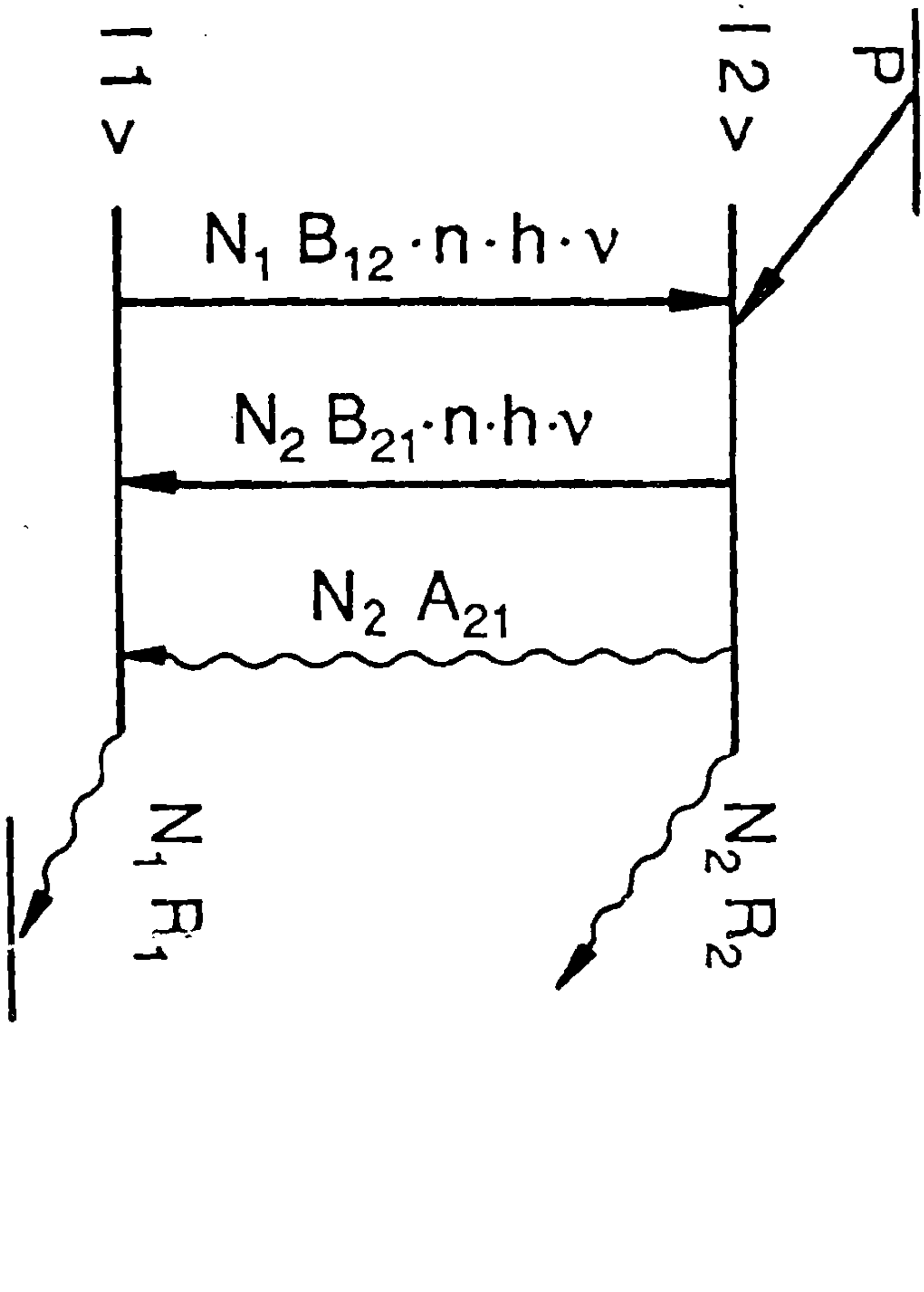
- Fluoreszenz ns
- Phosphoreszenz ms



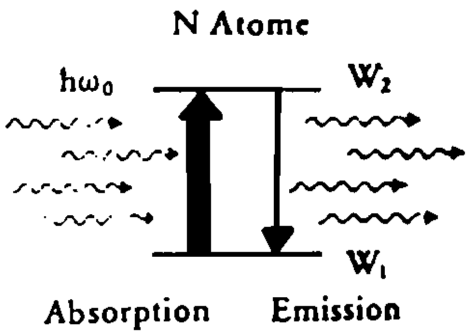

isotrope Abstrahlung
ohne Phasenbeziehung
inkohärent

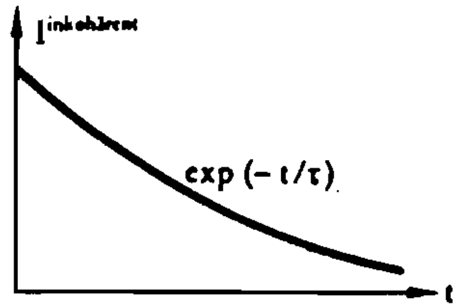
## Streuung

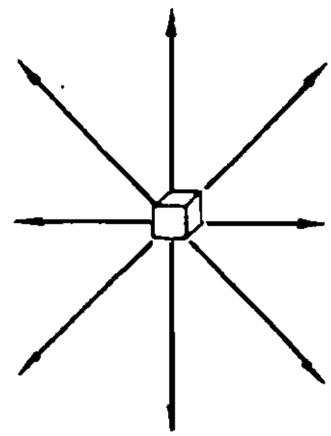
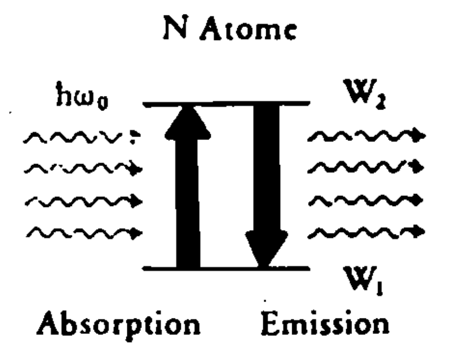


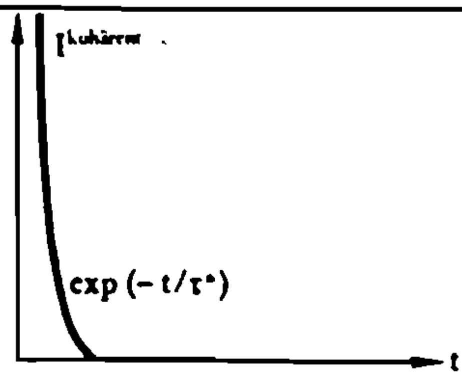


|1>
|2>
P
N1 B12·n·h·ν
N2 B21·n·h·ν
N2 A21
N1 R1
N2 R2

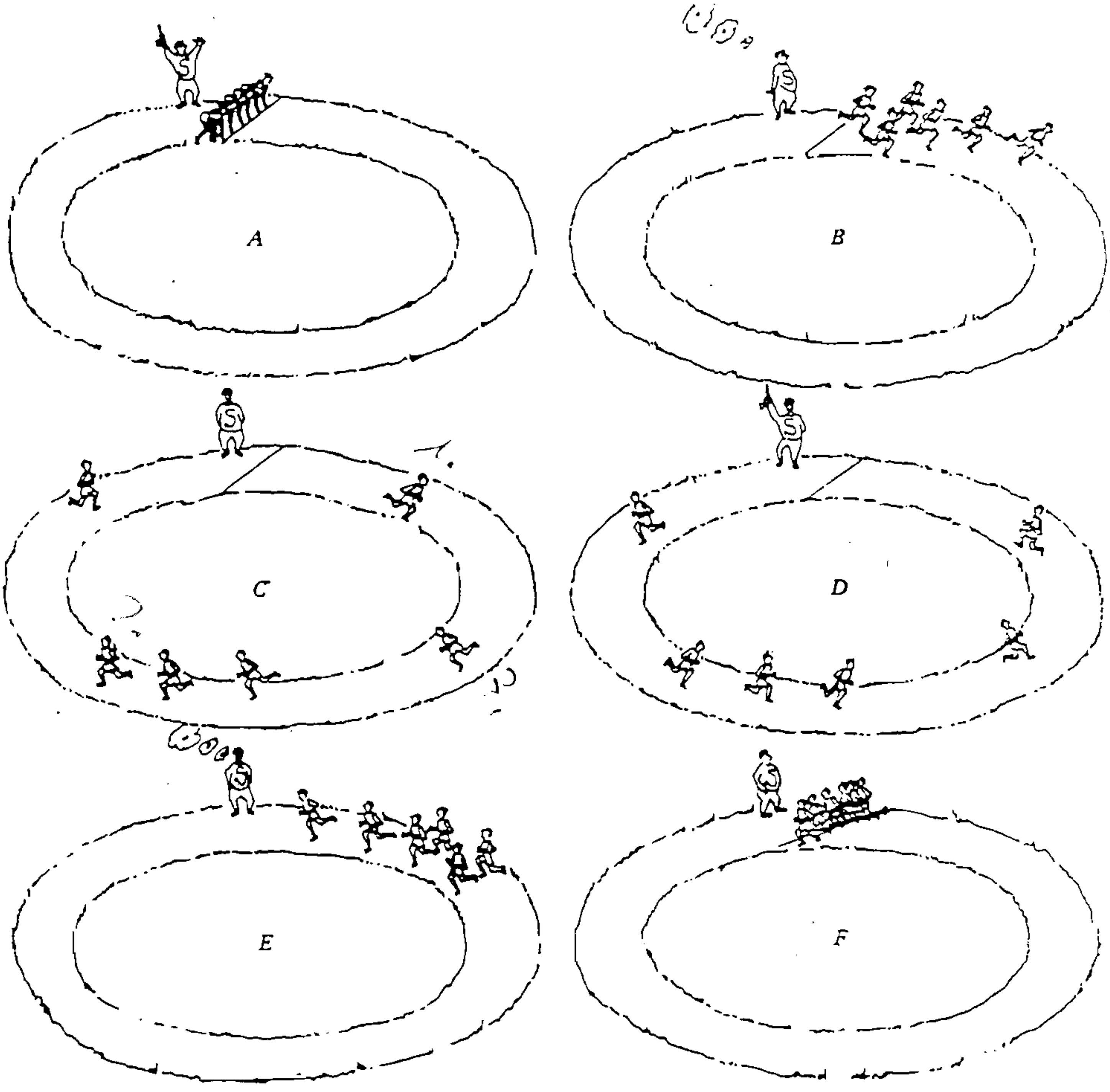
<table>
<tr><th>Energieniveauschema</th><th>Lumineszenz-Zerfall</th><th>Emission</th></tr>
<tr>
<td>

• Inkohärente Anregung und Emission: Es besteht keine Phasenbeziehung zwischen den einzelnen absorbierenden und emittierenden Atomen.</td>
<td>

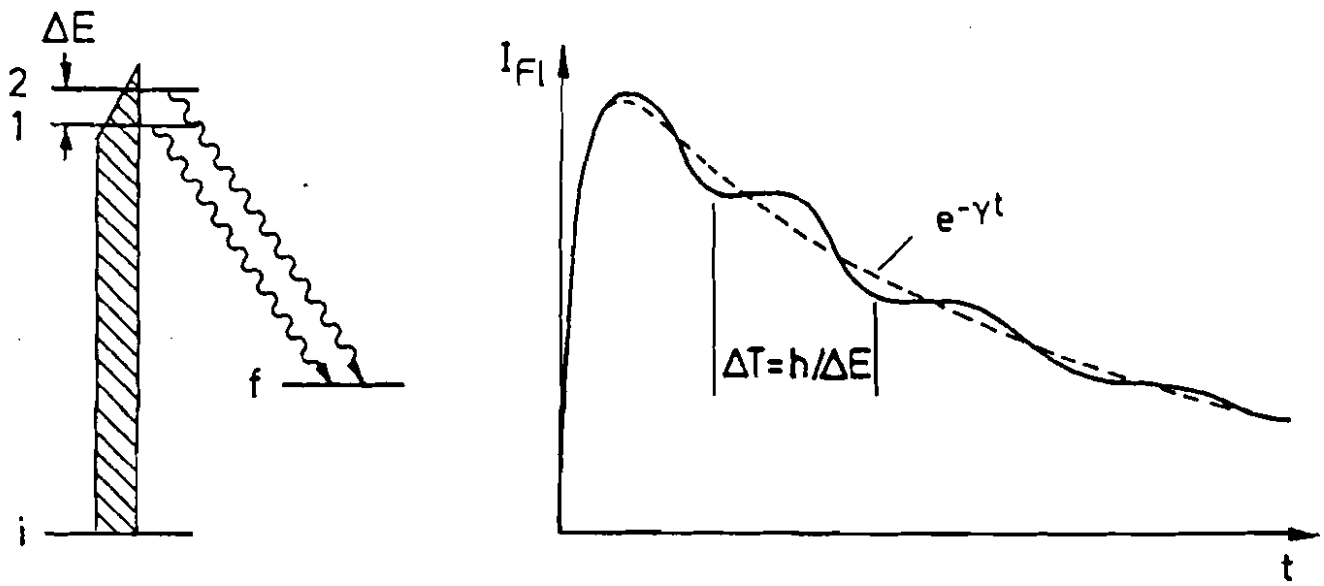
• Das Abklingen der Lumineszenz ist exponentiell. $\tau$ ist die Lebensdauer der angeregten Atome.</td>
<td>
• isotrope Abstrahlung</td>
</tr>
<tr>
<td>

• Kohärente Anregung und Emission:<br>Alle Atome absorbieren und emittieren in Phase.</td>
<td>

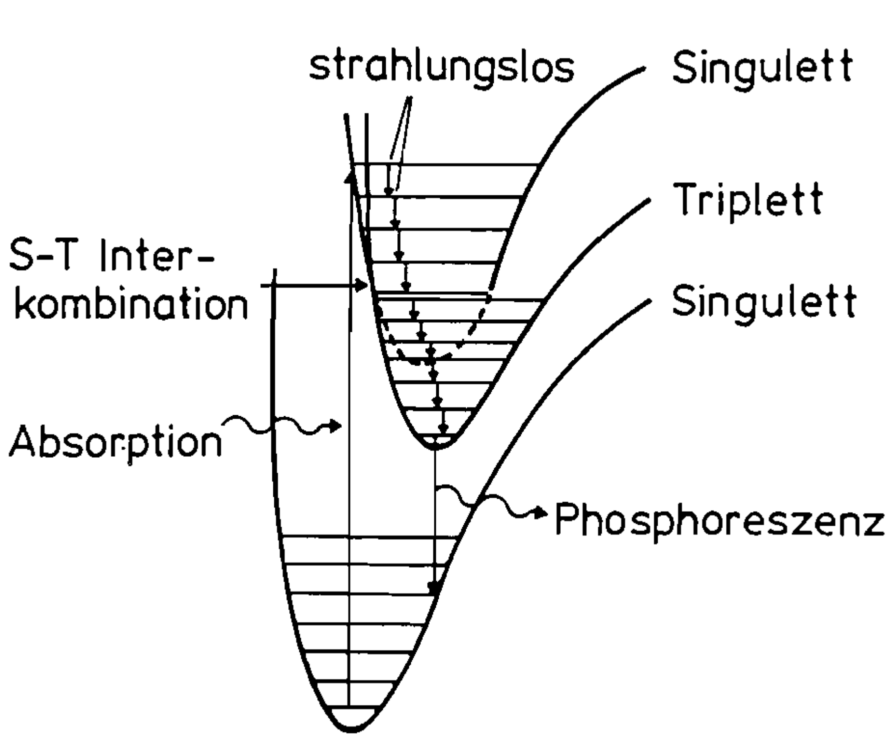
• Das Abklingen der kohärenten Emission wird durch die Phasenverlustzeit $\tau^*$ bestimmt. (Nach dem Phasenverlust erfolgt inkohärente Abstrahlung wie oben dargestellt).</td>
<td>
• anisotrope Abstrahlung.<br>Kohärent = in Phase wie die Anregung.</td>
</tr>
</table>



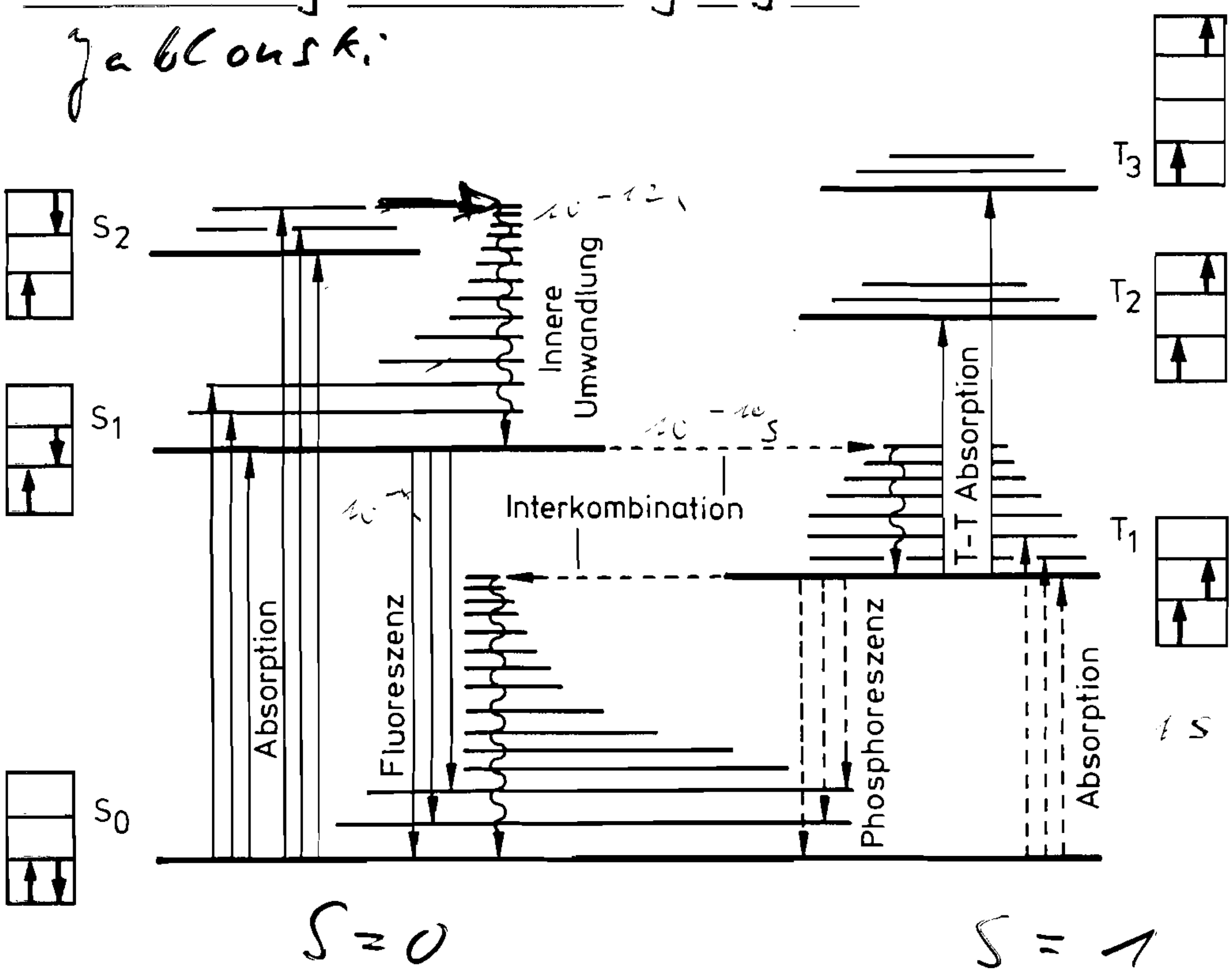

Dephasing and reversal on a race track, leading to coherent rephasing and an "echo" of the starting configuration. [From *Phys. Today*, front cover, November 1953. Reproduced by permission.]



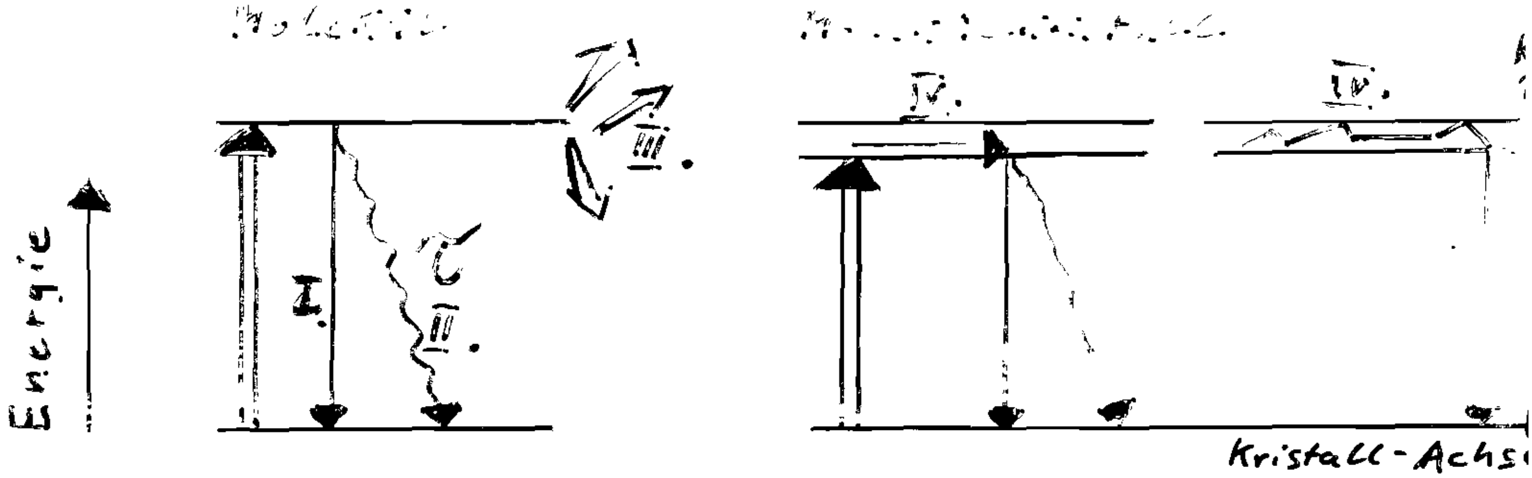

(a) (b)




Strahlungslose Übergänge
Jablonski



# Dynamik angeregter molekularer Zustände in kondensierter Phase



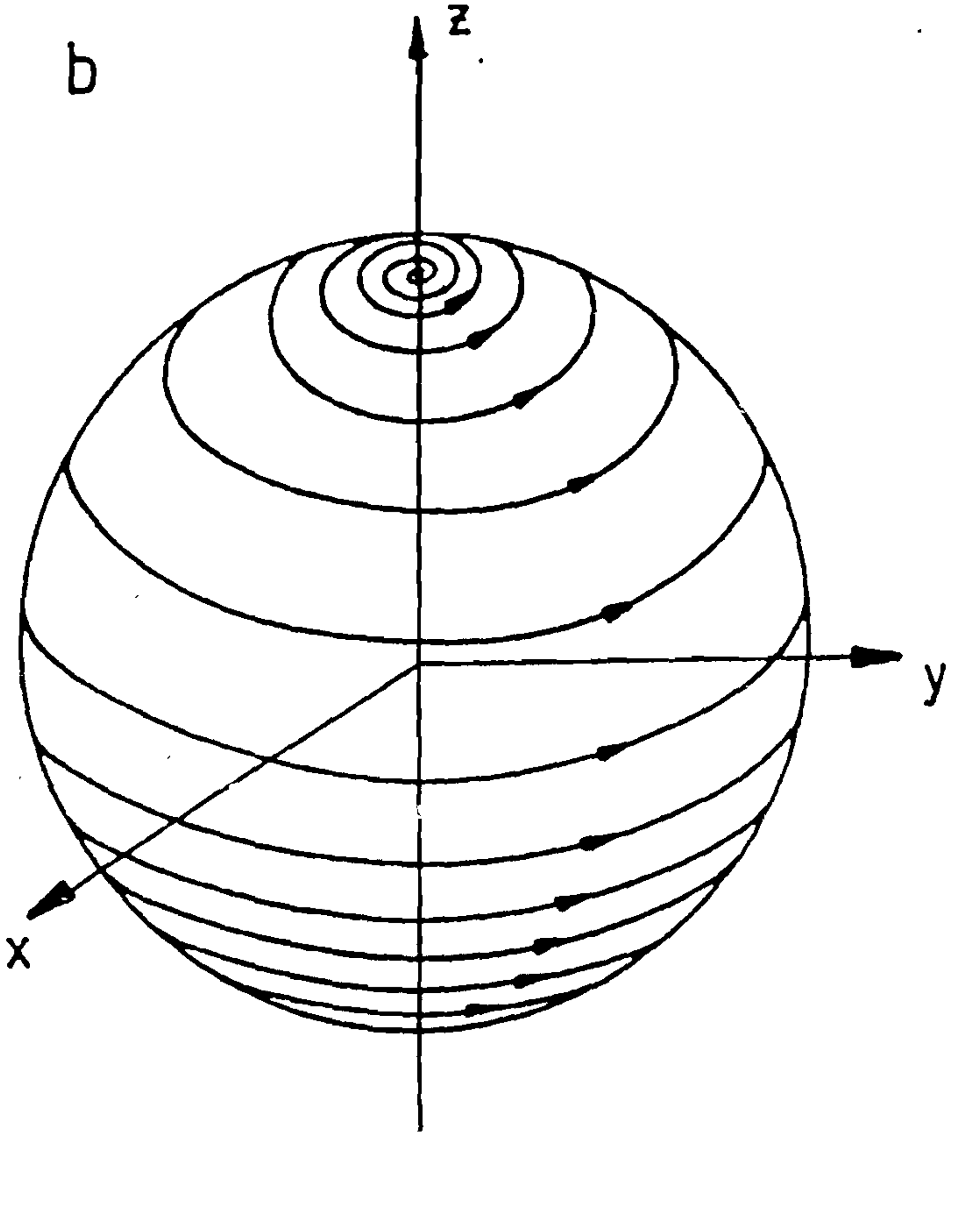

## Heisenbergsche Unschärferelation:

$$\Delta E \Delta t \geq \hbar$$


$$\Delta \nu \tau \geq \frac{1}{2\pi}$$

$$\Gamma_{hom} = \frac{1}{\pi T_2} = \frac{1}{2\pi T_1} + \frac{1}{\pi T_2^*}$$

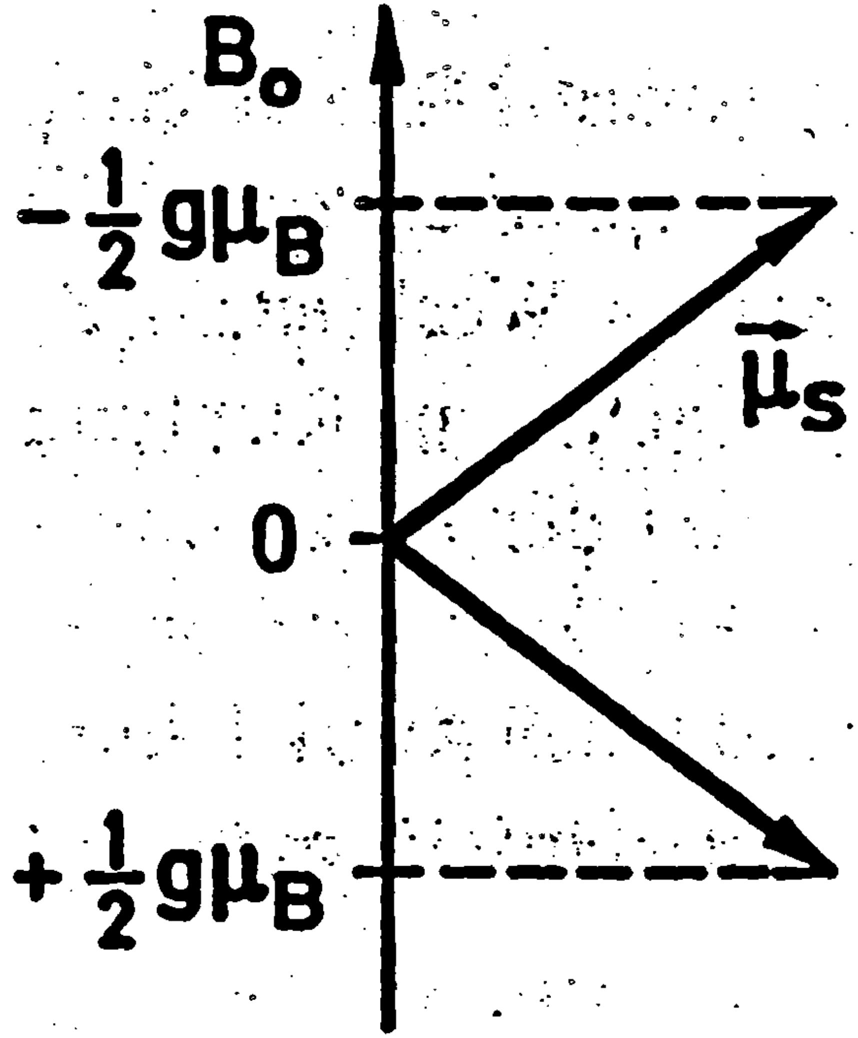
| | | |
|---|---|---|
| ↑ | ↑ I. II. III. | ↑ IV. |
| Linienbreite | Zerfall | [illegible] |
| 2. | 1. | 3. |



b
z
y
x

# Magnetic Resonance

- Electron Spin Resonance (ESR, EPR)
- Nuclear Spin Resonance




$$\mu_s = \sqrt{s(s+1)}\,\mu_B \cdot g_s$$

Electron $s = 1/2$ ; $g_s$ 2.0023

$\rightarrow m_s = \pm 1/2$

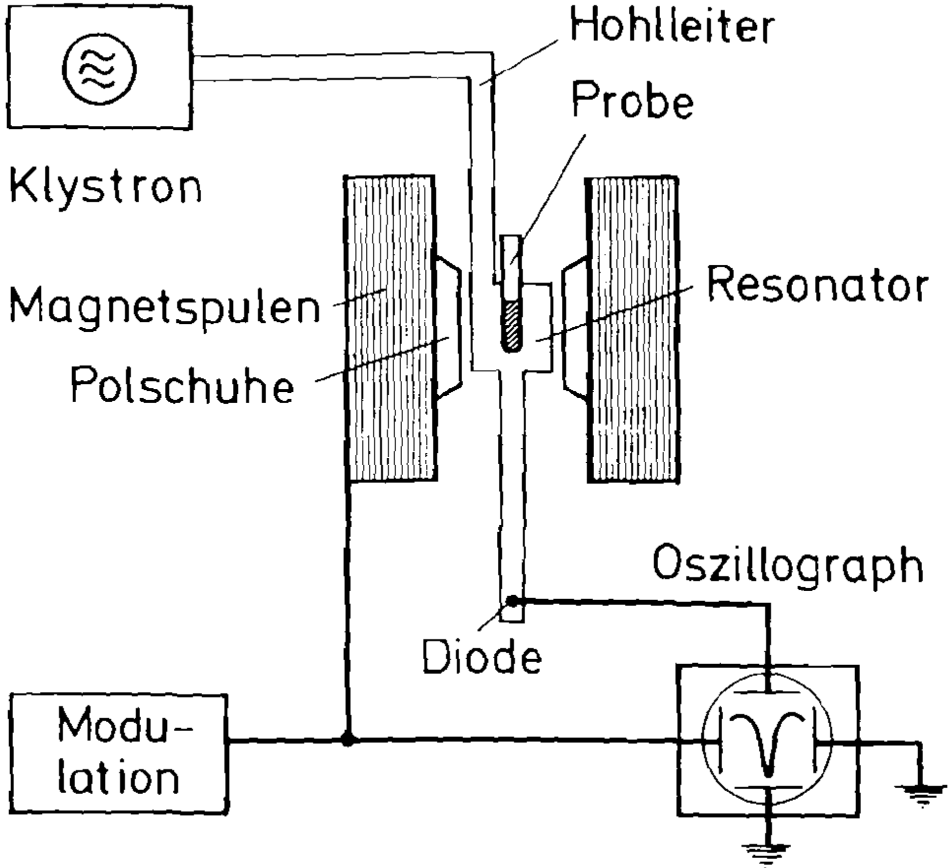
$$\Delta E = g_s \cdot \mu_B \cdot B_0 = h\nu = \hbar\omega$$

$S = 1 \longrightarrow m_s = 0, \pm 1$

Nuclei $\Delta E = g_I \mu_N B_0$

$(I = 1/2)$

# Spinresonanz



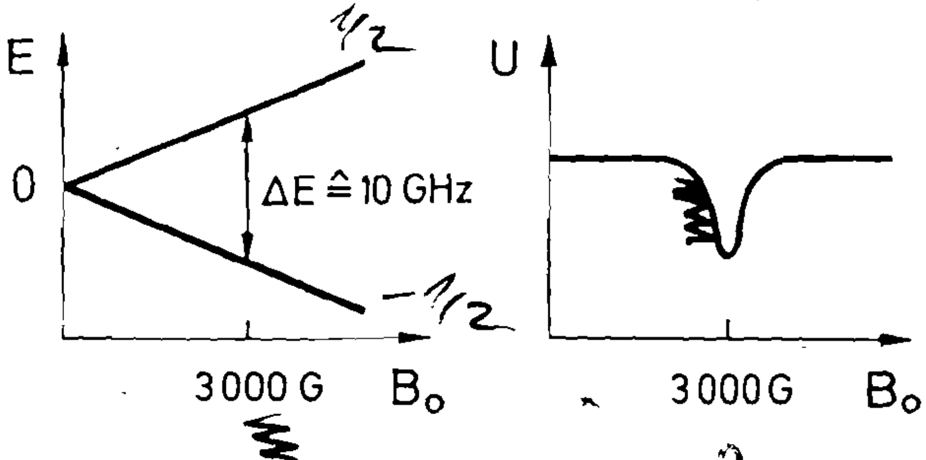

Freie Elektron,
Radikale

$g = 2.0032$ ; $\omega_L = \gamma B_0$

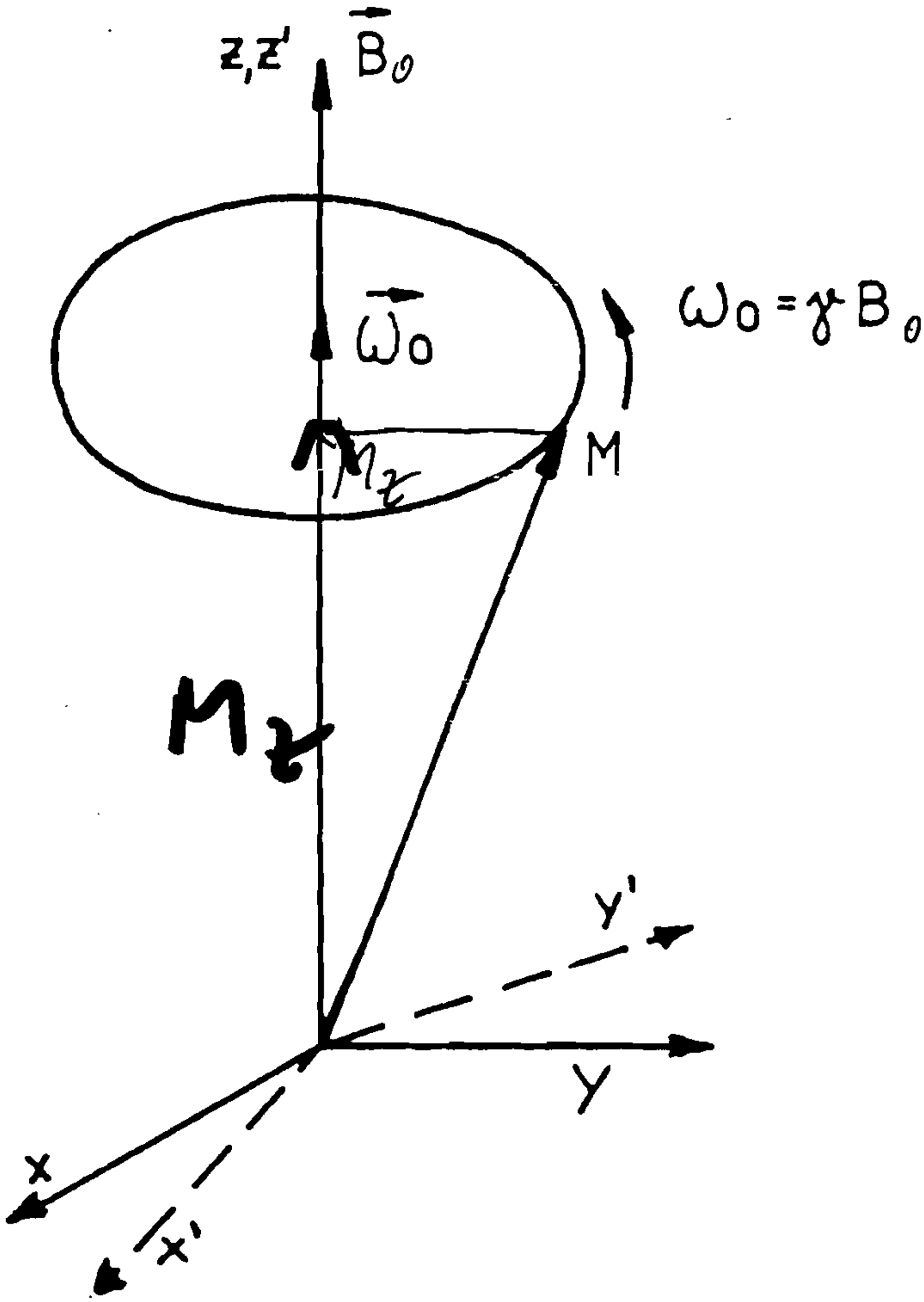
10 GHz $= 10^{10}$ Hz

3 kG $\hat{=}$ 0.3 Tesla

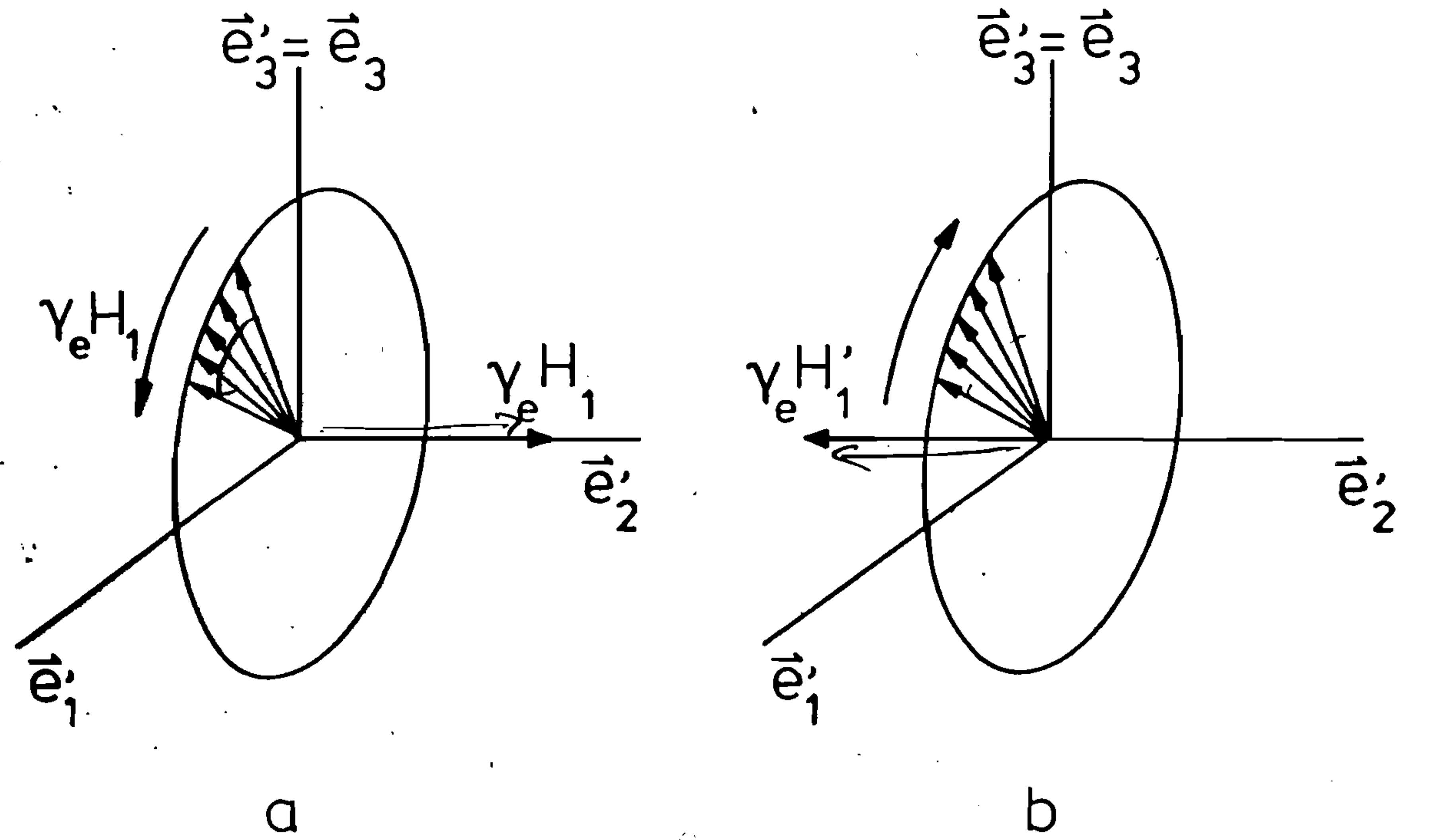
$\omega = \gamma \Gamma$



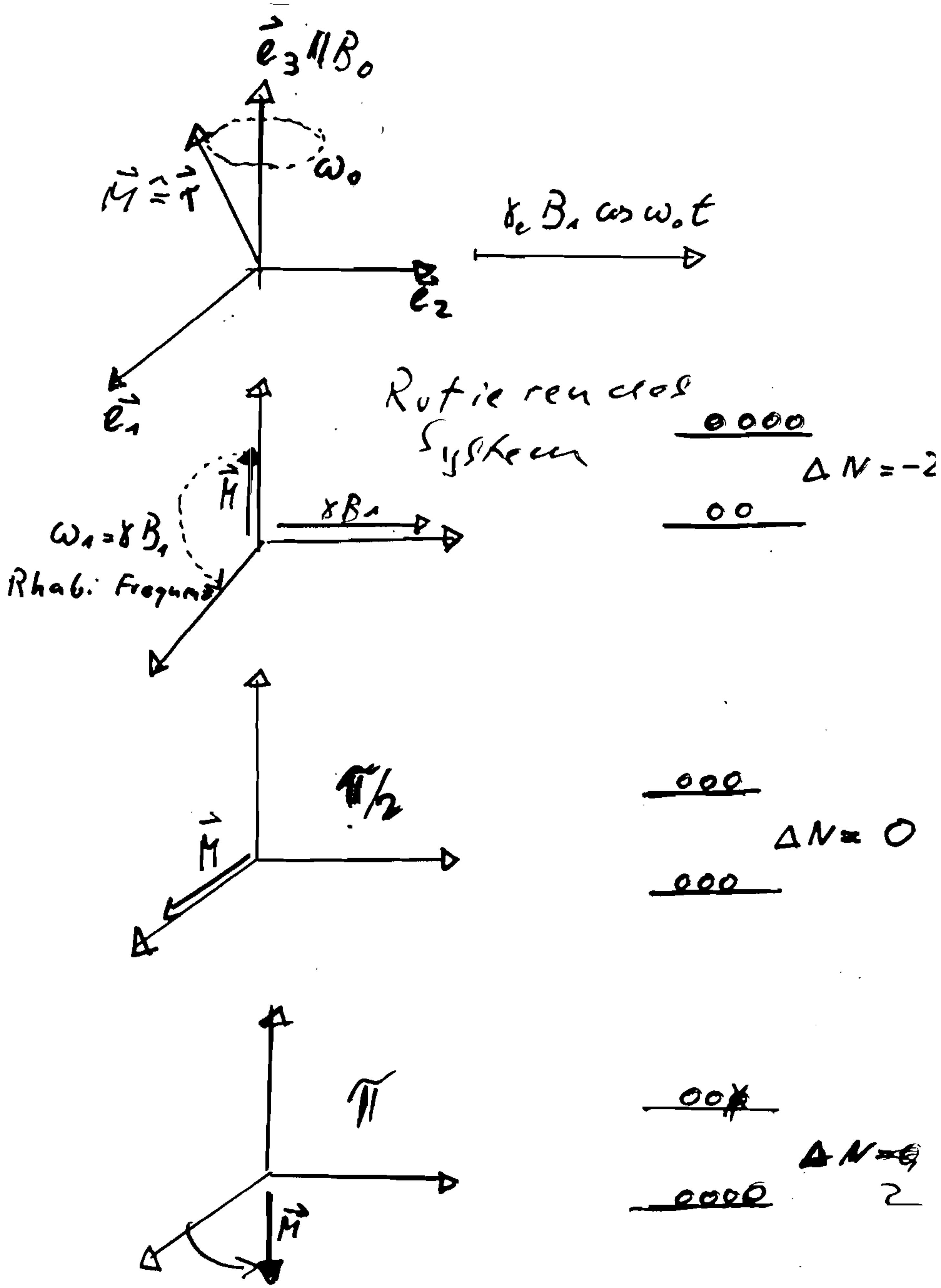

mit
Modulation



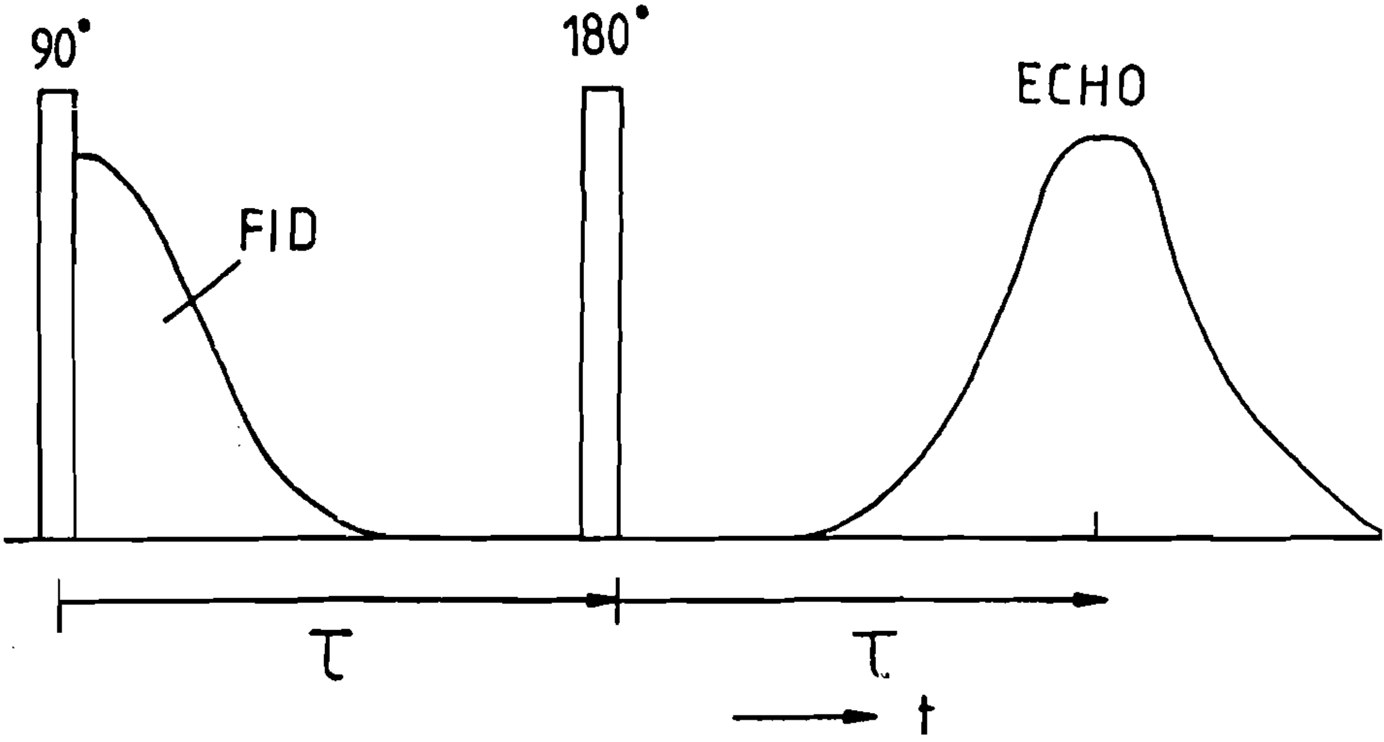
z,z'
$\vec{B}_0$
$\vec{\omega}_0$
$\omega_0 = \gamma B_0$
M
$M_z$
$M_z$
y'
Y
x
x'



$\vec{e}'_3 = \vec{e}_3$
$\gamma_e H_1$
$\gamma_e H_1$
$\vec{e}'_2$
$\vec{e}'_1$
a
$\vec{e}'_3 = \vec{e}_3$
$\gamma_e H'_1$
$\vec{e}'_2$
$\vec{e}'_1$
b

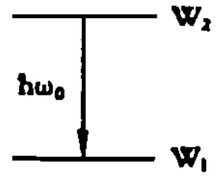


e3 ∥ B0
ω0
M ≙ r
γe B1 cos ω0 t
e2
e1
Rotierendes System
ΔN = -2
H
γB1
ω1 = γB1
Rhabi Frequenz
π/2
M
ΔN = 0
π
M
ΔN = 2

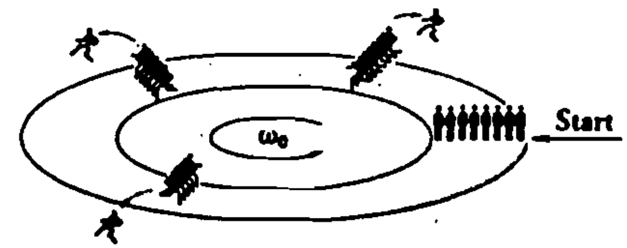


90°
180°
ECHO
FID
τ
τ
t

- $T_1$ = Lebensdauer der spontanen Emission
  = Longitudinale Relaxationszeit

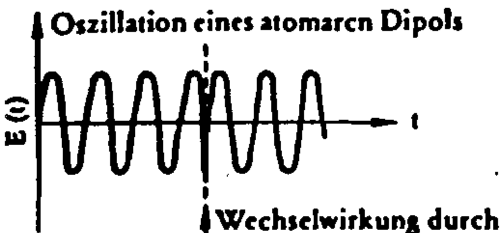


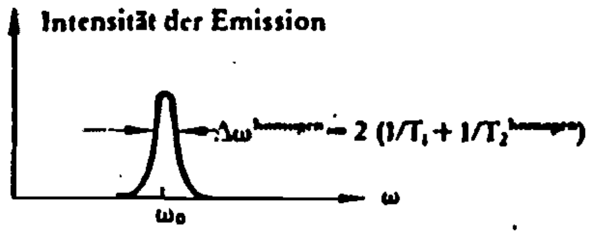

spontane Emission




Teilnehmerzahl nimmt ab

- $T_2^{homogen}$ = Phasenverlustzeit bei Atomen mit gleicher Umlauffrequenz $\omega_0$

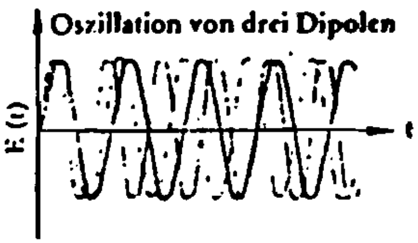


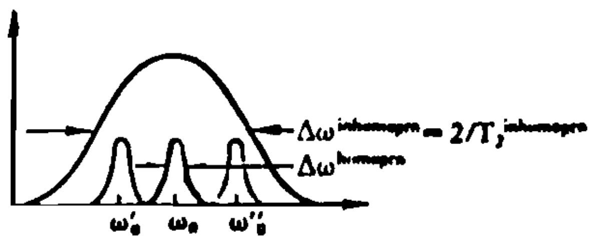



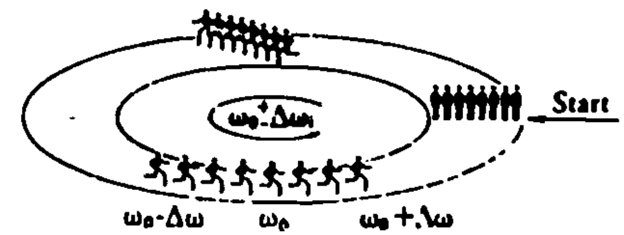


Phasenverluste z.B. beim Hindernislauf

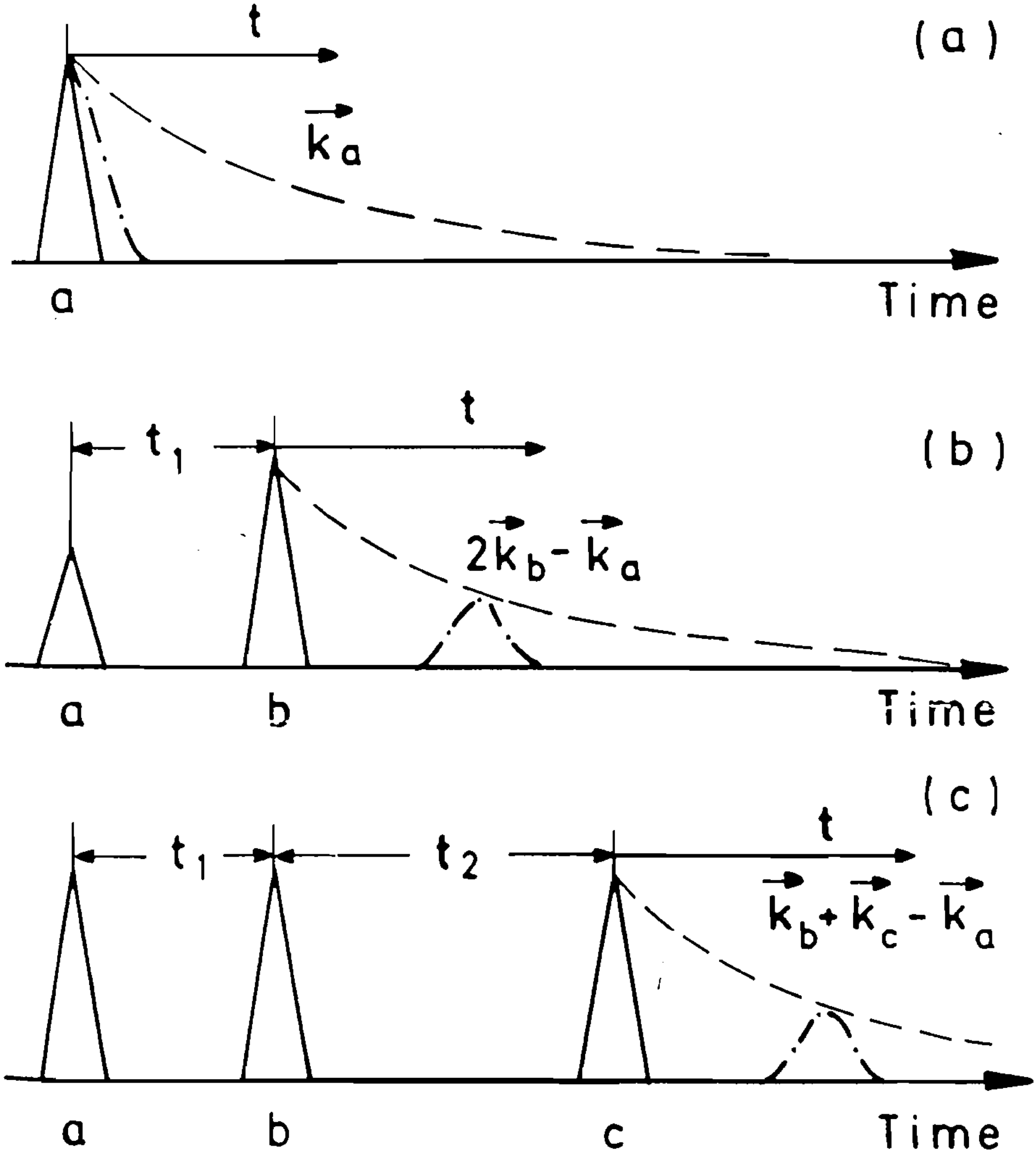
- $T_2^{inhomogen}$ = Phasenverlust bei Atomen mit unterschiedlicher Umlauffrequenz $\omega_0$




Auffächern wegen unterschiedlicher Schnelligkeit (bzw. Kreisfrequenz $\omega_0$) der Läufer



(a)
t
$\vec{k}_a$
a
Time
(b)
$t_1$
t
$2\vec{k}_b - \vec{k}_a$
a
b
Time
(c)
$t_1$
$t_2$
t
$\vec{k}_b + \vec{k}_c - \vec{k}_a$
a
b
c
Time

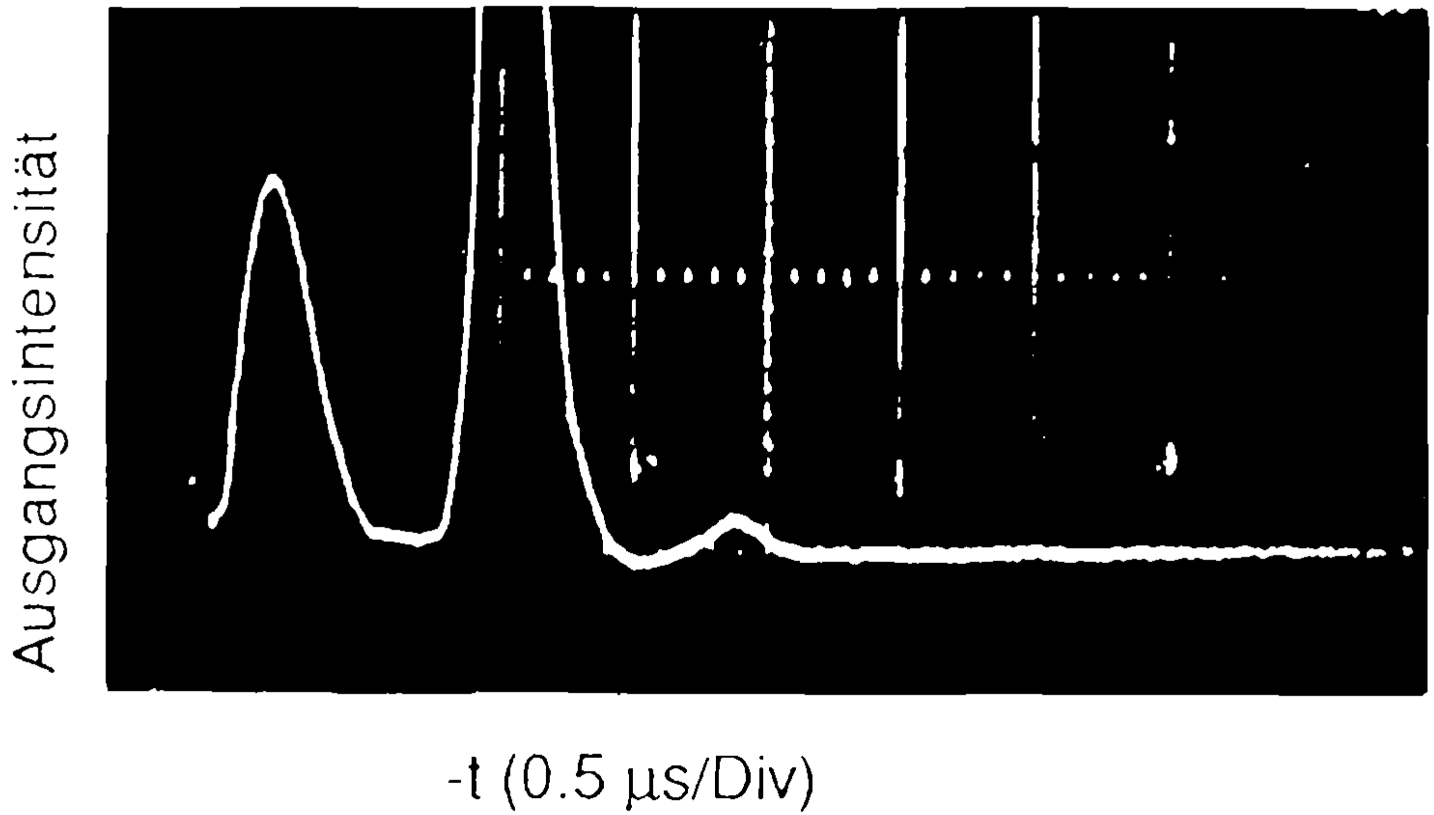



**Abb.12.11.** Oszillographenaufnahme des Photonen-Echos aus einer $SF_6$-Puls ist ein $\pi/2$-Puls eines $CO_2$-Lasers der 2. der $\pi$-Puls und der kleine d tonen-Echo [12.28]