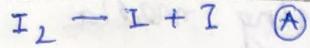
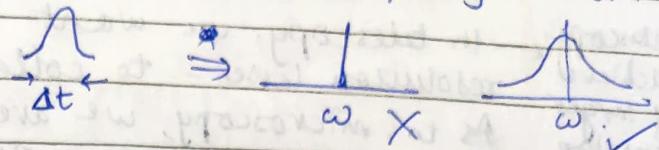
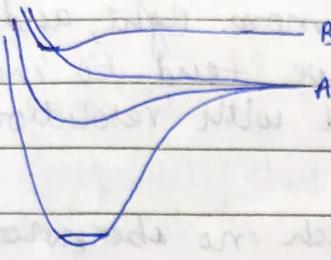


CSO 202



short pulse corresponds to a large no. of frequencies in frequency domain.



Δt inversely proportional to $\Delta\omega$.

Franck Condron principle.

internuclear separation

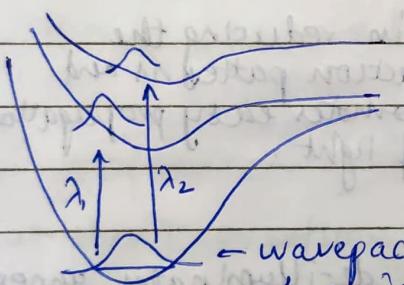
Note that the equilibrium (minima) distance of excited states are larger than ground state.

Born-Oppenheimer - motion of e^- is so fast, that their study can be done separately, assuming that the internuclear dist. is fixed.

620 nm

'6fs'

Gaussian pulse.
 $\exp(-at^2)$



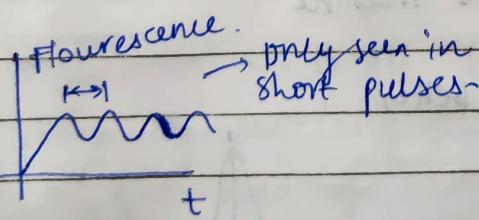
wavepacket.
not a single frequency
on exciting, it reaches different excited states.

Transform moment.
(point from where nothing else can change)
 $\Delta t \cdot \Delta\lambda \leq 0.44$
constant for a Gaussian

$$\Delta t \cdot \Delta\lambda \leq 0.44$$

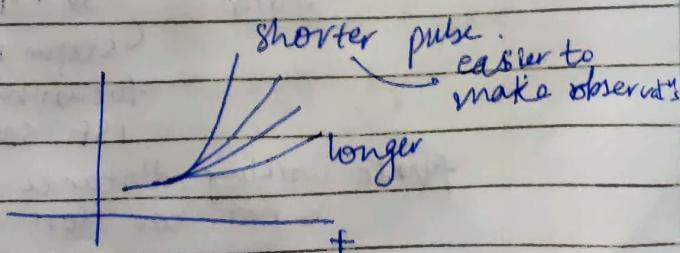
$$\lambda \cdot \Delta t = c$$

$$\Delta\lambda = -\frac{1}{c} \Delta t \cdot \Delta\lambda$$



wave packet interferes with itself;

put $\Delta t = 6\text{ fs}$, then get $\Delta\lambda$.
and $\lambda = 620\text{ nm}$, then you get
 $\Delta\lambda$. "the spread".



Tut 4

4. longer pulse vs. shorter pulse.

$$\text{f-number [f\#]} = \frac{f}{D} \approx \frac{1}{2NA} \rightarrow (n=1)$$

$$\theta = \frac{1.22\lambda}{D} = \frac{\lambda}{d}$$

$$N.A. = n \sin \theta$$

active area of the lens.



classmate

Date _____
Page _____

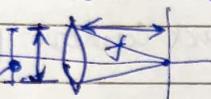
refractive index of the lensing media.

more the N.A., better the resolution.

^m telescope
achieved
by larger
lens size

In telescopes, we want to collect more light, and care about resolution lesser - to collect light, we tend to increase θ . As to microscopy, we are concerned with resolution, and to do so we again increase $\sin \theta$.

active diameter - distance upto which no aberration is present



$$\text{beam radius} = w_{\text{beam}}$$

$$w_{\text{lens}} = \frac{D}{4} = N.A. \cdot f/2$$

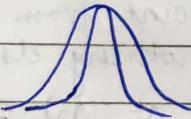
aperture
diameter

$$w_f = \frac{\lambda f}{\pi w_0} = \frac{4\lambda f}{\pi D} \approx \frac{2\lambda}{\pi(N.A.)} \rightarrow w_f \text{ is the size of the image of the beam formed at the focal length.}$$

If the numerical aperture is very large, then the paraxial approx. (ray optics) does not apply.

objective helps in reducing the diffraction pattern and index matching promotes easy propagation of light.

PSF. → how good you collect light



In STED, the PSF de-illuminates unnecessary parts.

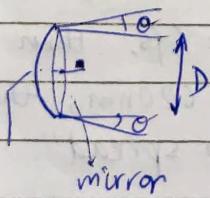
"Min flux": 2-3 nm: Stefan Hell's machine.

↳ "counterintuitive"

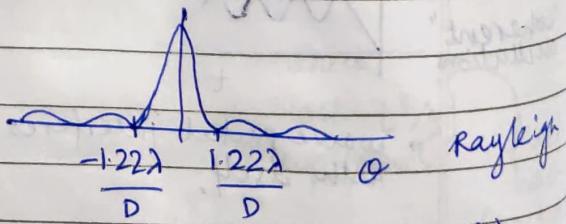
(In general) more light to see better.

Telescopy & Microscopy

How far you can see



$$\theta = \frac{1.22\lambda}{D}$$



$$\theta_{\min} = \frac{1.22\lambda}{D}$$

↳ 3D PSF.

↳ Stefan Hell's work was focussing on making this PSF smaller and smaller.

Finite working distance - safe enough - so that the objective is not too close enough to touch the object.

CSO 202.

Small angle approximation - works well if angle is small!

e.g. for optical trapping (Nobel 2018) always uses high N.A. where, where θ is large

Aim of module 2

(1) Collect max. light (2) Generate max. light.

"laser". "Fluorescence".

→ a) scattering b) fluorescence.

→ energy states. (E)

Observable parameters in quantum mechanical systems, has been studied. Energy states are a basic parameter, for which measurement can be made.

"Observable" under ~~operator~~ "operator math", given by Dirac

$\hat{H}f$

operator function

e.g. $\hat{H}\Psi = E\Psi$ Time integrated

E : observable

Ψ cannot be measured. It is present, but only $|\Psi|^2$ can be measured.

$|\Psi|^2$ is the observable.

probability

$$\begin{cases} \equiv \langle \Psi_2 \rangle \\ (\Psi_2^* \Psi_2) \end{cases}$$

$$\begin{cases} \equiv E_2 \\ (\Psi_2^* \Psi_2) \end{cases}$$

$$\begin{cases} \equiv E_1 \\ (\Psi_1^* \Psi_1) \end{cases}$$

$$\begin{cases} \equiv E_0 \\ (\Psi_0^* \Psi_0) \end{cases}$$

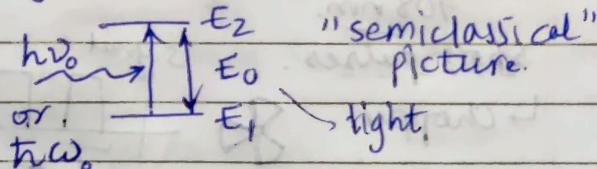
"Two-level systems"

which allow energy interactions.

basic system needed for interaction

complex conjugate.

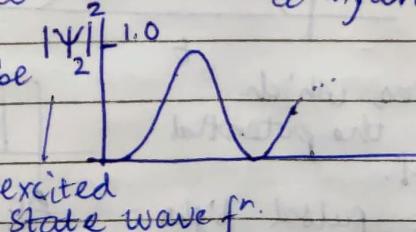
light matter interaction.



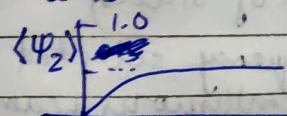
Elementary particles - electrons, photons } show the important property called "duality"

laws of nature hold, and it tries to come from excited state back to ground state.

There can also be oscillations "Rabi oscillations".



If we continuously illuminate a hydrogen gas sample, note that the gas moves around and it does not have a single energy (due to K.E.) so, only some molecules get resonant. And these oscillations occur, and result is



Maser discovered first.

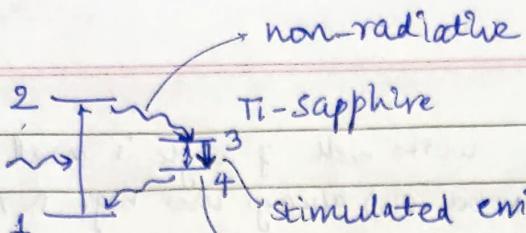
"inversion state".

Ruby laser - 3 level system

"Spontaneous emission"

decay from excited state.

to have this in 2-state Never we have more system is impossible. to Ψ_1 as compared to Ψ_2 .



stimulated emission

very low populated state, so we can stimulate the emission by sending the resonant energy.

"stimulated emission" is NOT coherent.

spontaneous emission is coherent

The emission in the initial times generated is random, but once they are present in the system other photons generated are coherent with these pre-existing photons, and also directional.

In all the above, we obtain a "continuous laser".

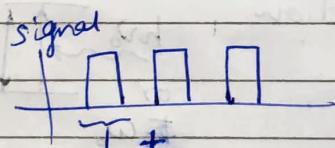
In real life it is not easily possible to have this continuous laser. The gain β of a cavity does not always remain so high to remain a constant and continuous laser.

There is ripples & oscillations.

Rb ω_0
↓
708 nm.

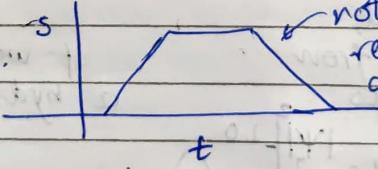
short pulses.

↳ chopper.



so we use chopper leads to all currents which further introduces errors.

expand timescale.



not exact rectangle, it is a trapezoid.

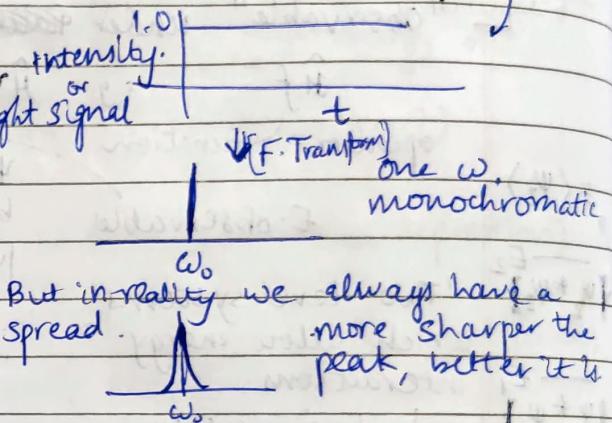
wavepacket: a group of states, which would also move in the potential like a classical object.

Zewail introduced these pulsed lights to study atoms. But can't do individual atoms/ ~~states~~ states, only wavepacket (bunch of states)

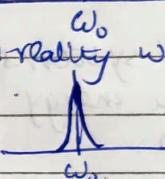
frequency selected molec. beam

continuous beam: technique: "Individual objects" alone"

solutions: when we study solutions, and claim that we are studying single molecule, it was "statistically" single molecule (one molecule in a region of study, statistically on an avg.)



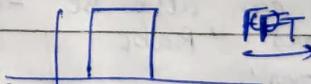
But in reality we always have a spread.



NMR: looking for correct frequency which is resonant.

earlier they used to probe over all freq. individ.

later they realised on-off pulse is best.



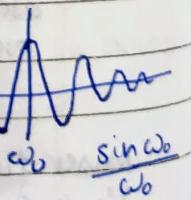
Δt

$\Delta \nu$ or $\Delta \omega$

of \rightarrow

$\Delta \tau$

FFT



CS0202

S Moerner :
& Betzig. → single molecule fluorescence. } done by continuous lasers
could see due to turning on and off.

Pulsed lasers: half reaction \rightarrow photochemistry.
Lasers doing on/off.

work on individual reaction system

- STED by Stefan Hell.
- ① turn on by base.
- ② turn off using donut beam

"turn on turn off"

single molecule fluorescence,
Blinking,
molecular beams.

the blinking on/off is due to individual fluorophores.

"seeing & resolving them"

Minsky

confocal microscopy. → uses C.W. lasers.

fluorescence is collected from exactly one frame, by using an aperture so that only one frame's light passes thru.



light can be generated by different planes.
↓ depth it gets focussed at different planes

multiphoton microscopy. - selecting one plane, no need for aperture

Single molecule localization microscopy (PALM)

uses pulsed laser. since multiphoton microscopy has non-linearity.

it involves $\mathbb{P}(X, E)$ polarisability

$\xrightarrow{\text{no interaction}} X^{(0)} \cdot E^{(0)} \rightarrow \text{C. field}$
 $\xrightarrow{\text{no dependency}}$

e.g. $X^{(2)} \cdot E^{(2)}$
term is non-zero
only if the system
is not centrosymmetric. $\xrightarrow{\text{ignored.}}$
 $X^{(1)} \cdot E^{(1)}$ → linear effects
 \dots
 \dots non linear.

(All even order terms vanish in centrosymmetric systems).

$X^{(3)} \cdot E^{(3)}$ → non-linear effects which is present in all general systems.

Since water does not absorb these. λ .

400 nm → useful for electronic transition studies.
Second harmonic of 800 nm.

gets generated due to non-centrosymmetric crystal used.

In C.W. lasers, before the non-linear interaction occurs, other processes take place.

If pulsed interaction is there, there is a possibility of $\xrightarrow{\text{e.g. heat effect.}}$ the non-linear effects.

All the non-linear effects are studied using pulsed lasers.

Groen
Mayer
units.
(cross sectn
wrt linear)

$10^{-6}, 7, 8 \rightarrow$ if the (reaction) cross section of linear $\chi^{(1)} E_0$
 $10^{-12}, 13, 14 \rightarrow$ processes as '1', then the cross section of $\chi^{(2)} E_0$
& $\chi^{(3)} E_0$ is 10^{-6} & 10^{-12} resp.

Pulse shaping, grating \rightarrow physical Fourier transform.

Time domain:

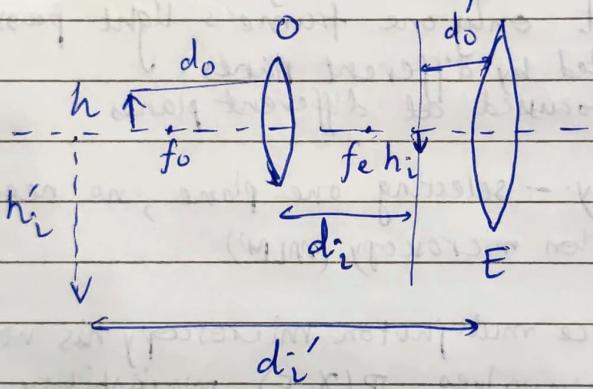
DAPI remains & TexasRed bleaches out.

unless & until you know how & where to measure, the perfect measurement is still not there, and PALM/STORM

- ① Modules
- ② Halina-Lasers
- ③ McQuarrie Ch-28
- ④ Barnwell · Hangouts & forums

Tutorial-5

Q2.



$$m = m_o m_e$$

$$m_o = \frac{d_i}{d_o} \quad m_e = \frac{d_i'}{d_o}$$

$$\frac{1}{f} = \frac{1}{f_o} + \frac{1}{d_i'}$$

$$d_i + d_o' = 280 \text{ mm}$$

$$d_o = 620 \text{ mm}$$

g1. Rayleigh criterion

Above limit

$$d_{\min} = \frac{1.22\lambda}{D} \quad d = \frac{\lambda}{2n \sin \alpha} = \frac{\lambda}{2 \cdot NA}$$

→ Diffraction of light from slits

→ Microscopy

→ Angular resolution (for objects only apart)

→ spatial resolution
(for close by object)

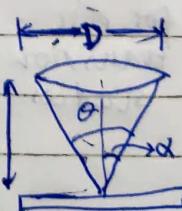
$$\left[\frac{0.61\lambda}{n \sin \alpha} = \frac{0.61\lambda}{NA} \right]$$

$$\left[\frac{0.5\lambda}{NA} \right] \text{ in microscopy}$$

$$NA = n \sin \alpha$$

$$\alpha = \sin \alpha = \frac{\theta}{2} = \frac{D}{2d}$$

$$\alpha = \sin \alpha = \frac{\theta}{2} = \frac{D}{2d}$$



$$\theta = \frac{1.22\lambda}{D}$$

acceptance angle

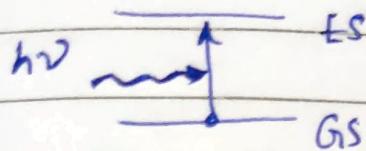
$$\theta = \frac{0.61\lambda}{5 \sin \alpha}$$

$$\theta = \frac{1.22\lambda}{25P}$$

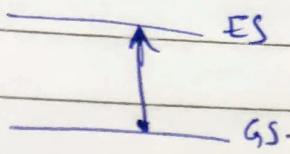
Now since

$$\theta = \frac{\lambda}{d} = \frac{1.22\lambda}{D}$$

CSO202



naturally tends to come down to G.S. from ES.

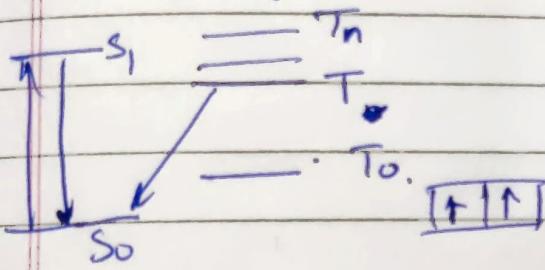


stimulated emission

light shined on E.S.-molecules.

phase of light emitted by $ES \rightarrow GS$ transition & the light shined on it is same (coherent)

Sablonsky diagram.



fluorescence: $S_1 \rightarrow S_0$.

phosphorescence: $T_1 \rightarrow S_0$.

cross system.
(singlet \leftrightarrow triplet)

photo bleaching : molecules losing the ability to undergo fluorescence.

synergistic effect

excitation laser } phase difference
depletion laser }