

# Polarization Spectroscopy

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**PHYS 605** Advanced Topics: Laser Spectroscopy

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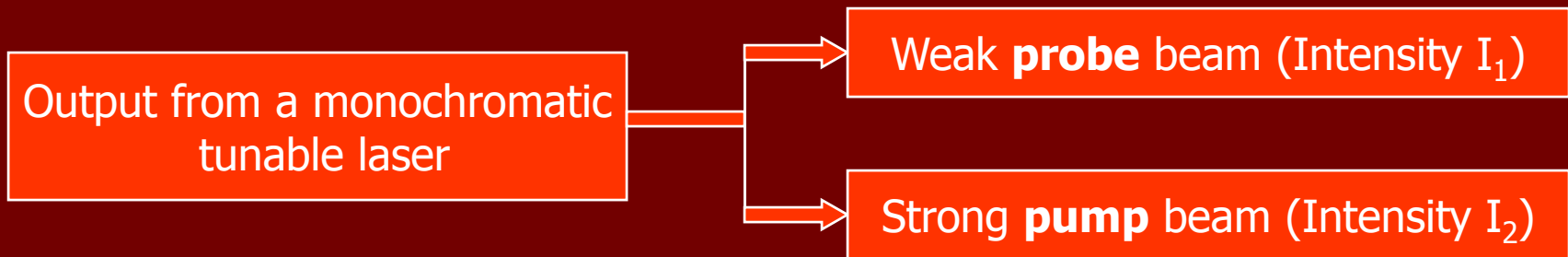
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# Polarization Spectroscopy

A set of spectroscopic techniques based on polarization properties of light.

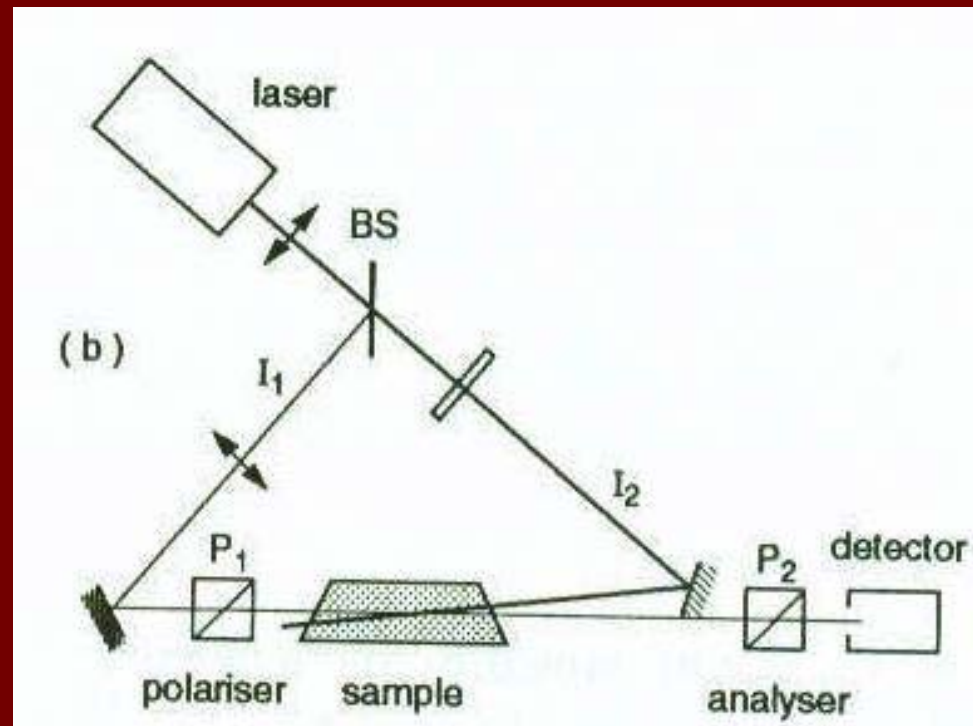
# Basic Principle

- The output from a monochromatic tunable laser is split into a 'weak' probe beam (with the intensity  $I_1$ ) and a 'stronger' pump beam (with the intensity  $I_2$ )



# Basic Principle

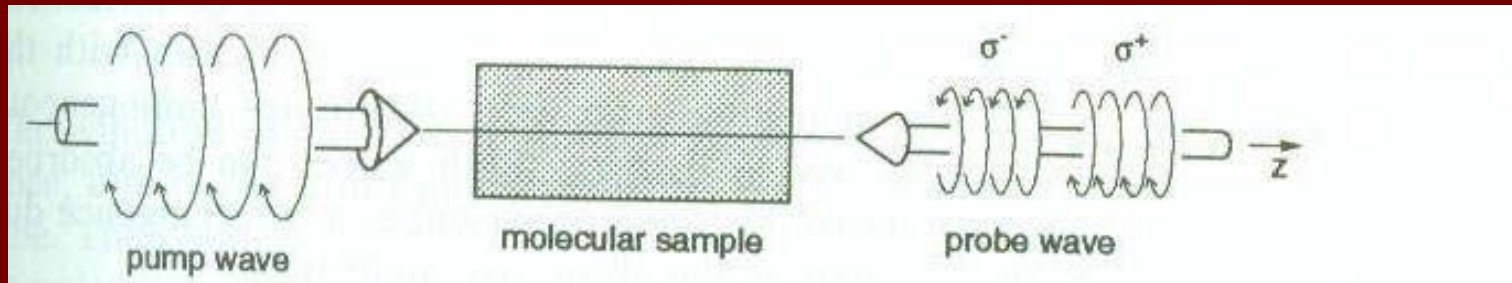
- The **probe** beam passes through a linear polarizer ( $P_1$ ), the sample cell, and a second linear polarizer ( $P_2$ ) which is crossed with  $P_1$ .



# Basic Principle

- Without the pump laser the sample is isotropic and the detector D behind  $P_2$  receives only a very small signal caused by the residual transmission of the crossed polarizer.
- After having passed through a  $\lambda/4$  plate which produces a circular polarization, the pump beam travels in the opposite direction through the sample cell.
- When the laser frequency  $\omega$  is tuned to a molecular transition  $(J'',M'') \rightarrow (J',M')$ , molecules in the lower level  $(J'',M'')$  can absorb the pump wave.
- The quantum number M which describes the projection of J onto the direction of light propagation, follows the selection rule  $\Delta M = \pm 1$  for the transitions  $M'' \rightarrow M$  induced by  $\sigma^+$ -circularly polarized light ( $M'' \rightarrow M' = M'' + 1$ ).

# Basic Principle



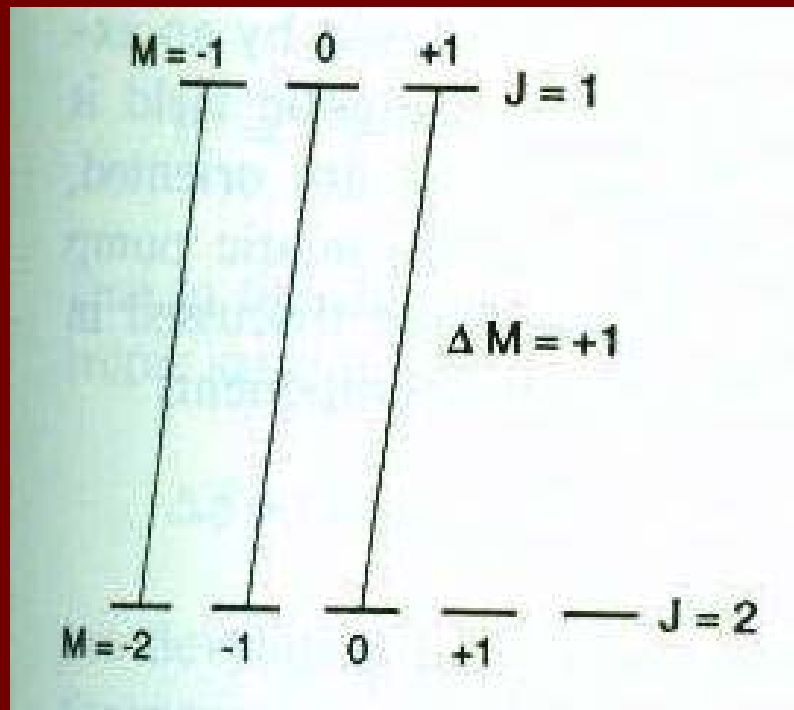
Linearly polarized probe wave as a superposition of  $\sigma^+$  and  $\sigma^-$  components

# Basic Principle

- Due to saturation the degenerate  $M$  sublevels of the rotational level  $J''$  become partially or completely depleted.
- The degree of depletion depends on the pump intensity ( $I_2$ ), the absorption cross section  $\sigma(J'',M'' \rightarrow J',M')$ , and on possible relaxation processes which may repopulate the level ( $J'',M''$ ).
- The cross section  $\sigma$  depends on  $J''$ ,  $M''$ ,  $J'$ , and  $M'$ .

# Basic Principle

- In the case of P or R transitions  $\Delta J = -1$  or  $+1$ , not all the M sublevels are pumped.



Level scheme for a P transitions  $J=2 \rightarrow J=1$

# Basic Principle

- For example, from levels with  $M''=+J$  no P transitions with  $\Delta M=+1$  are possible while for transitions the levels  $M'=J'$  are not populated.
- This implies that the pumping process produces an unequal saturation and with it a nonuniform population of the  $M$  sublevels which is equivalent to anisotropic distribution for the orientations of the angular momentum vector  $J$ .
- Such an anisotropic sample becomes birefringent for the incident, linearly polarized probe beam.
- Its plane of polarization is slightly rotated after having passed the anisotropic sample. (analogous to Faraday effect)


# Basic Principle

- For Polarization spectroscopy no magnetic field is needed.
- Contrary to the Faraday effect where all molecules are oriented, here only those molecules which interact with the monochromatic pump wave show this nonisotropic orientation.
- This is the subgroup of molecules with the velocity components:

$$V_z \pm \Delta V_z = \frac{(\omega_0 - \omega)}{k} \pm \frac{\gamma}{k}$$

Where  $\Delta V_z$  is determined by the homogenous linewidth  $\delta\omega = \gamma$

# Basic Principle

- For  $\omega \neq \omega_0$  the probe wave which passes in the opposite direction through the sample interacts with a different group of molecules in the velocity interval , and will therefore not be influenced by the pump.
- If, however, the laser frequency  $\omega$  coincides with the center frequency  $\omega_0$  of the molecular transition within its homogenous linewidth  $\delta\omega$  (i.e.,  $\omega = \omega_0 + \delta\omega \rightarrow V_z = 0 \pm \Delta V_z$ ), both waves can be absorbed by the same molecules and the probe wave experiences a birefringence due to nonisotropic M distribution of the absorbing molecules.
- Only in this case will the plane of polarization of the probe wave be slightly rotated by  $\Delta\theta$  and the detector D will receive a Doppler-free signal every time the laser frequency  $\omega$  is tuned across the center of a molecular absorption line.

# References

- 7.4, Polarization Spectroscopy, Laser Spectroscopy by Wolfgang Demtröder

Thank You