

ЛЕКЦИЯ 4

*Классическая модель
взаимодействия лазерного
излучения с веществом :
спектроскопия и фазовое
управление молекулярными
колебаниями*

Основы взаимодействия излучения с веществом

$\alpha(Q)$ - поляризуемость

$$\alpha(Q) = \alpha_0 + \left(\frac{\partial \alpha}{\partial Q} \right)_0 Q + \dots$$

$$P = N\alpha(Q)E$$

$$P = N\alpha_0 E + N \left(\frac{\partial \alpha}{\partial Q} \right)_0 QE$$

Энергия взаимодействия
молекулы со световой волной

$$H = -pE = -\alpha(Q)E^2$$

Сила воздействия на
молекулярные колебания

$$F = -\frac{\partial H}{\partial Q} = \frac{\partial \alpha}{\partial Q} E^2$$

Материальные уравнения нелинейной среды

$$\operatorname{rot} \vec{E} = -\frac{1}{c} \frac{\partial \vec{H}}{\partial t} \quad \operatorname{rot} \vec{H} = \frac{1}{c} \frac{\partial \vec{D}}{\partial t} \quad \operatorname{div} \vec{D} = 0 \quad \operatorname{div} \vec{H} = 0 \quad \vec{D} = \vec{E} + 4\pi \vec{P}$$

Волновое уравнение

$$\operatorname{rot} \operatorname{rot} \vec{E} + \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = -\frac{4\pi}{c^2} \frac{\partial^2 \vec{P}}{\partial t^2}$$

$$\Delta \vec{E} - \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = \frac{4\pi}{c^2} \frac{\partial^2 \vec{P}}{\partial t^2}$$

Материальные уравнения нелинейной среды

$$\overset{\vee}{P} = \overset{\vee}{P}(\overset{\vee}{E}) \quad P = \kappa E + \chi^{(2)} E^2 + \chi^{(3)} E^3 + \dots$$

$$\overset{\vee}{P} = \overset{\vee}{P}_l + \overset{\vee}{P}_{nl} \quad \Delta \overset{\boxtimes}{E} - \frac{1}{c^2} \frac{\partial^2 \overset{\vee}{E}}{\partial t^2} - \frac{4\pi}{c^2} \frac{\partial^2 \overset{\vee}{P}_l}{\partial t^2} = \frac{4\pi}{c^2} \frac{\partial^2 \overset{\vee}{P}_{nl}}{\partial t^2}$$

$$\begin{aligned} P_\alpha(t) = & \int_0^\infty \kappa_{\alpha\beta}(\tau) E_\beta(t-\tau) d\tau + \\ & + \int_0^\infty \int_0^\infty \chi_{\alpha\beta\gamma}^{(2)}(\tau_1, \tau_2) E_\beta(t-\tau_1) E_\gamma(t-\tau_2) d\tau_1 d\tau_2 + \\ & + \int_0^\infty \int_0^\infty \int_0^\infty \chi_{\alpha\beta\gamma\delta}^{(3)}(\tau_1, \tau_2, \tau_3) E_\beta(t-\tau_1) E_\gamma(t-\tau_2) E_\delta(t-\tau_3) d\tau_1 d\tau_2 d\tau_3 \end{aligned}$$

Элементарная модель гармонического осциллятора

$$\frac{d^2 Q}{dt^2} + 2\gamma \frac{dQ}{dt} + \omega_0^2 Q = F(t)$$

$$Q(t) = \int_0^{\infty} F(t - \theta) h(\theta) d\theta$$

$h(\theta)$ - функция Грина

$$h(0) = 0$$

$$\ddot{h} + 2\gamma \dot{h} + \omega_0^2 h = 0$$

$$\dot{h}(0) = 1$$

$$h(\theta) = \frac{1}{\Omega} \exp(-\gamma\theta) \sin(\Omega\theta)$$

$$\Omega = (\omega_0^2 - \gamma^2)^{1/2}$$

Монохроматическая накачка

$$F(t) = F_0 \exp(i\omega t)$$

$$Q(t) = F_0 \int_0^{\infty} \exp[i\omega(t - \theta)] h(\theta) d\theta = F_0 \exp(i\omega t) \int_0^{\infty} h(\theta) \exp(-i\omega\theta) d\theta$$

$$Q(t) = Q_0 \exp(i\omega t) \quad Q_0 = F_0 \chi(\omega)$$

$$\chi(\omega) = \int_0^{\infty} h(\theta) \exp(-i\omega\theta) d\theta$$

$$\chi(\omega) = \frac{1}{\omega_0^2 - \omega^2 + 2i\gamma\omega}$$

Накачка сверхкоротким импульсом

$$F(t) = C\delta(t) \qquad Q(t) = Ch(t)$$

Соотношения между восприимчивостью
и функцией Грина

$$\chi(\omega) = \int_{-\infty}^{\infty} h(\theta) \exp(-i\omega\theta) d\theta$$

$$h(\theta) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \chi(\omega) \exp(i\omega\theta) d\omega$$

Пара коротких импульсов

$$F(t) = C\delta(t) + C\delta(t - \tau)$$

$$Q(t) = C \begin{cases} h(t), & t < \tau \\ h(t) + h(t - \tau), & t \geq \tau \end{cases}$$

$$\gamma = 0 \qquad h(\theta) = \frac{1}{\omega_0} \sin(\omega_0 \theta)$$

$$Q(t) = \frac{C}{\omega_0} \begin{cases} \sin(\omega_0 t), & t < \tau \\ \sin(\omega_0 t) + \sin[\omega_0(t - \tau)], & t \geq \tau \end{cases}$$

Фазовое управление

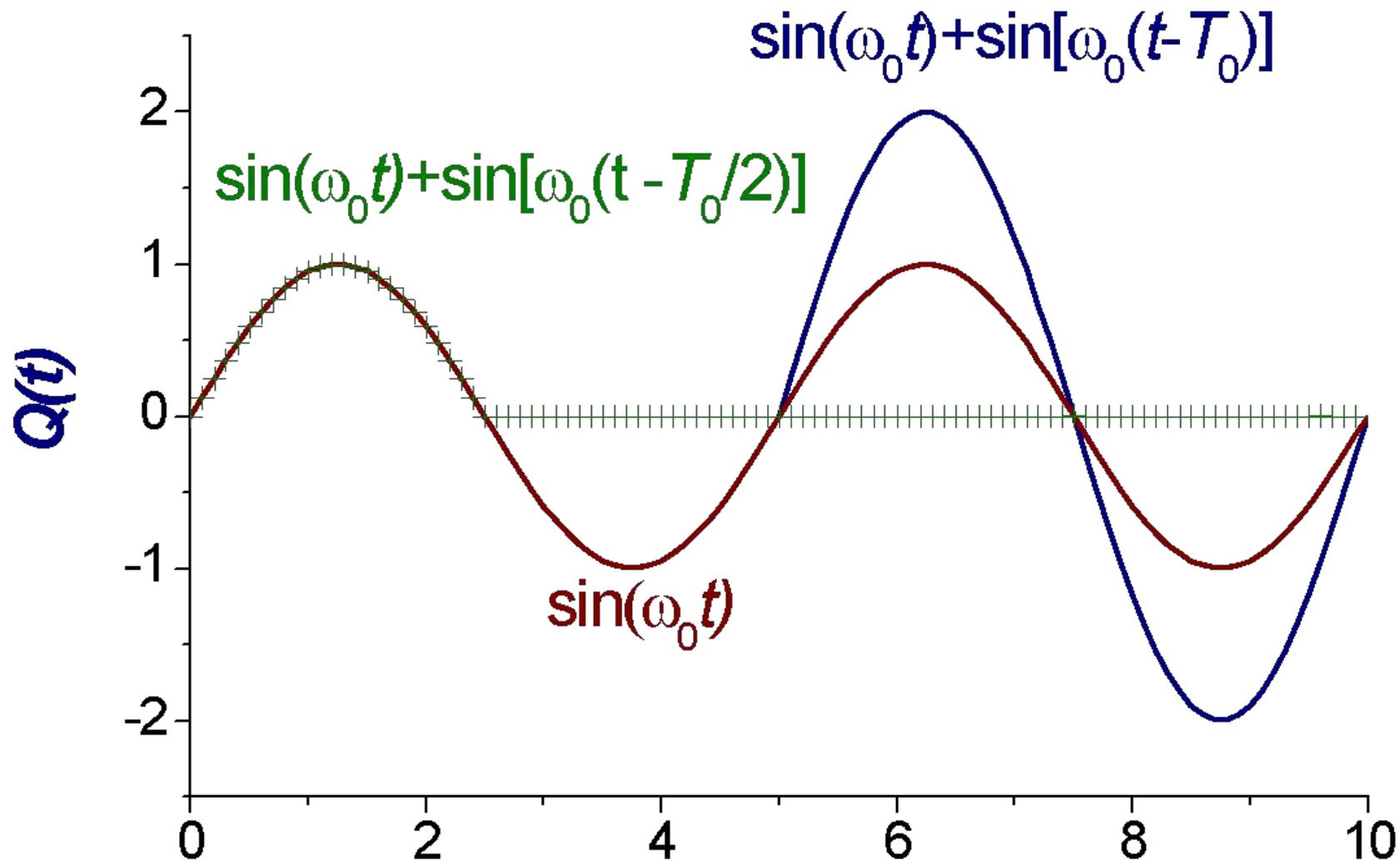
$$\tau = T_0/2 = \pi/\omega_0 \quad \sin[\omega_0(t - \tau)] = \sin(\omega_0 t - \pi) = -\sin \omega_0 t$$

$$Q(t) = \frac{C}{\omega_0} \begin{cases} \sin(\omega_0 t), & t < \tau \\ 0, & t \geq \tau \end{cases}$$

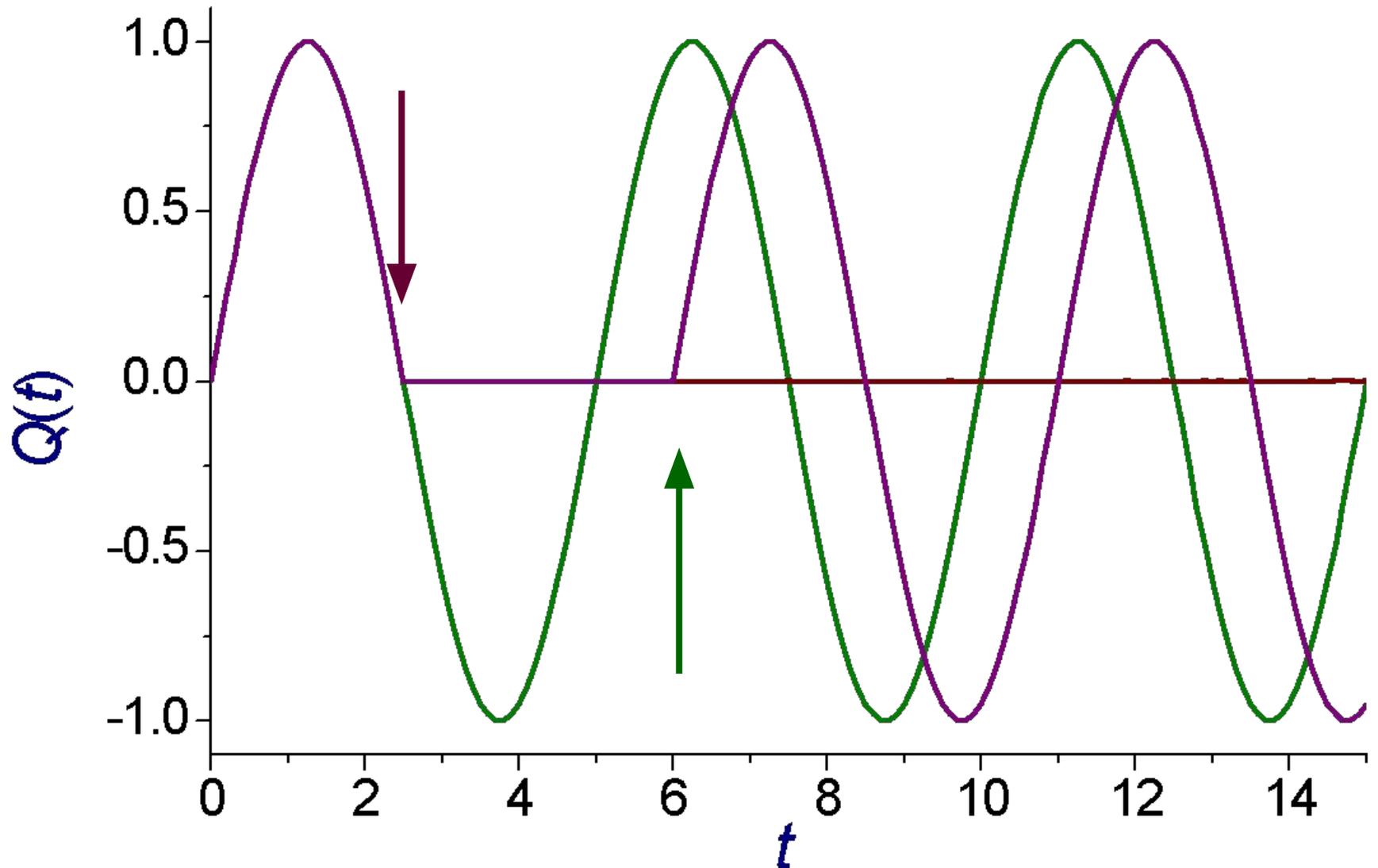
$$\tau = T_0 = 2\pi/\omega_0$$

$$Q(t) = \frac{C}{\omega_0} \begin{cases} \sin(\omega_0 t), & t < \tau \\ 2\sin(\omega_0 t), & t \geq \tau \end{cases}$$

Фазовое управление гармоническим осциллятором



Гашение и возбуждение гармонических колебаний



Цуг коротких импульсов

$$F(t) = C \sum_{n=0}^N \delta(t - n\tau) \quad Q(t) = C \sum_{n=0}^N h(t - n\tau), t > N\tau$$

$$\gamma = 0 \quad h(\theta) = \frac{1}{\omega_0} \sin(\omega_0 \theta)$$

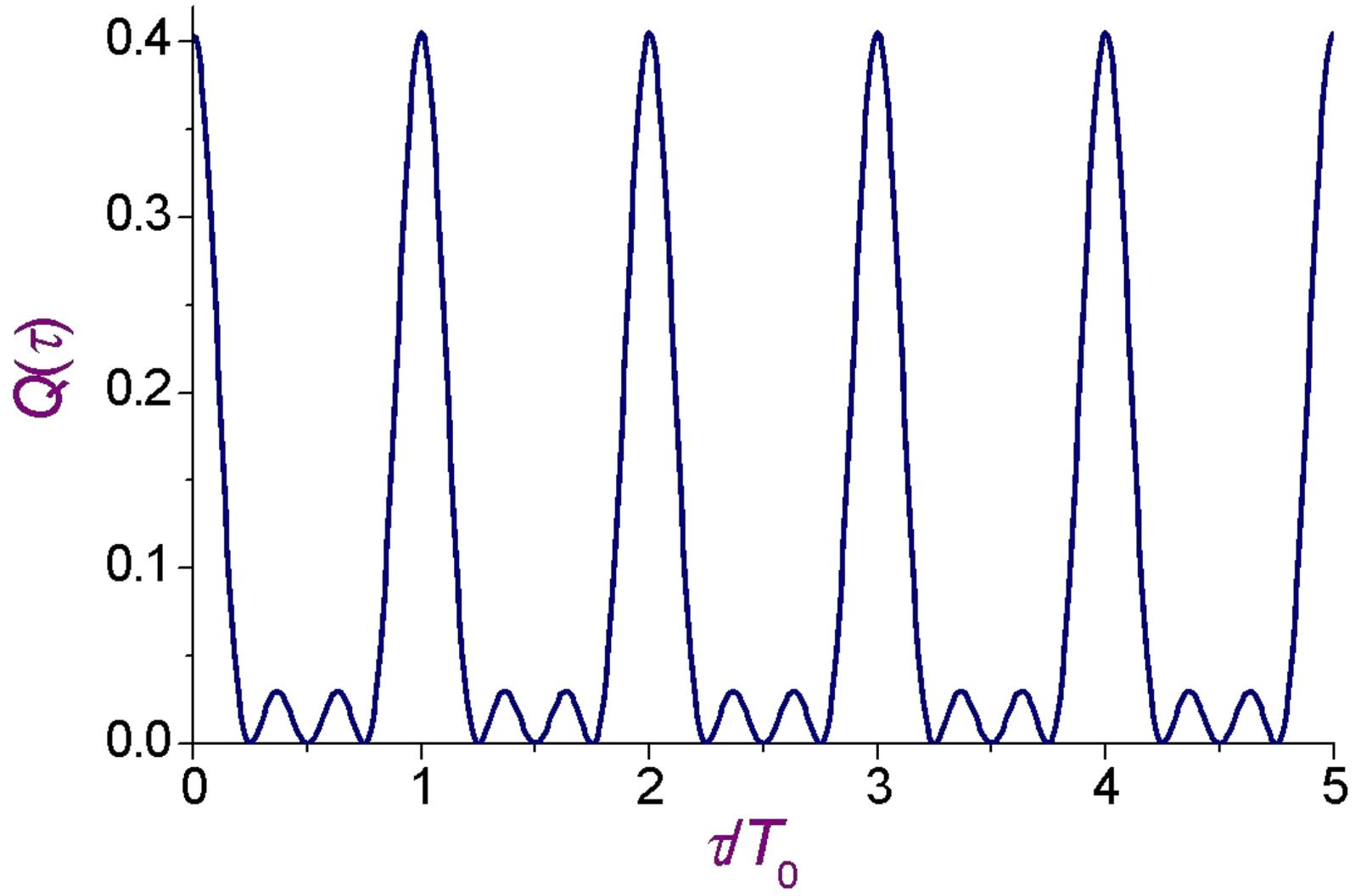
$$Q(t) = C \sum_{n=0}^N \frac{1}{\omega_0} \sin[\omega_0(t - n\tau)]$$

$$Q_0(\tau) = \frac{CT_0}{2\pi} \frac{\sin\left(\frac{\pi N\tau}{T_0}\right)}{\sin\left(\frac{\pi\tau}{T_0}\right)}$$

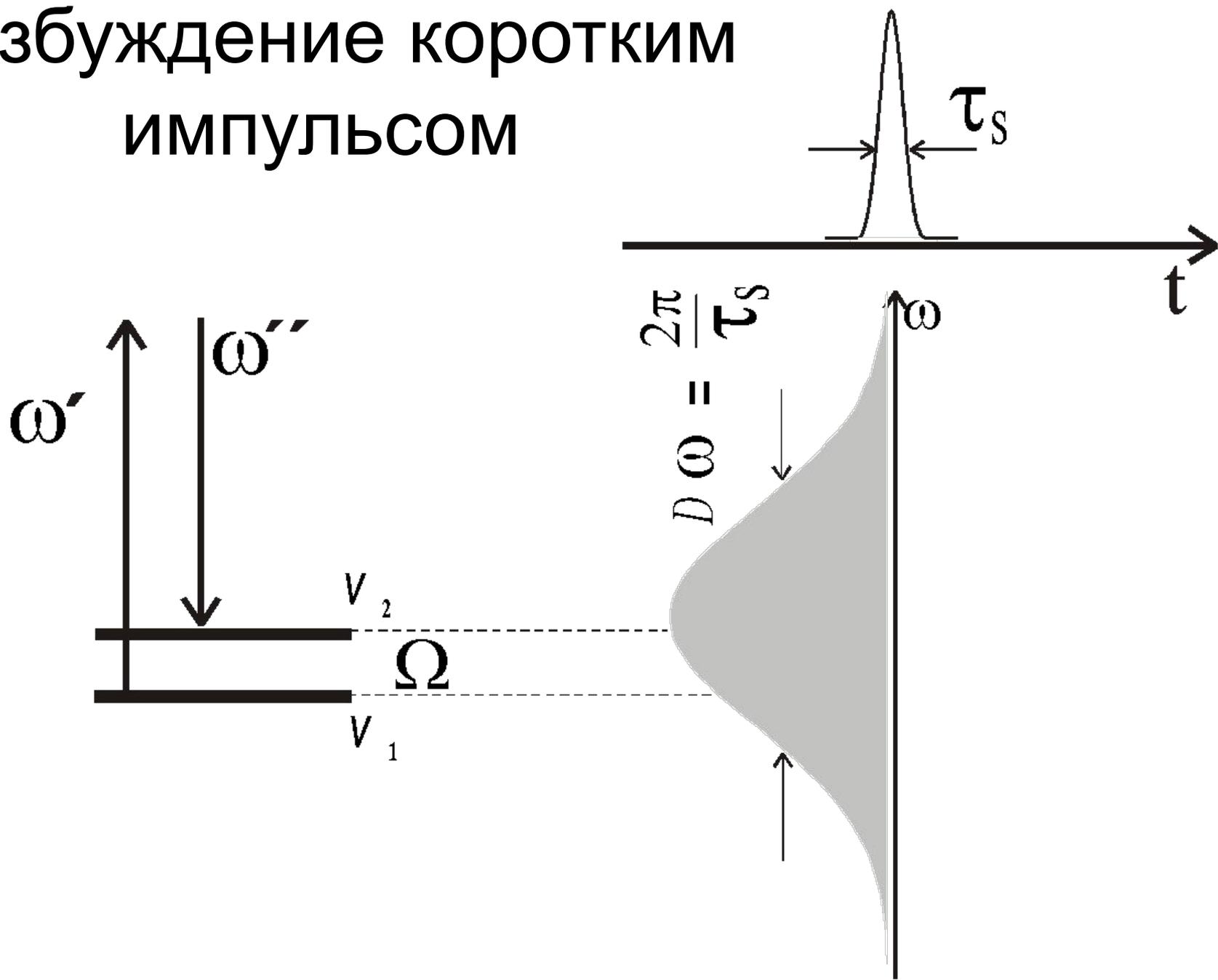
$$Q(t) = Q_0(\tau) \sin[\omega_0(t - t_0)]$$

$$t_0 = \frac{N-1}{2} \tau$$

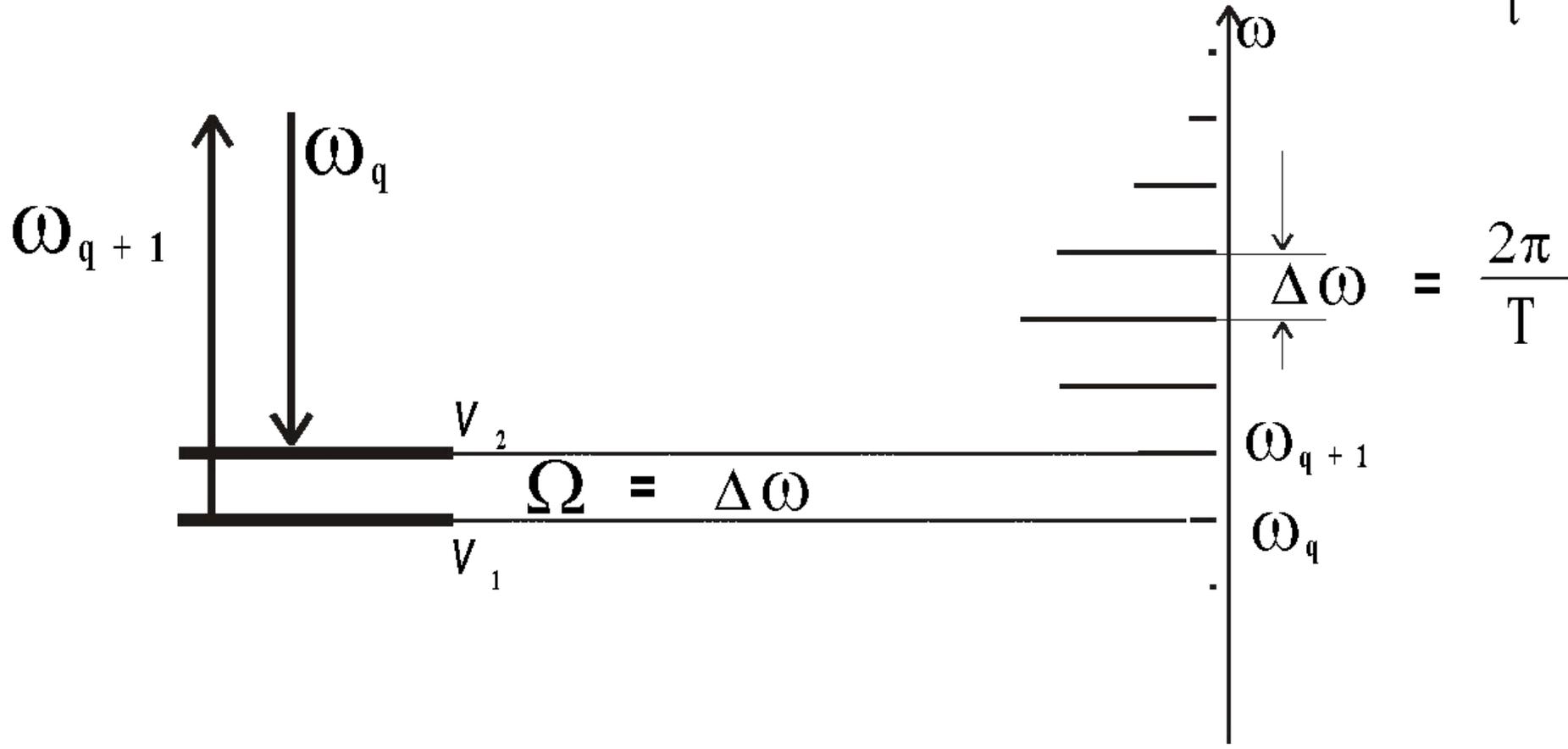
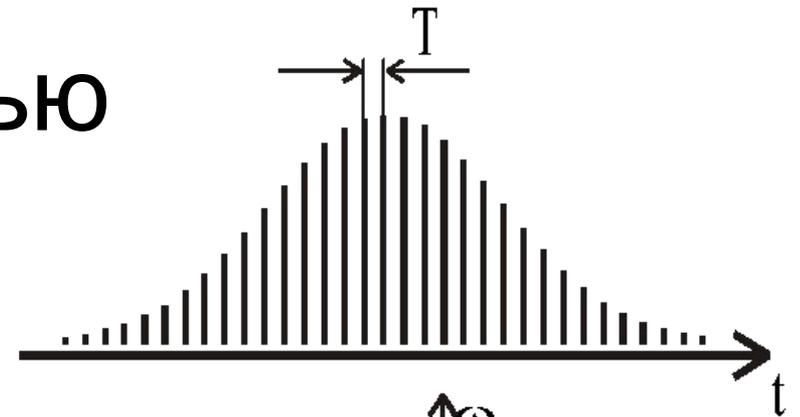
Синхронное возбуждение



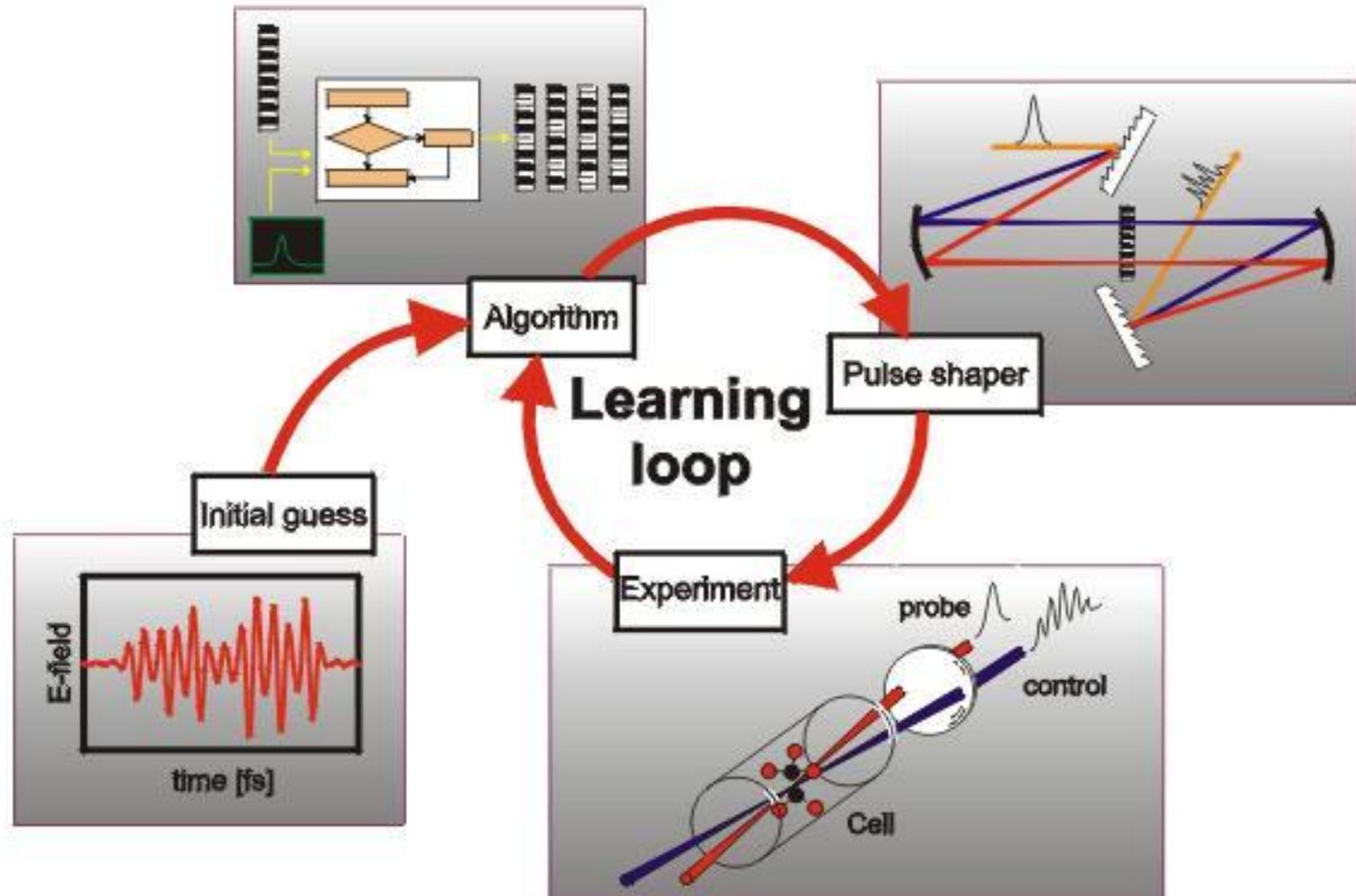
Возбуждение коротким импульсом



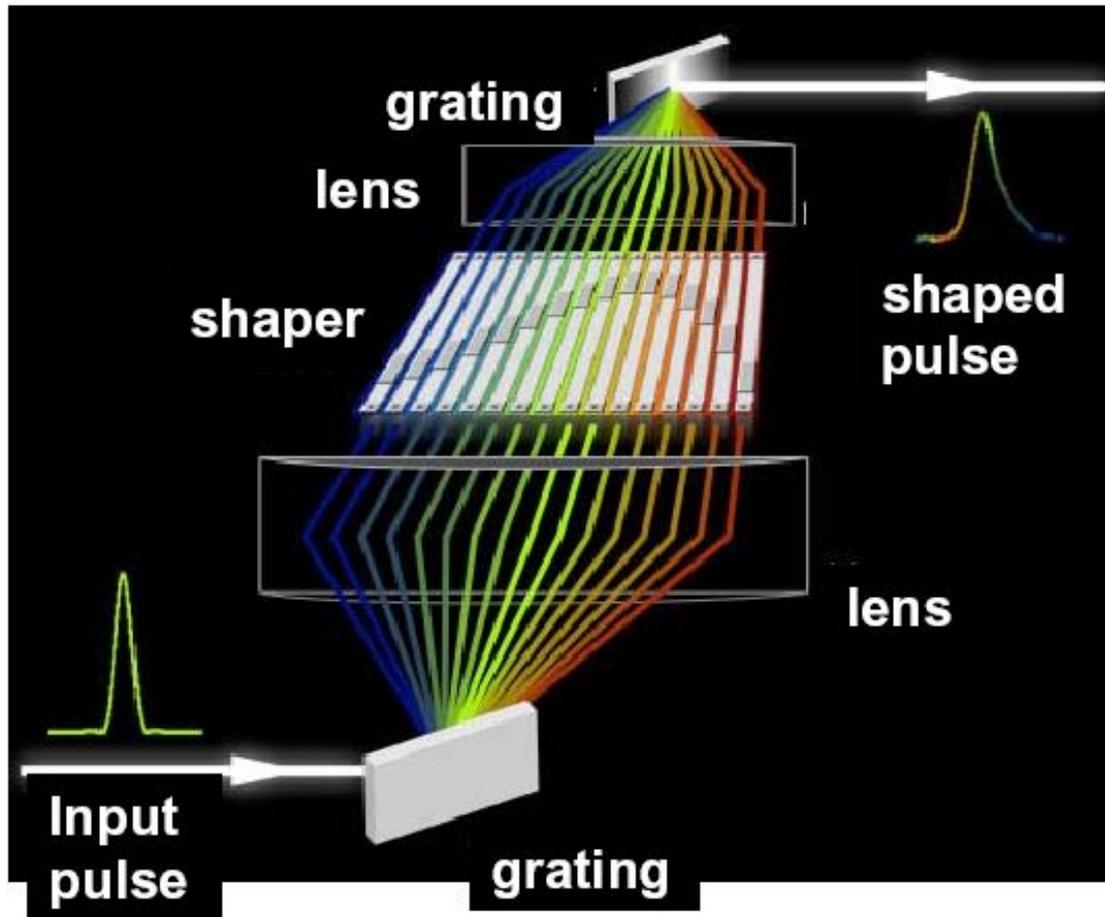
Возбуждение последовательностью импульсов



Оптимальный контроль

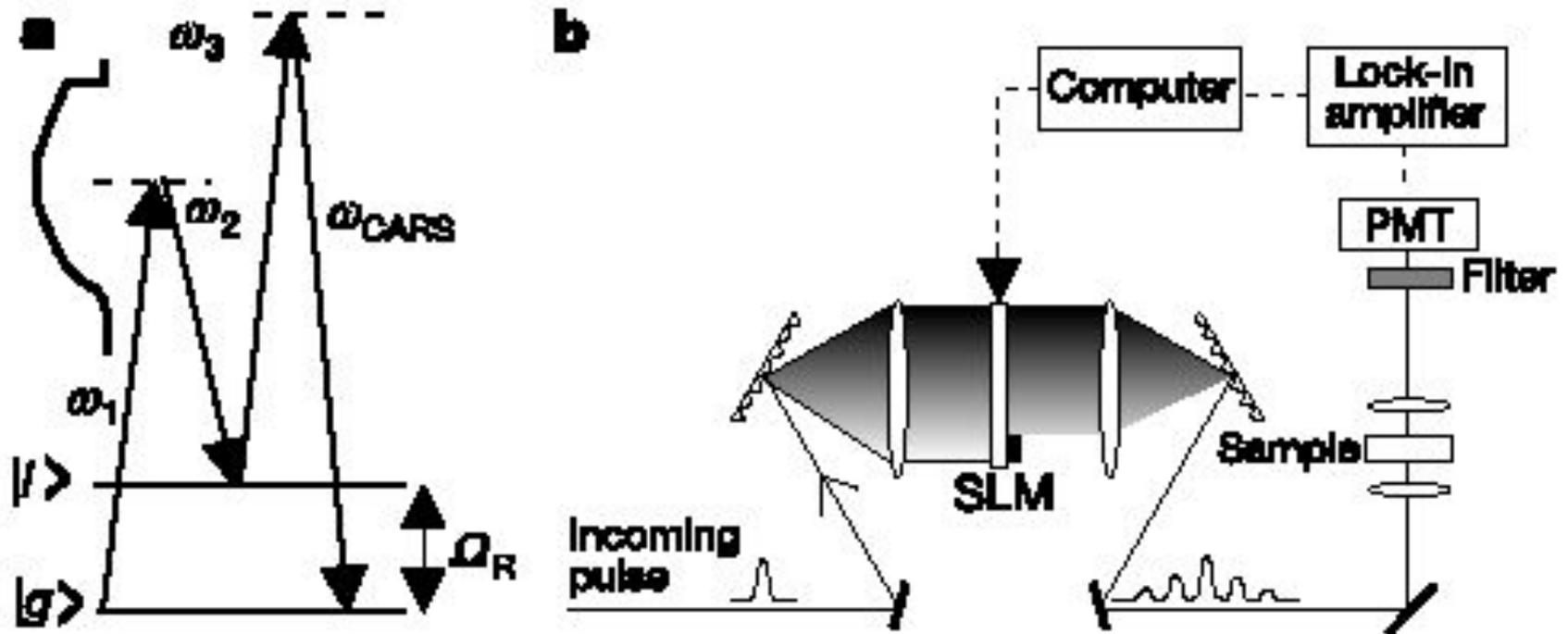


Pulse shaping



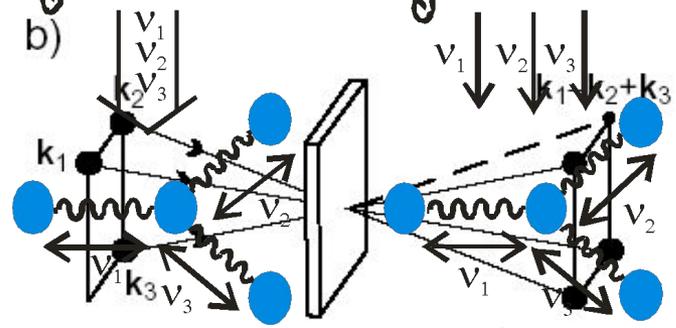
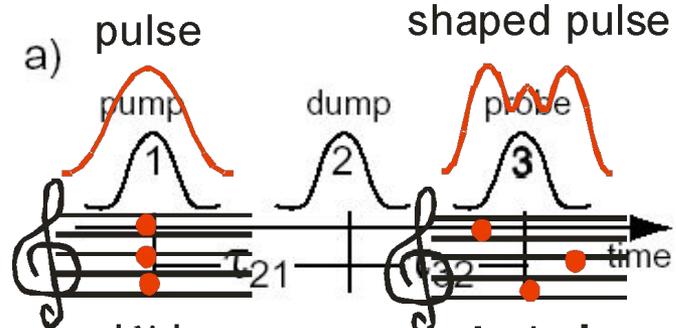
(A.M. Weiner)

Квантово-управляемое КАРС

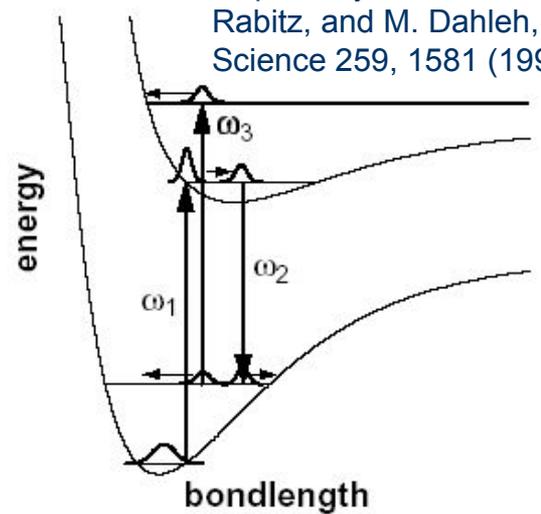


Playing a unique melody... to a molecule

transform-limited

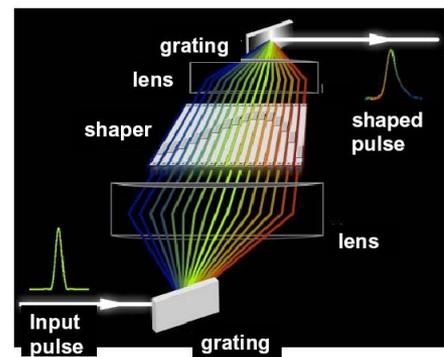


Inspired by W.S. Warren, H. Rabitz, and M. Dahleh, Science 259, 1581 (1993).



Frequency shifting, spectral tailoring, pulse shaping... Why should we bother?

Tools

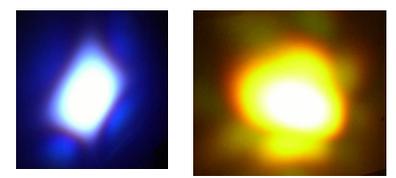


Spatial light modulator

by A.M. Weiner

Photonic-crystal fiber

Frequency-shifted, spectrally tailored, optimally time-ordered output



- Supercontinuum generation
- Frequency shifting
- Spectral tailoring
- Pulse shaping

