Electromagnetically induced transparency for x rays

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Atomic, Molecular, and Optical Physics Group

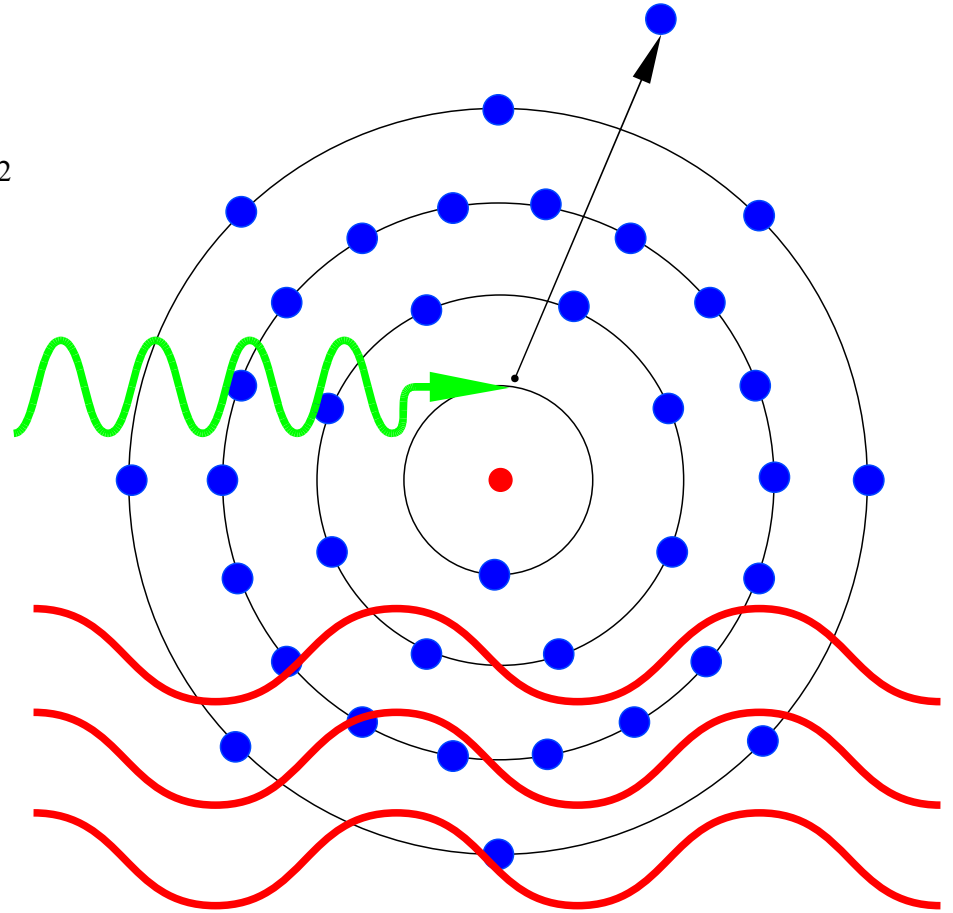Chemistry Division

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Contents

X-ray probe of laser-dressed atoms

- Atoms are in the field of an **optical laser** (800 nm, $I = 10^{13}\ \mathrm{W\,cm^{-2}}$ Ti:Sapphire laser system)

- Atomic ground state electrons are neither excited nor ionized

- Rydberg final states are **dressed**

- Probed by x rays

- Strong laser-Rydberg electron interaction

- Need **sophisticated** theoretical treatment!

**[Buth, Santra, Phys. Rev. A 75, 033412 (2007),
Buth, Santra, Young, Phys. Rev. Lett. 98, 253001 (2007)]**

Quantum electrodynamic description of atoms

- Non-relativistic **quantum electrodynamics** in electric dipole approximation; two modes (laser plus x rays)

- **Hartree-Fock-Slater** one-electron model

- Complex absorbing potential (CAP) to treat continuum electron

- Diagonalization of **Floquet-type** matrix for laser-dressed atomic energy levels

- Core excited state relaxes by Auger decay => leads to additional line width

- X-ray probe is one-photon process
  => Non-Hermitian Rayleigh-Schrödinger perturbation theory

[Buth, Santra, Phys. Rev. A 75, 033412 (2007)
Buth, Santra, Cederbaum, Phys. Rev. A 69, 032505 (2004)]
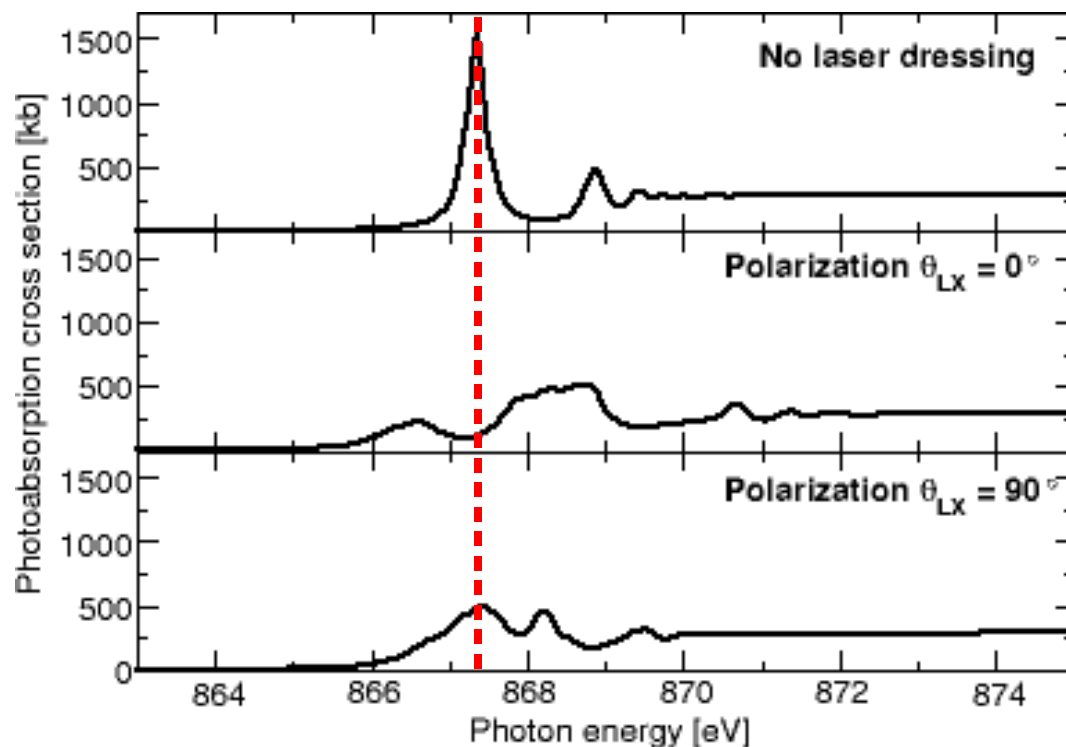
Total x-ray absorption cross section

$$\sigma_{1s}(\omega_X, \vartheta_{LX}) = \sigma_{1s}^{\parallel}(\omega_X)\cos^2(\vartheta_{LX}) + \sigma_{1s}^{\perp}(\omega_X)\sin^2(\vartheta_{LX})$$

- Atom is **cylindrically deformed** along the laser polarization axis

- Dependence on angle between polarizations ϑ_{LX}

- Atomic properties described by $\sigma_{1s}^{\parallel}(\omega_X)$, $\sigma_{1s}^{\perp}(\omega_X)$

- Electron correlations and **non-dipole effects** ignored
  => manifest in deviations from the angular behavior

[Buth, Santra, Phys. Rev. A 75, 033412 (2007)]
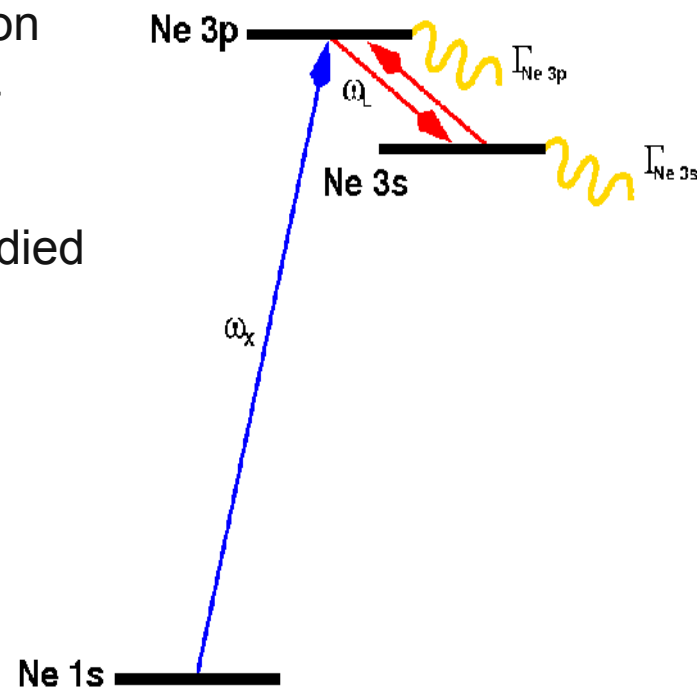
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Neon K edge

- For **parallel laser and x-ray polarizations** transparency at the $1s \rightarrow 3p$ transition

- Suppression but no transparency for **perpendicular polarizations**

- Absorption and emission of up to **20 laser photons** to converge calculations

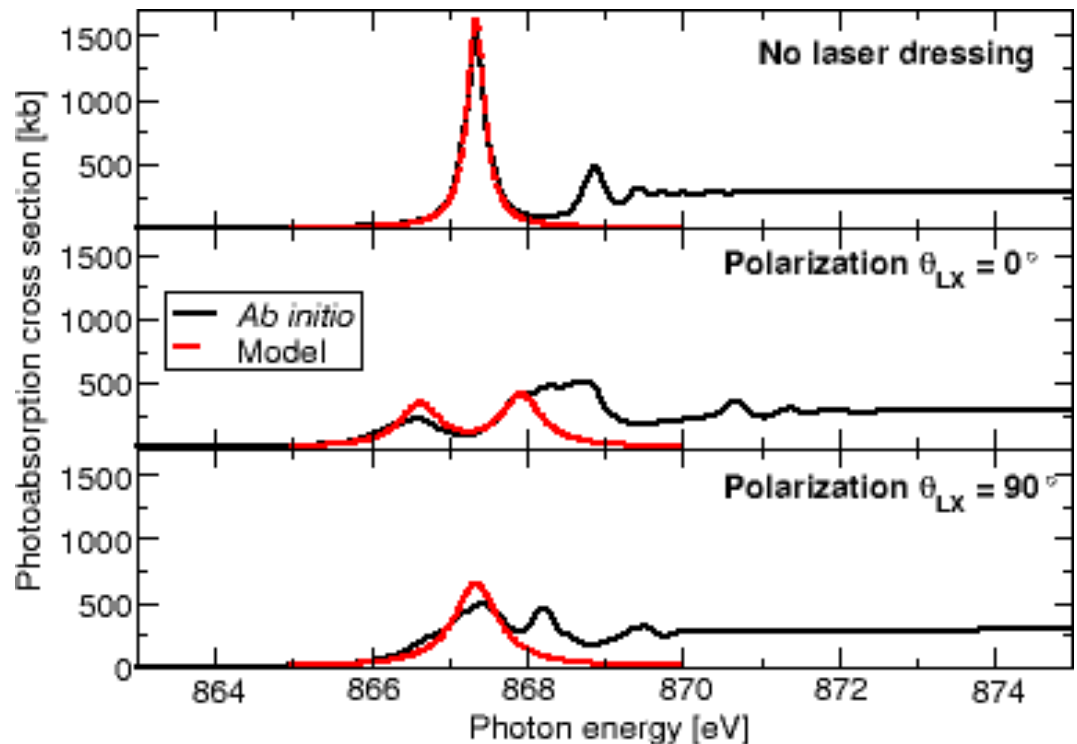**[Buth, Santra, Young, Phys. Rev. Lett. 98, 253001 (2007)]**

Electromagnetically induced transparency (EIT)

- Gas is **opaque** for light at an intraatomic transition
- Gas becomes **transparent** for this light by laser-dressing

- So far EIT for **optical** wavelengths has been studied
- We investigate EIT for **x rays**

- **Review:** Fleischhauer, Imamoğlu, Marangos, **Rev. Mod. Phys. 77, 633 (2005)**

- EIT in terms of a Λ -type three-level model
- Two-color light
  - Probe transition $\mathrm{Ne\,1s} \rightarrow \mathrm{Ne\,3p}$
  - Laser coupling $\mathrm{Ne\,3p} \rightarrow \mathrm{Ne\,3s}$
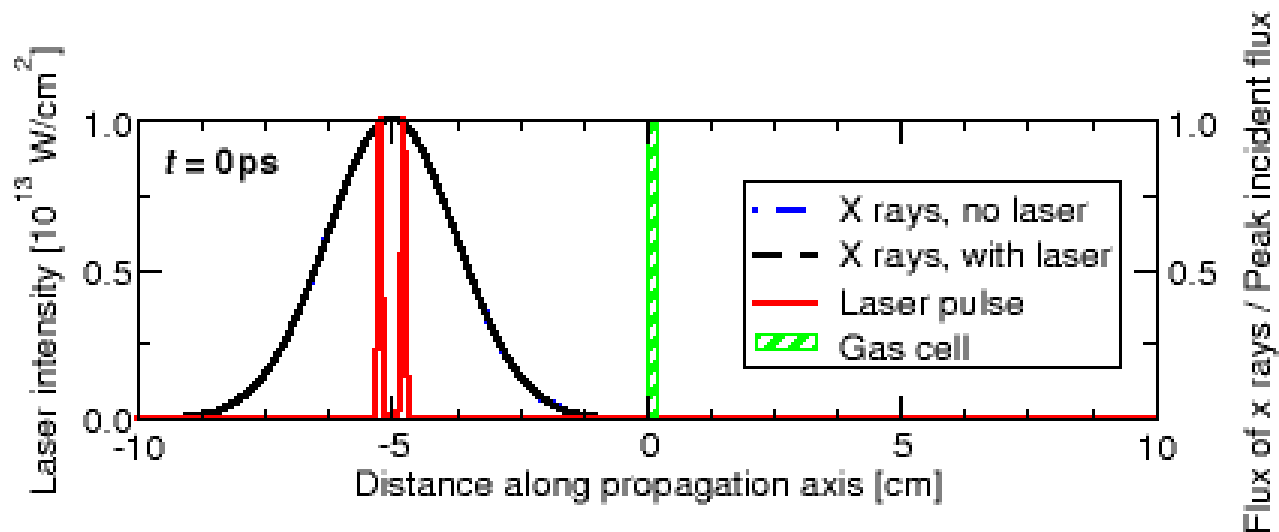
Λ-type EIT model for neon

- Assume dominant physics results from **three levels** of neon: $1s$, $3s$, and $3p$

- Parameters are level energies and widths; dipole moments between $3p$ and $1s$, $3s$

- **Other levels** contribute

- Multiphoton processes

[Buth, Santra, Young, Phys. Rev. Lett. 98, 253001 (2007)]
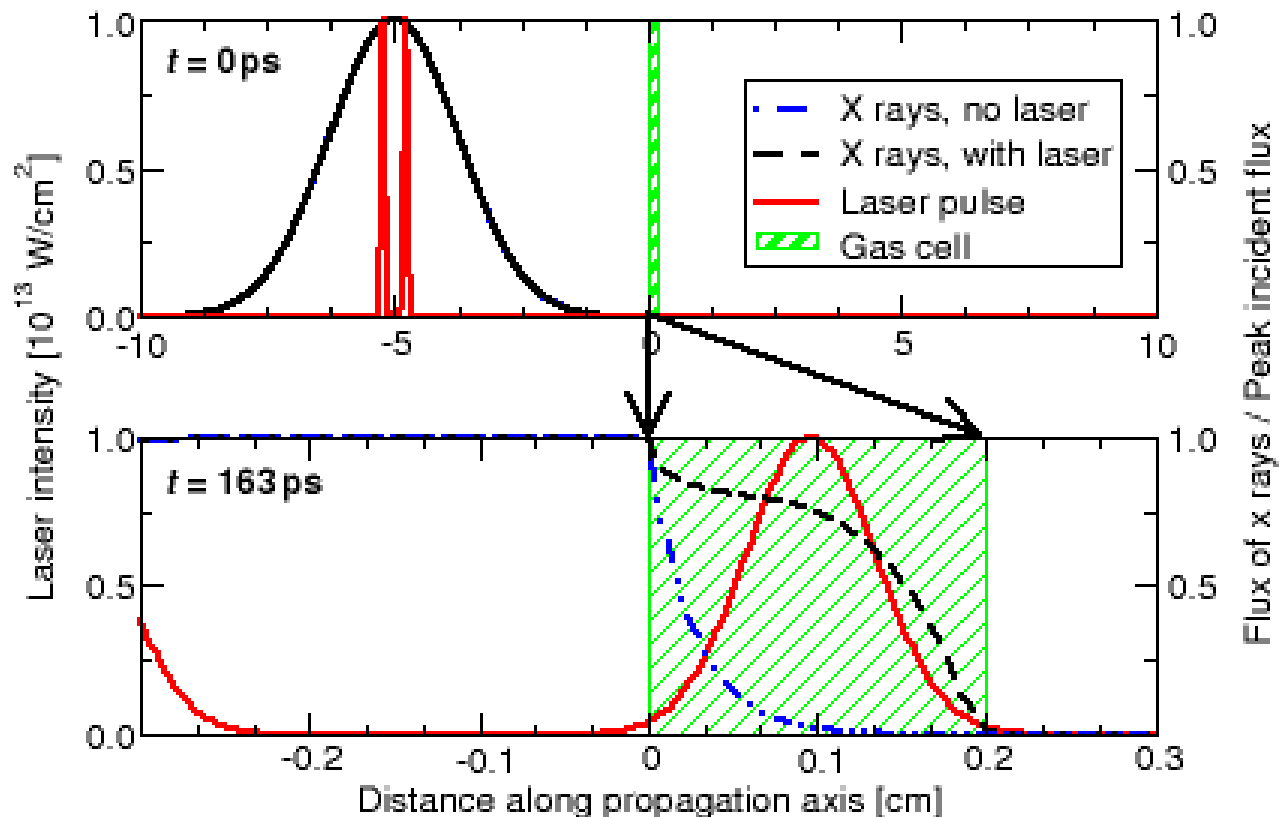
Ultrashort pulse shaping of x rays

- Neon gas cell

- Laser pulse shape is **imprinted** on x rays

- **Femtosecond** x-ray pulses

- All x-ray pump-probe experiments

- Amplitude modulation only

[Buth, Santra, Young, Phys. Rev. Lett. 98, 253001 (2007)]

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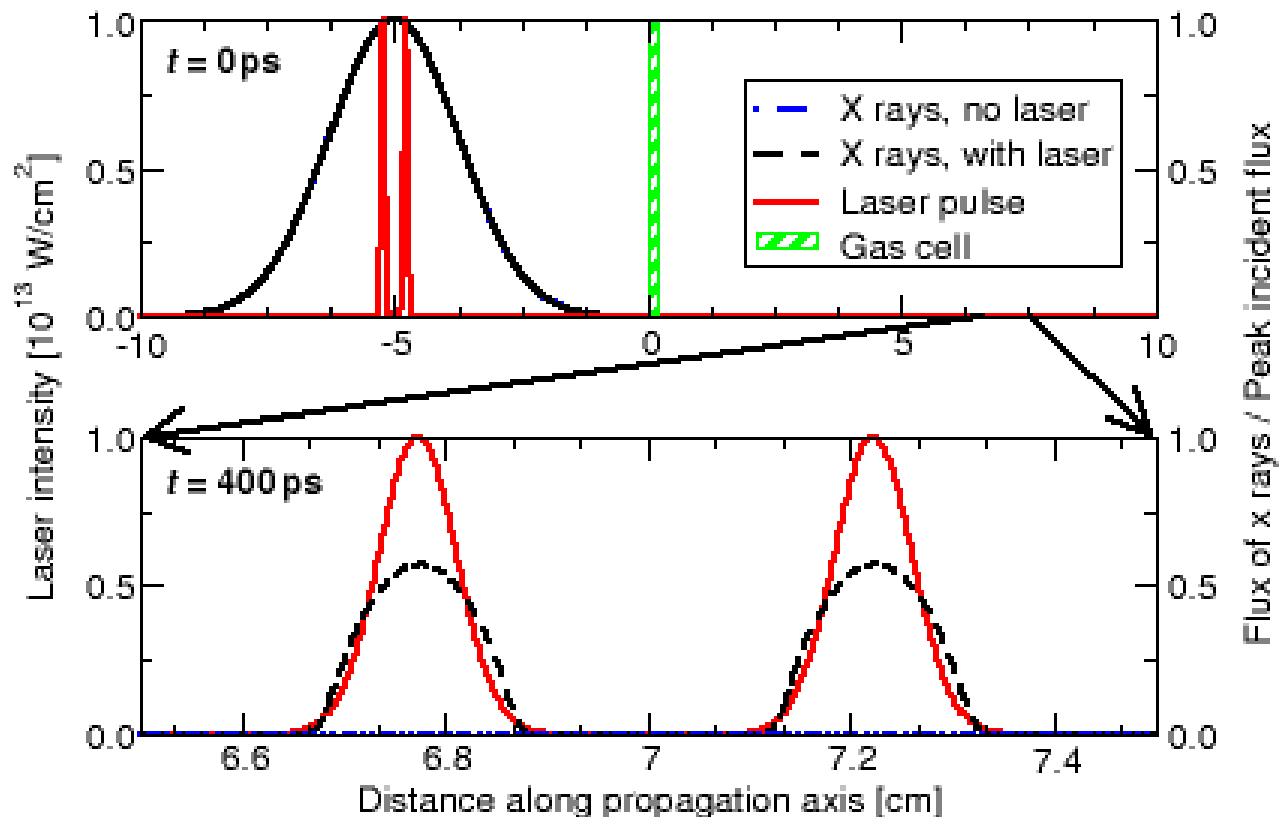
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Conclusion

- Developed theory of laser-dressed atoms probed by x rays
- Atoms described using **Hartree-Fock-Slater** approximation and nonrelativistic **quantum electrodynamics**

- Laser dressing causes **strong field multiphoton physics**
- X-ray probe is treated as a **one-photon** process
- Formalism for multiphoton x-ray processes (for x-ray free electron lasers)

- Find **electromagnetically induced transparency (EIT)** effect for **x rays** in neon
- EIT effect can be measured in neon
- EIT for pulse shaping of x rays on a **femtosecond** timescale

Acknowledgment

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