X-FEL Radiation – Electric and Magnetic Fields

Power density:
\[ S = E \times H = 5 \times 10^{21} \text{ W/m}^2 \]

Peak electric field: \[ E = 1.5 \times 10^{12} \text{ V/m} = 150 \text{ V/Angstrom} \]

Peak magnetic field field: \[ H = 3 \times 10^9 \text{ A/m} = 5 \times 10^3 \text{ Tesla} \]

How can materials survive?

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Electrons and Spins in High Photon Fields

Laser (~ 4 eV) and X-Ray FEL (~ 4 keV)

1 fs

frequencies very different!

1 as

Electron amplitude in field is: \( A = eE/m\nu^2 \)

In \( E = 150 \text{ V/Å} \) field, \( A \) is 260 nm (4 eV) - 0.26 pm (4 keV)

Bohr frequency of valence electron \(~ 1 \text{ fs}\)

Field ionization

Electron quivers

Spin precession angle in field is: \( \alpha = eH/m\nu \)

In \( H = 5 \times 10^3 \text{ T} \) field, \( \alpha \) is 60° (4 eV) - 0.06° (4 keV)

Ferromagnetic exchange correlation time is \(~ 1 \text{ fs}\)

Spin disorder

Spin quivers

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LCLS Beam can **Probe** or **Manipulate** Matter

- Flux density can be varied by focussing: factor $10^6$

- X-ray absorption can be varied by tuning energy: factor $10 - 10^2$

- X-ray absorption depends on atomic number: factor $10^5$

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LCLS - The First Experiments

Femtochemistry

Nanoscale Dynamics in Condensed Matter

Atomic Physics

Plasma and Warm Dense Matter

Structural Studies on Single Particles and Biomolecules

Report developed by international team of scientists working with accelerator and laser physics communities.
Utilize Peak Brightness and Ultrafast Pulses:

- "single shot" experiments – $10^{12}$ ph/shot, $10^9$ coh.-ph./shot
  - Creating and probing new states of matter
  - Ultrafast imaging
  - Multi-photon processes
- Probe-probe experiments: equilibrium dynamics
  - Dynamic imaging
  - Correlation spectroscopy
- Pump-probe experiments: non-equilibrium dynamics
  - molecular, cluster, liquid, solid state dynamics
  - probing extreme states of matter
Structural Biology: The Damage Problem

- Biological samples are highly radiation sensitive
- Conventional methods cannot achieve atomic resolution on non-repetitive (or non-reproducible) structures
- The limit to damage tolerance is about 200 $X$-ray photons/Å$^2$ in crystals (conventional experiments)
- The conventional damage barrier can be stretched by very fast imaging

Structural Studies on Single Particles and Biomolecules

Conventional method: x-ray diffraction from crystal

Proposed method: diffuse x-ray scattering from single protein molecule

Implementation limited by radiation damage:

<table>
<thead>
<tr>
<th>Crystals</th>
<th>Limit to damage tolerance is about $200 \text{ x-ray photons/Å}^2$</th>
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<tbody>
<tr>
<td>Single protein molecules</td>
<td>Need about $10^{16} \text{ x-ray photons/Å}^2$ (for 2Å resolution)</td>
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Lysozyme

Calculated scattering pattern from lysozyme molecule
A bright idea: X-Ray Diffraction from a Single Molecules

Use ultra-short, intense x-ray pulse to produce scattering pattern before molecule explodes

Just before LCLS pulse

Just after pulse

Long after pulse

The million dollar question: Can we produce an x-ray pulse that is short enough? intense enough?

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