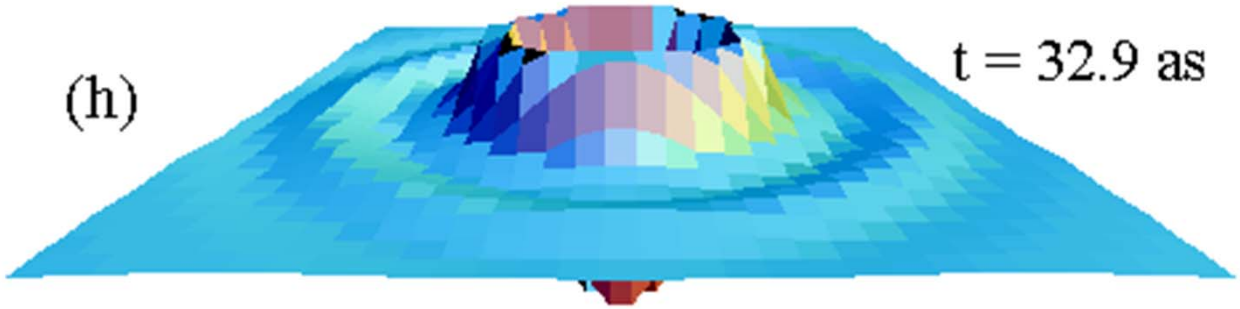
How science works

… and life too.



millisecond = 10^{-3} seconds

microsecond = 10^{-6}

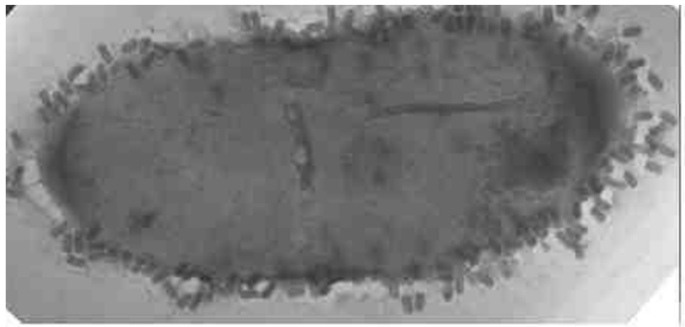
nanosecond = 10^{-9}

picosecond = 10^{-12}

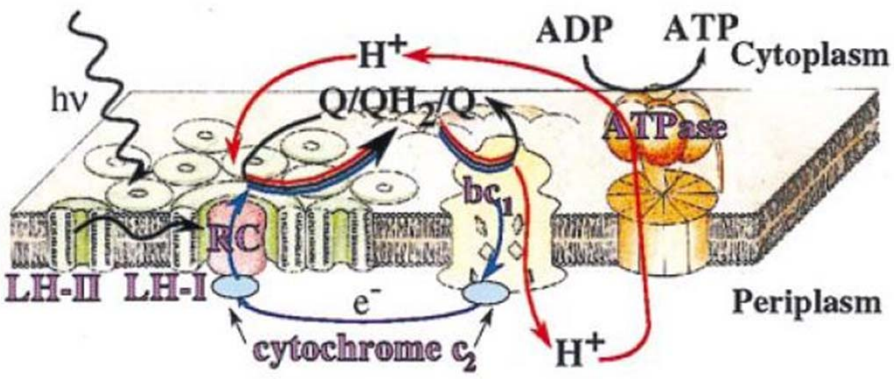
femtosecond = 10^{-15}

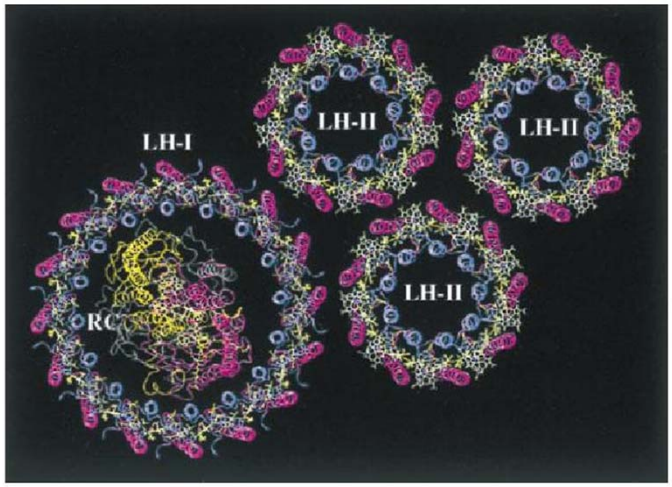
attosecond = 10^{-18} seconds

Quantum coherence in LHC – *c*. 2001

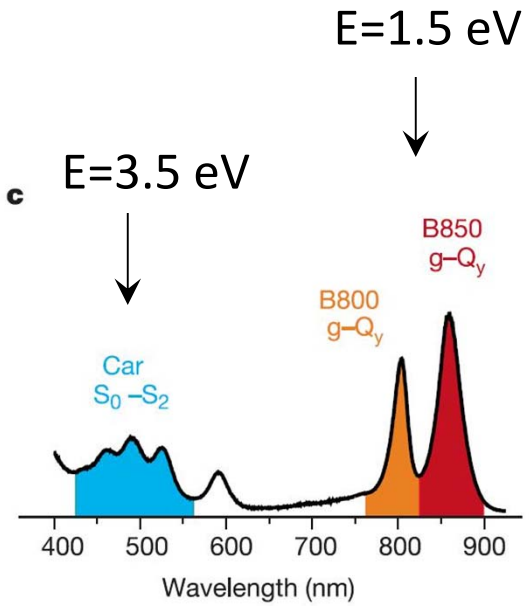


Rhodobacter Sphaeroides



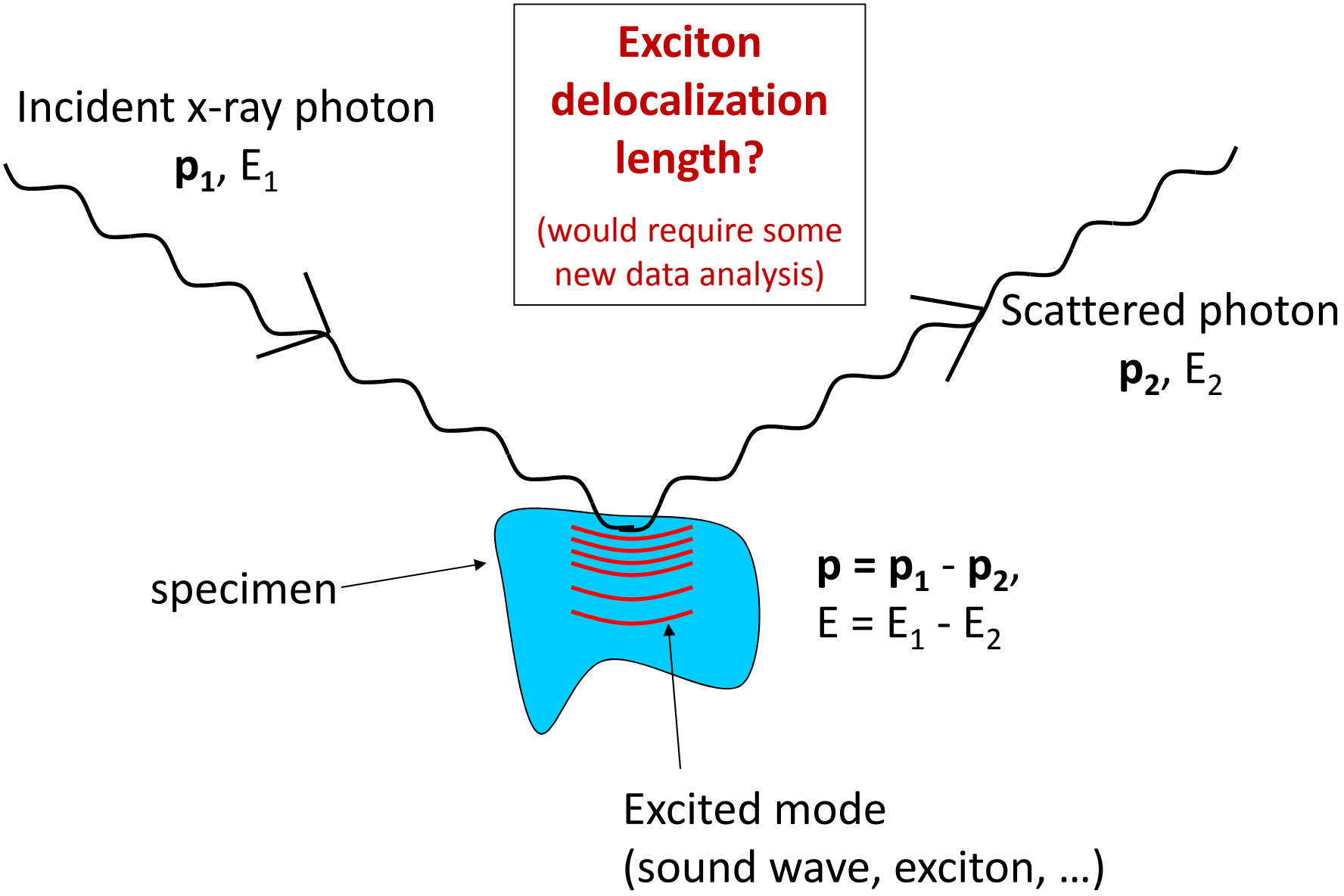


Light Harvesting Complex (LHC)



(Images courtesy of K. Schulten group)

Inelastic X-Ray Scattering (IXS)



Quantum coherence in LHC

Cornell

Sol Gruner

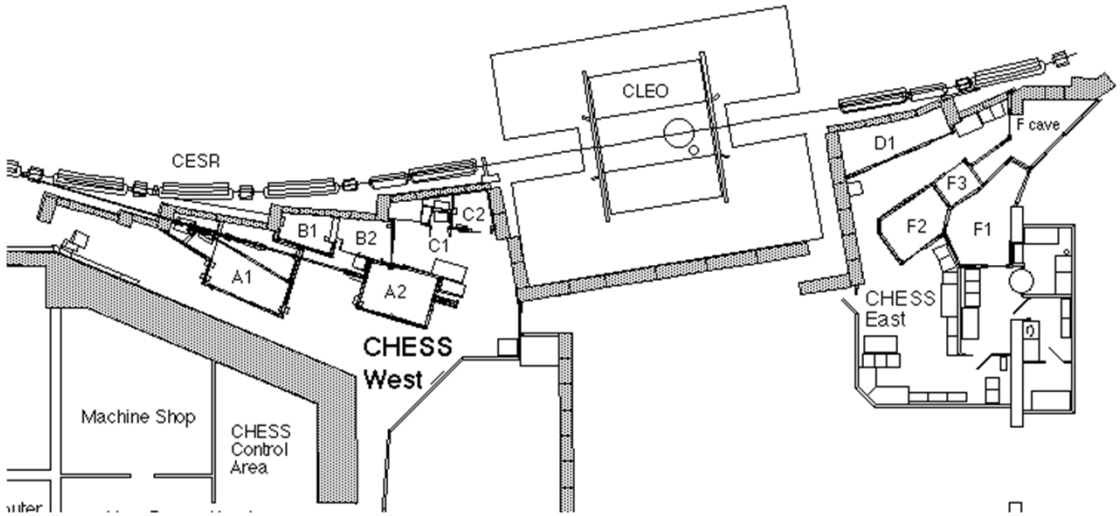
Ken
Finkelstein

CESR /
CHESS

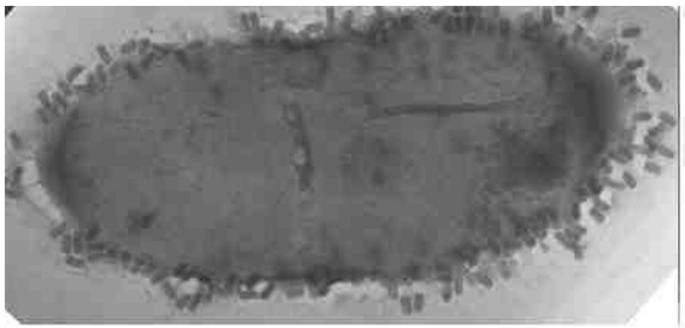
Jim Shapleigh

Preparation (6 mo.)

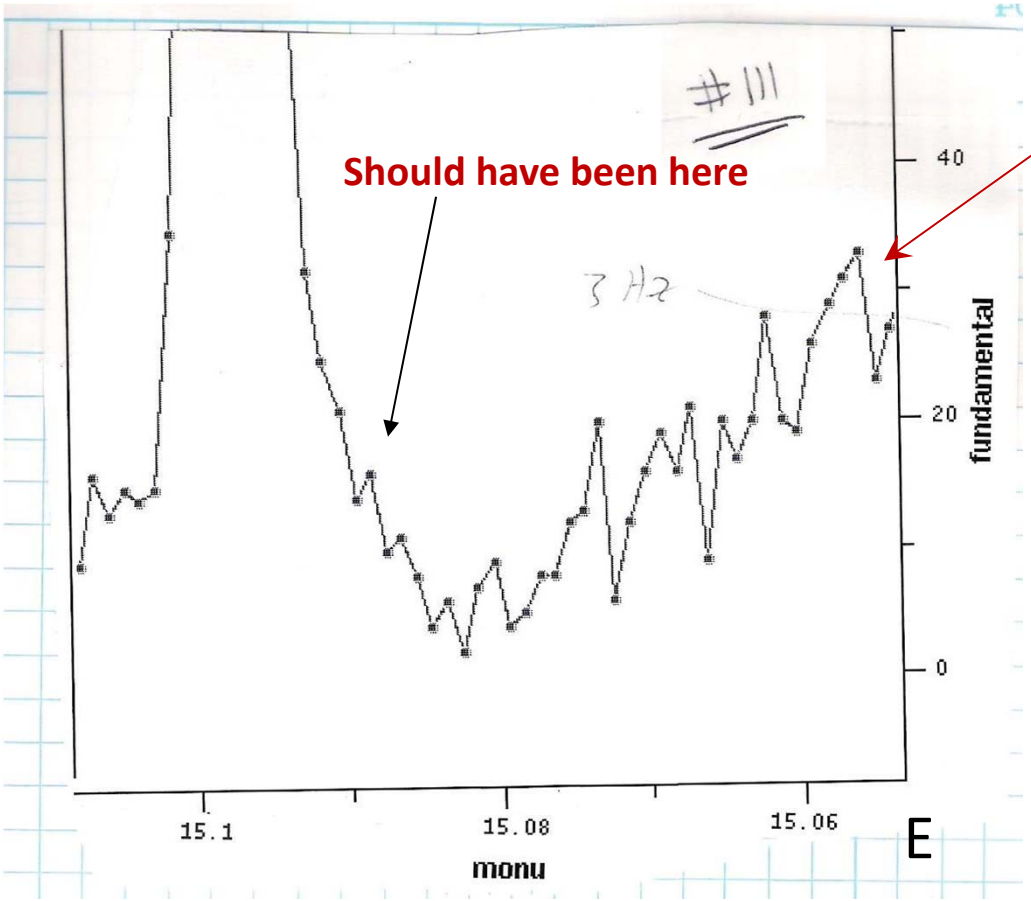
- Rebuild beam line optics (monochromator, analyzer)



- Grow R. sphaeroides, purify LHC

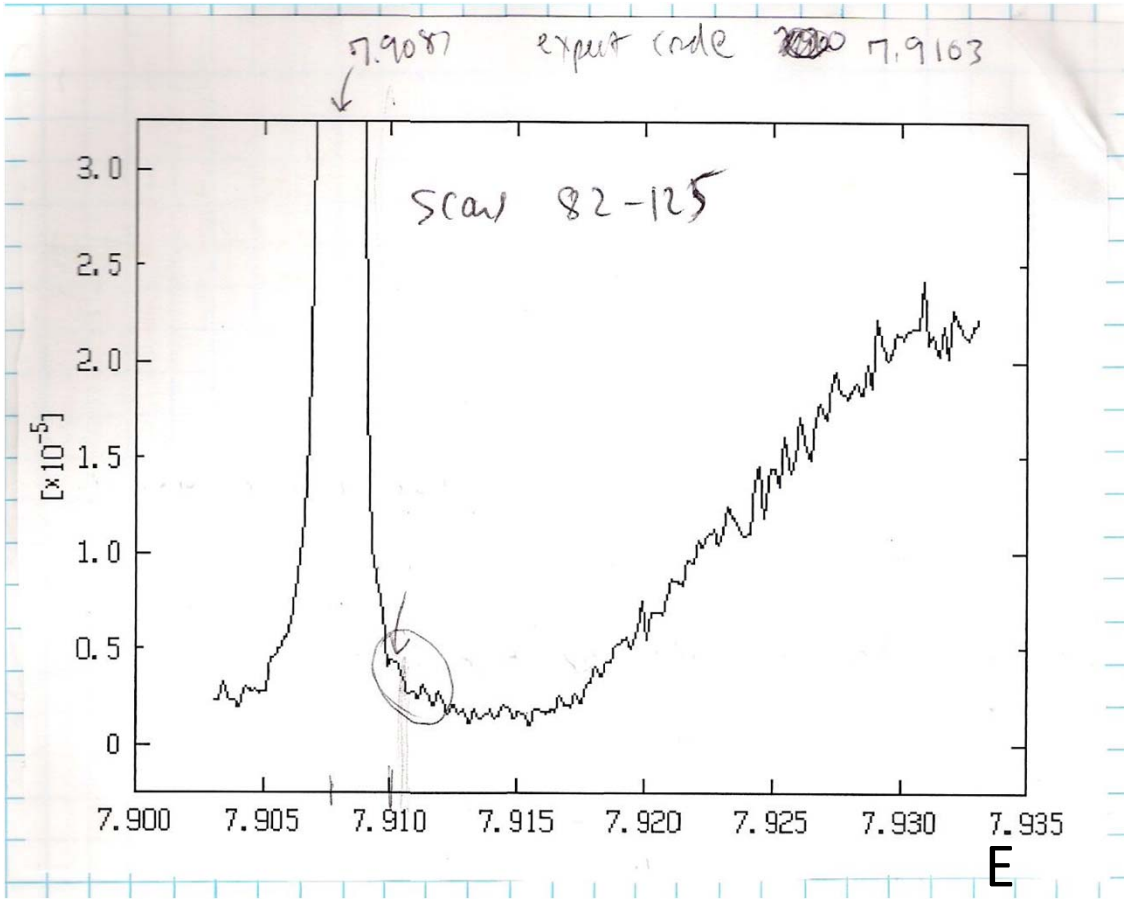


First attempt: LHC in dilute solution



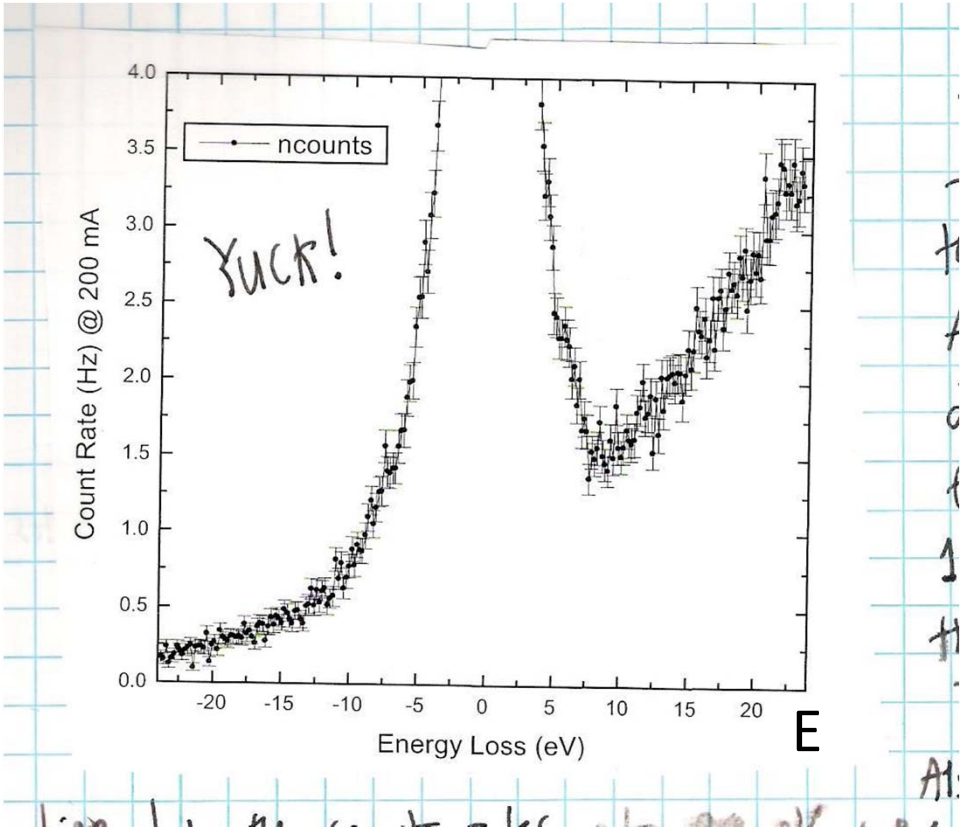
- Protein not concentrated enough?
- Concentrate into gel in ultracentrifuge (2 mo.)

Second attempt: LHC in sedimented gel



- Protein *still* not concentrated enough?
- Sediment into dried pellet (3 mo.)

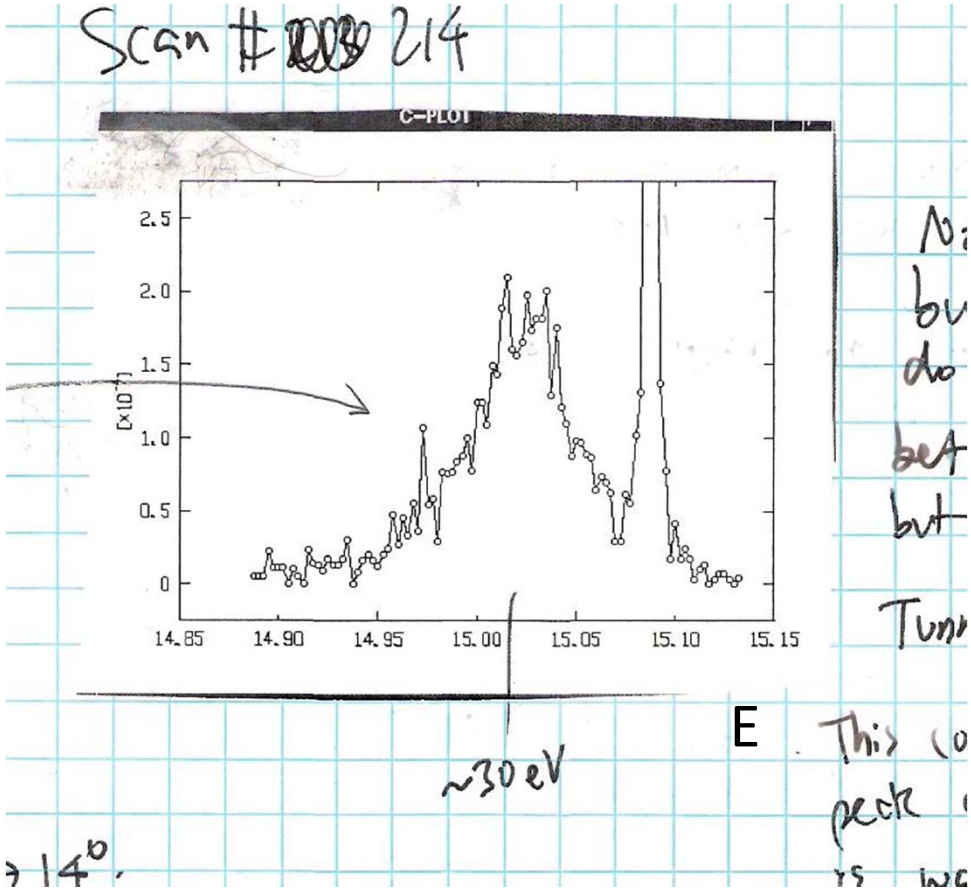
Third attempt: Dried, ultra-concentrated LHC "pellet"



- Photoactive levels still not visible above strange background
- 14 months into project ⇒ experiment is not feasible
- Impending facility review for Ken – lose funding?
- What is this background?!

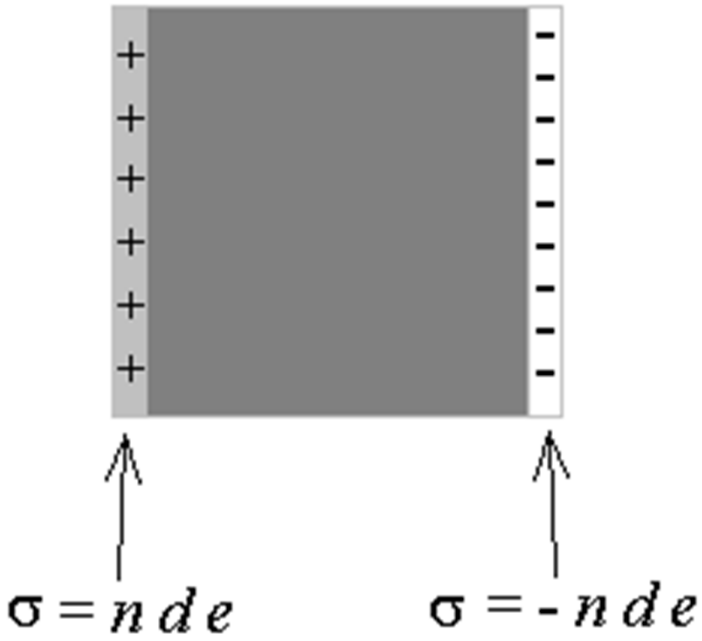
Third attempt: Dried, ultra-concentrated LHC “pellet”

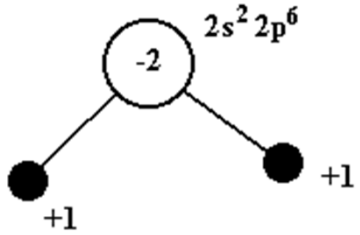
Liquid water



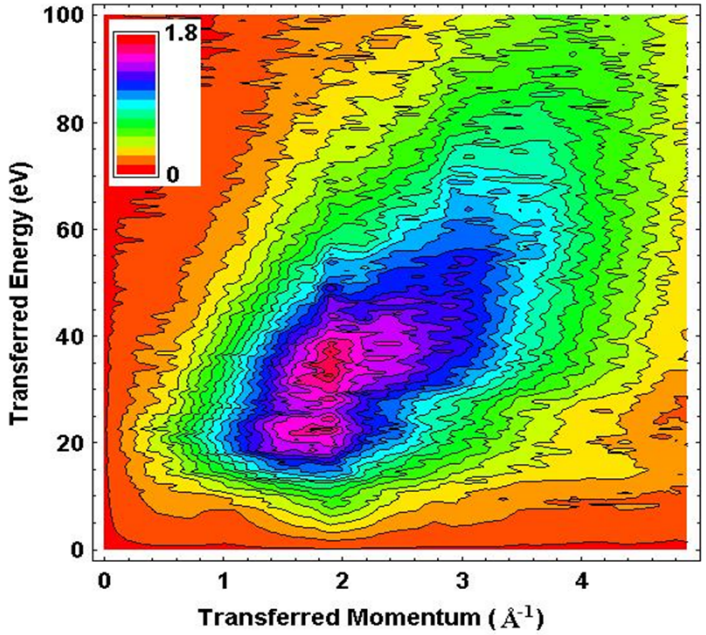
- Peak at $\hbar\omega$ = 30 eV – evidence for some “particle”
- Repeated experiment on plain water – still there.
- What is this thing?

Plasma oscillations in water





– Im[$\chi(k,\omega)$] (as/Å^3)



- 8 valence electrons / molecule
- ρ = 1 g/cm^3 $\Rightarrow$ n = 0.20 e/Å^3
- $\omega_p = \sqrt{(4\pi ne^2/m)}$ = 16.6 eV

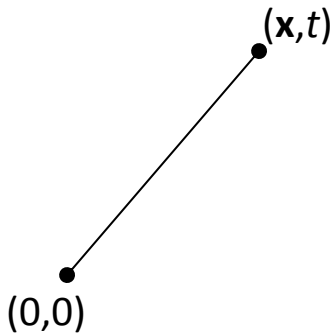
Inverting a plasmon?

$\chi(\mathbf{k},\omega)$:

- density Green's function
- density propagator
- susceptibility

Describes how disturbances in electron density travel about the medium.

$$\chi(\mathbf{x}_1,\mathbf{x}_2,t_2-t_1) = -\frac{i}{\hbar}\left\langle\left[\hat{n}(\mathbf{x}_2,t_2),\hat{n}(\mathbf{x}_1,t_1)\right]\right\rangle\theta(t_2-t_1)$$



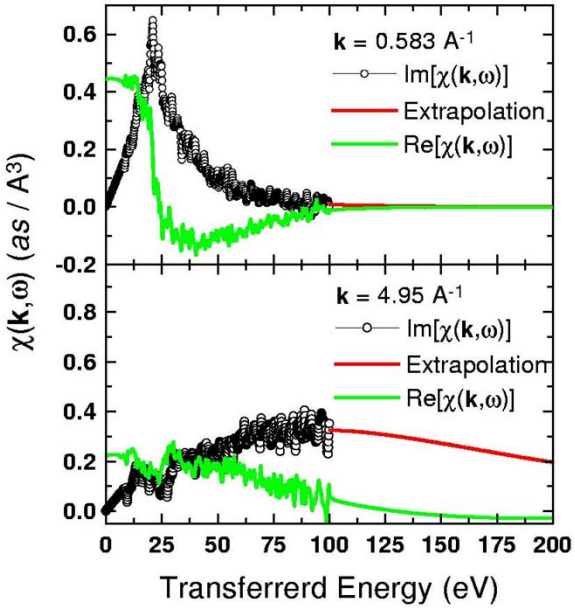
Causality

Inverting a plasmon?

Problem #1:
Im[$\chi(\mathbf{k},\omega)$] must be defined on *infinite* ω interval for KK transform

Solution:
Extrapolate.

Side Effects:
$\chi(\mathbf{x},t)$ defined at all times (infinitely narrow Δt)



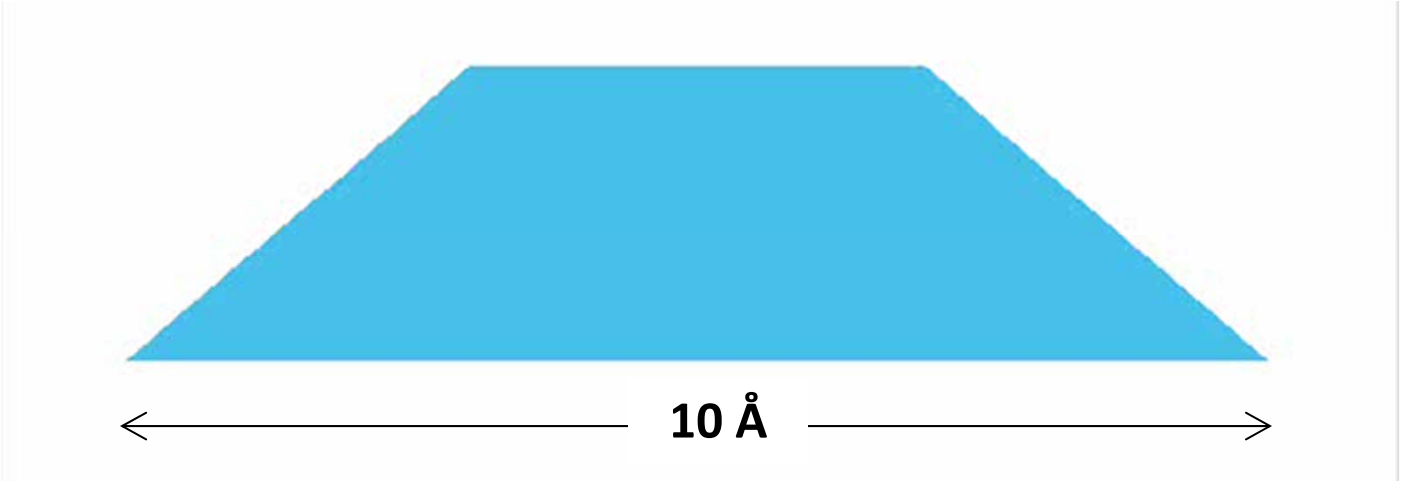
Problem #2:
Discrete points violate causality
Im[$\chi(\mathbf{k},\omega)$] must be defined on continuous w interval.

Solution:
Analytic continuation (interpolate)

$$\chi(\mathbf{k},t) = \int_0^\infty \frac{d\omega}{\pi} \left[\sin(\omega t)\, Im\chi(\mathbf{k},\omega) + \cos(\omega t)\, Re\chi(\mathbf{k},\omega)\right]$$

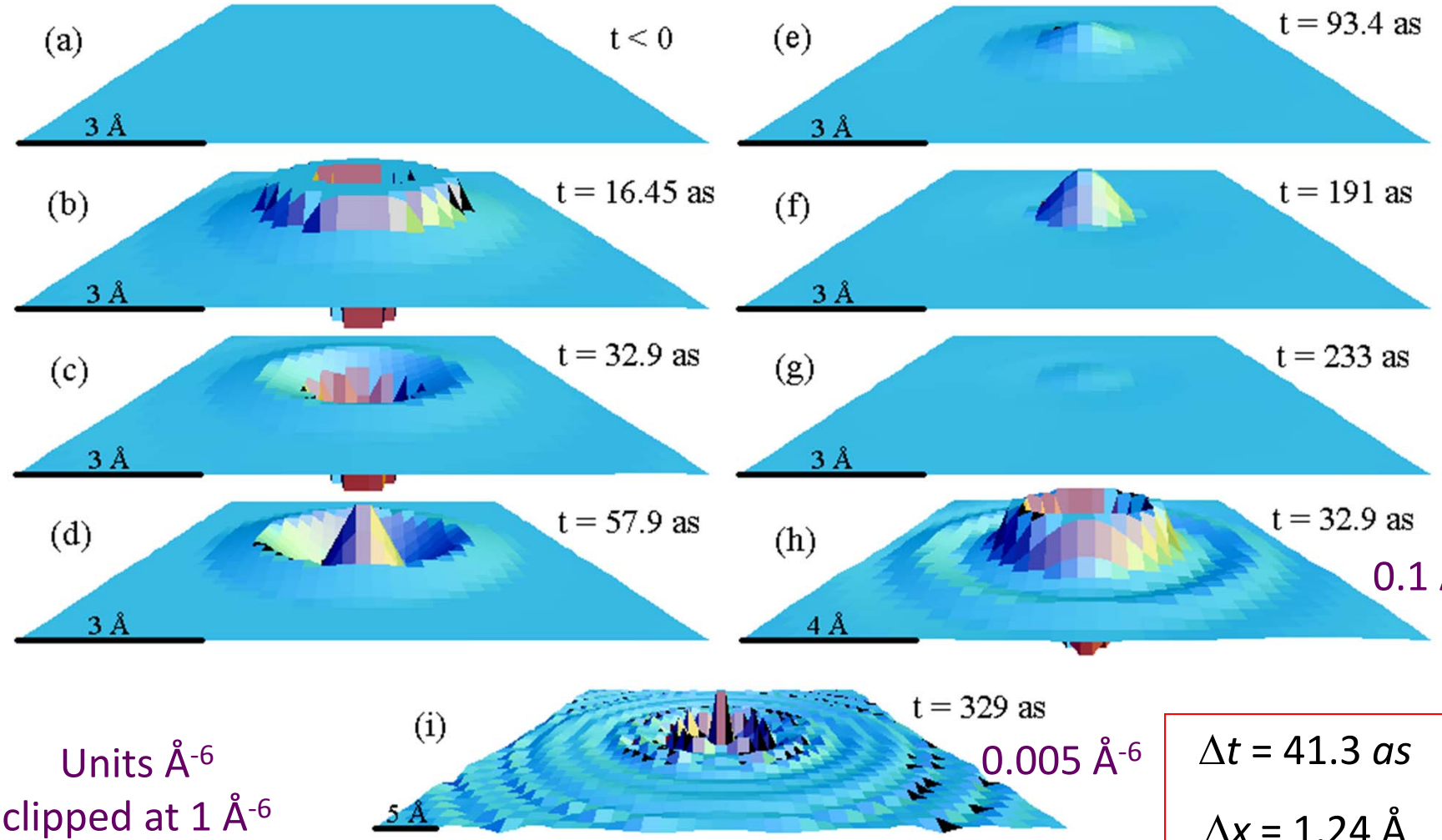
Side effects:
$\chi(\mathbf{x},t)$ defined forever, vanishes for $t < 0$, but repeats with period T = 13.8 femtoseconds

Disturbance from a point perturbation.



Electron dynamics in water (Δt = 41.3 as), PRL **92**, 237401 (2004)

Disturbance from a point perturbation – frame-by-frame



- Events transpire in 350 as – *light travels 100 nm in vacuum*
- *Causality ⇔ Analytic properties ⇔ Rise of entropy ⇔ Arrow of time*

“Attoscience”

news

Electron movements pinned down to the split second

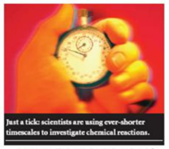
Mark Peplow, London

Physicists in Austria say they that have observed events separated by the shortest time interval ever, and plan to use the technique to study atomic phenomena.

A group led by Ferenc Krausz of Vienna University of Technology used pulses of laser light to watch electrons moving around atoms, and were able to distinguish events that took place 100 attoseconds — or 10^{-16} seconds — apart (see page 817 of this issue).

Krausz and his team say that the research could improve understanding of the role of electrons in superconductivity and in giant magnetoresistance, a magnetic effect used in data-storage devices. “It’s only on the attosecond timescale that you see these things happening,” says Roger Falcone, a physicist at the University of California, Berkeley.

The attosecond (10^{-18} s), also known as a quintillionth of a second, is the timescale of atomic events. In Niels Bohr’s 1913 model of a hydrogen atom, it takes about 150 attoseconds for an electron to orbit the proton.



Just a tick: scientists are using ever-shorter timescales to investigate chemical reactions.

Krausz used ultraviolet-light pulses of 250-attosecond duration to excite electrons in atoms of neon, raising them to a higher energy level. These electrons come out of the atoms with a range of different momenta. A second pulse of light, delivered just after the first, then gives the electrons an extra jolt. Changing the delay between these two pulses produces a different distribution of momentum values for the electrons, which the scientists measured with a sensitive electron detector called a ‘streak camera’. Comparing these distributions gave the team a snapshot of how the electrons differed when hit with an early or late second pulse.

Krausz thinks that the technique could soon be refined to track events a few tens of attoseconds apart, telling physicists how electrons rearrange themselves inside an atom when they move between different orbits.

Recent progress in using fleeting laser flashes to study short time scales has opened up the field of femtochemistry, in which the motion of atoms and molecules is tracked on the femtosecond (10^{-15} s) timescale, to see how they rearrange themselves during chemical reactions. Probing even shorter timescales could provide more insight.

“Every time we get shorter pulses, chemists say that we don’t really need them,” says David Klug, a photochemist at Imperial College, London. “But then they find a way to use them. Once it becomes convenient, people will find applications for it.”

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Science magazine

Originally published in Science Express as 10.1126/science.1059499 on February 15, 2001
Science, Vol. 291, Issue 5510, 1911-1913, March 9, 2001

LASER PHYSICS:
Toward Attosecond Pulses

Derryck T. Reid*

In which scientific discipline would you expect to find the fastest recorded events? Surprisingly, the answer is not electronics, or even atomic physics, but optics. In the last decade, laser science has succeeded in generating pulses of light lasting less than 10 femtoseconds (fs), where 1 fs = 10^{-15} seconds. Femtosecond pulsed lasers have provided unprecedented insights into molecular processes such as reaction dynamics. So far, most research has concentrated on pulses in the visible or near-infrared part of the light spectrum. At these wavelengths, the optical wave takes about 3 fs to complete one oscillation, so that state-of-the-art 5-fs laser pulses correspond to less than two optical cycles. Optical pulses much shorter than this require substantial effort to produce, and, because light propagates as an oscillating electromagnetic wave, they are fundamentally limited to the "single-cycle" duration of about 3 fs.

Now, a new area of experimental physics is emerging, one sufficiently radical to be defined by its own prefix—attosecond science. By using femtosecond optical pulses to generate wavepackets in the soft x-ray region, where wave cycles last for only about 50 attoseconds (as) or 50 x 10^{-18} seconds, it should be possible to produce multicycle x-ray pulses with subfemtosecond durations. In this issue, Drescher et al. (1) report a first step in this direction. The authors have both created and measured x-ray pulses with durations below the carrier wave period of the original optical pulse.

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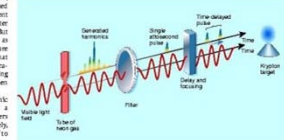
news and views

Laser science

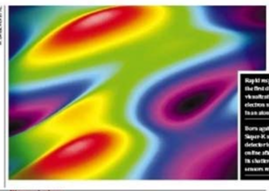
Physics at the attosecond frontier

Yaron Silberberg

Ultrashort laser pulses allow physicists and chemists to watch fast molecular motion as it happens. But many fundamental atomic processes are even faster and require the shortest pulses ever created.



2002 in context

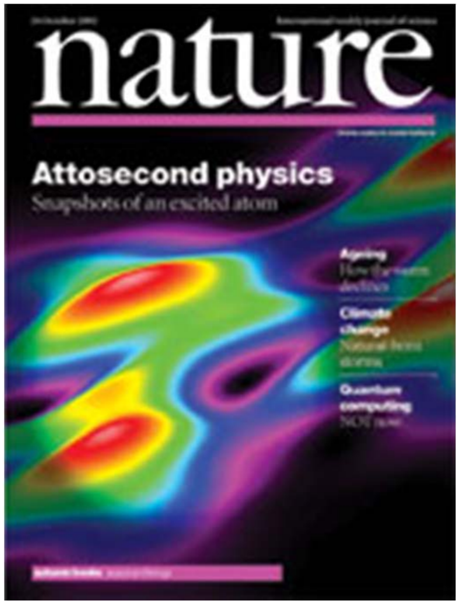


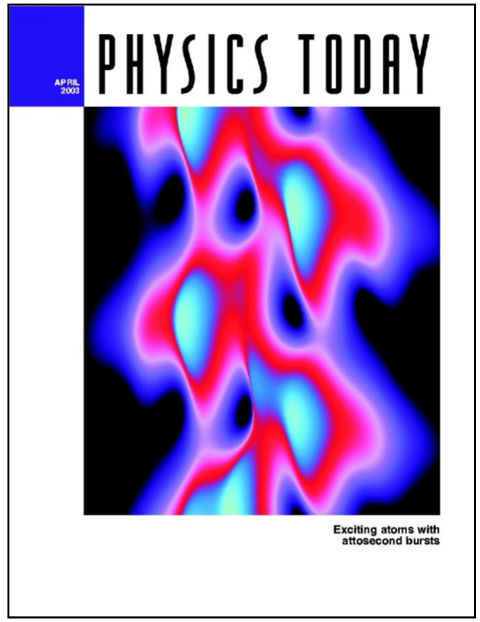
Attosecond science

The fast show

Comeback: Neutrino physics

Tanked up and ready for action





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news and views

Atomic photography

Louis F. DiMauro

No ordinary camera can capture the motion of electrons inside an atom. But the advent of ultrafast laser pulses brings the necessary ‘shutter speed’ for snapping them as they tumble between energy levels close to the nucleus.

Figure 1 Spot the ball — the limitations of action photography.

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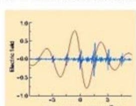
news and views

Laser physics

Attosecond pulses at last

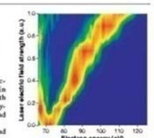
Paul Corkum



PERSPECTIVES: PHYSICS

Resolving Physical Processes on the Attosecond Time Scale

Maciej Lewenstein



How to steer electrons.

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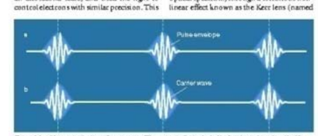
news and views

Attophysics

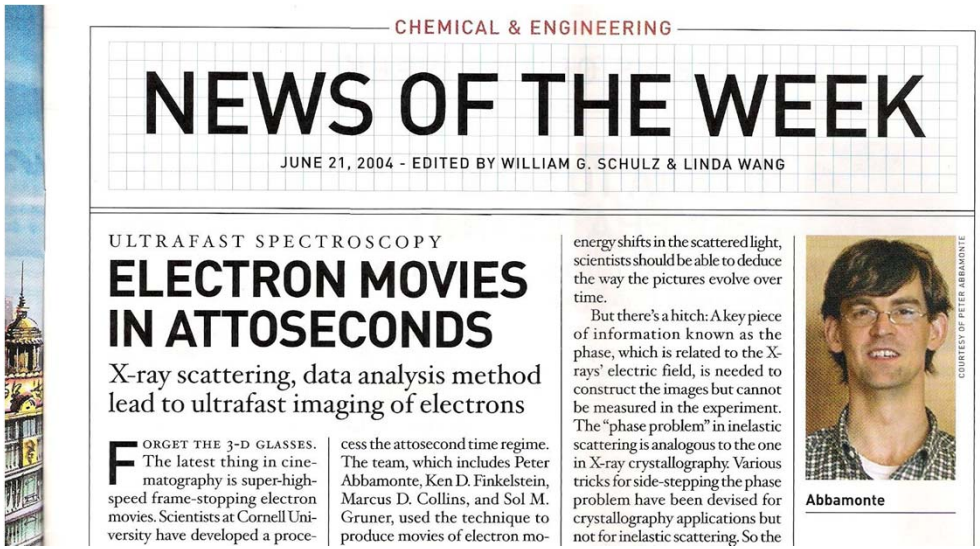
Ultrafast control

Philip H. Bucksbaum

The successes of two pioneering groups are now brought together to create trains of identical ultrashort laser pulses that can control what’s happening inside an atom.



“Fastest movies ever made”



CHEMICAL & ENGINEERING

NEWS OF THE WEEK

JUNE 21, 2004 - EDITED BY WILLIAM G. SCHULZ & LINDA WANG

ULTRAFAST SPECTROSCOPY

ELECTRON MOVIES IN ATTOSECONDS

X-ray scattering, data analysis method lead to ultrafast imaging of electrons

FORGET THE 3-D GLASSES. The latest thing in cinematography is super-high-speed frame-stopping electron movies. Scientists at Cornell University have developed a process the attosecond time regime. The team, which includes Peter Abbamonte, Ken D. Finkelstein, Marcus D. Collins, and Sol M. Gruner, used the technique to produce movies of electron motion. The movies show energy shifts in the scattered light, scientists should be able to deduce the way the pictures evolve over time.

But there's a hitch: A key piece of information known as the phase, which is related to the X-rays' electric field, is needed to construct the images but cannot be measured in the experiment. The "phase problem" in inelastic scattering is analogous to the one in X-ray crystallography. Various tricks for side-stepping the phase problem have been devised for crystallography applications but not for inelastic scattering. So the

COURTESY OF PETER ABBAMONTE

Abbamonte

Chemical & Engineering News

Physical Review Focus

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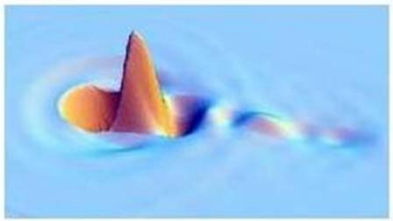
Previous Story / Next Story / January - June 2004 Archive

Phys. Rev. Lett. 92, 237401
(issue of 11 June 2004)
Title and Authors

14 June 2004

X-Rayed Movie

A research team has produced the fastest movies ever made of electron motion. Created by scattering x rays off of water, the movies show electrons sloshing in water molecules, and each frame lasts just 4 attoseconds (quintillionths of a second). The results, published in the 11 June *PRL*, could let researchers "watch" chemical reactions even faster than those viewable with today's "ultrafast" pulsed lasers.



P. Abbamonte/Brookhaven National Lab

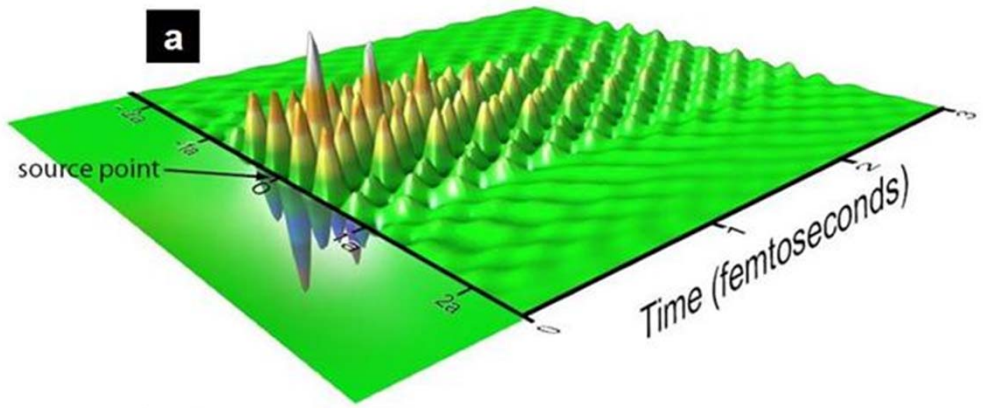
Ripple effect. Researchers used x rays to visualize the sloshing of electrons in water

X rays can reveal atomic-scale spatial details in liquids and solids because their wavelengths are as

Phys. Rev. Focus

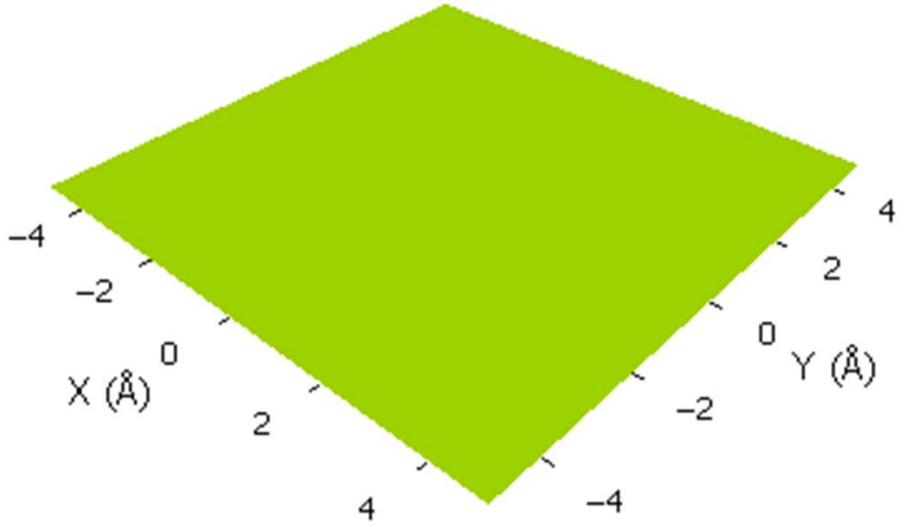
Ongoing studies in “attoscience”

Excitons in salt



time = 0. as

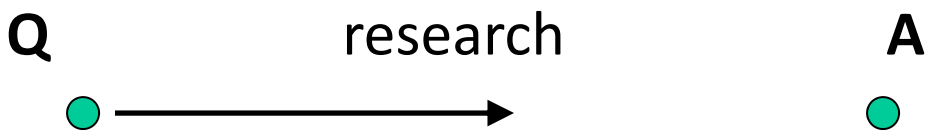
Screening in graphene



How most people think science works*

*Note: Thinly veiled metaphor for life

How most people think science works*



*Note: Thinly veiled metaphor for life

How most people think science works*

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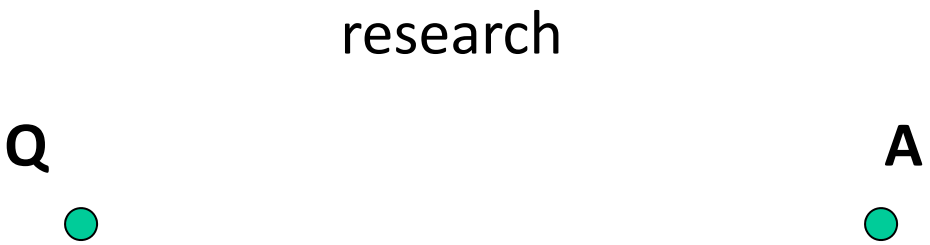
How science *really* works*



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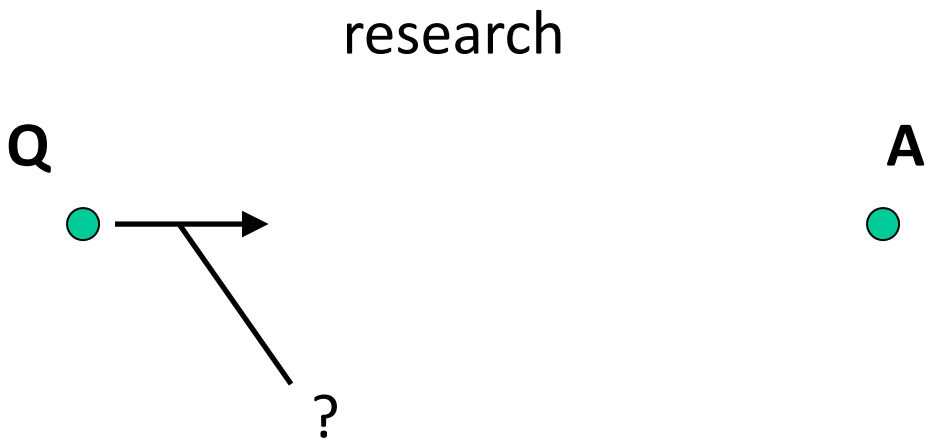

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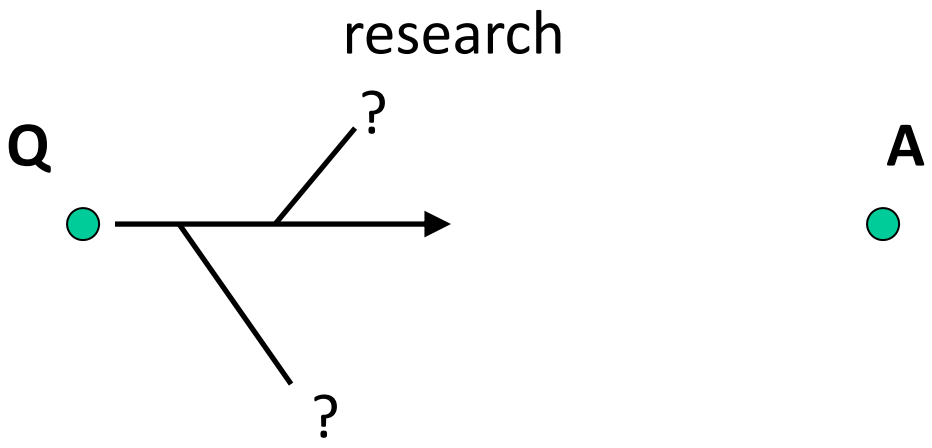

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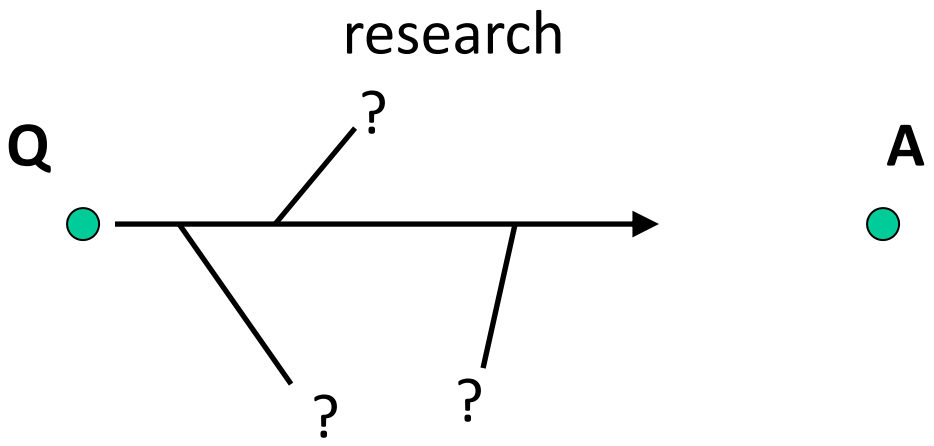

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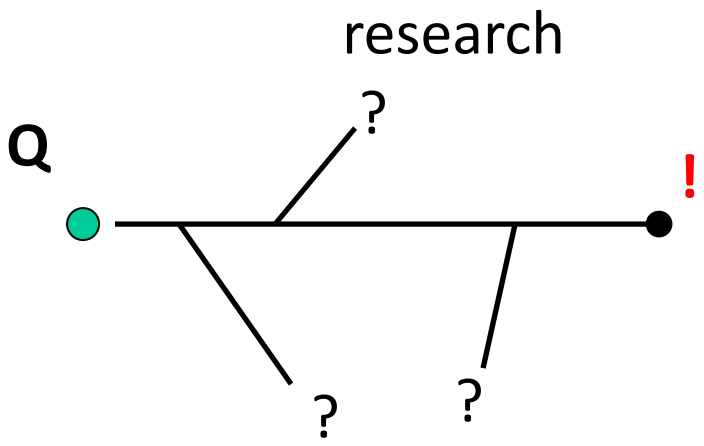
How science *really* works*



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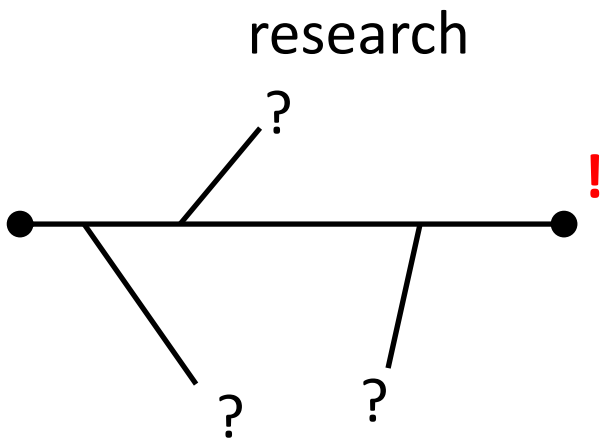
How science *really* works*



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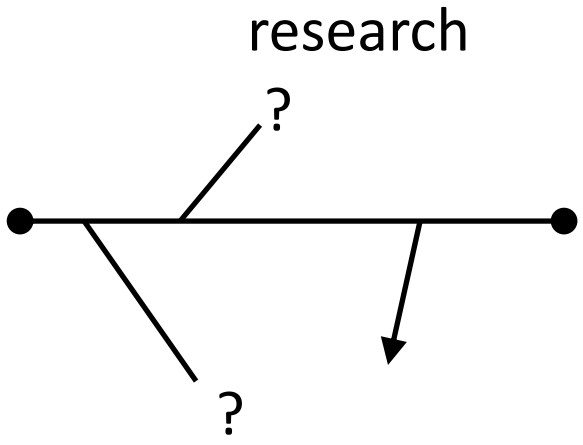

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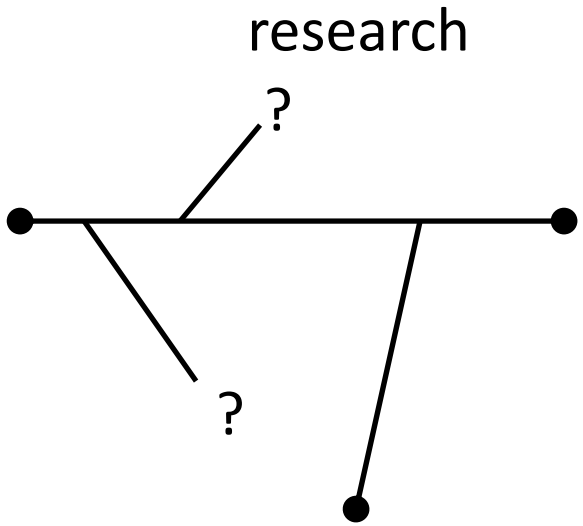

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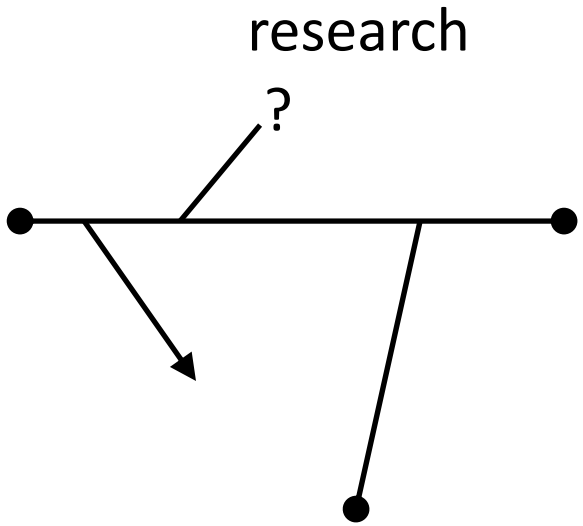
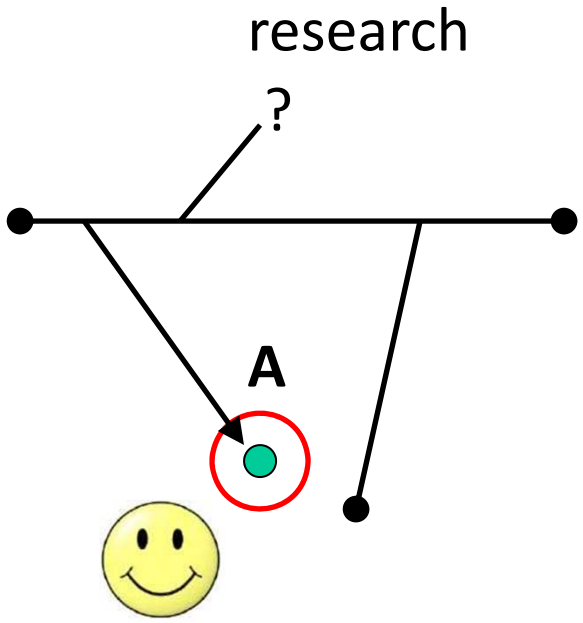
How science *really* works



***Note: Thinly veiled metaphor for life**

How science *really* works*



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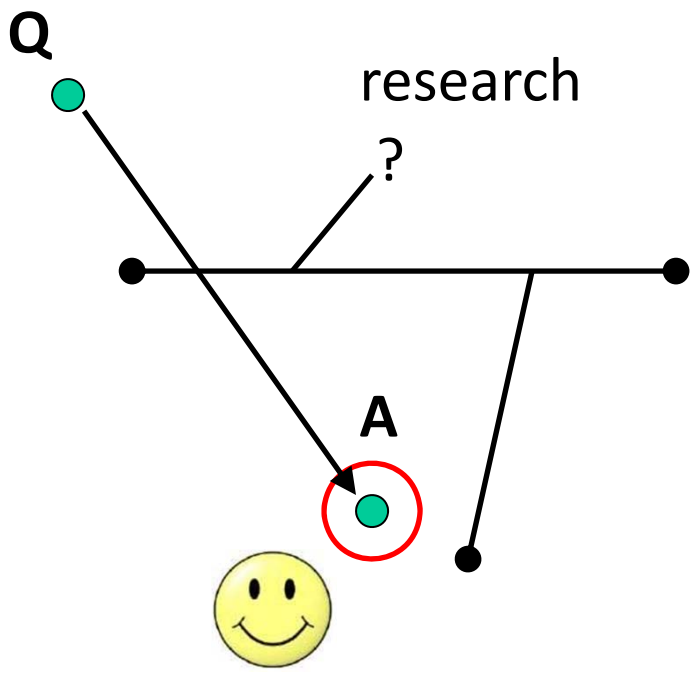
How science *really* works*



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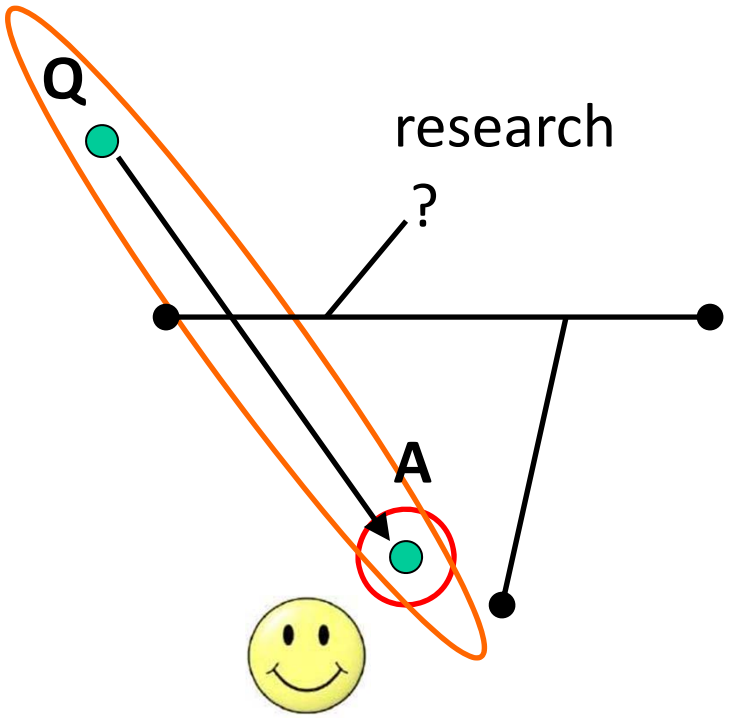

*Note: Thinly veiled metaphor for life

Thoughts for the Class of 2013:

1. **Champion a cause.** Pursue the unknown. Pioneer a new area, found a startup company, etc. *Drive change or it will drive you.*

2. **Make plans, but don't follow them.** Life is not a straight line. Make a five year plan, and update it every two weeks ("Plans are nothing; planning is everything" – Eisenhower).

3. ***Don't waste time on the unimportant.*** Pursue happiness, not entertainment. The latter, ironically, will leave you miserable.

4. ***Show some chutzpah.*** When cold, dark reality sets in, get scared, but get busy.