Inelastic electron interactions with biomolecules: from gas phase to complex systems

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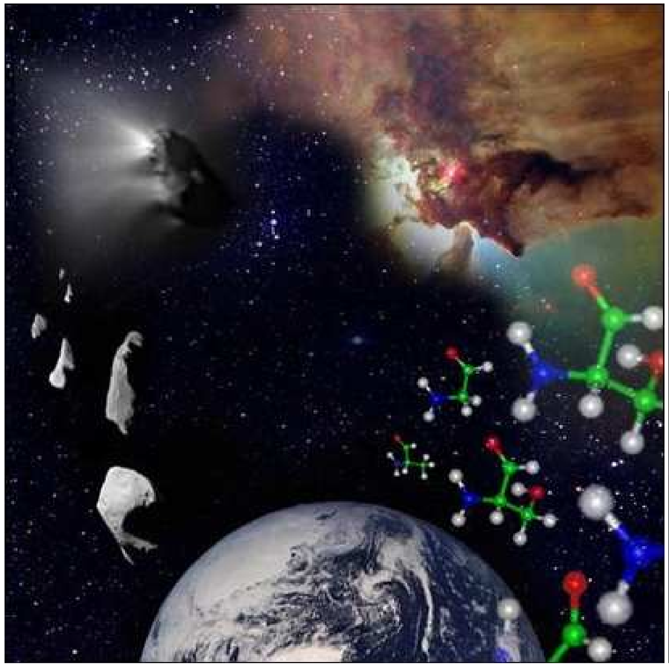
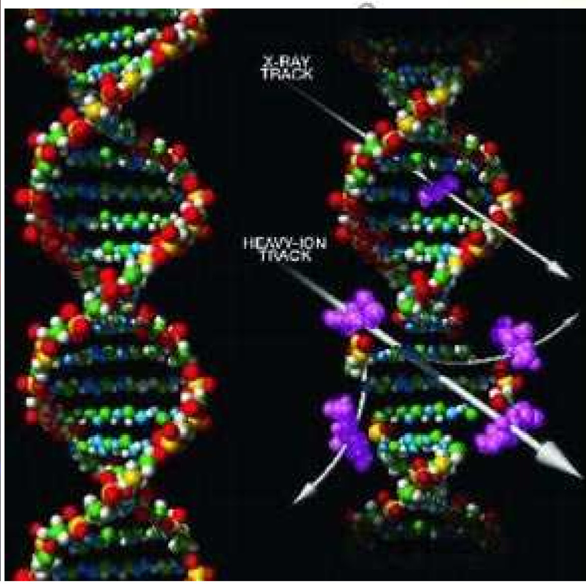
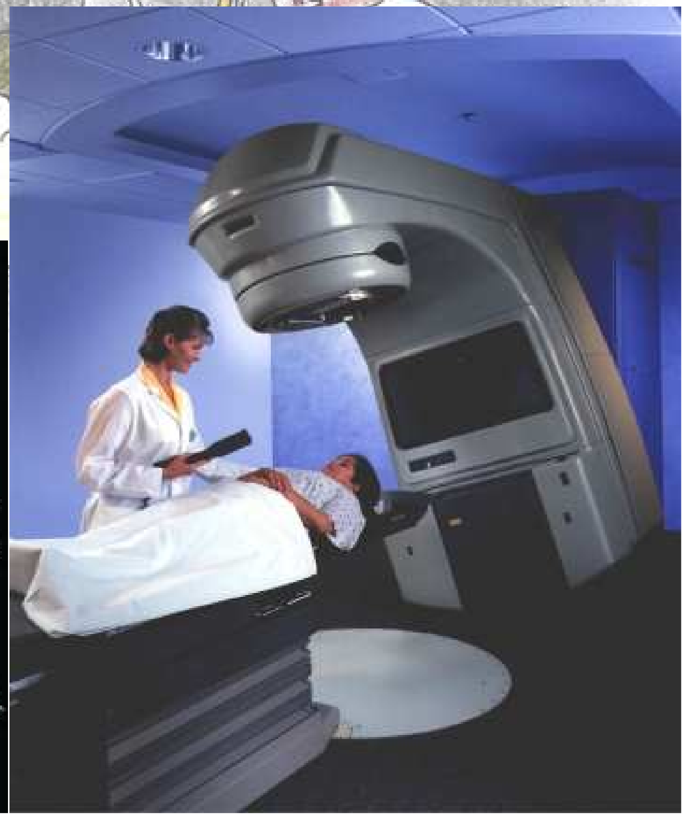
Radiation Damage in Biomolecular Systems Tutorial
COST Action P9
19th June 2007
The Royal College of Surgeons, Dublin, Ireland

Motivation

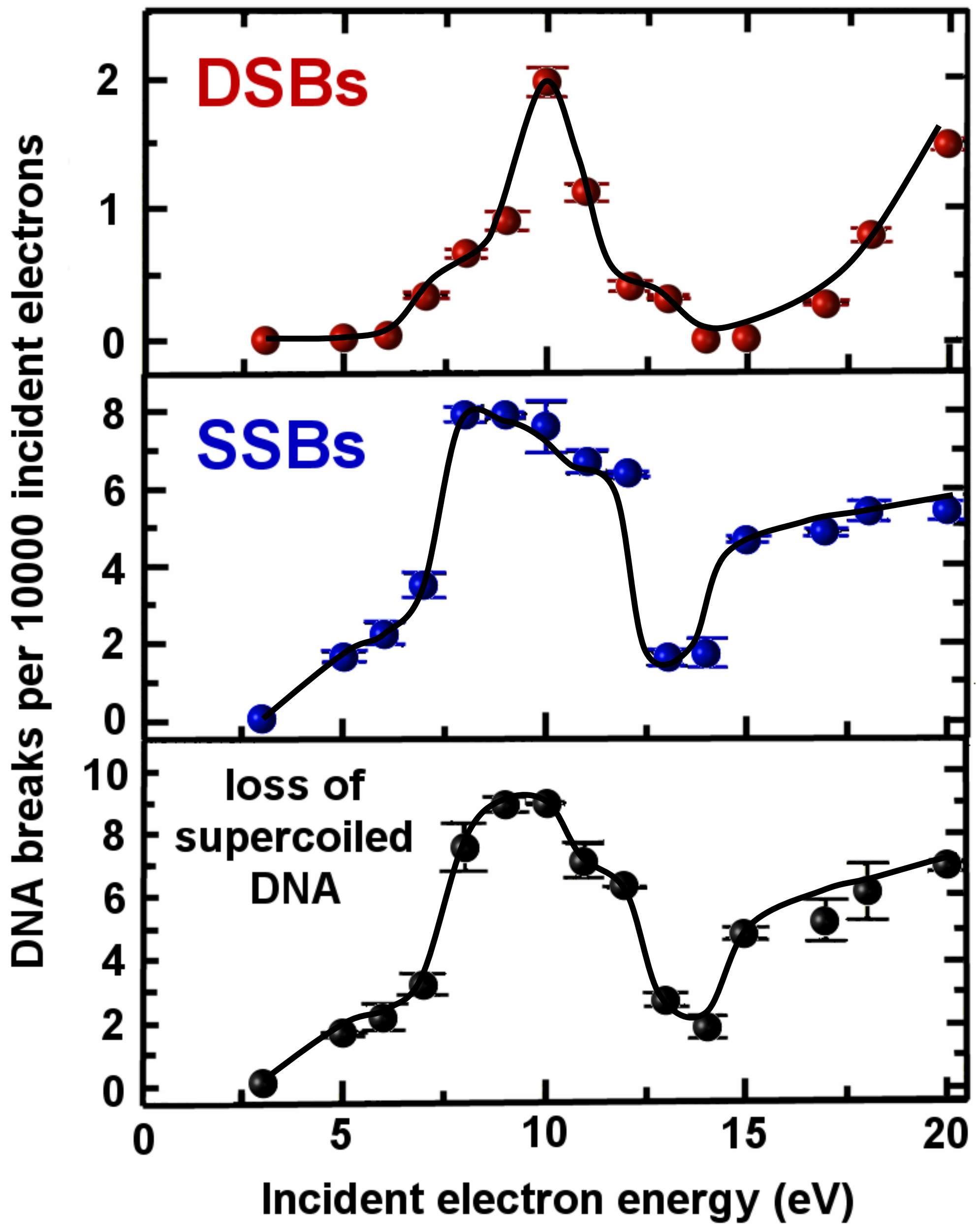
- Origin of life
- Life in space
- Radiation damage at a molecular level

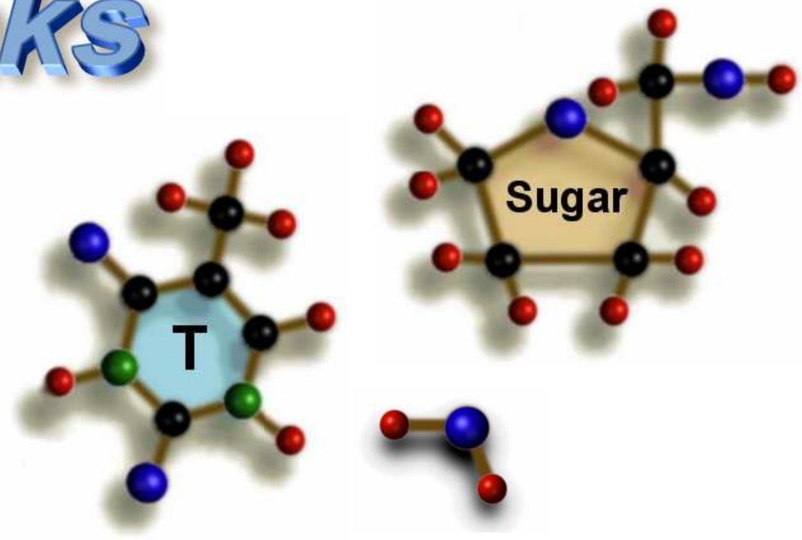


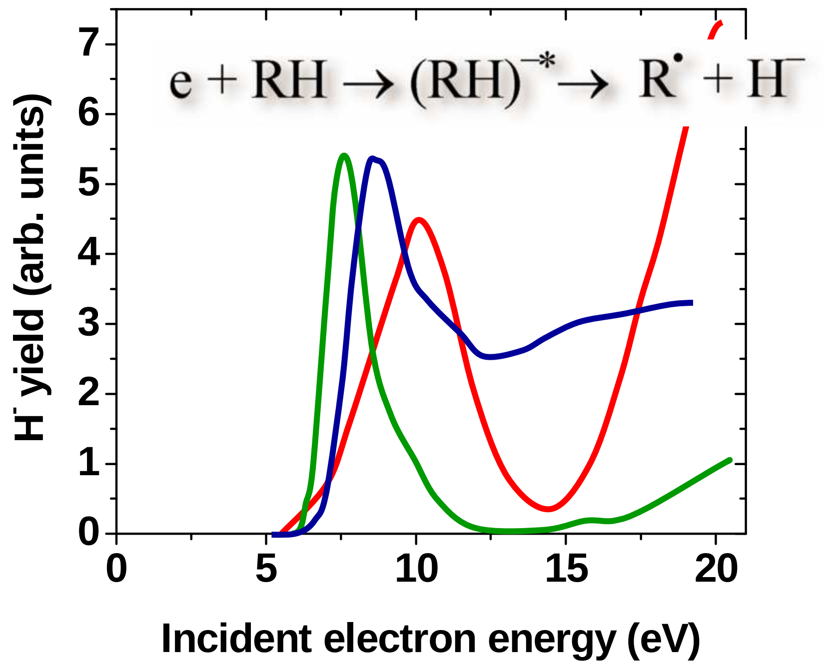




DNA-strand breaks

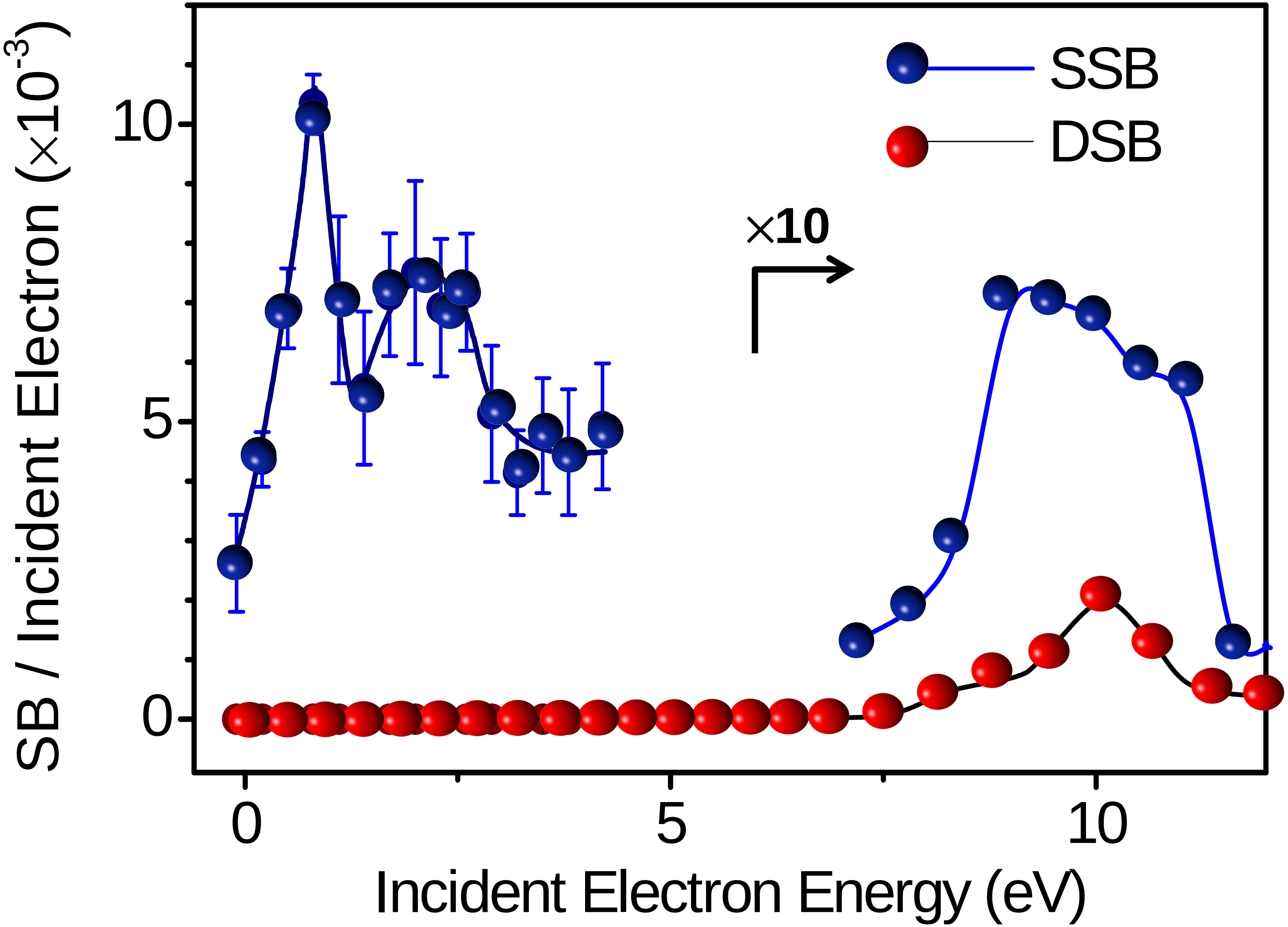






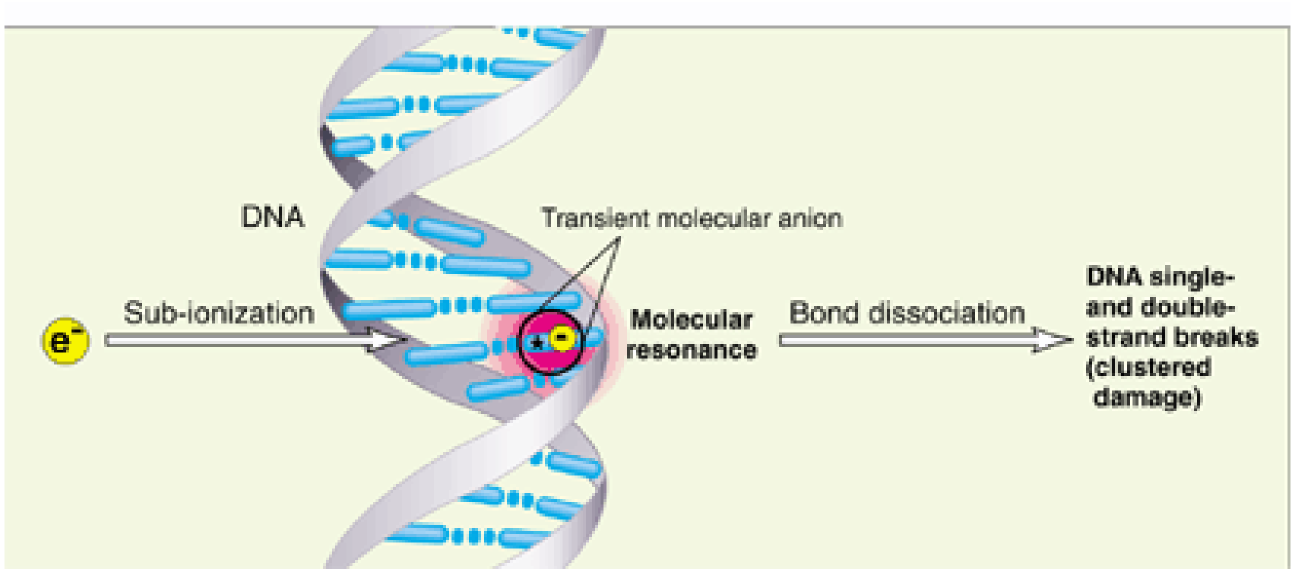
Sanche a.c. Science, 287 (2000) 1658

Sbs at low energies



Sanche a.c. PRL, 93 (2004) 068101

DNA damage by low energy electrons

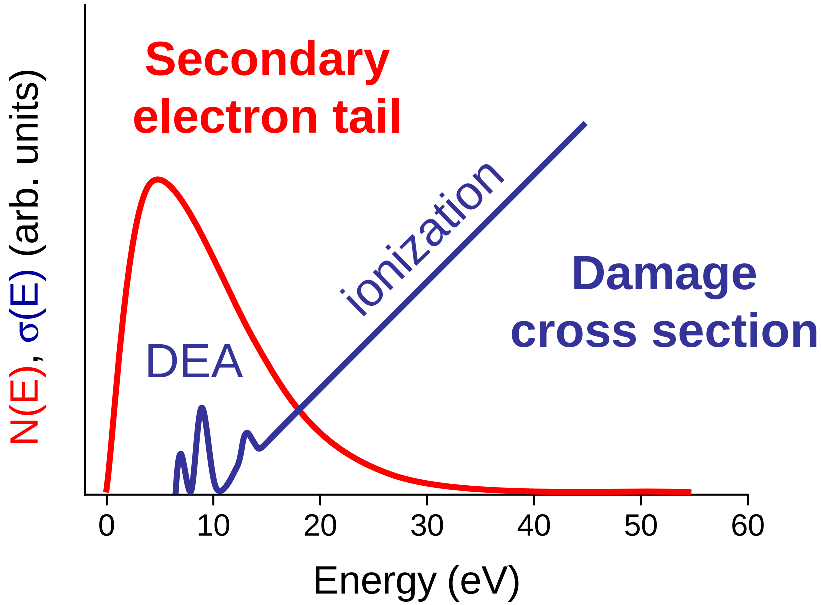


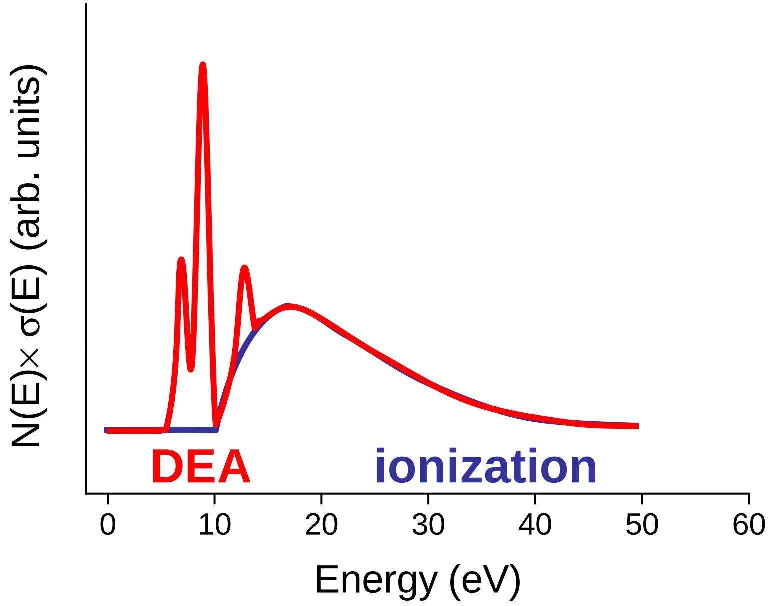
´A Sting in the Tail of Electron Tracks´
Barry D. Michael and Peter O'Neill
Science 3 March 2000:
Vol. 287. no. 5458, pp. 1603 - 1604

A large number of secondary electrons (~40000 electrons per MeV) with kinetic energies below about 20 eV are produced along the radiation track.

Why low energy electrons ?

- Low-energy electrons have high cross sections





Why gas phase ?

- Unambiguous identification of (charged) products formed

- No secondary effects like in surface experiments

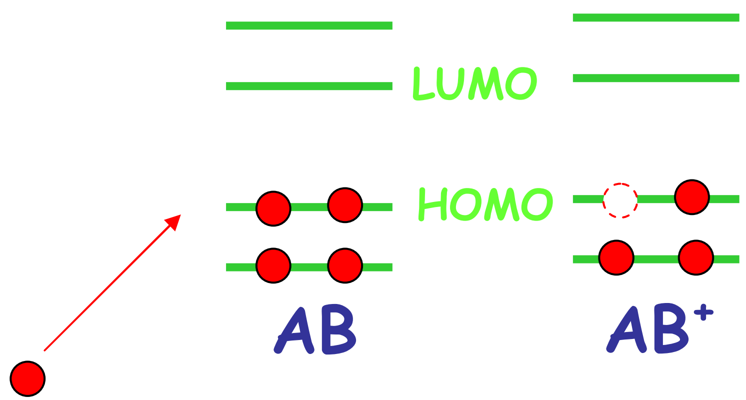
Interaction of low energy electrons (<15eV)

Formation of positive ions:

$$e^- + AB \rightarrow AB^+ + 2e$$

$$\rightarrow A^+ + B + 2e$$

Ionization

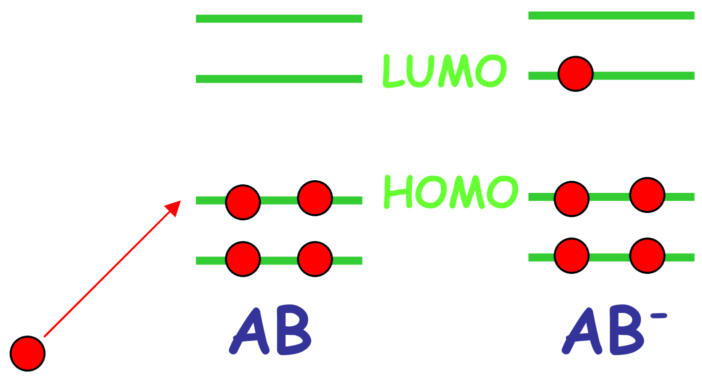


Formation of negative ions:

$$e^- + AB \rightarrow (AB)^{-*} \rightarrow \ldots\ldots$$

Transit negative ion (TNI)

Electron attachment



Electron attachment

$e^- + AB \rightarrow (AB)^{-*}$

$\rightarrow AB + e^-$

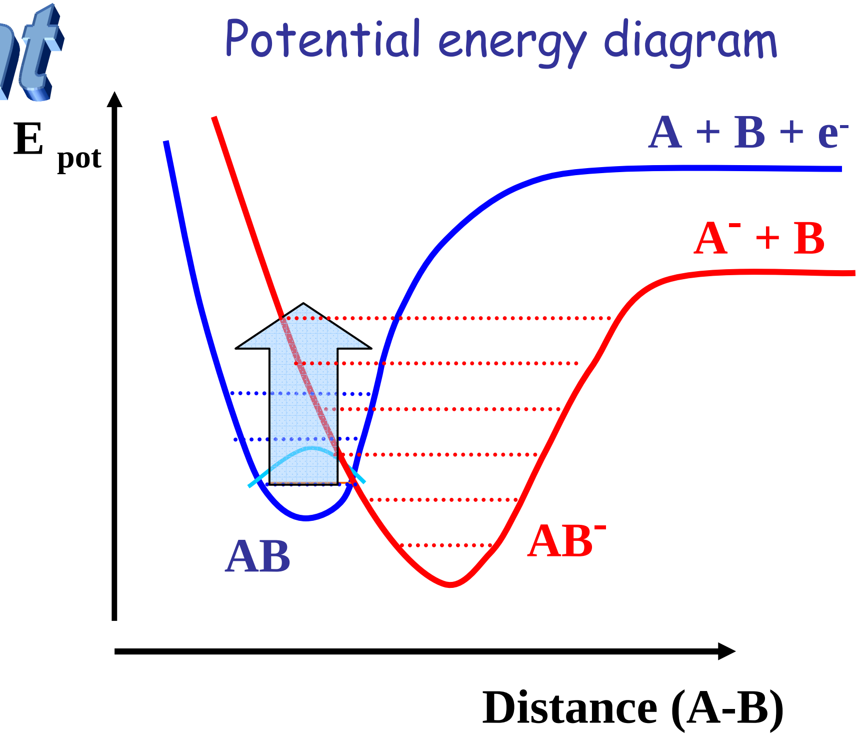
autodetachment

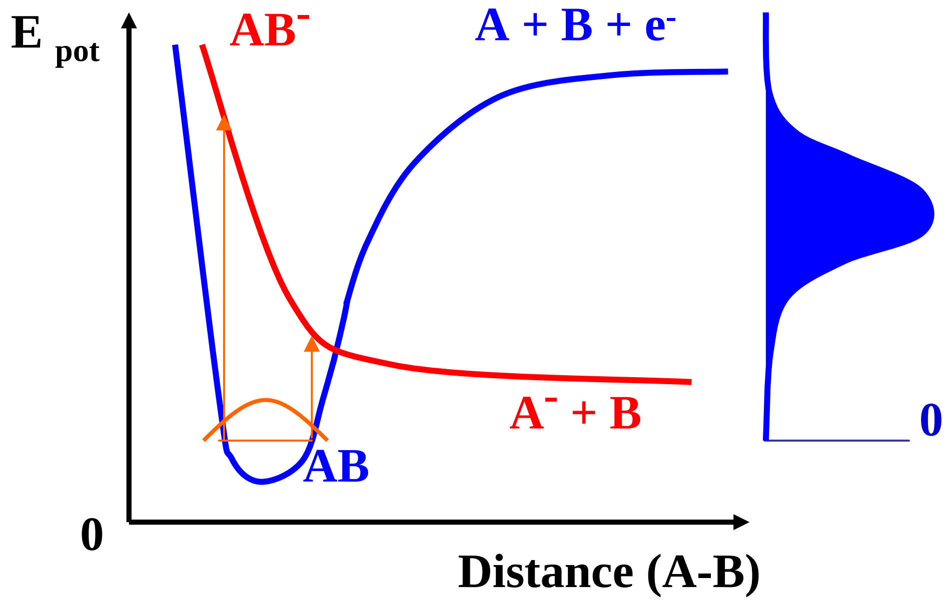
$\rightarrow AB^- + h\nu$

molecular anion

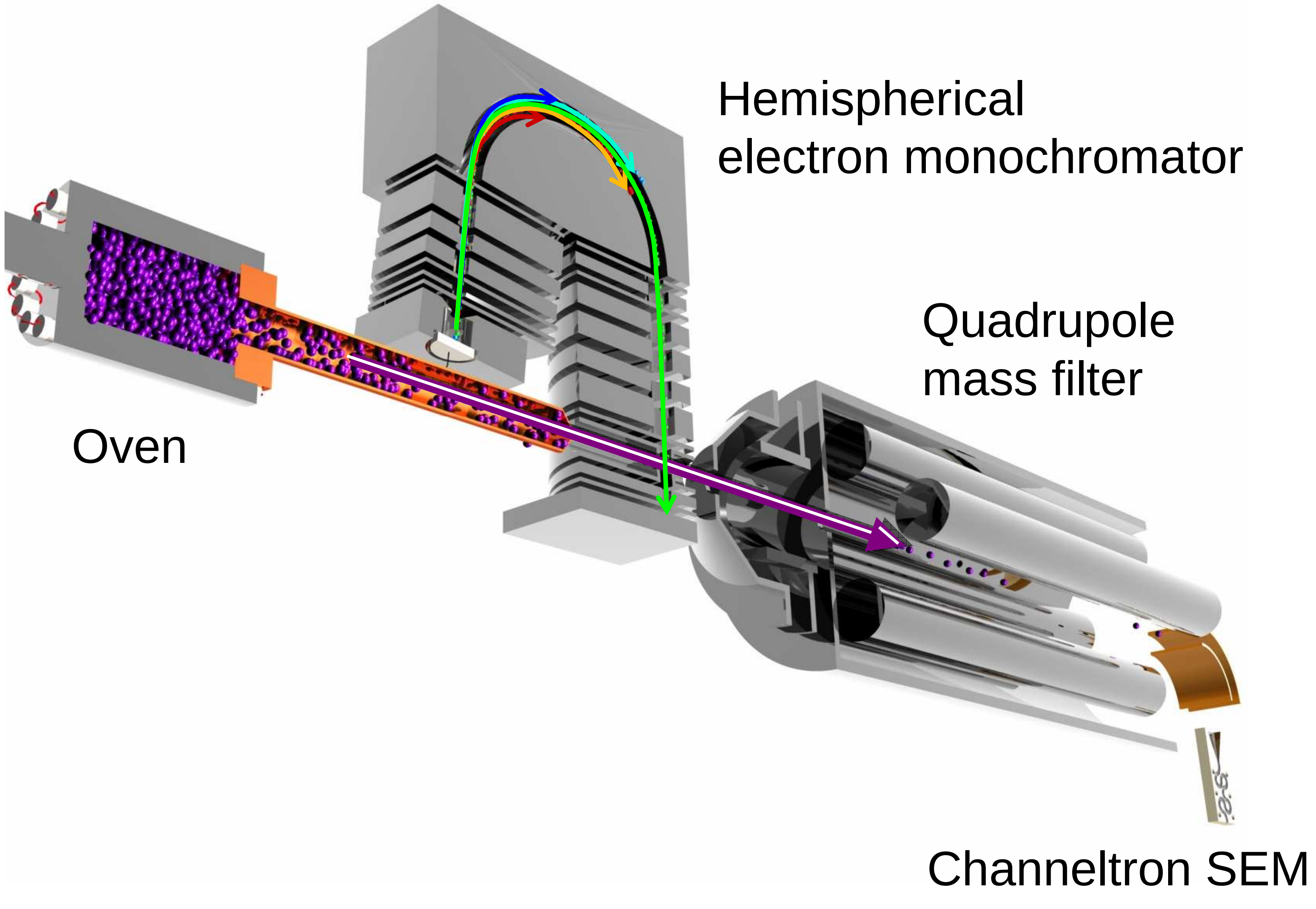
$\rightarrow A^- + B$

dissociative electron attachment (DEA)



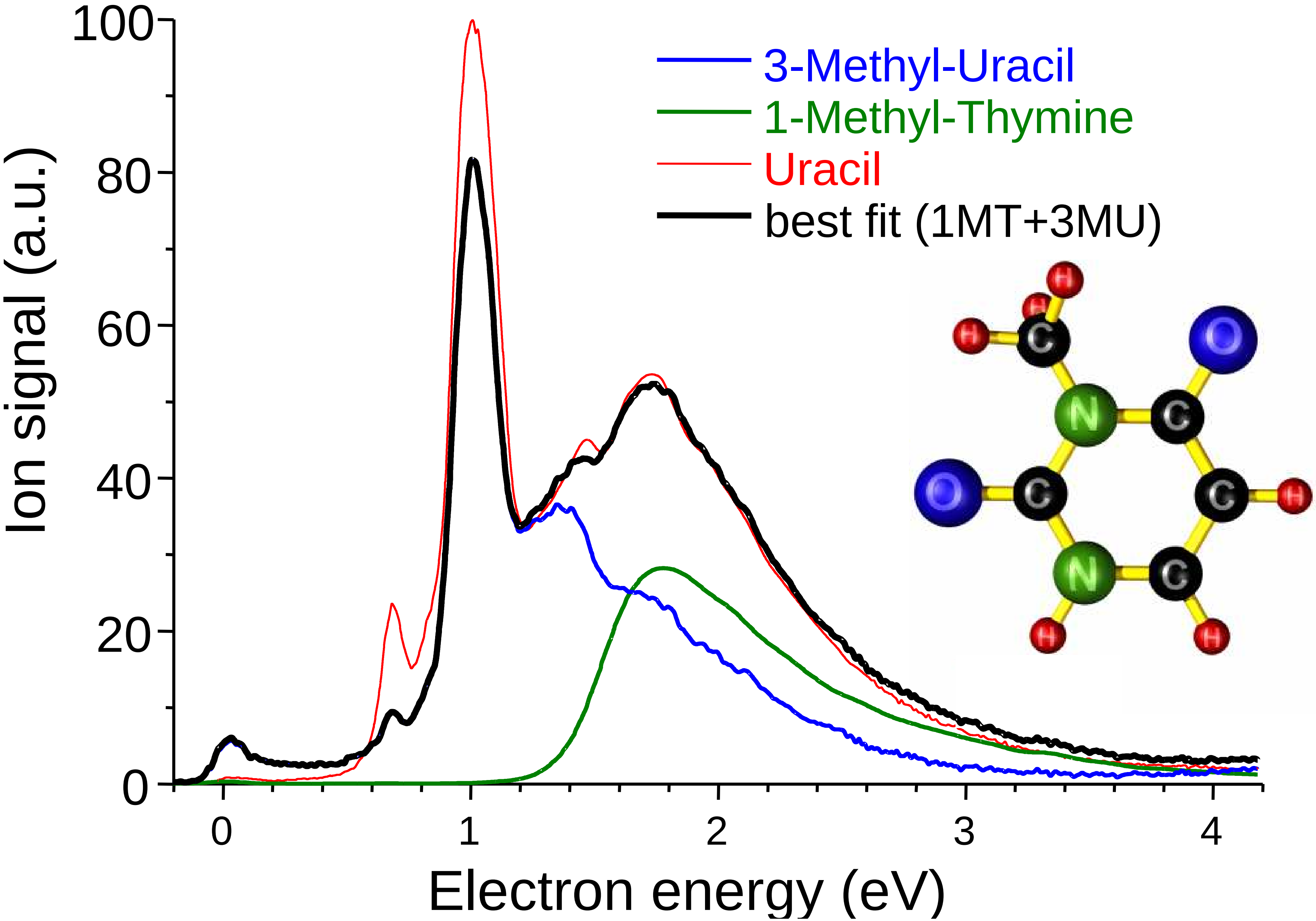


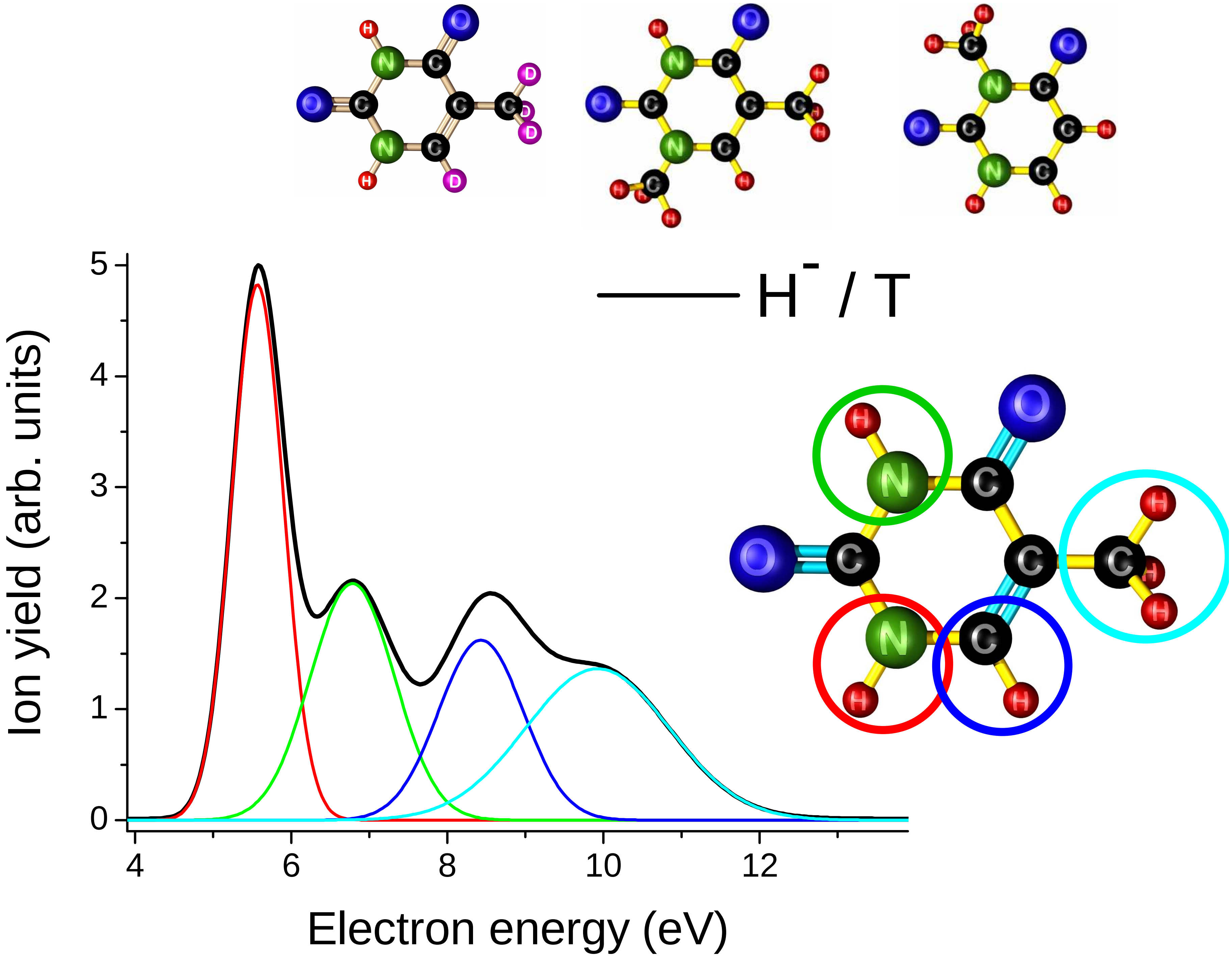
Apparatus


Hemispherical
electron monochromator
Quadrupole
mass filter
Oven
Channeltron SEM

$Nb + e^- \longrightarrow (Nb\text{-}H)^- + H$

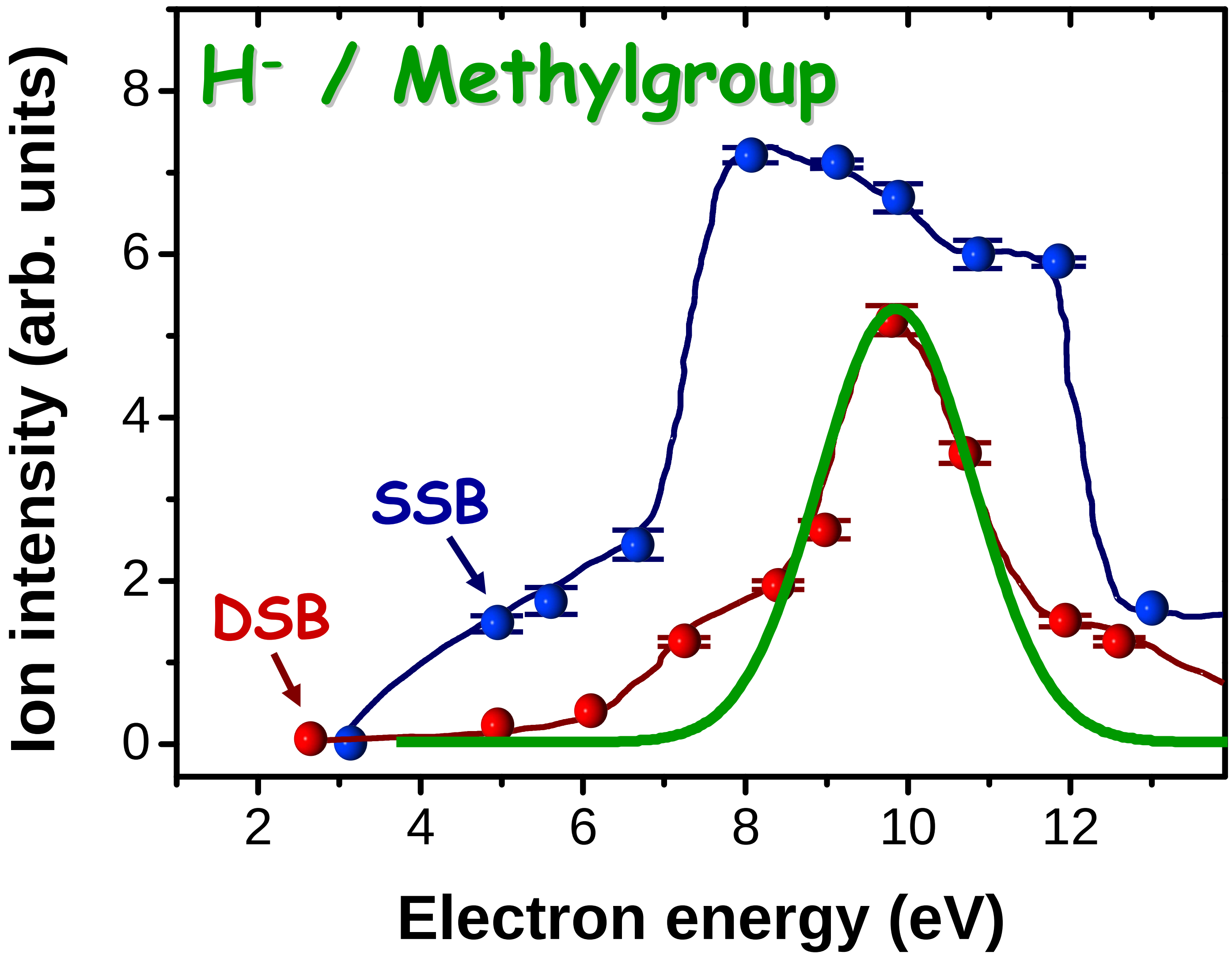
S. Ptasinska et al. *Angew. Chem. Int. Ed.* **44** (2005) 6941





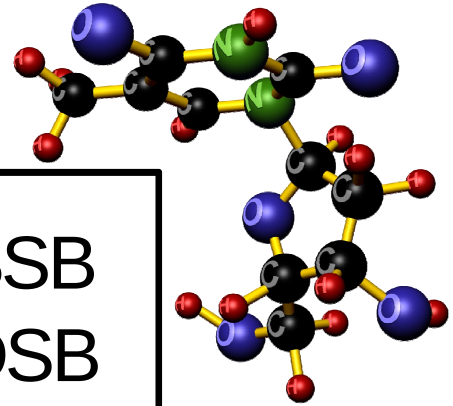
H
N
C
O
D
H⁻ / T
Ion yield (arb. units)
Electron energy (eV)
0
1
2
3
4
5
4
6
8
10
12

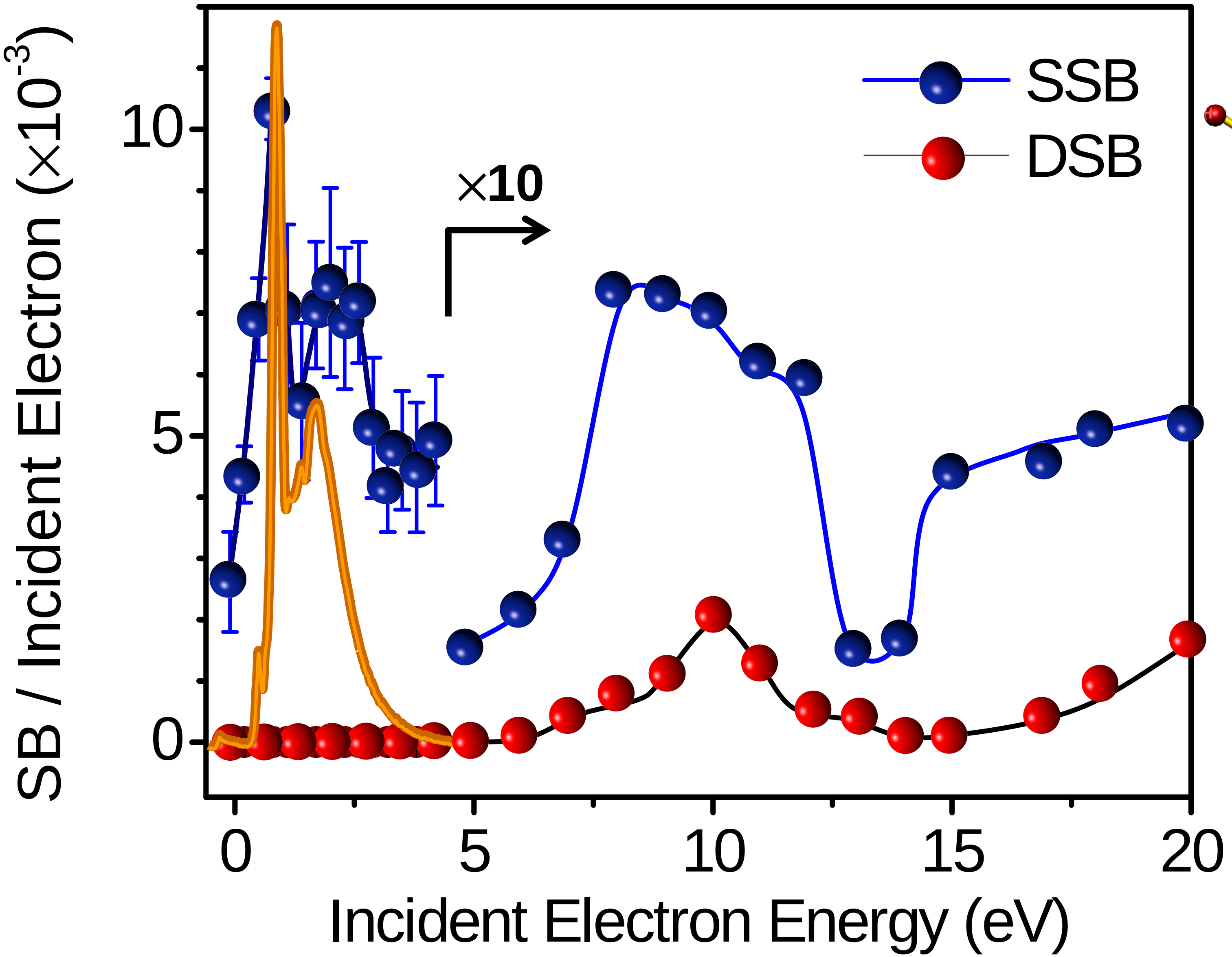
Comparison to strand breaks



Sanche a.c. Science, 287 (2000) 1658

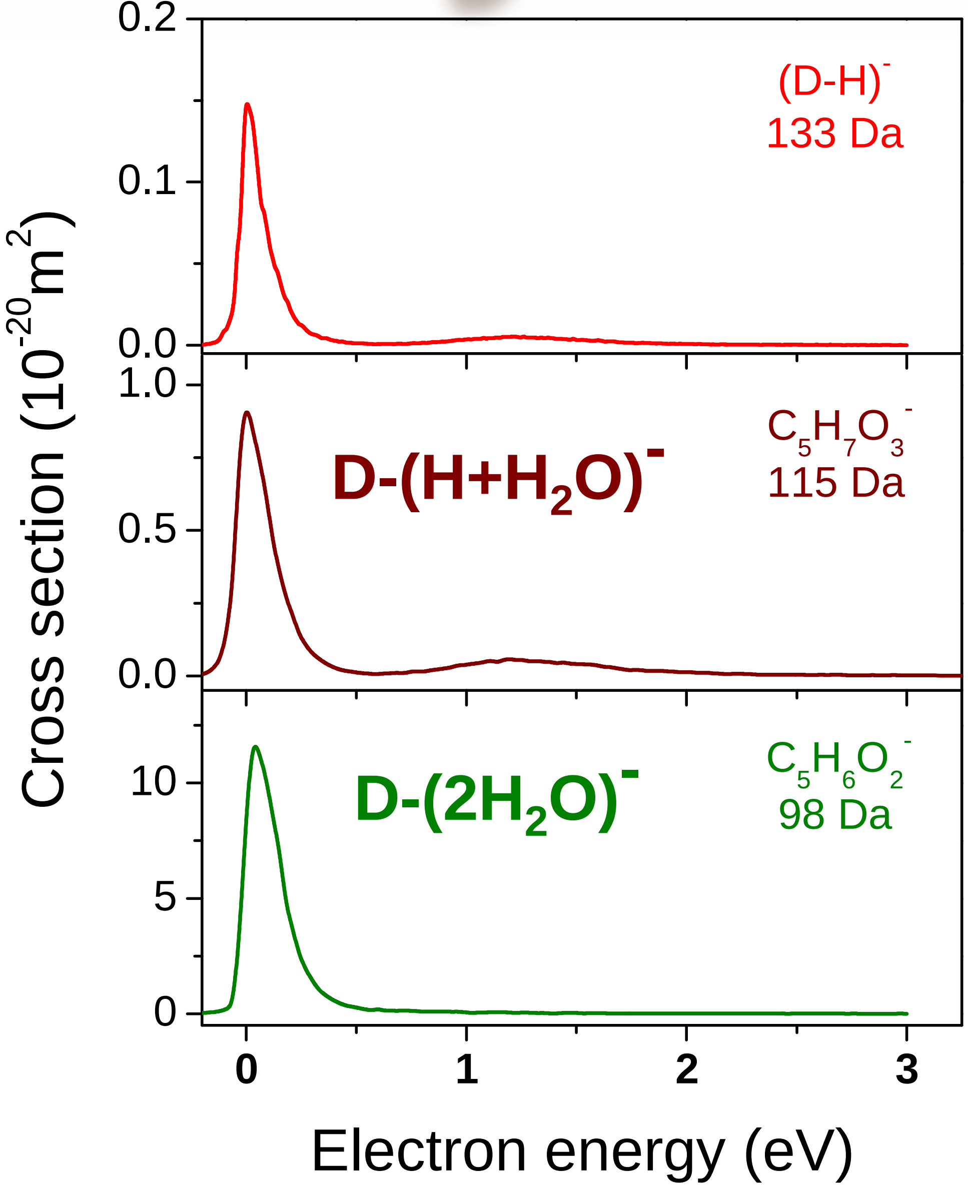
$T + e^- \rightarrow (T\text{-}H)^- + H$

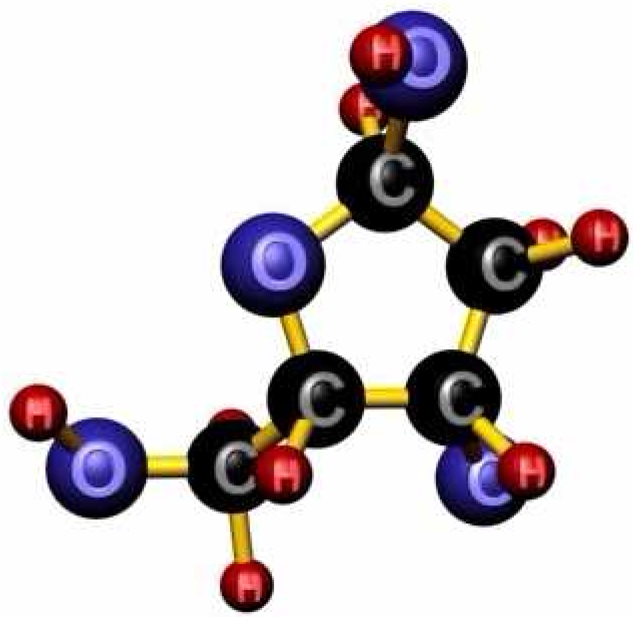




Sanche a.c. PRL, 93 (2004) 068101

Deoxyribose





S. Ptasinska et al. *J. Chem. Phys.* **120** (2004) 8505

Dissociative Electron Attachment to Phosphoric Acid Esters: The Direct Mechanism for Single Strand Breaks in DNA

Constanze König, Janina Kopyra,* Ilko Bald,† and Eugen Illenberger
Institut für Chemie und Biochemie - Physikalische und Theoretische Chemie, Freie Universität Berlin, Takustrasse 3, D-14195 Berlin, Germany
(Received 22 March 2006; published 7 July 2006)

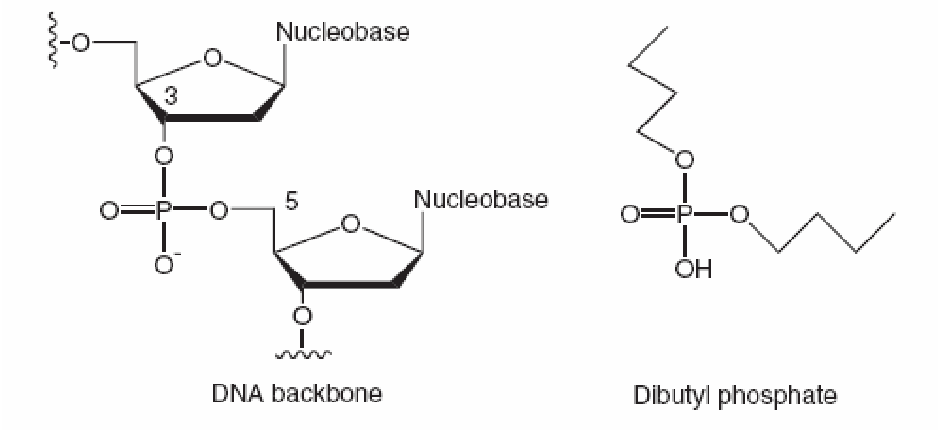


FIG. 1. Molecular structure of dibutyl phosphate (DBP) compared to the structure of the DNA backbone. Positions 3 and 5 of the sugar are labeled.

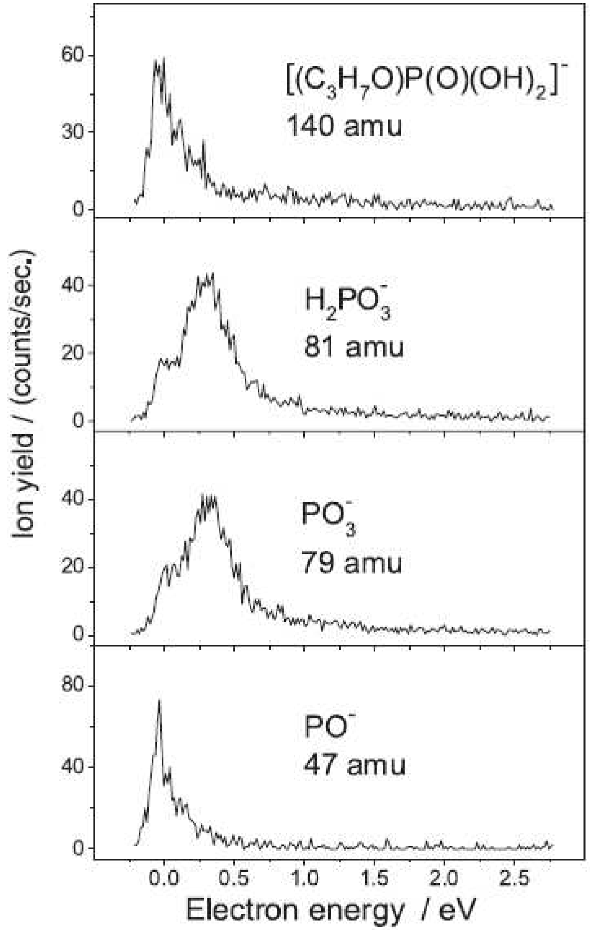
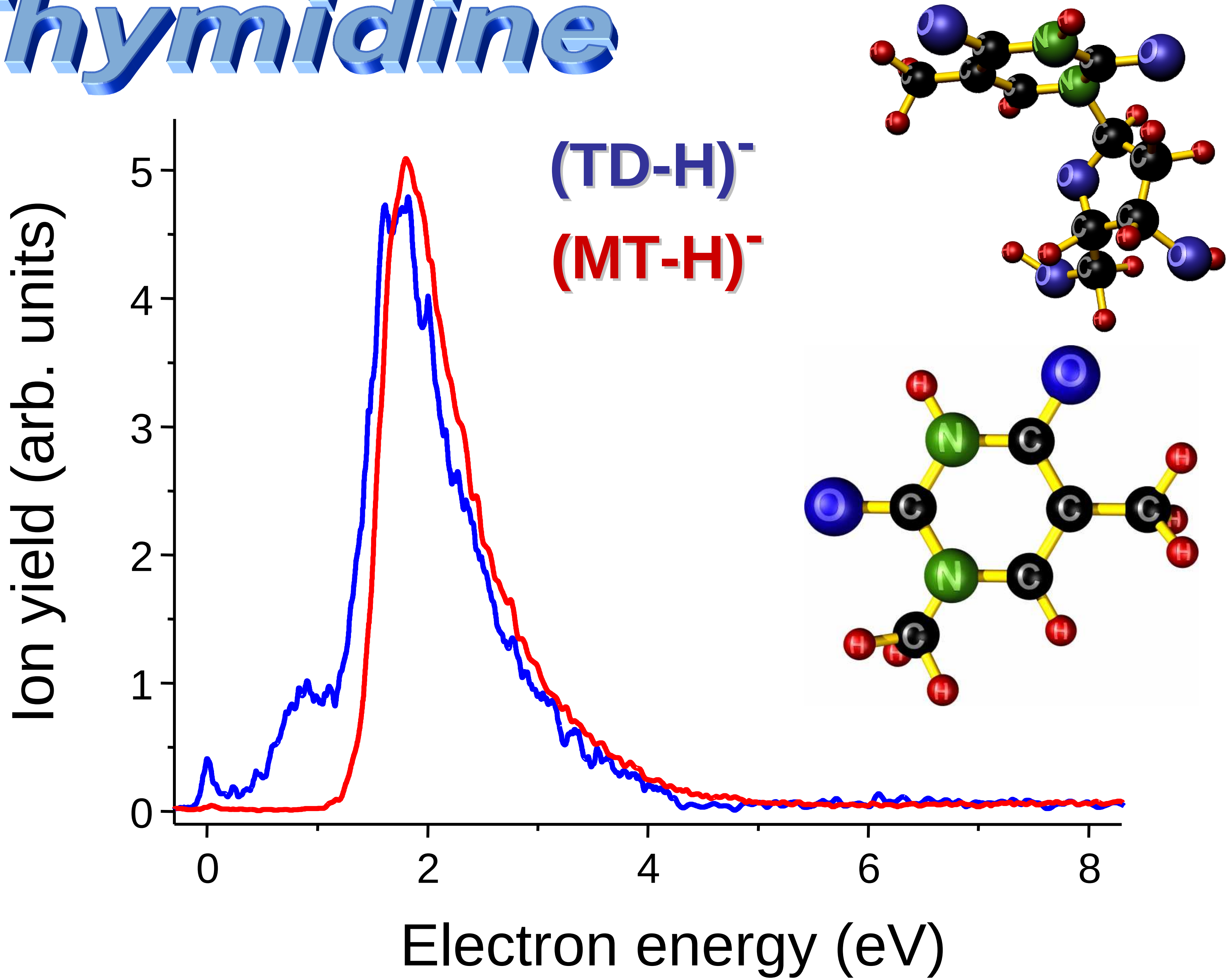


FIG. 3. Ion yields from dibutyl phosphate (DBP) at low energy.

Thymidine

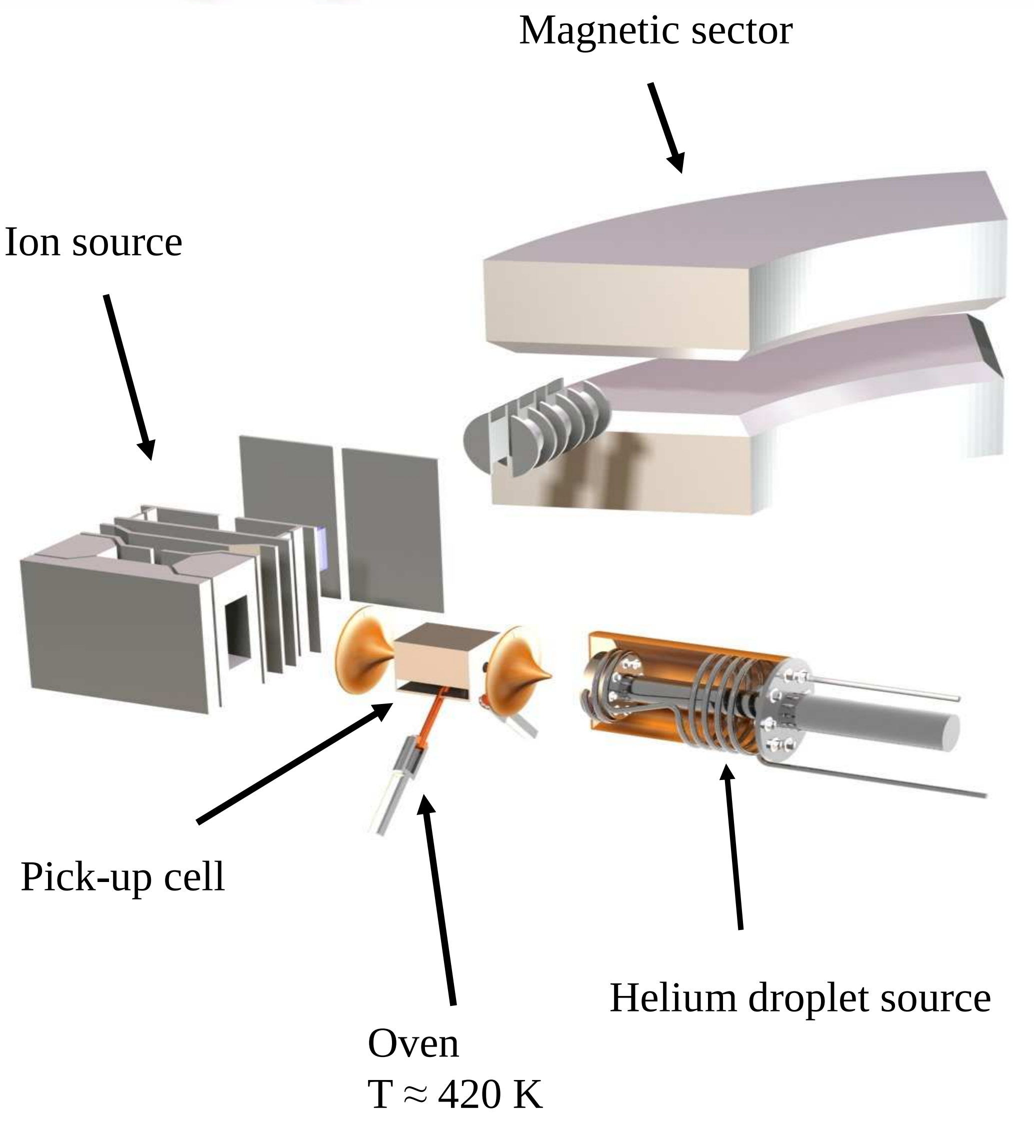


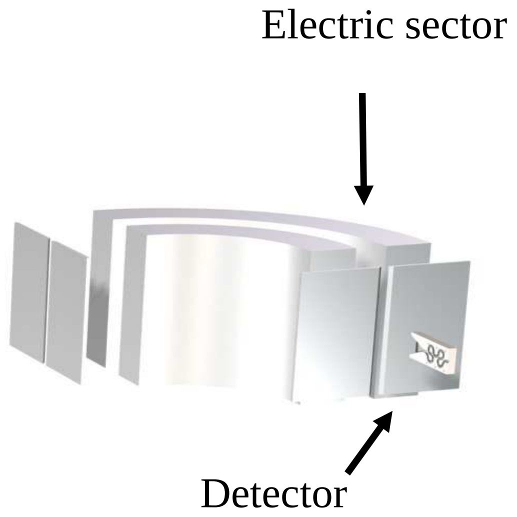
(TD-H)-
(MT-H)-
5
4
3
2
1
0
Ion yield (arb. units)
0
2
4
6
8
Electron energy (eV)
O
N
C
H

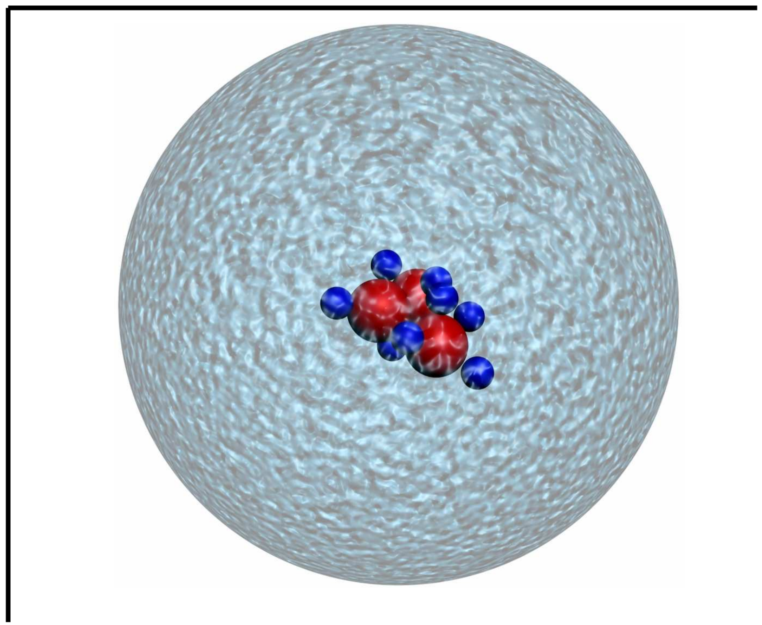
Summary

- Large number of studies with isolated biomolecules → Implications for DNA damage by e^-
- Close to zero eV: Direct damage of sugar unit
- Close to zero eV: Direct damage of phosphorus group
- Alternative process at low electron energies: Electron attachment to base and subsequent charge transfer to sugar phosphate backbone (J. Simons and coworkers, JACS 126, 6441 (2004))
- 5-10 eV: H^- formation

Apparatus

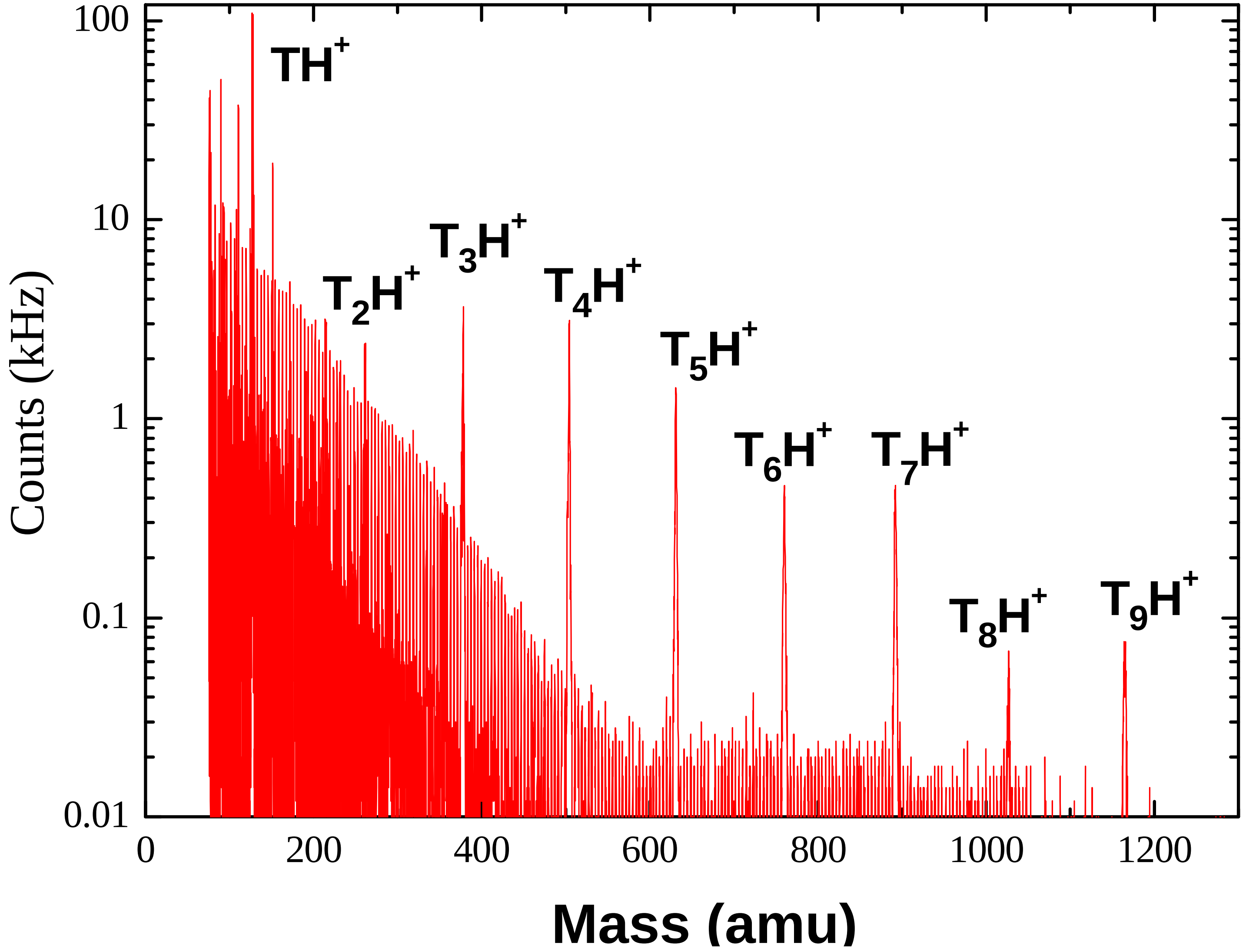

Magnetic sector
Ion source
Pick-up cell
Helium droplet source
Oven
T ≈ 420 K

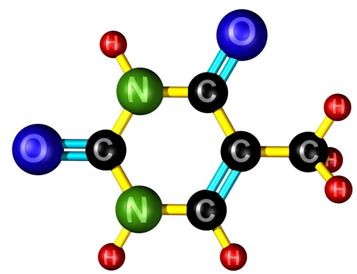

Electric sector
Detector



Thymine pickup by He_n

Positive ions at the electron energy of 150 eV: $e^- + T_nHe_m \rightarrow (TH^+)_{n-1} + 2e^-$





Electron Attachment to “Naked” and Microsolvated Nucleotide Anions: Detection of Long-Lived Dianions

Bo Liu, Shigeo Tomita, Jimmy Rangama,
Preben Hvelplund,* and Steen Brøndsted Nielsen*[a]

CHEMPHYSCHEM **2003**, *4*, 1341 – 1344

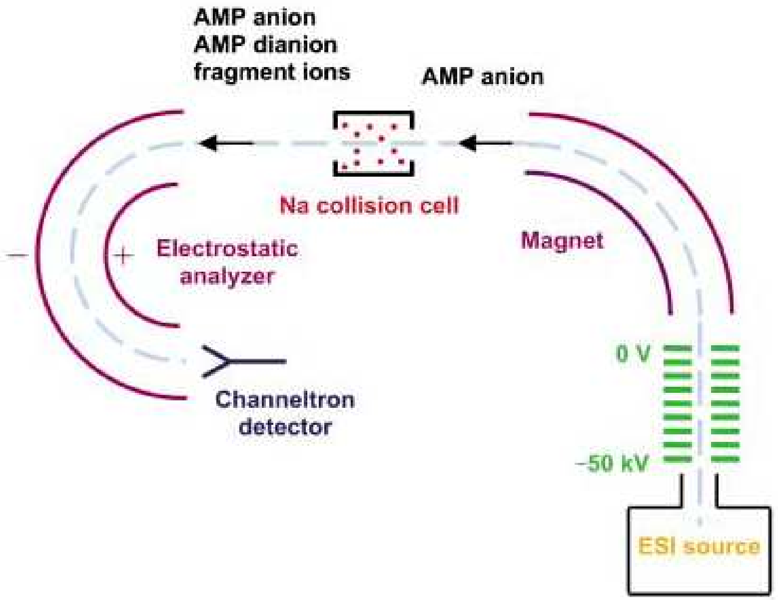
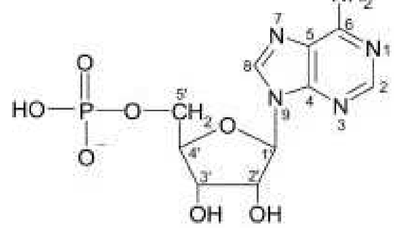


Figure 4. Diagram of the experimental layout.



Scheme 1. Numbering scheme for the AMP anion.

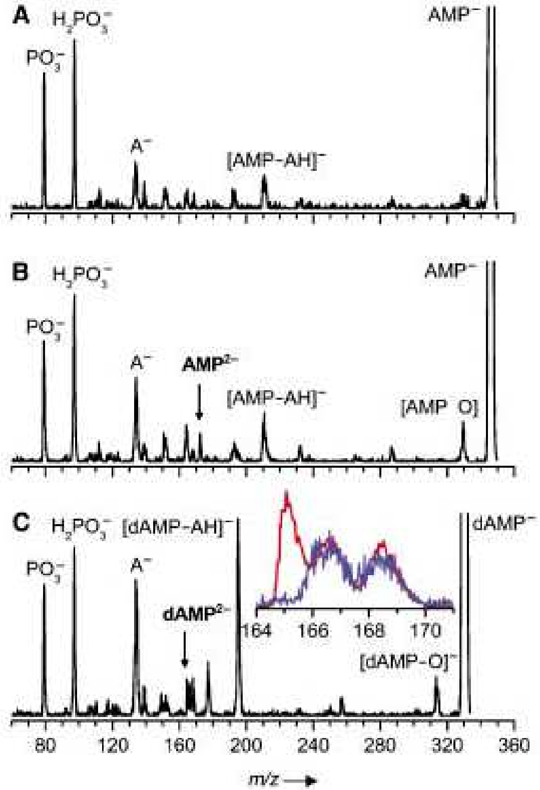
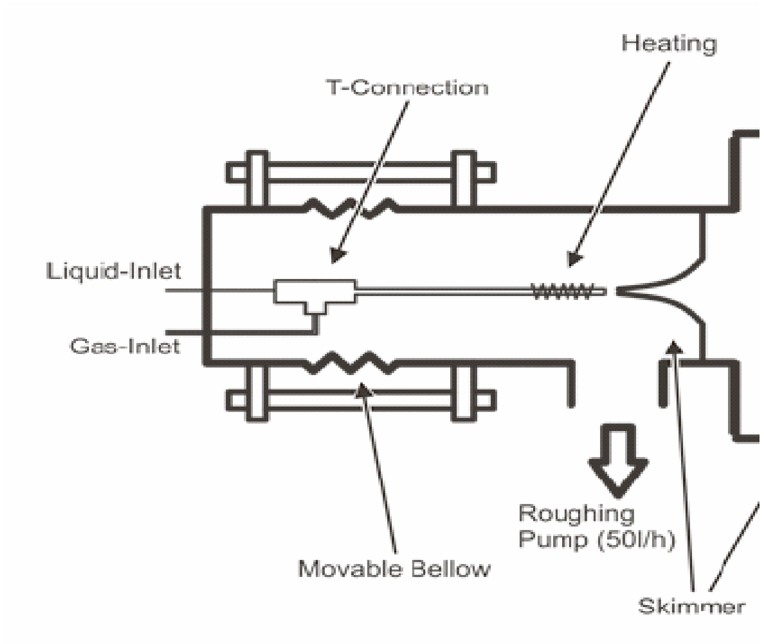
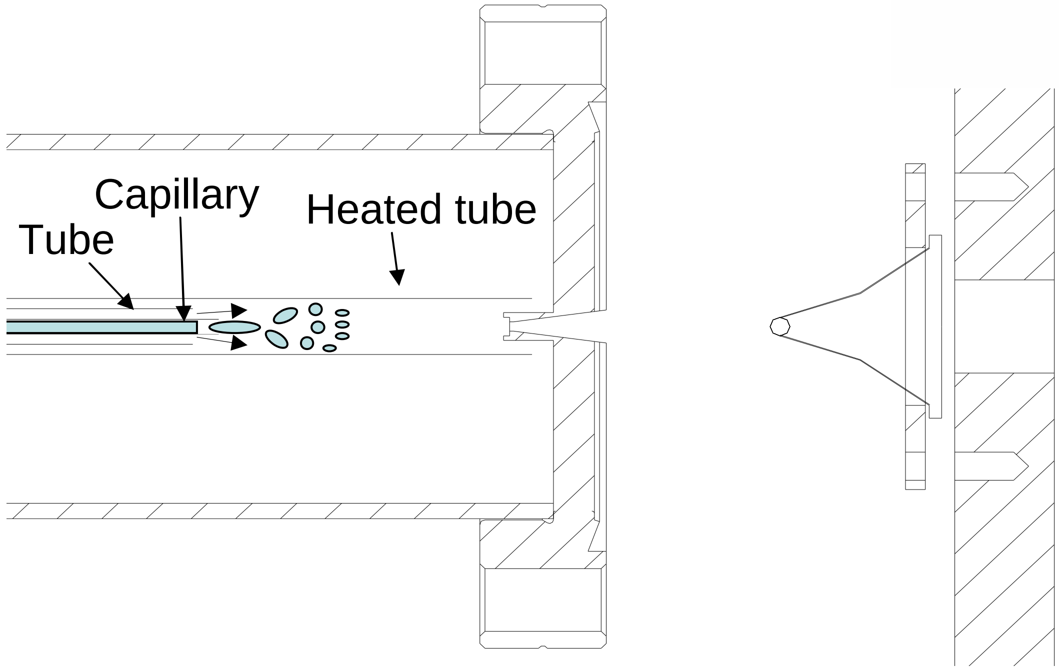


Figure 1. Spectra obtained after collisions between AMP anions and neon (A) and sodium (B) and between dAMP anions and sodium (C). The inset in (C) shows the region around half the m/z of the dAMP anion for neon (blue curve) and sodium (red curve) as collision gases.

Cold molecular sources

Sonic spray



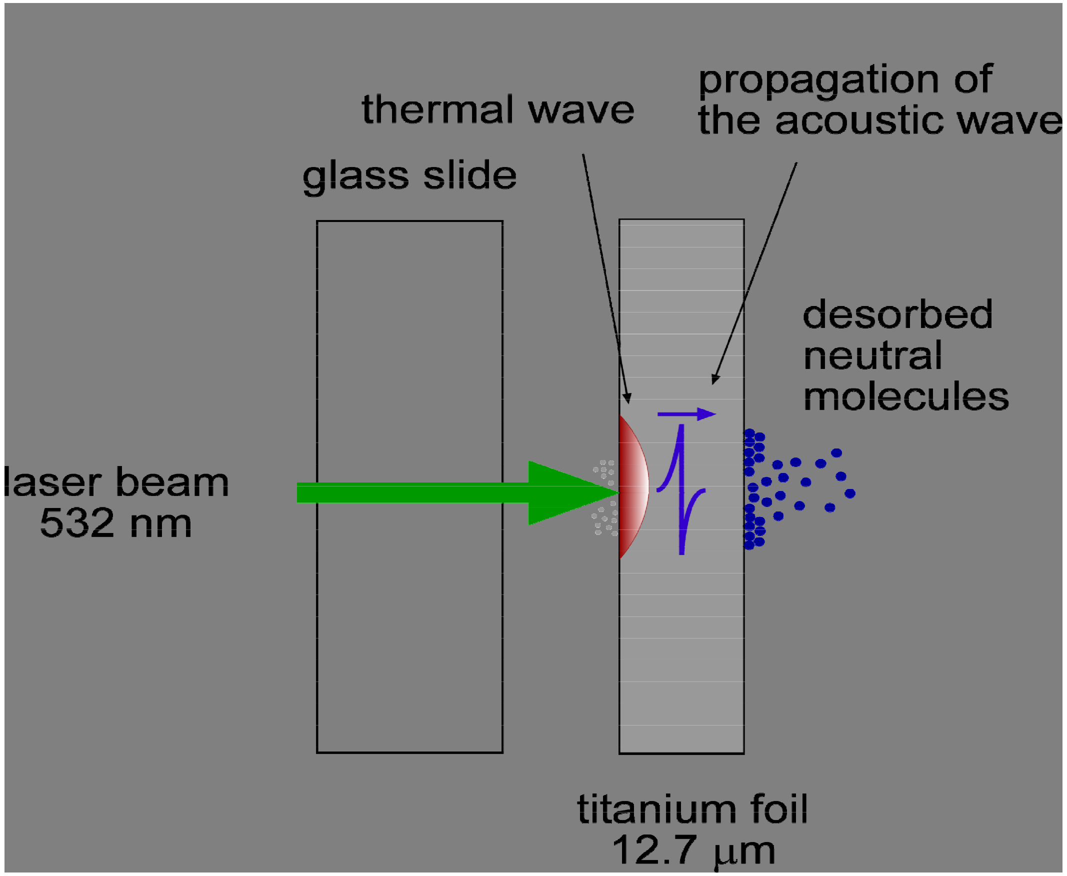


Thermospray

(Alexandre Guiliani and coworkers)

Laser-Induced Acoustic Desorption (LIAD)

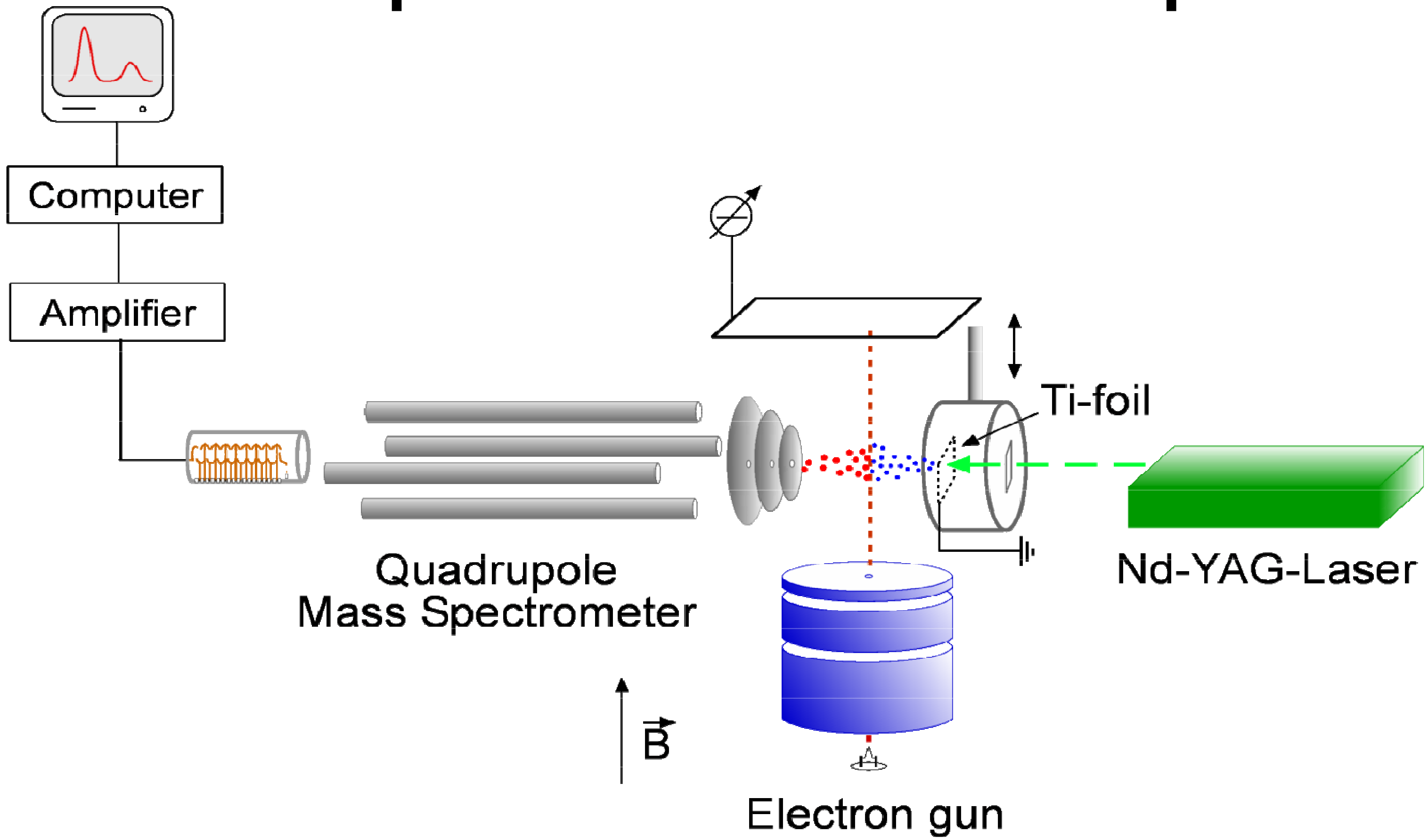
- desorption of intact and neutral molecules
- standard techniques ESI and MALDI generate ions in the gas phase
- LIAD is a gentle method to desorb neutral molecules
- backside irradiation on a titanium foil (13 µm)



R.C. Shea, H.I. Kenttämaa et al., Anal. Chem. 78 (2006) 6133.

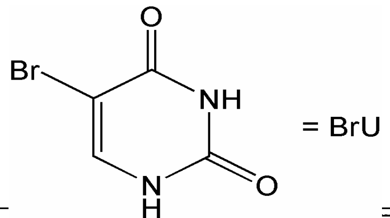
Ilko Bald et al.

Experimental Setup

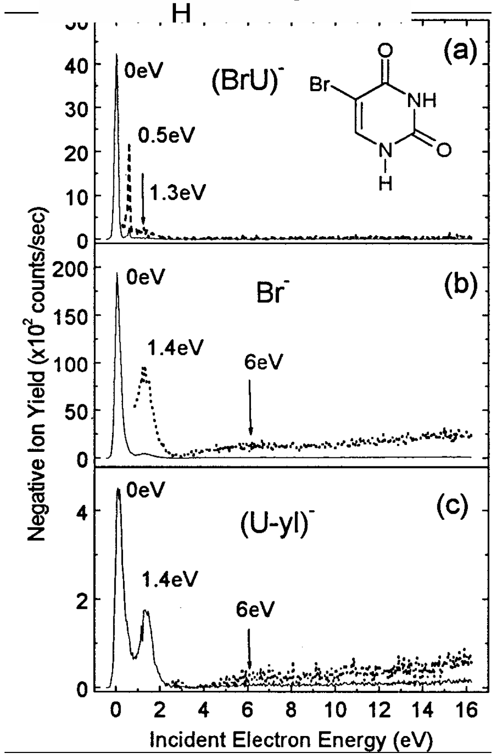


Ilko Bald et al.

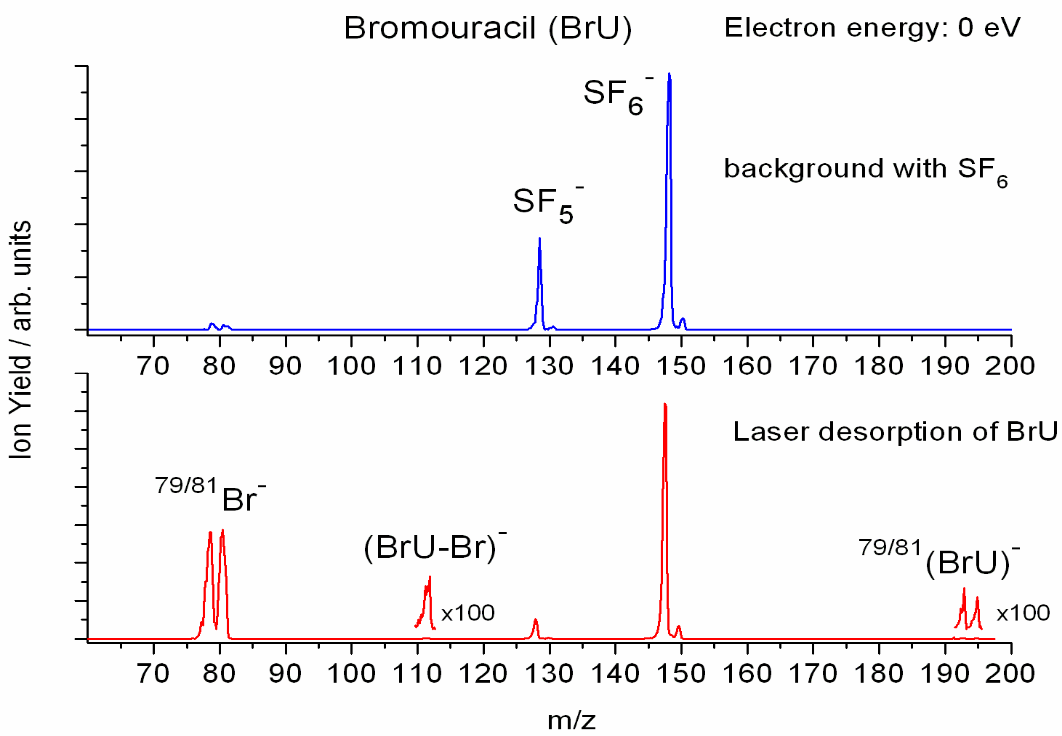
Results: Bromouracil (BrU)



- e^- (0 eV) +BrU → $[BrU]^{-\#}$ → Br^- + U
  → $(BrU\text{-}Br)^-$ + Br

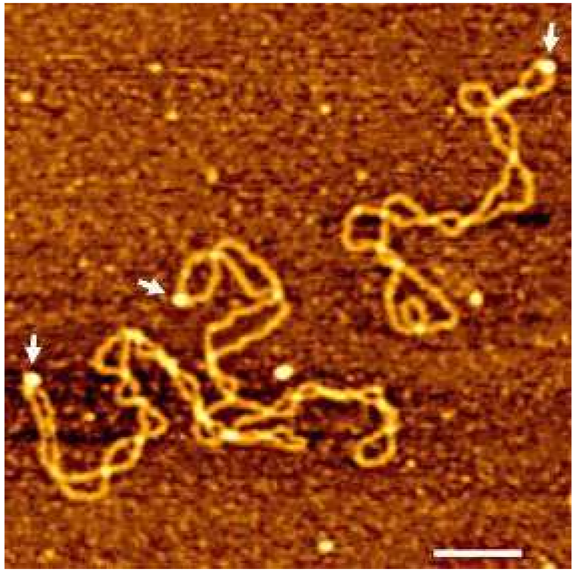


Abdoul Carime et al., J. Chem. Phys. 113 (2000) 2517.

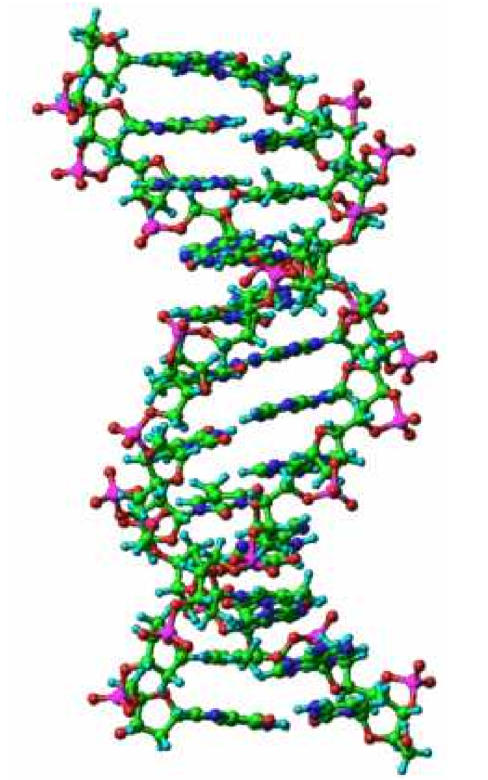


Ilko Bald et al.

More complex (life like) targets



- All fragment ions detectable!
- Therefore gas phase exp.
- No thermal decomposition!
- Effect of water
- Custom made oligonucleotides (clean)



Our strategy in Ibk:

- Presently pick-up of building blocks
- Thermospray source in development

Paul Scheier
Tilmann Märk
Michael Probst
Sylwia Ptasinska (now Milton Keynes)
Fabio Zappa
Philipp Sulzer
Ingo Mähr
Julien Lecointre (Liege)
Flaminia Rondino (Rome)

Eugen Illenberger (Freie Universität Berlin, Germany)

Olof Echt (University of New Hampshire, Durham, USA)

Paul Burrow (Lincoln, Nebraska, USA)

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