Detection of Negative Charge Carriers in Superfluid Helium Droplets: The Metastable Anions He^{*-} and He_2^{*-}

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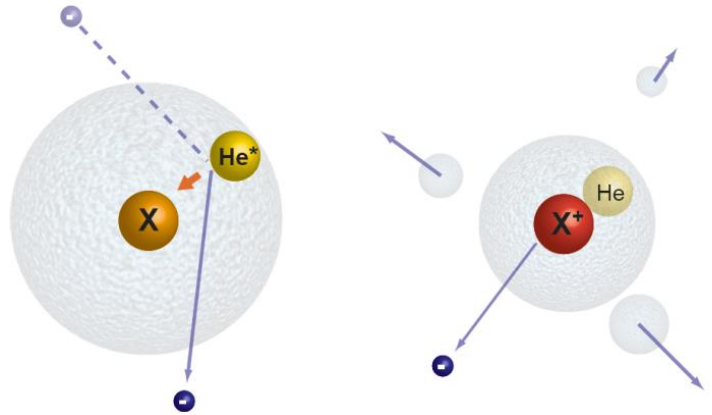
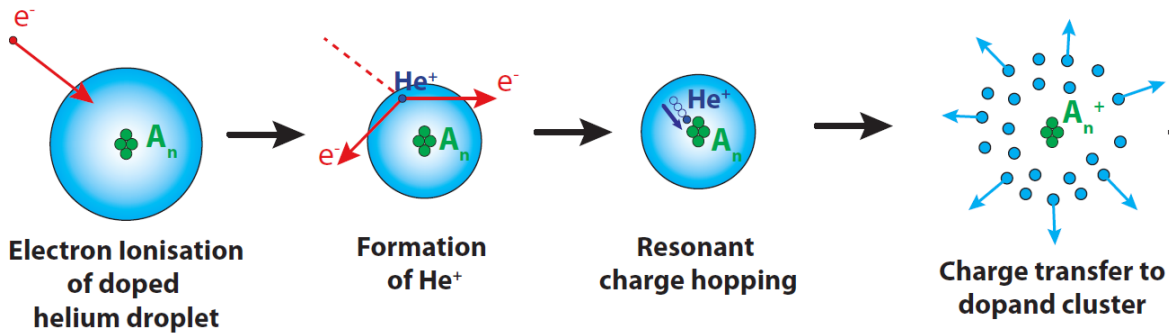
The Environment: Helium Nano Droplets

- HND provide a unique environment:
  - 0.37 K weakly interacting matrix
  - Cooling by evaporation of helium
  - Superfluidity
  - Transparent in wide range of wavelengths (IR to UV)
- Used for low temperature chemistry
- Several ionization mechanisms for dopants
  - $X + He^+ \rightarrow X^+ + He$
  - $X + He^* \rightarrow X^+ + He + e^-$
  - $X + e^- \rightarrow X^-$

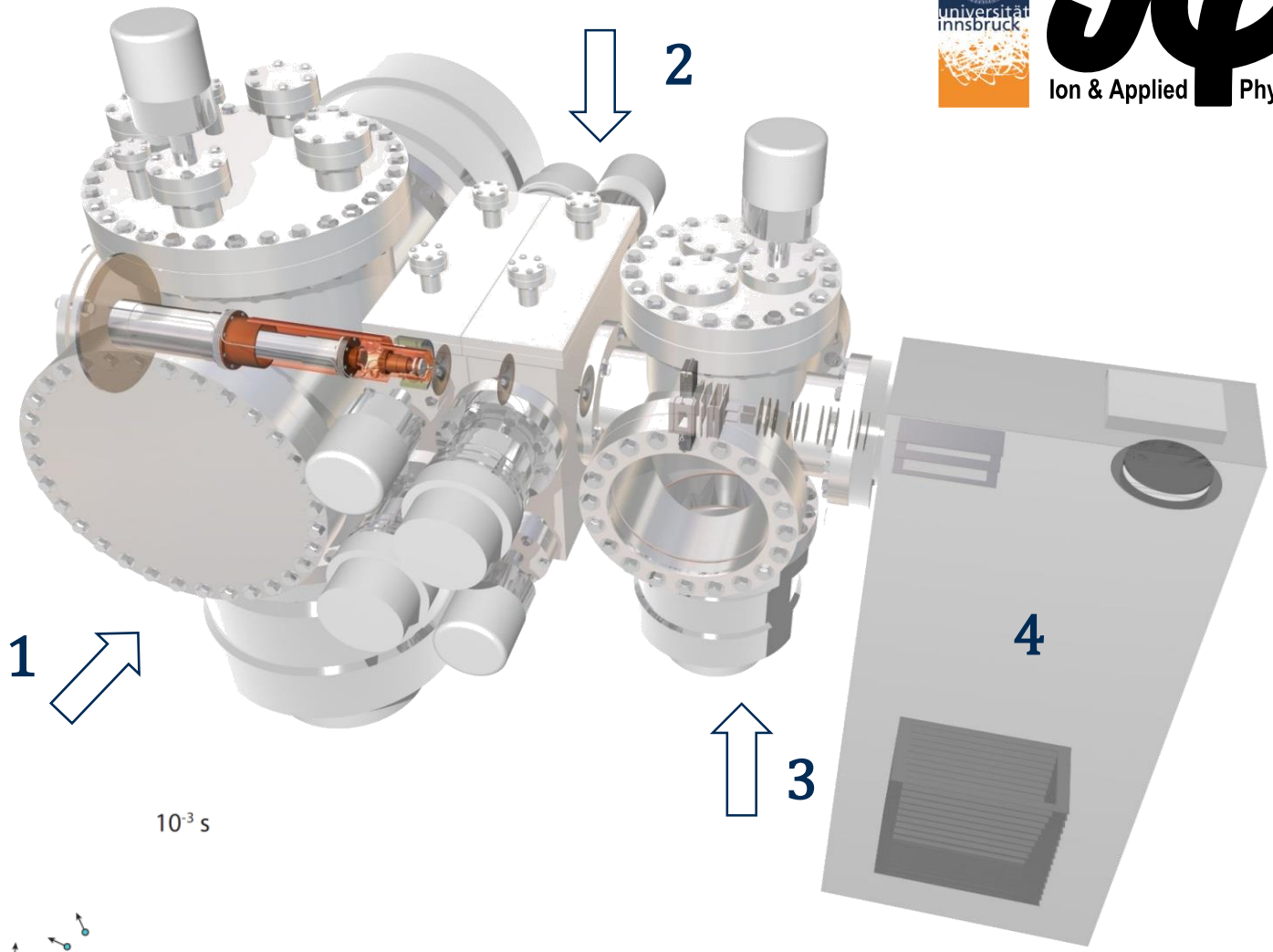


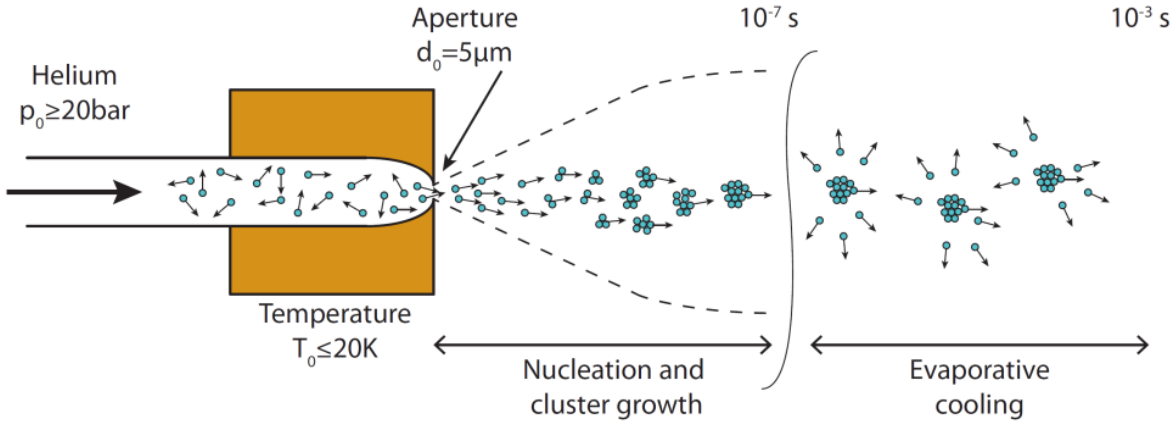


Apparatus

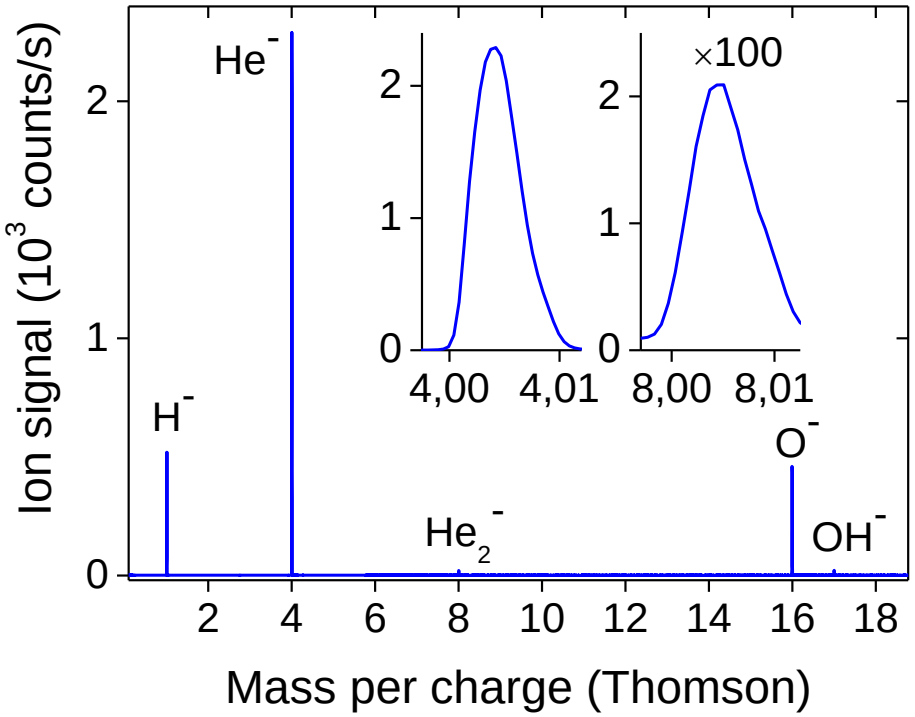
Cluster-**S**ource **T**ime-**O**f-**F**light – CLUSTOF

1) He-Cluster source
2) Pickup-Chambers
3) Ion source
4) TOF

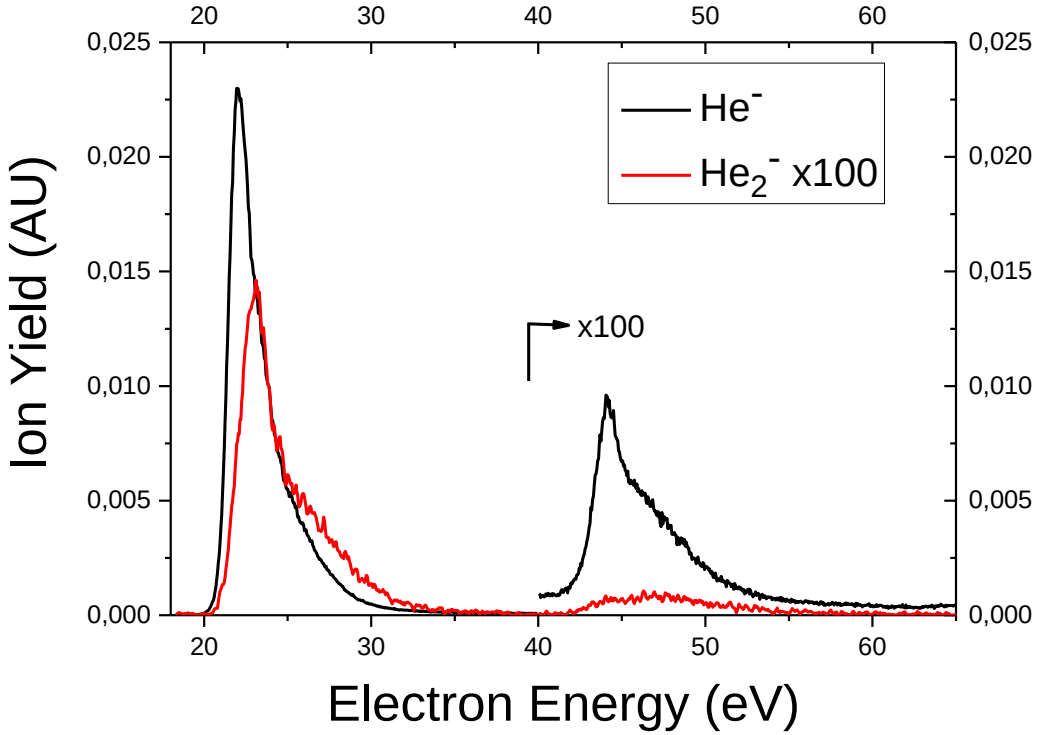




He^{*-} and He_2^{*-}



- Clearly visible in the mass spectra
- Dimer about 100 times smaller
- (measured at 22 eV)



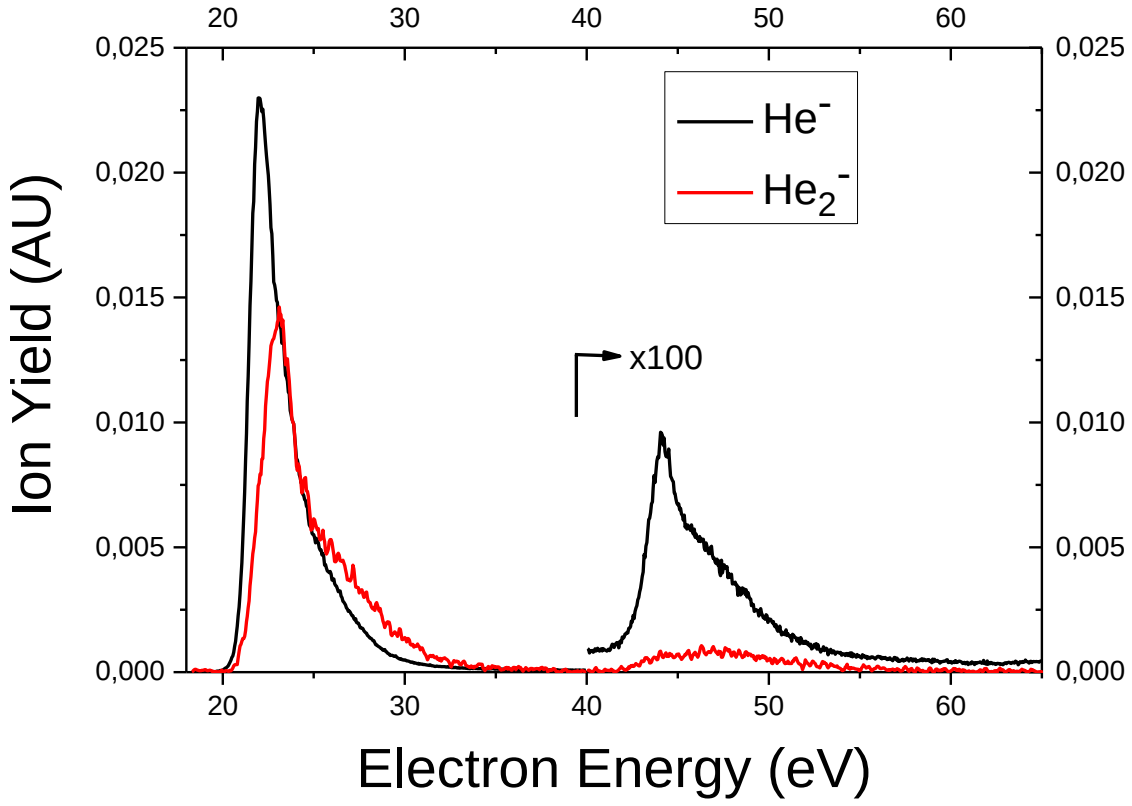
- Distinct peaks around 22 to 25 eV
- Repetition due to inelastic scattering of e^- at roughly 20 eV more energy

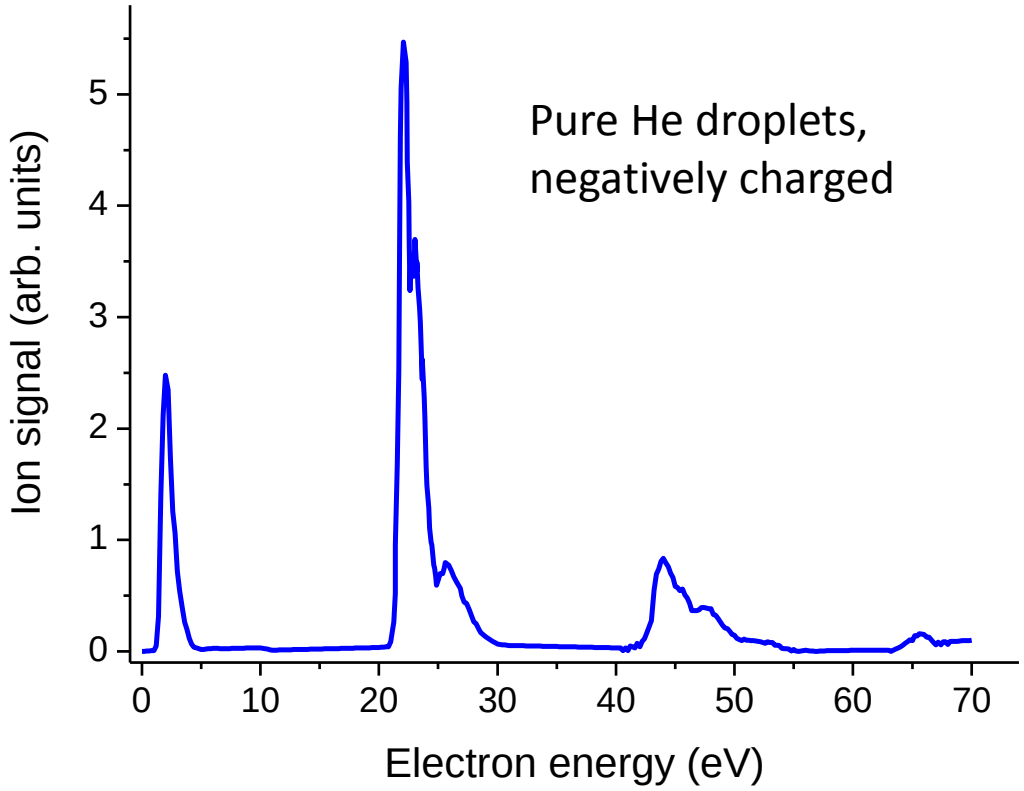
He^{*-} and He_2^{*-}

	He^{*-}	He_2^{*-}
First metastable state	$1s2s2p\ ^4P$	$1\sigma^2_g1\sigma_u2\sigma_g2\pi_u\ ^4\Pi_g$
Related state	$1s2s\ ^3S$	$1\sigma^2_g1\sigma_u2\sigma_g\ a^3\Sigma^+_u$
Binding energy [5, 6]	77 meV	0.23 eV
Lifetime [1, 2]	359 ± 0.9 µs (j = 5/2) 10 µs (j = 3/2; 1/2)	135 ± 15 µs
Year of Detection [3, 4]	1939	1984

[1] H. T. Schmidt et al., in International Conference on Photonic, Electronic and Atomic Collisions (IOP Publishing, 2011).
[2] T. Andersen et al., J. Phys. B **27**, 1135 (1994).
[3] J. Hiby, Ann. Phys (N.Y.) **34**, 473 (1939)
[4] Y. K. Bae et al., Phys. Rev. Lett. **52**, 747 (1984)
[5] T. Brage and C.Froese Fischer, Phys. Rev. A 44, 72 (1991)
[6] S. E. Huber et al., Mol. Phys., 112:5-6, 794-804 (2014)

Formation





[1] U. Henne et al., J. Chem. Phys. **108**, 9327 (1998).

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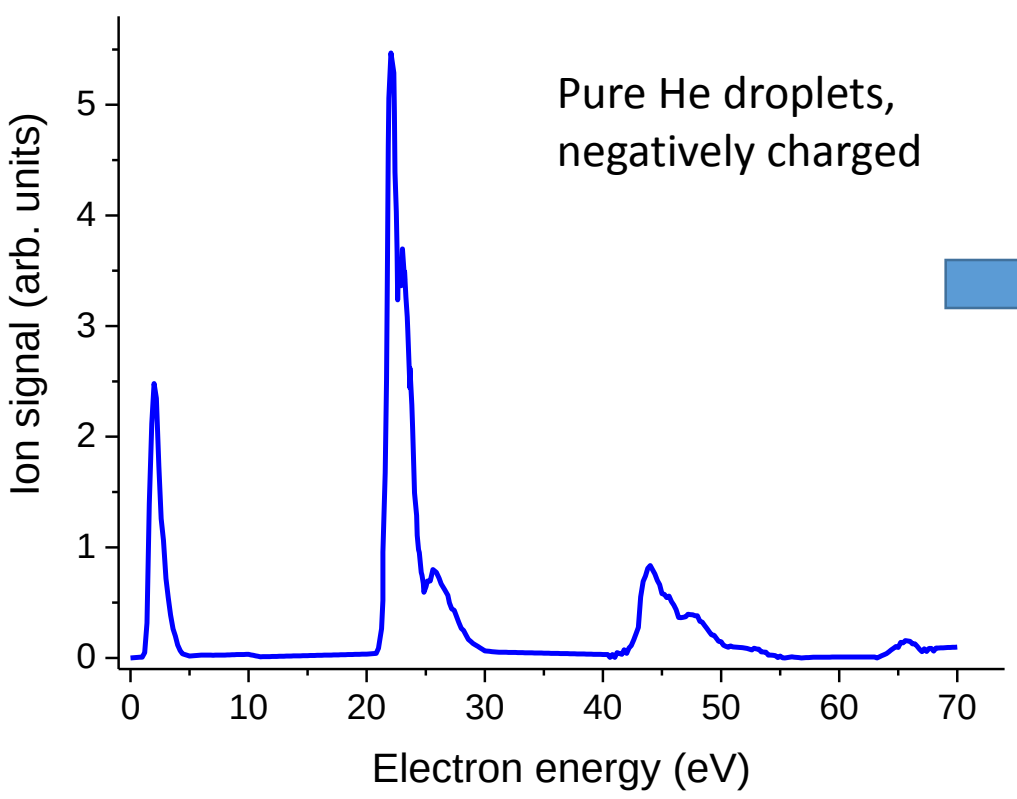

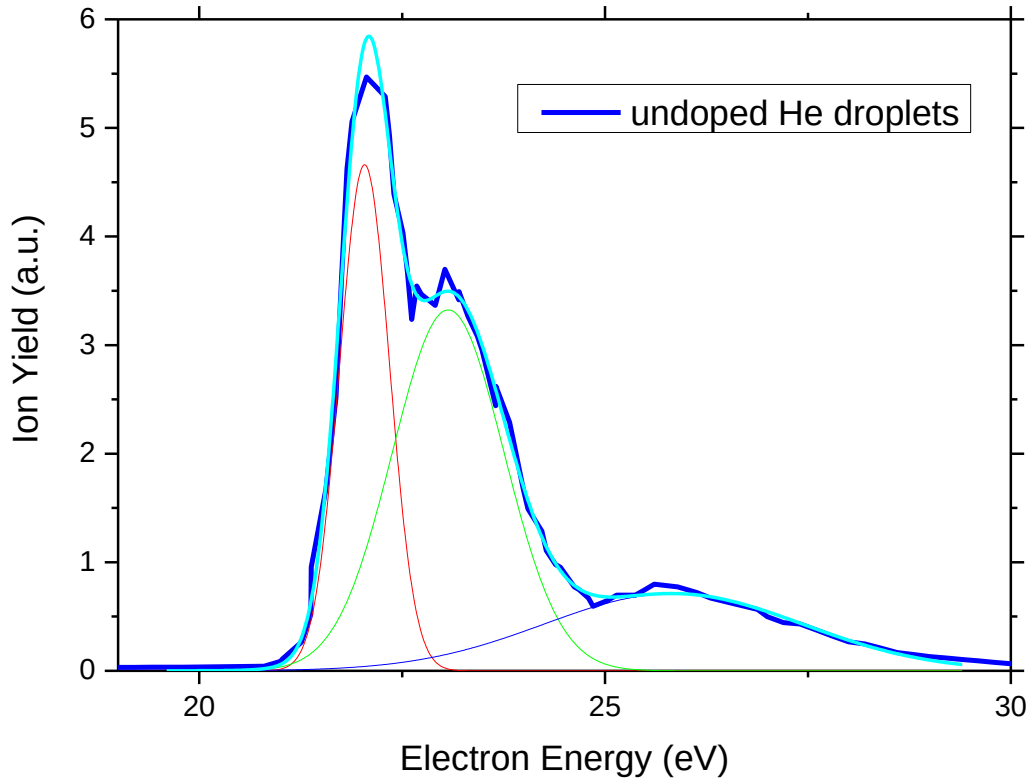

[1] U. Henne et al., J. Chem. Phys. **108**, 9327 (1998).

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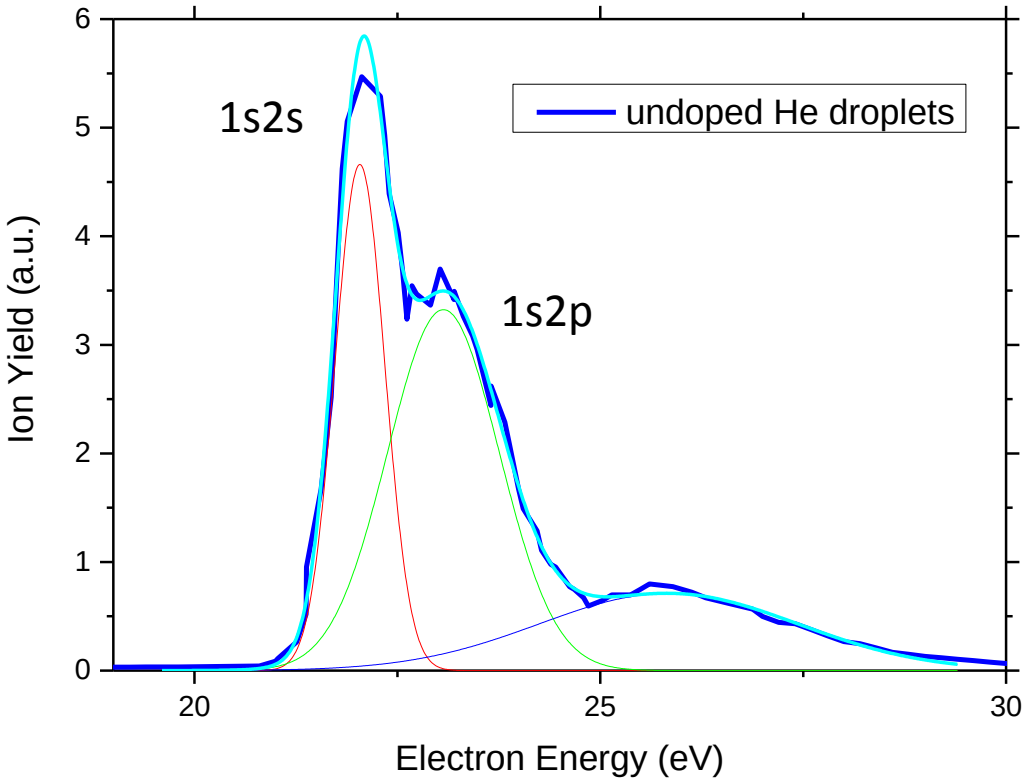

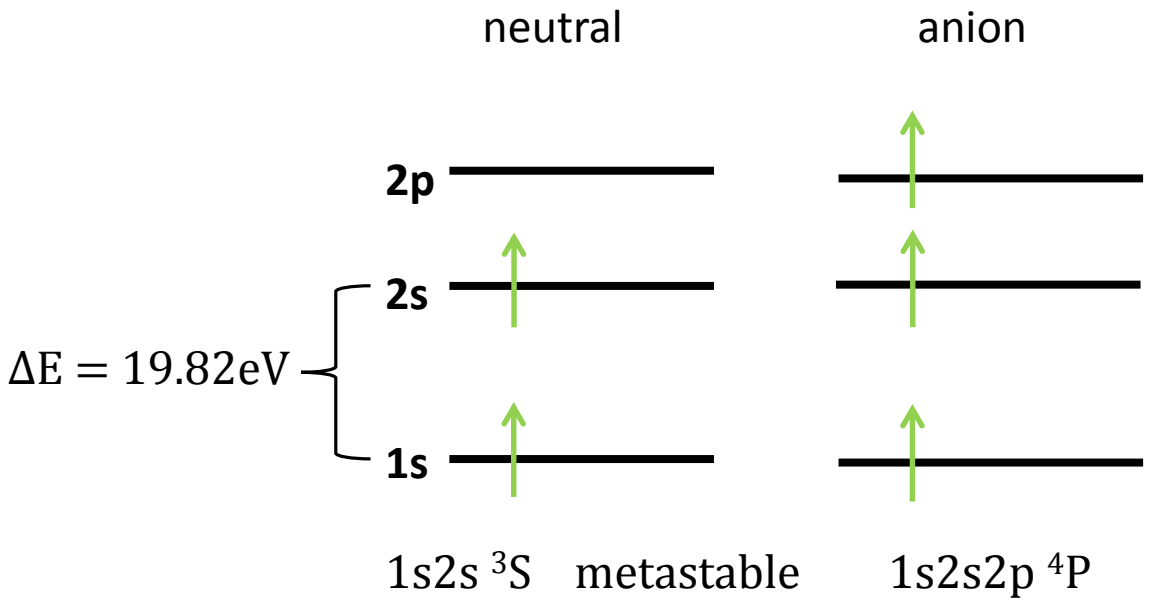

- 19.7 eV ≠ 22 eV 2.3 eV missing!
- Several other effects:
  - Helium barrier for the e^-: 1.25 eV
  - Blueshift due to interaction with He: 0.80 eV

[1] U. Henne et al., J. Chem. Phys. **108**, 9327 (1998).

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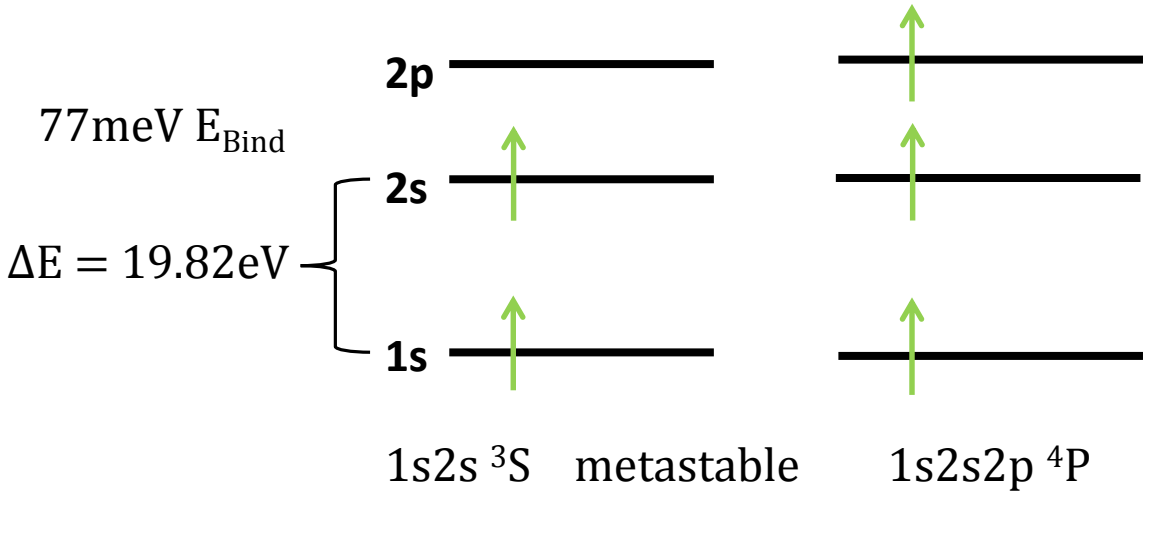
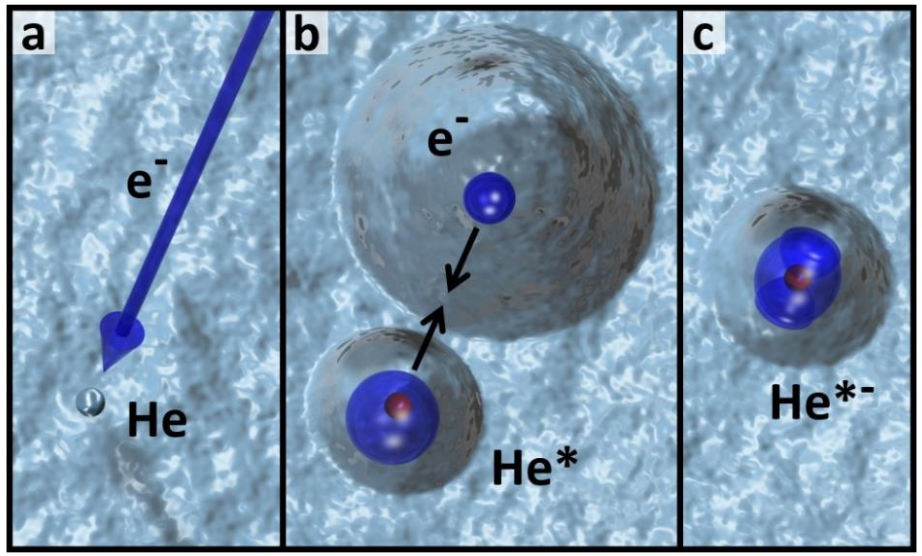




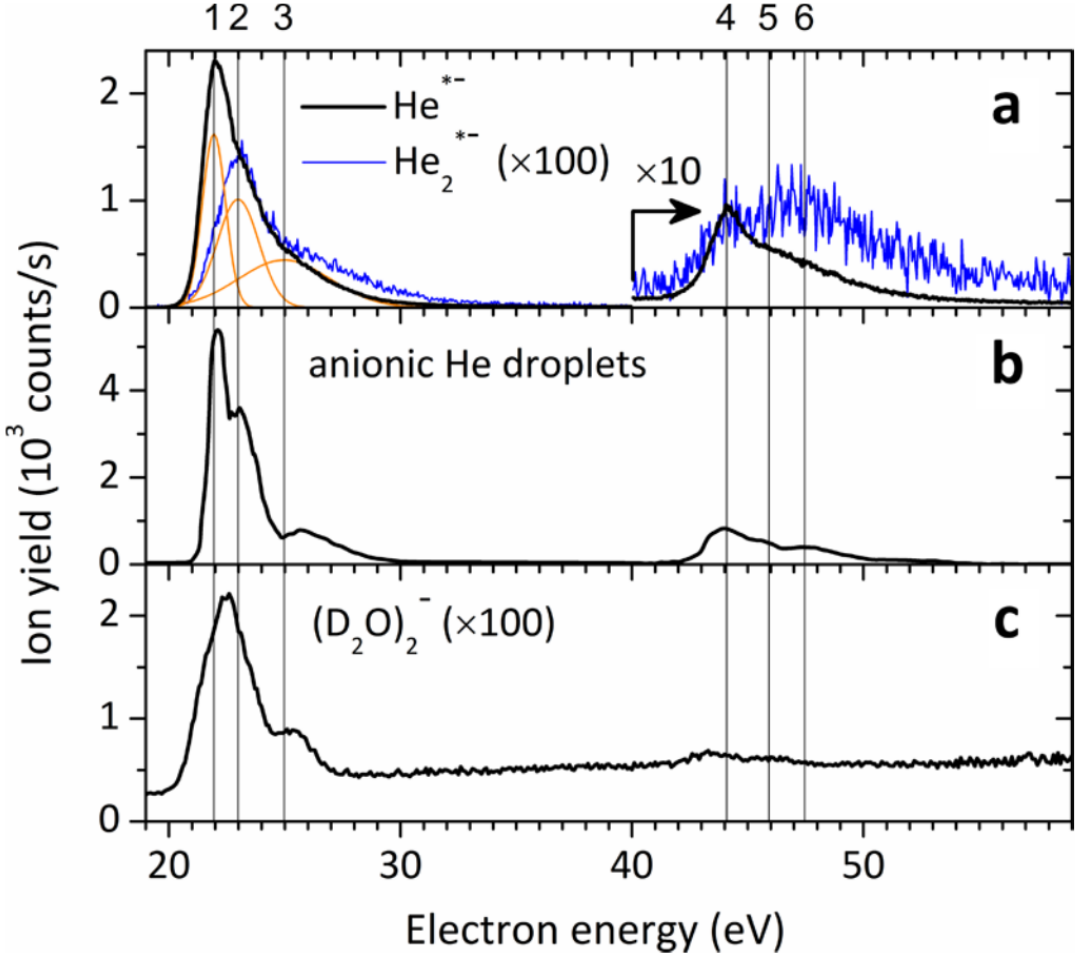
- 19.7 eV ≠ 22 eV 2.3 eV missing!
- Several other effects:
  - Helium barrier for the e^-: 1.25 eV
  - Blueshift due to interaction with He: 0.80 eV[1]

a) e^- scatters with He, exciting it to one of three states
b) slowed-down e^- forms bubble (as well as the excited He^*)
c) e^- attaches to He^* and bubbles combine, because they gain energy in that process

[1]: estimation by K. v. Haeften - Calculations only available for singlett states

Importance

- New ionization channels in addition to the aforementioned ones:
  - $He^{*-} + X \rightarrow X^{+} + He + e^{-}$
  - $He^{*-} + X \rightarrow X^{2-} + He^{+}$
  - $He^{*-} + AB \rightarrow A^{-} + B + He$
- He^{*-} might be the exotic fast negative charge carrier [1]

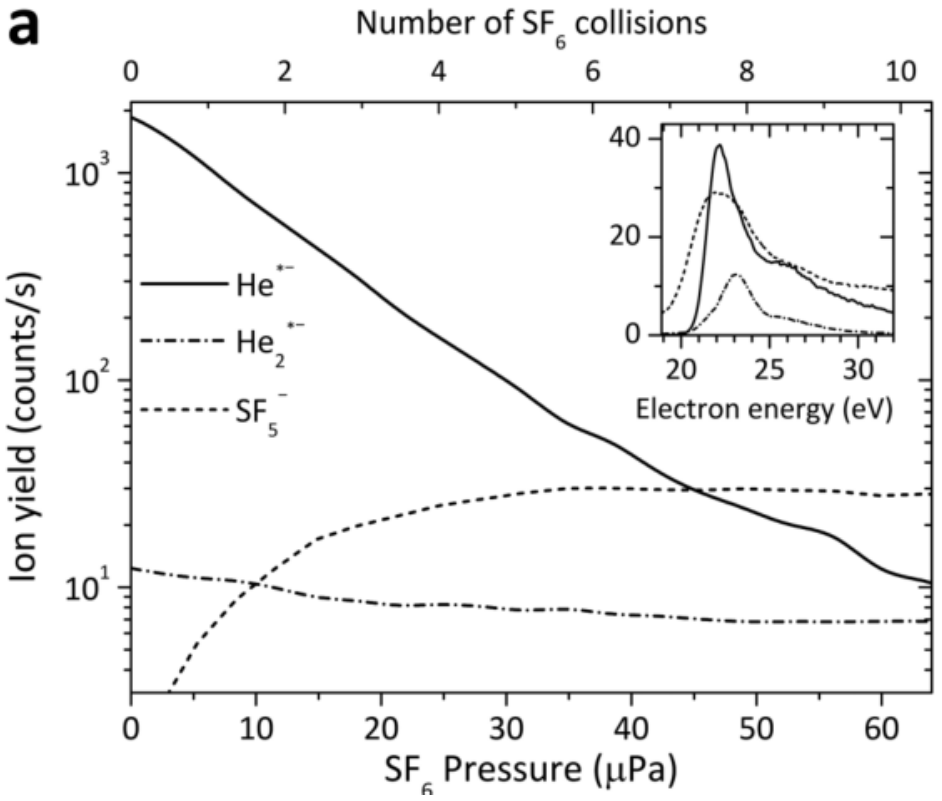


[1] W. Wei et al., Journal of Low Temperature Physics 171,178 (2013).

Properties

- CCSD(T) calculations [1]
- He^{*-} heliophilic, whereas He_2^{*-} is heliophobic
- Higher mobility of He^{*-}

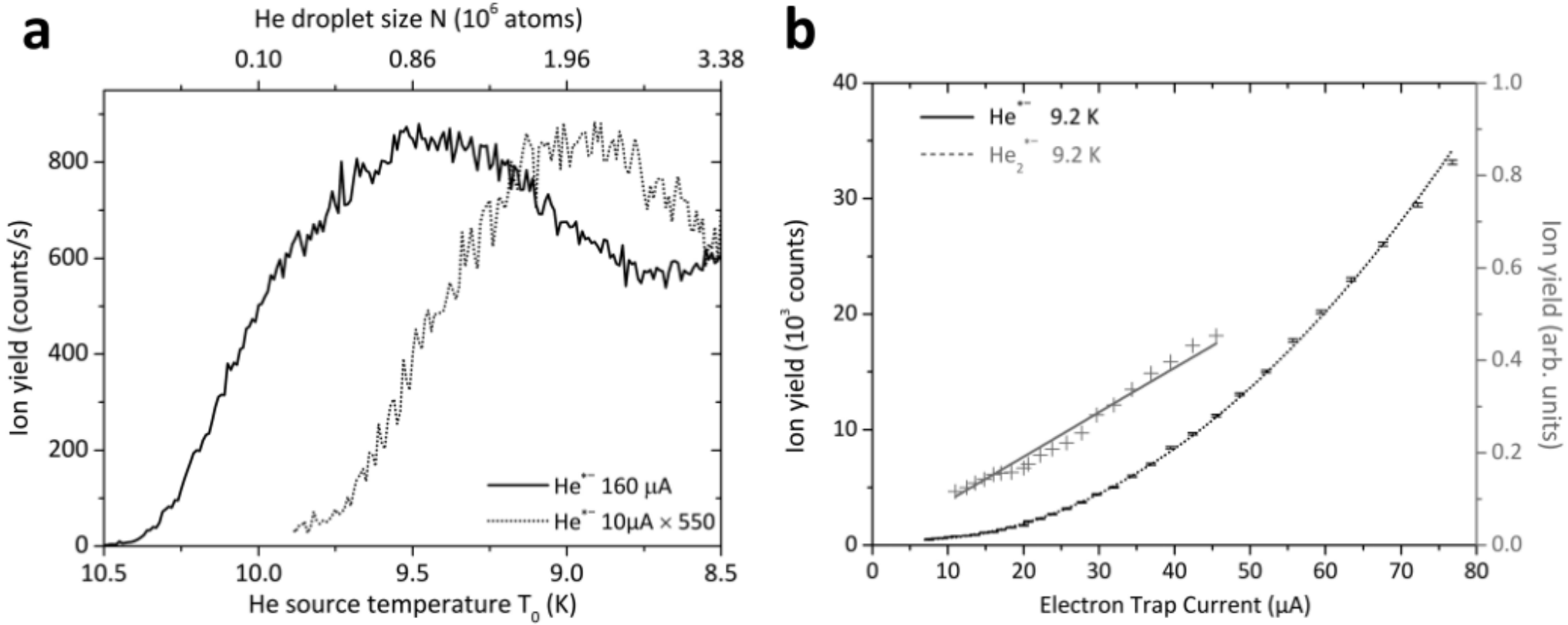
	E_{Gain} (meV)	E_{Cost} (meV)	E_{Gain} / E_{Cost}
He	36.53	15.87	**2.30**
He^*	70.74	78.07	**0.91**
He^{*-}	211.47	76.97	**2.75**
He_2^{*-}	14.49	46.50	**0.31**



[1] S. E. Huber, A. Mauracher (2014) Mol. Phys., 112:5-6, 794-804, DOI: 10.1080/00268976.2013.863403

Ejection?

- So if He^{*-} is heliophilic, why does it leave the droplet?



Summary

- It is possible to create He^{*-} with electron impact in HND
- He^{*-} is highly mobile and might be the exotic fast negative charge carrier in liquid helium
- He^{*-} might add new ionization mechanisms
- He_2^{*-} stays at the surface and is not involved in ionization processes

Thank you for your attention!

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Der Wissenschaftsfonds.