A new method to measure photoabsorption cross-sections questions the value of the photodetachment cross-section of H$^-$

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Summary

- A new method to measure a photoexcitation cross-section
- H^- photodetachment at λ=1064 nm
- Comparison with former experimental and calculated values

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« *Laser measurement of the photodetachment cross section of* H^- *at the wavelength 1064 nm* »

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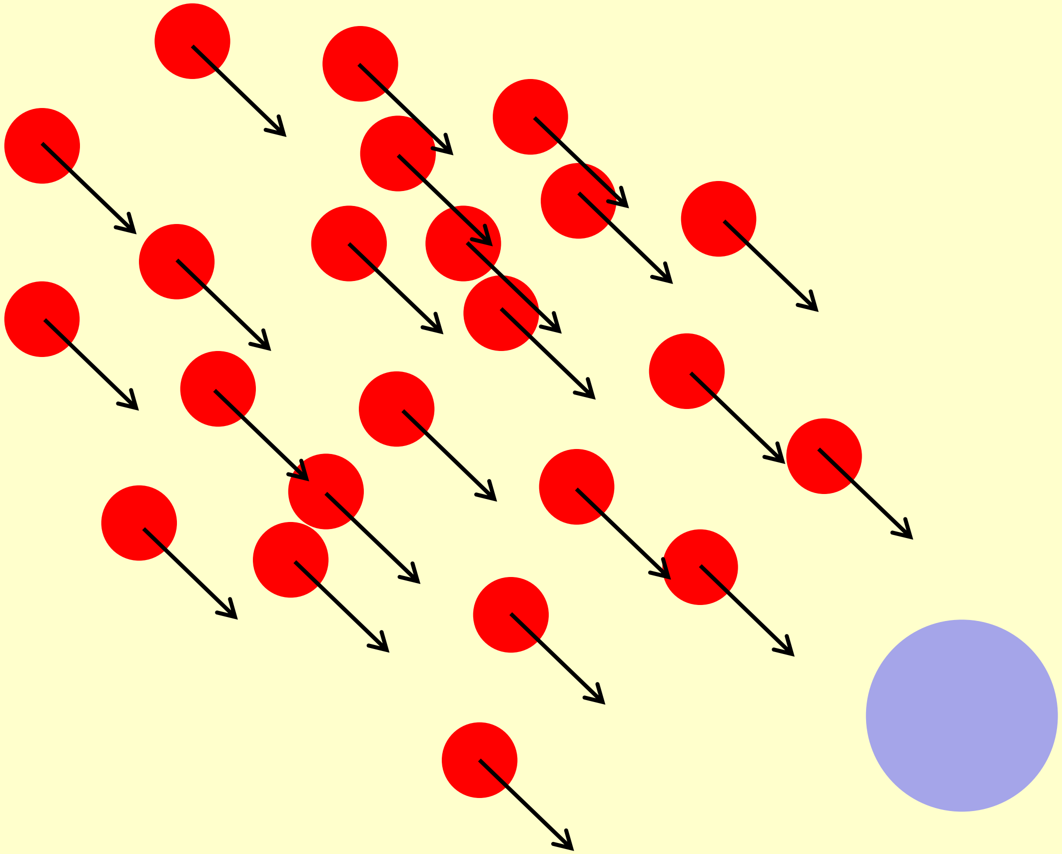
Definition of the cross-section



Flux $\Phi = n\|\vec{v}\|$

target

Collision probability dP/dt = $\boldsymbol{\sigma}\Phi$

First method : calibrate everything

Excitation probability : $P = \boldsymbol{\sigma}\Phi T$ →

$$\boxed{\sigma = N/N_0\,(T\phi)^{-1}}$$

Measure

- Number N_0 of illuminated atoms
- Number N of excited atoms
- Time of illumination T
- Incident flux Φ

No non-linear effect ? Have all targets undergone the same illumination ϕ ? For the same time T ?
Do N and N_0 countings have identical efficiencies ?

Photodetachment : **$H^- + h\nu \rightarrow H + e^-$**

How are the number N of neutral atoms produced and the number N_0 of illuminated ions measured?

Final uncertainty: ≥ 15%

An important quantity for atomic physics

The **one-photon probability** given by Fermi golden rule, for transitions to a continuum of states, has the form

$$\mathrm{d}P/\mathrm{d}t = \frac{\pi}{2\hbar} \|\langle f|D|i\rangle\|^2 \rho \times E^{\,2}$$

With

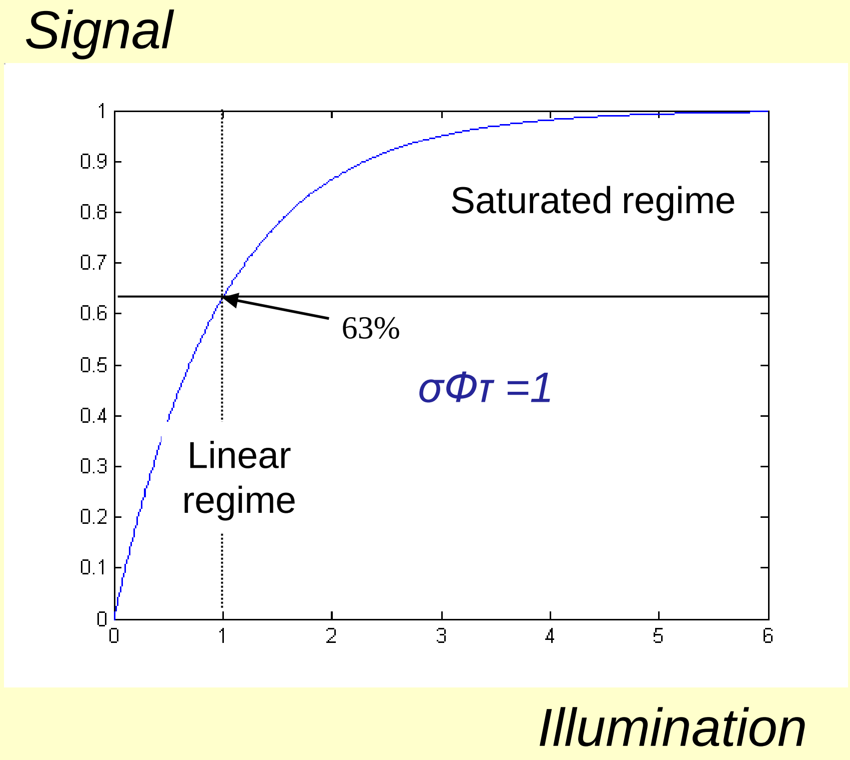
- D the electric dipole operator
- ρ the density of final states
- E the amplitude of the electric field
- $|\mathrm{i}\rangle$ and $\langle\mathrm{f}|$ the initial and final atomic state vectors

This is a d*P*/d*t* = *σΦ,* with

$$\boxed{\sigma = \frac{\pi}{\varepsilon_0 c} \;\omega\; \|\langle f|D|i\rangle\|^2 \rho}$$

Second method : use saturation to set the probability scale

Detachment probability cannot increase indefinitely as $\sigma\Phi\tau$



$$\boxed{P = 1 - \exp(-\sigma\Phi T)}$$

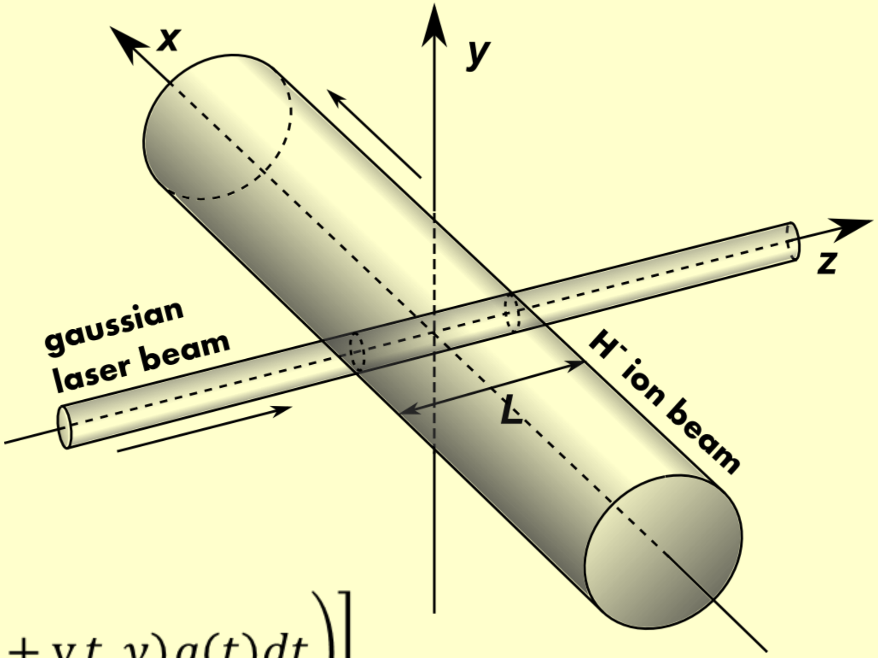
Saturation gives a natural probability scale. No need to measure N nor N_0 !

Calibration remains necessary only for the light flux and interaction time.

Third method : asymptotic properties of the saturated regime

Density of detached ions

$$n = n_0\left(1 - \exp\left[-\sigma\int\phi(t)dt\right]\right)$$



With a laser spatial profile f(*x*,*y*) and time profile g(*t*), with ions moving at velocity v:

$$n = n_0\left[1 - \exp\left(-\sigma\int_{-\infty}^{+\infty}\frac{E}{\hbar\omega}f(x + \mathrm{v}\,t, y)g(t)dt\right)\right]$$

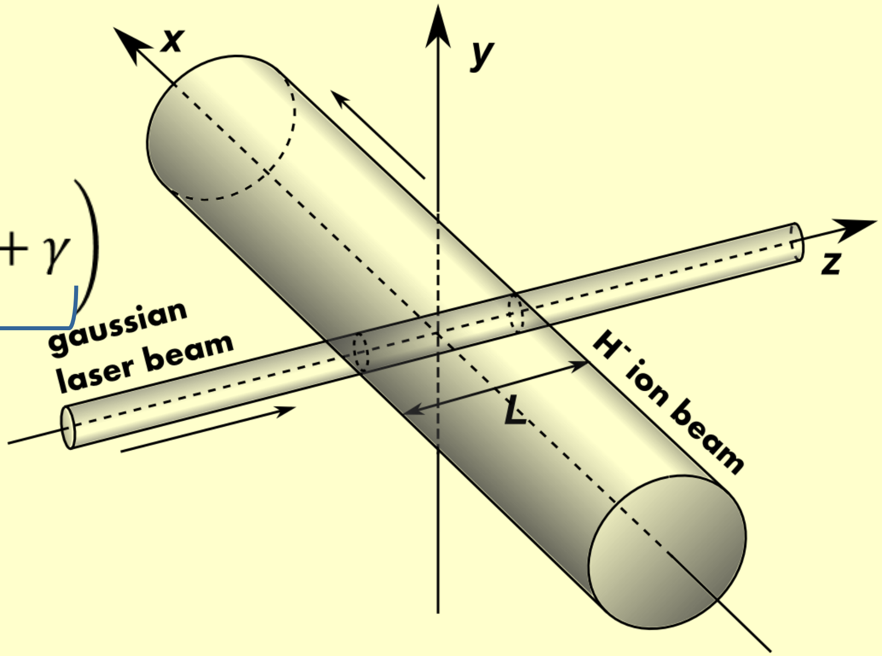
With a **Gaussian** beam, after volume integration, with $\delta = \sqrt{w_0{}^2 + v^2\tau^2}$

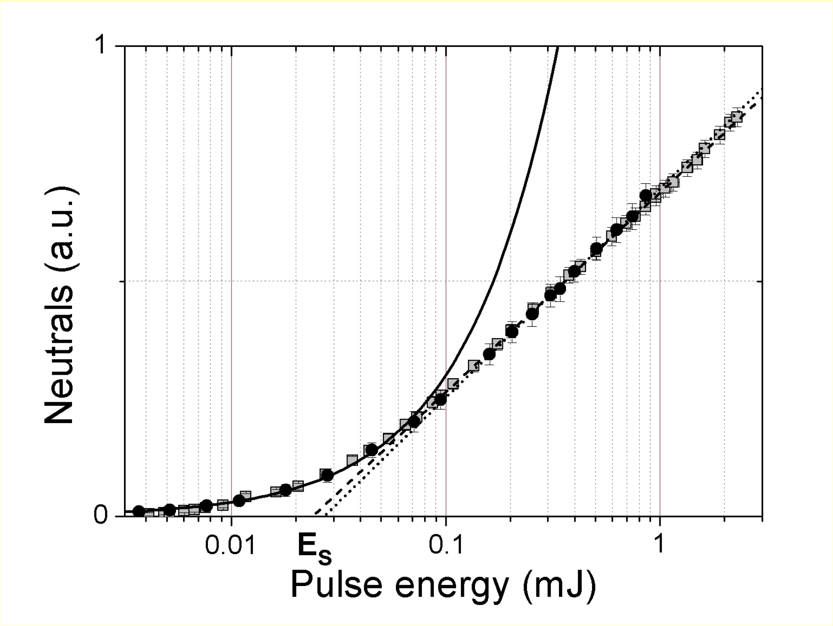
$$N = n_0\frac{\pi}{2}Lw_0\delta\left[\ln E - \ln\left(\frac{\pi w_0\delta\hbar\omega}{2\sigma}\right) + \gamma - \mathrm{Ei}(-A)\right]$$

Third method : asymptotic properties of the saturated regime

Asymptotically

$$N = n_0\frac{\pi}{2}Lw_0\delta\left(\ln E \;-\underbrace{\ln\left(\frac{\pi}{2}\frac{w_0\delta}{\sigma}\hbar\omega\right)+\gamma}_{\ln(E_S)}\right)$$





$$\boxed{\sigma = \frac{\pi e^{-\gamma}}{2}\frac{\hbar\omega}{E_S}w_0\delta}$$

Third method : asymptotic properties of the saturated regime

The lin/log plot was already used, but to measure saturation **intensities**.

S. M. Hankin,
D. M. Villeneuve,
P. B. Corkum &
D. M. Rayner,
“*Intense field laser ionization rates in atoms and molecules*”,
Phys. Rev. A **64** (2001) 013405

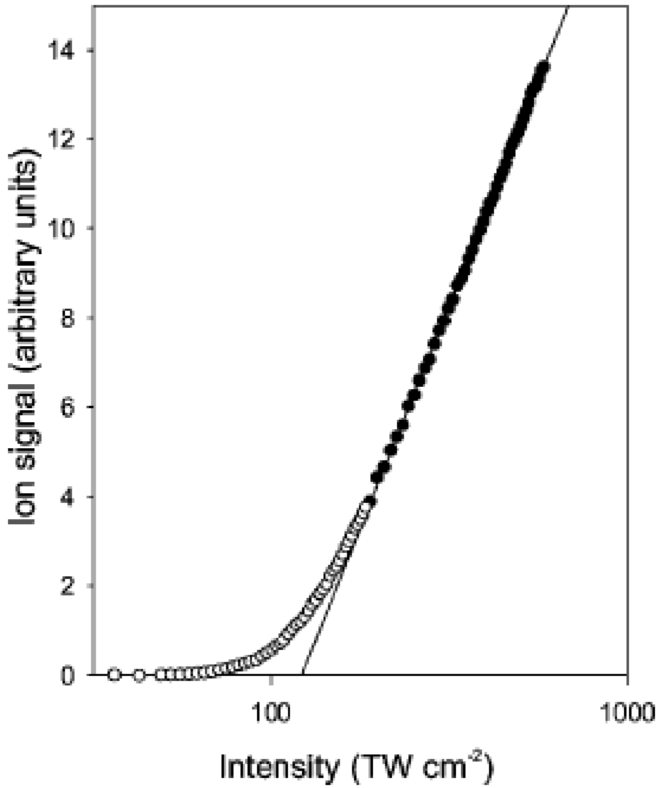
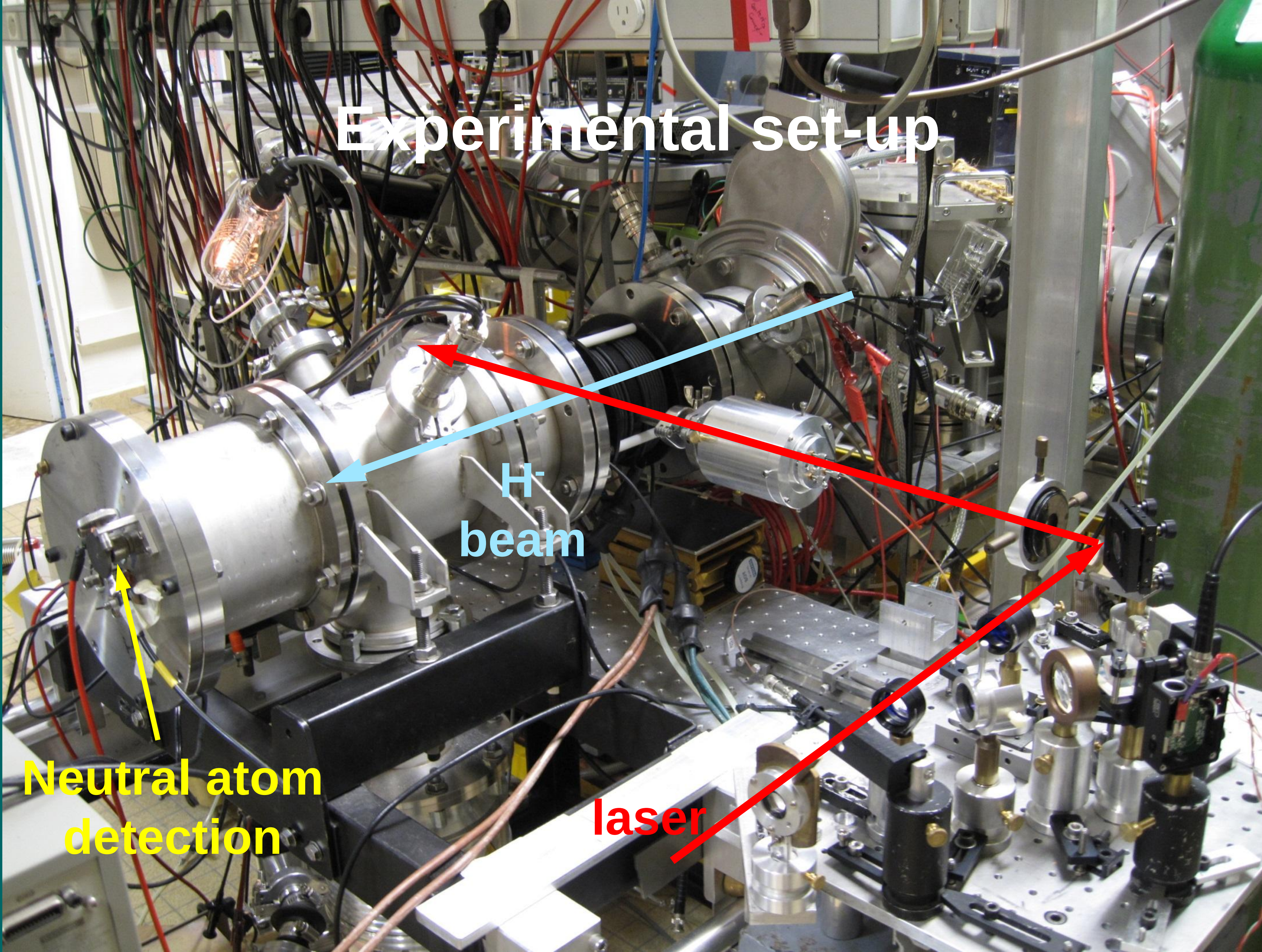


FIG. 5. Xe ion yield as a function of laser intensity in the form suggested in Sec. II, S vs $\ln(I_0)$. The points are the sum of the yields of all channels yielding singly and multiply charged ions. With sequential ionization dominating in this intensity regime, this sum is the yield of the first ionization step.

Experimental set-up

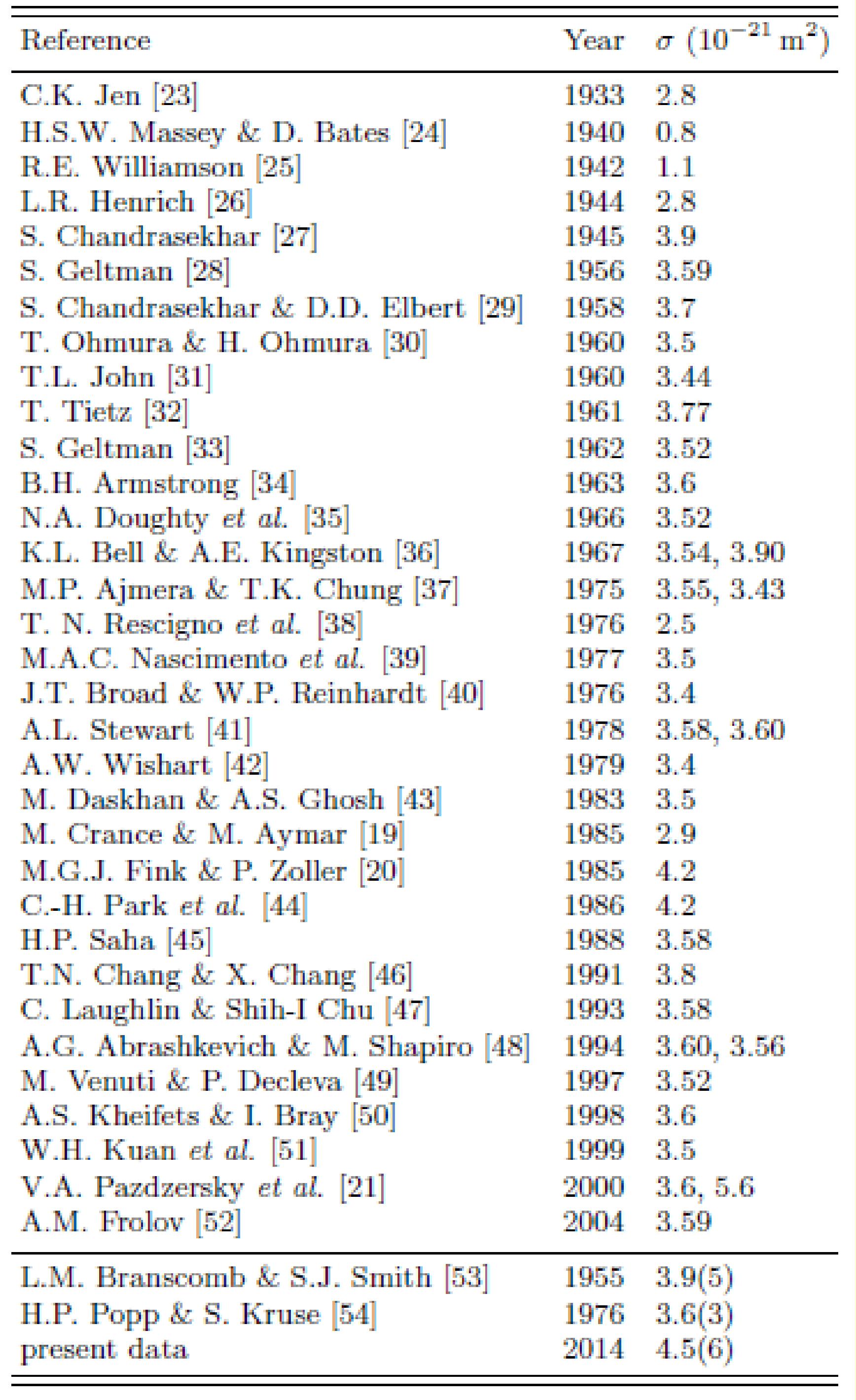


Photodetachment cross-section (1064 nm)

Waist (µm)	σ (10^{-21} m^2)
~70	4.3(16)
	4.5(11)
	4.9(12)
~80	4.5(18)
	4.9(27)
	4.6(7)

Uncertainties :
Waist : ± 2 µm
Duration : ± 1 ns
Pulse energy : ± 3%
+ Statistical : ± 6%

Merging with the 2nd method :
4.5(6) 10^{-21} m^2



Reference	Year	σ (10^{-21} m^2)
C.K. Jen [23]	1933	2.8
H.S.W. Massey & D. Bates [24]	1940	0.8
R.E. Williamson [25]	1942	1.1
L.R. Henrich [26]	1944	2.8
S. Chandrasekhar [27]	1945	3.9
S. Geltman [28]	1956	3.59
S. Chandrasekhar & D.D. Elbert [29]	1958	3.7
T. Ohmura & H. Ohmura [30]	1960	3.5
T.L. John [31]	1960	3.44
T. Tietz [32]	1961	3.77
S. Geltman [33]	1962	3.52
B.H. Armstrong [34]	1963	3.6
N.A. Doughty *et al.* [35]	1966	3.52
K.L. Bell & A.E. Kingston [36]	1967	3.54, 3.90
M.P. Ajmera & T.K. Chung [37]	1975	3.55, 3.43
T. N. Rescigno *et al.* [38]	1976	2.5
M.A.C. Nascimento *et al.* [39]	1977	3.5
J.T. Broad & W.P. Reinhardt [40]	1976	3.4
A.L. Stewart [41]	1978	3.58, 3.60
A.W. Wishart [42]	1979	3.4
M. Daskhan & A.S. Ghosh [43]	1983	3.5
M. Crance & M. Aymar [19]	1985	2.9
M.G.J. Fink & P. Zoller [20]	1985	4.2
C.-H. Park *et al.* [44]	1986	4.2
H.P. Saha [45]	1988	3.58
T.N. Chang & X. Chang [46]	1991	3.8
C. Laughlin & Shih-I Chu [47]	1993	3.58
A.G. Abrashkevich & M. Shapiro [48]	1994	3.60, 3.56
M. Venuti & P. Decleva [49]	1997	3.52
A.S. Kheifets & I. Bray [50]	1998	3.6
W.H. Kuan *et al.* [51]	1999	3.5
V.A. Pazdzersky *et al.* [21]	2000	3.6, 5.6
A.M. Frolov [52]	2004	3.59
L.M. Branscomb & S.J. Smith [53]	1955	3.9(5)
H.P. Popp & S. Kruse [54]	1976	3.6(3)
present data	2014	4.5(6)

H^- photodetachment cross-section variation with energy

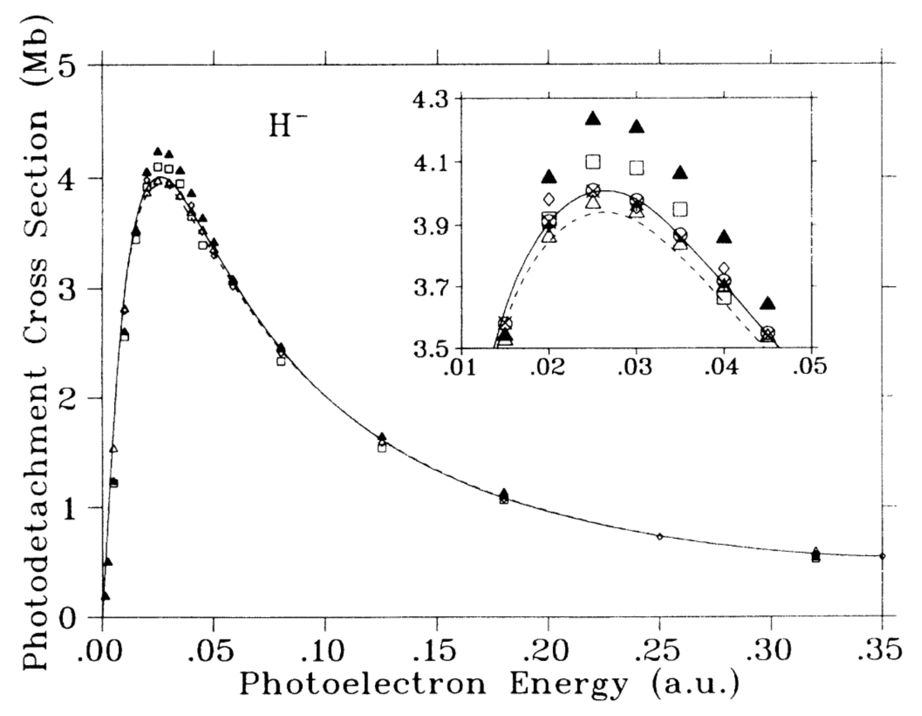


FIG. 6. $H^-(^1S)+h\nu\rightarrow H\,(1s)(^2S)+e^-(kp)$ photodetachment cross section vs photoelectron energy ——, present length-form results; — — —, present acceleration-form results; length-form results of: *o*, Stewart [51]; ▲, Bell and Kingston [52]; △, Ajmera and Chung [53]; ◇, Broad and Reinhardt [47]; +, Wishart [48]; □, Daskhan and Ghosh [54]; ×, Saha [11].

A.G. Abrashkevich & M. Shapiro, Phys. Rev. A **50** (1994) 1205

Conclusion

- A new method to measure photoexcitation cross-sections : from the saturated regime only
- The first laser measurement* of the photodetachment cross-section of H^- yields a value slightly greater than previously measured and than most calculated values

* Except from one experimental check of its order of magnitude, M. Bacal & G.W. Hamilton, Phys. Rev. Lett. **42** (1979) 1538