Uniform Electrical Discharge through Solid Xenon

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The goal of this study

is to use

the electrical discharge in a solid

to reveal the nature of excitons and polarons

similarly as

the electrical discharge in a gas

is commonly used

to study the excitations

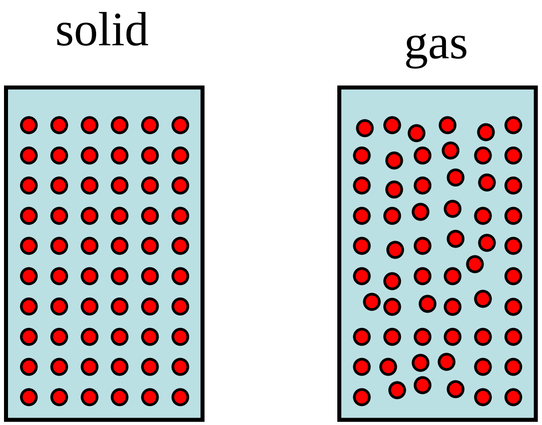
of separate molecules, radicals and ions

The scheme of electrical discharge

- primary electrons →
- their acceleration in electric field →
- their multiplication by ionization in electron avalanche →
- positive feedback (primary electrons restoration)

The bulk electrical discharge
is known to be impossible
in a gas with density close to that
in a liquid or solid (P = 1000 bar)

Could the free electron drift in condensed state be different from that in a gas of the same density?



At the first glance the difference should not be significant because

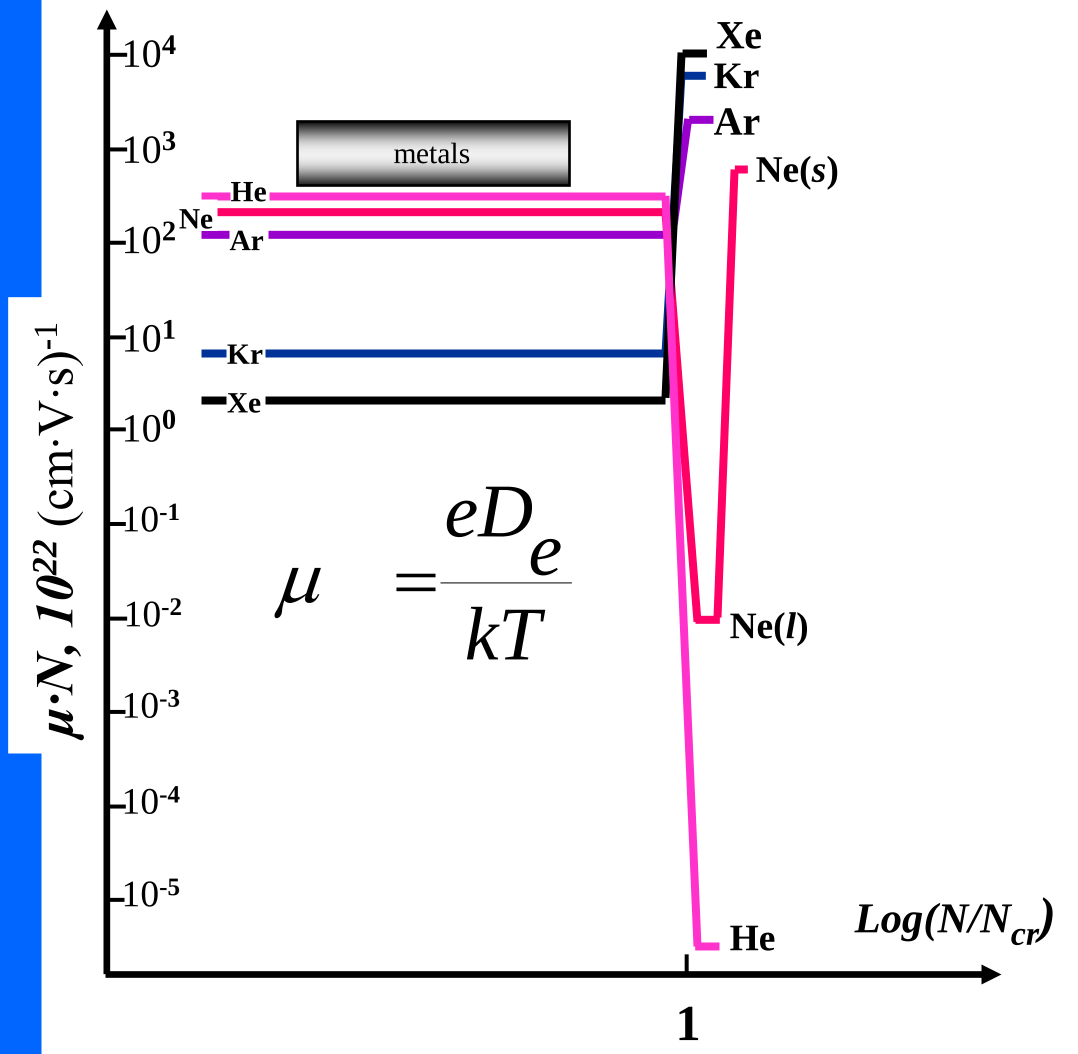
electron mobility →

its diffusion coefficient →

cross-section of elementary process of free electron elastic scattering on atom

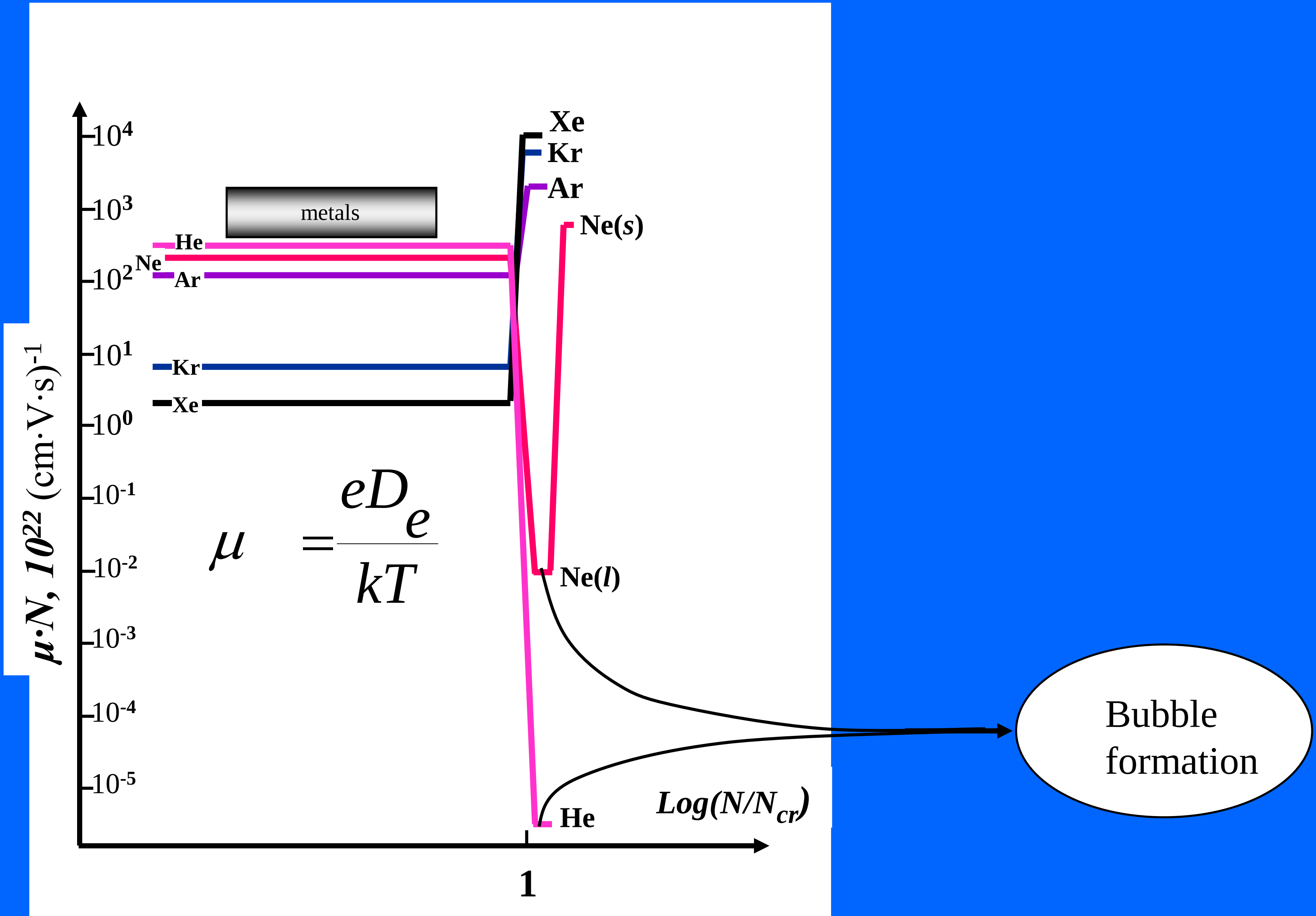
That is not true – tremendous effect of phase state on electron mobility

Excess electron mobility in gaseous, liquid and solid rare gases (experiment)

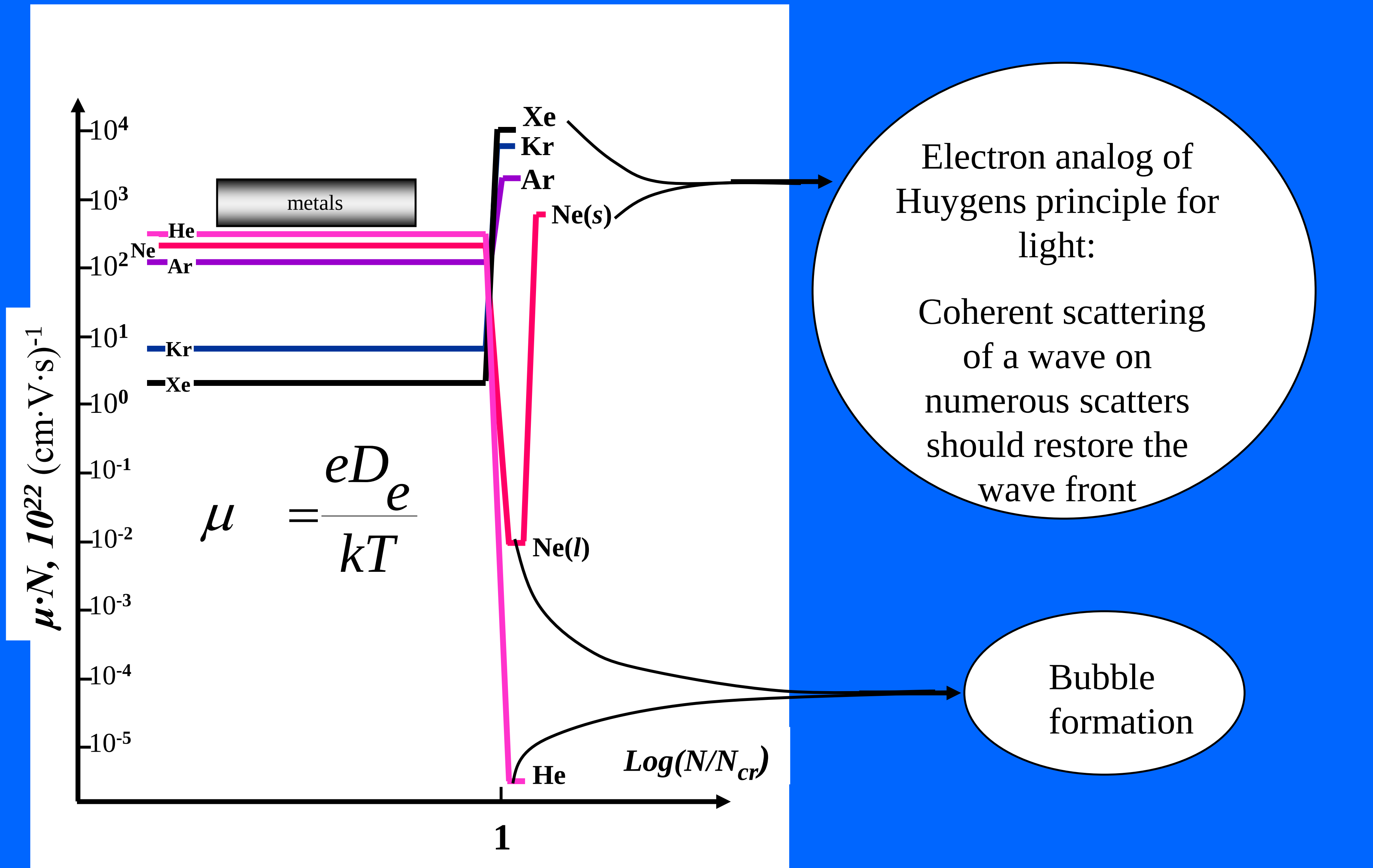


$$\mu = \frac{eD_e}{kT}$$

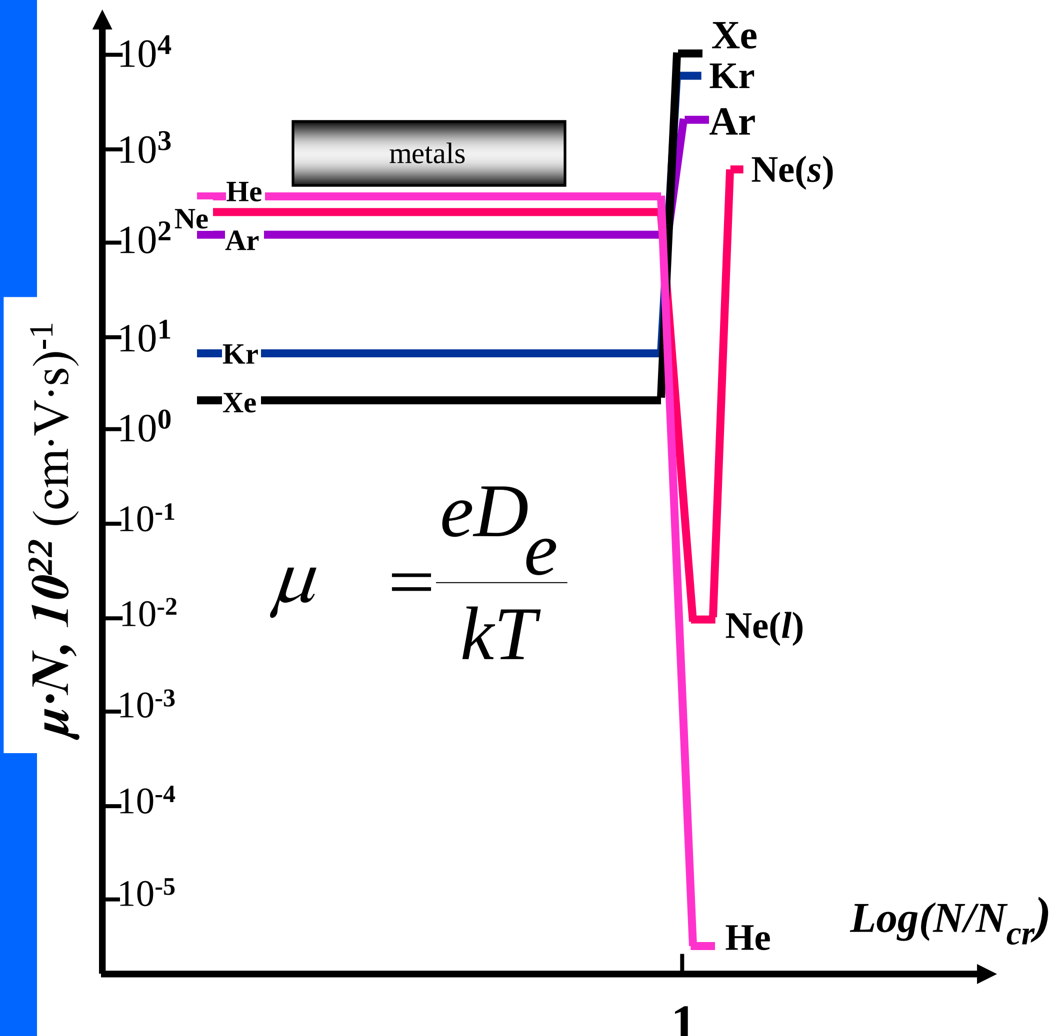
Excess electron mobility in gaseous, liquid and solid rare gases (experiment)



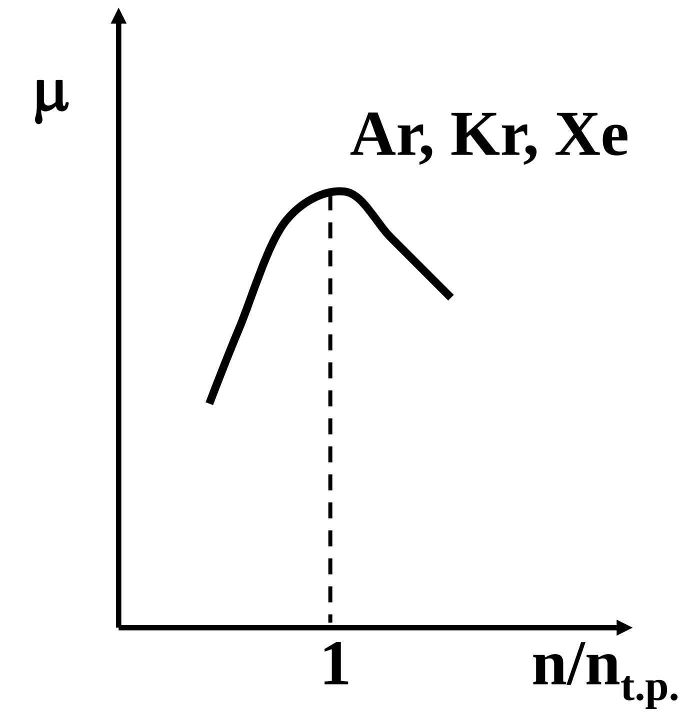
Excess electron mobility in gaseous, liquid and solid rare gases (experiment)



Excess electron mobility in gaseous, liquid and solid rare gases (experiment)



$$\mu = \frac{eD_e}{kT}$$



Coincidence or rule?

The electron drift in solid Xe

is similar to that in

Xe gas at pressure lower than 100 mbar

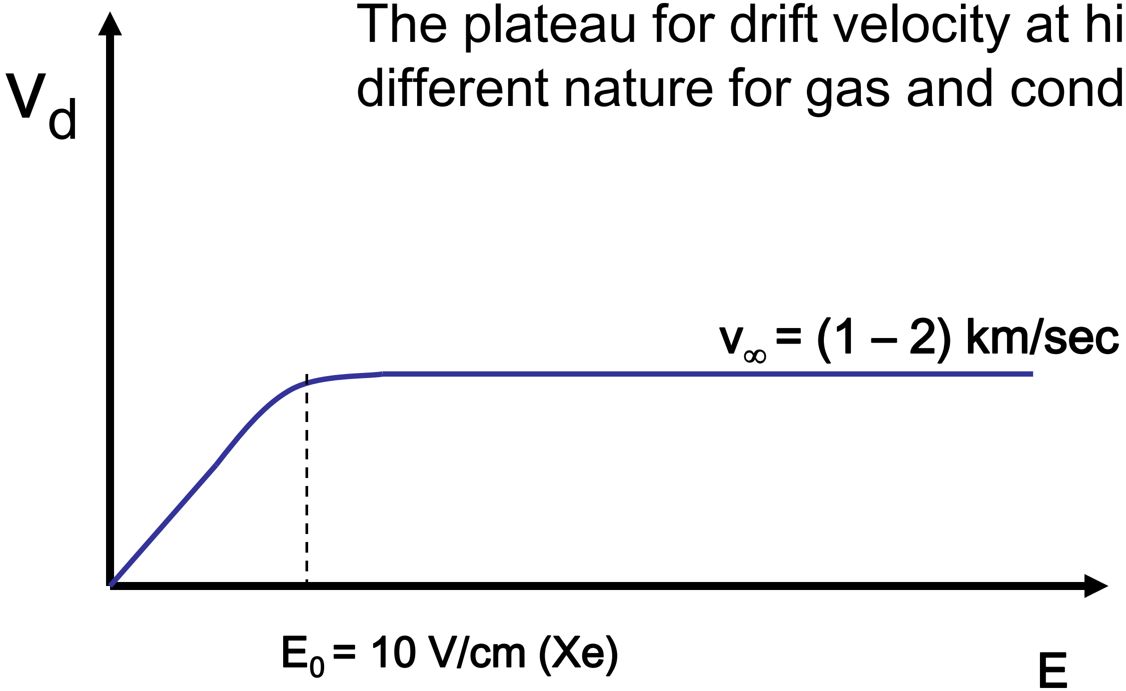
That makes our aim promising

but

this is only the beginning of our way

Question #1
Could the high mobility save for sufficiently hot (several *eV*) electrons ?

The plateau for drift velocity at high E should be of different nature for gas and condensed state



$V/v_d \approx (M/m)^{1/2}$

≈ 1000 (Xe)

Question #1
The wave-like behavior of electron weaken with its energy – the answer only by experiment

YES –

Observation of VUV exciton electroluminescence

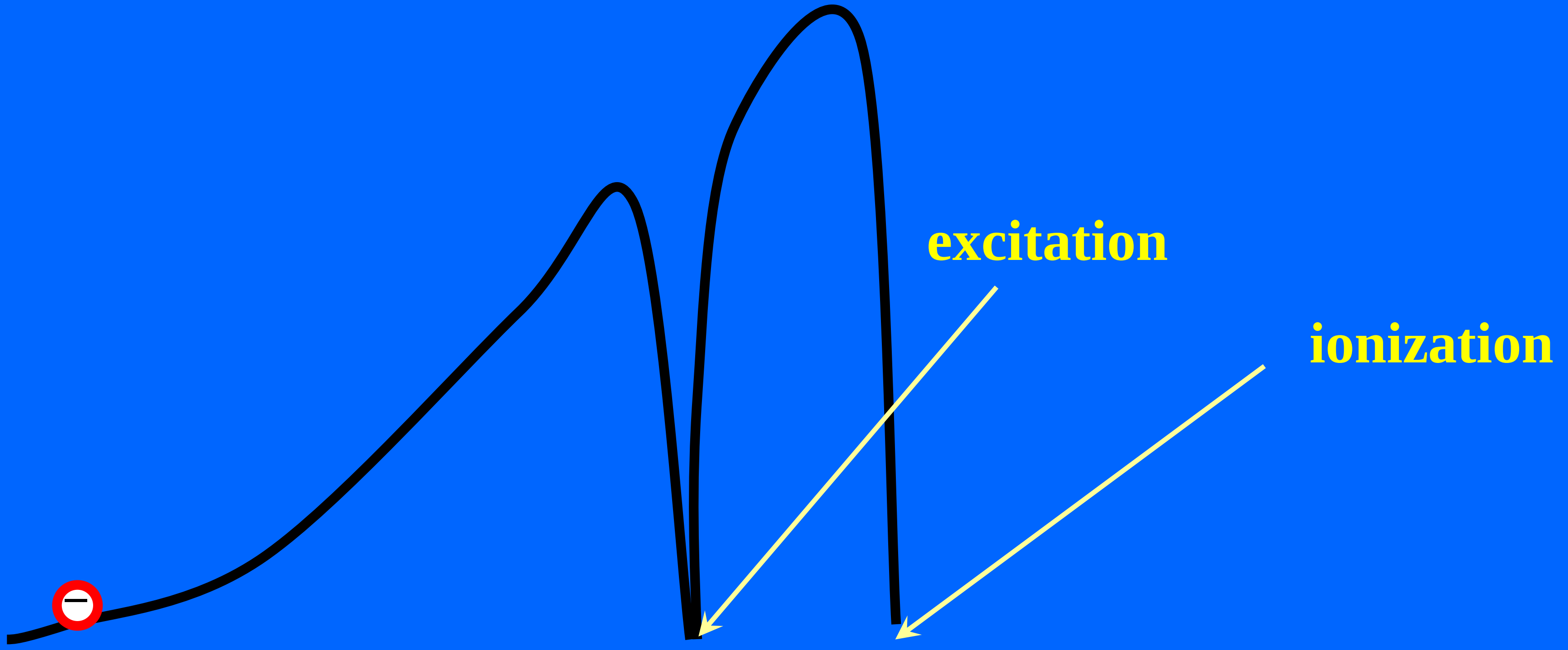
S. Schussler, J. Burghoorn, P. Wyder, et al., Appl.Phys. Lett**. 2000, **77**, 2786 **(liquid)

A. Usenko, G. Frossati and E. B. Gordon, Phys.Rev.Lett.**, 2003, **90, 153201 (solid)

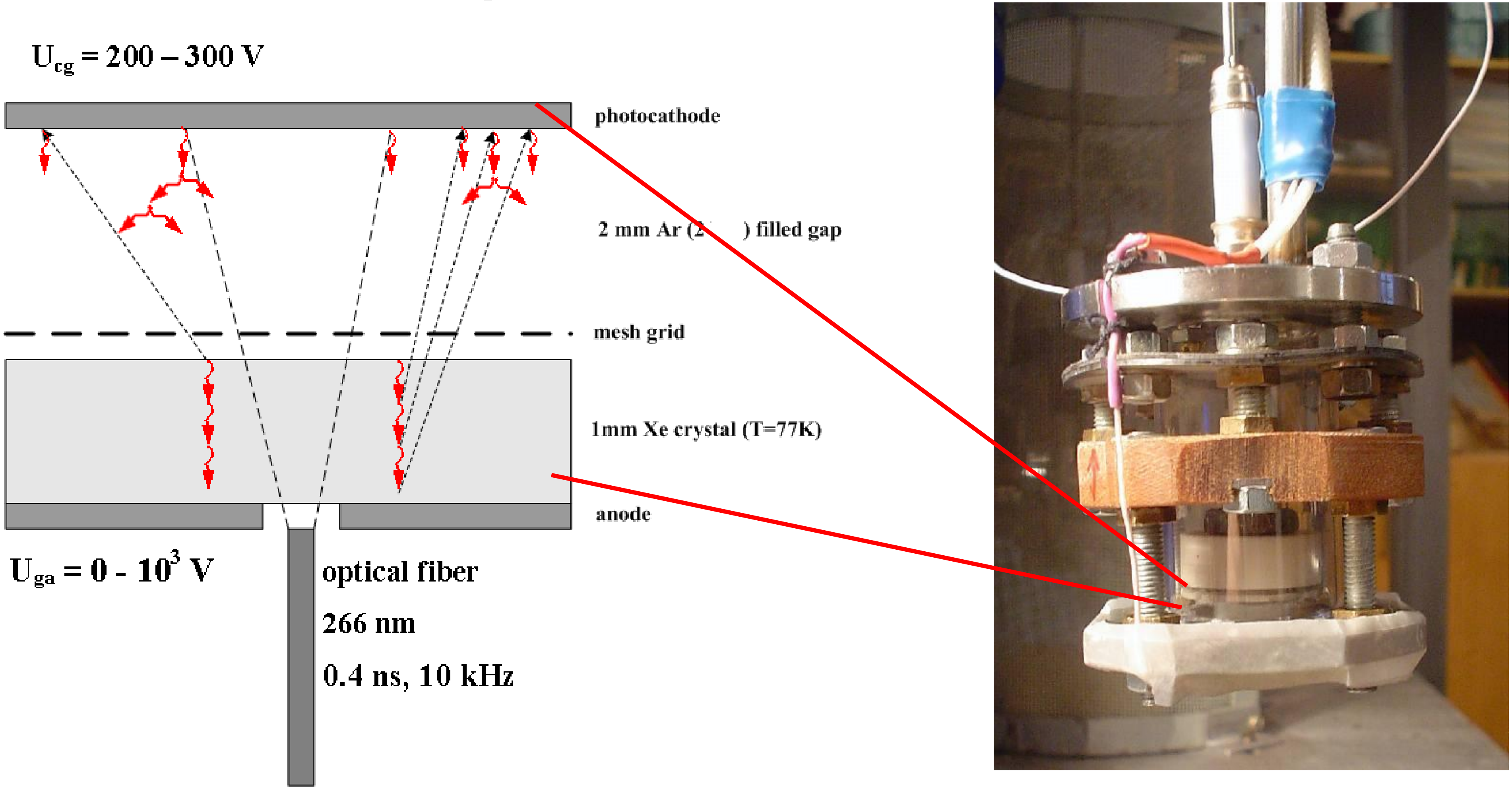
Question #2
Is it possible to ionize a matrix by fast drifted electrons

NO

No chance to be overheated above the excitation threshold to achieve the ionization potential



Idea of the experiment and its realization



1. Positive feedback – VUV photons from Xe crystal
2. Electron avalanche – in low density gas

Gas multiplicator gain coefficient ~ 10^3

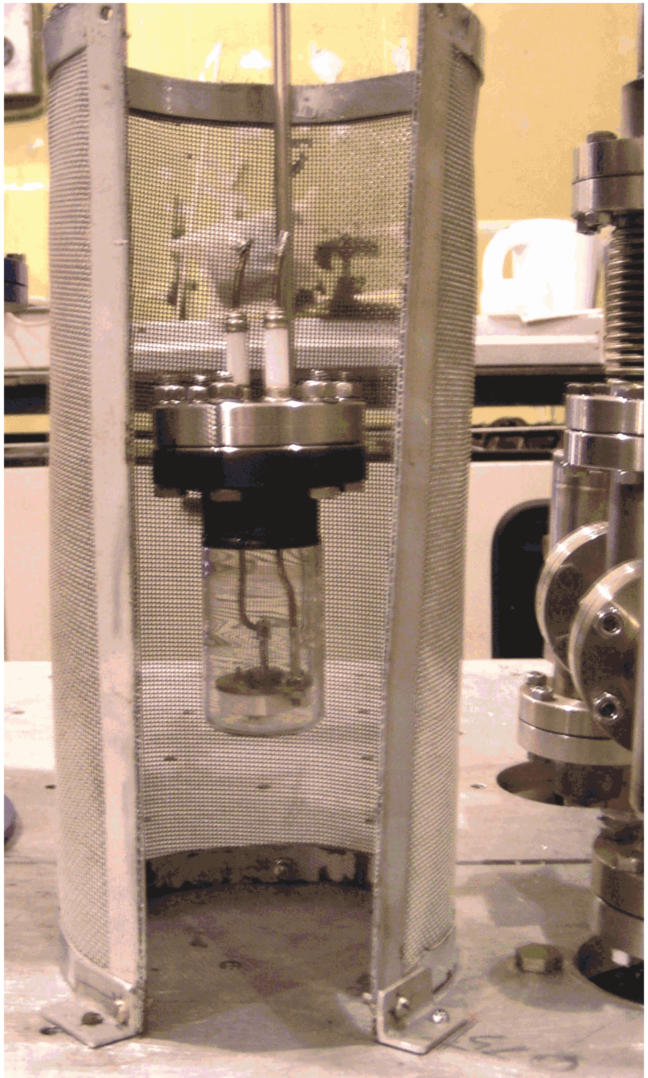
Efficiency of photoelectron emission from Zn ~ 10^{-3}

VUV emission yield per electron drifted through Xe crystal – 10 – 1000

Experimental setup

(high vacuum components, turbopump)

Embedded system of xenon deep (10^{-10}) purification (electrospark technique)



Optical cryostat (77 – 150K) with sapphire windows

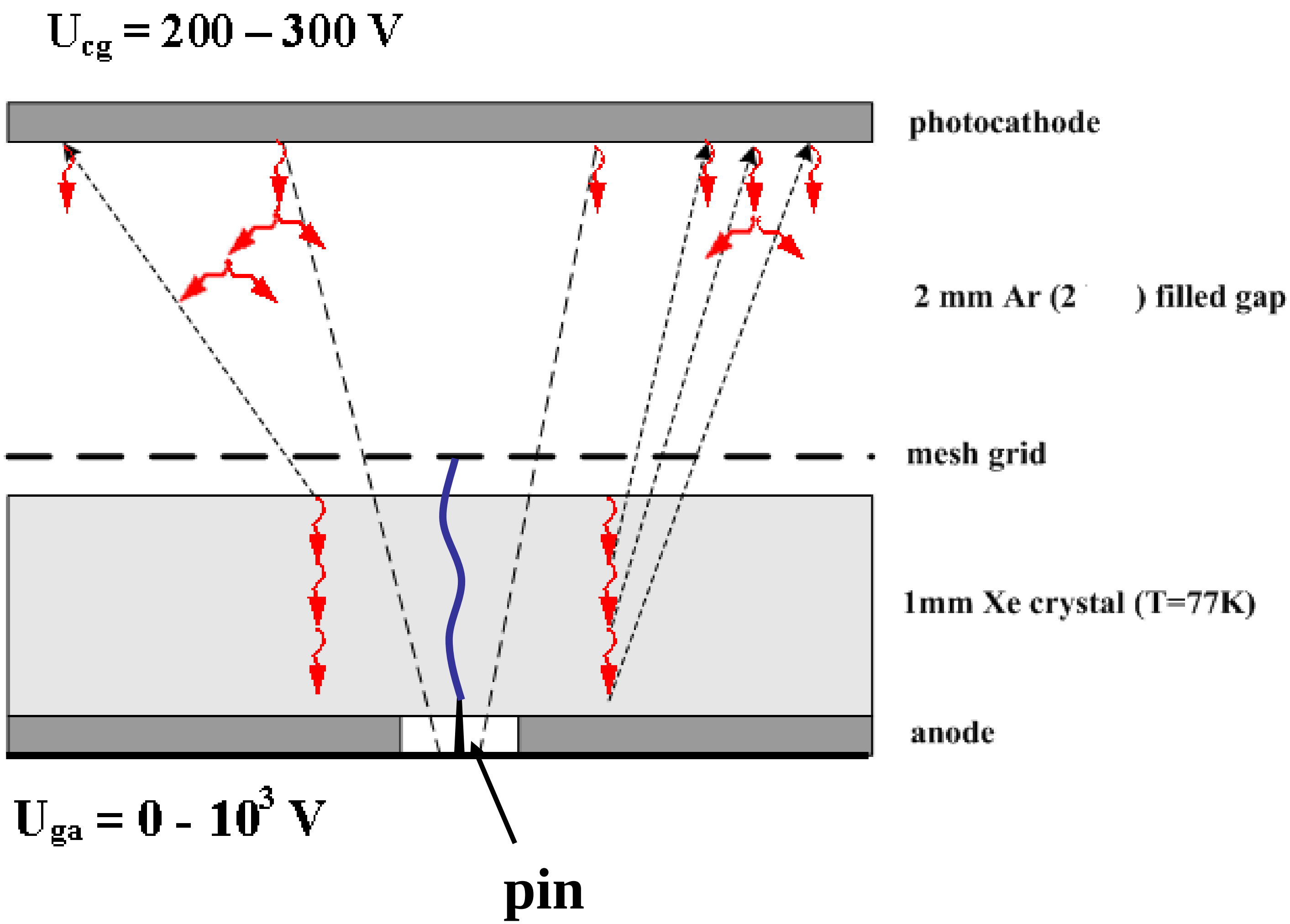
Two regimes of solid state discharge take place

- **Normal, limited by space charge of impurities gradually filled by drifting electrons.**

  Sample should be remelt in a short time

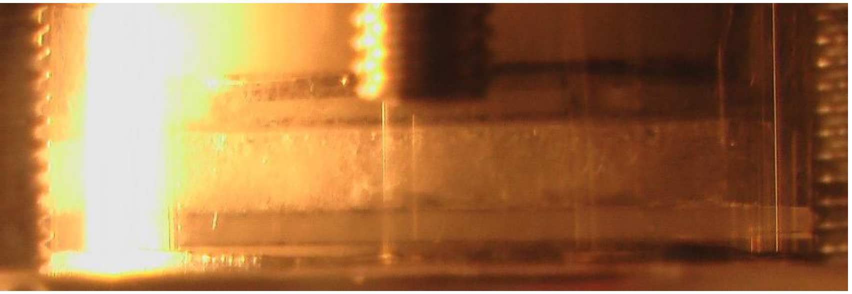
- **Powerful, when the process of electron traps depopulation by drifting electrons keeps the space charge low enough (it can be achieved only by pre-ionization).**

  e + $(Imp)^{-} \rightarrow$ 2e + Imp;   W $\approx (n_e)^2$



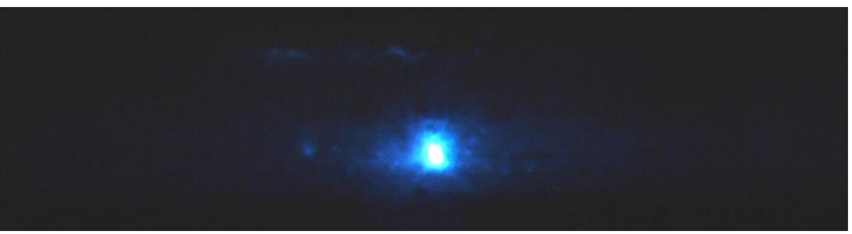
The application of the spark from Tungsten wire to ignite powerful CW discharge

CW discharge in Xe crystal (spark ignition)
The different regimes of electron current



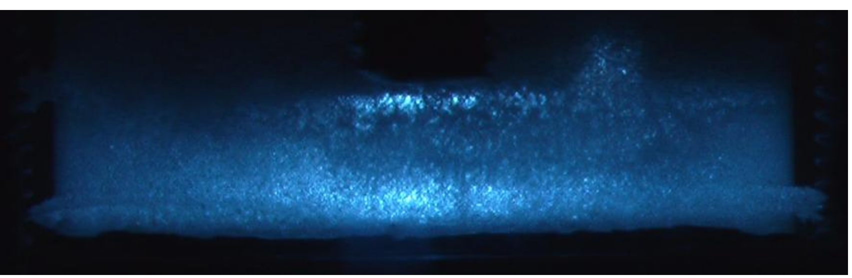
U_{ga} = 2.4 kV; U_{cg} = 0

← **Sample without discharge**



U_{ga} = 2.4 kV; U_{cg} < 100V

← **Short spark**



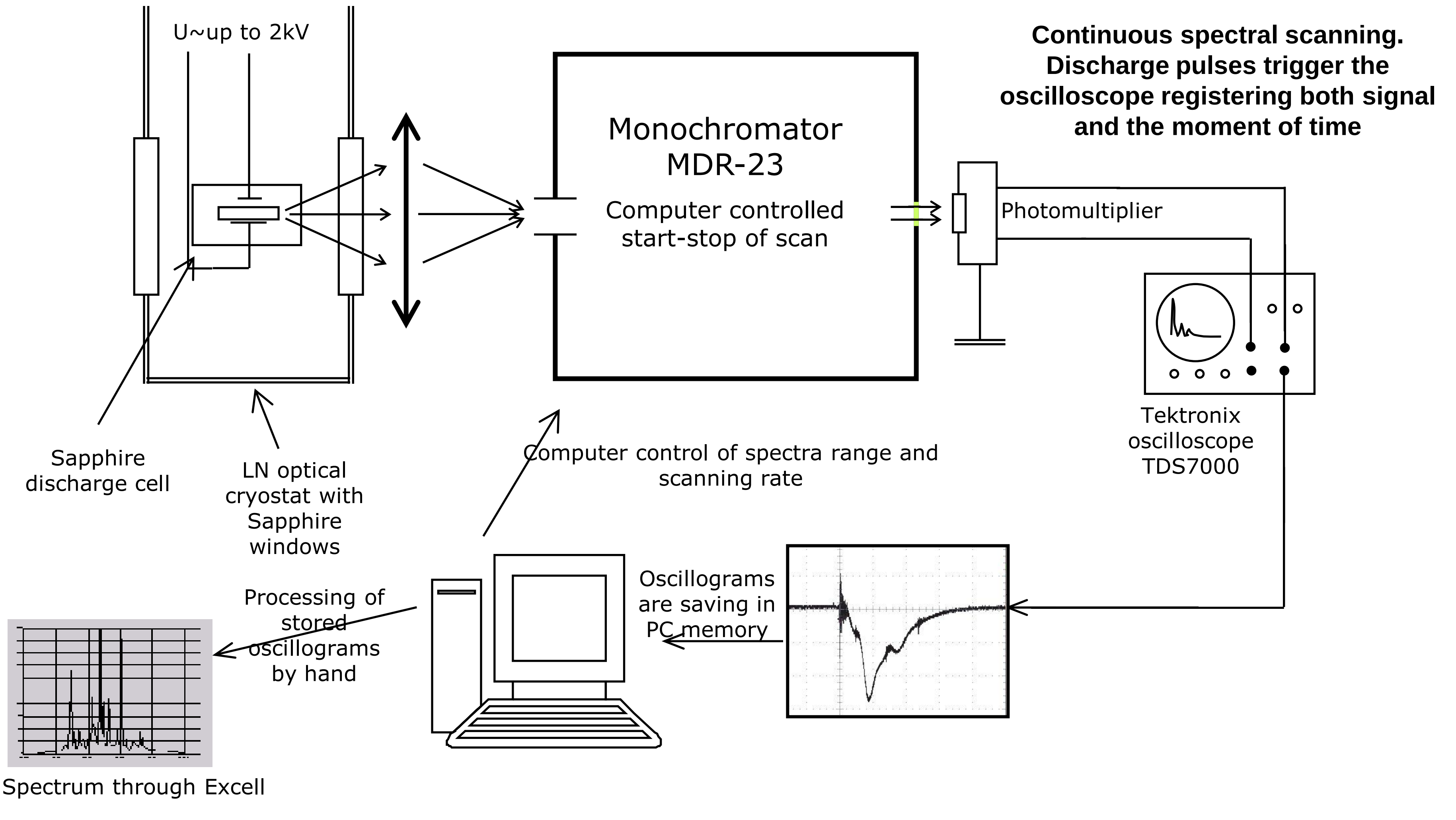
U_{ga} = 2.4 kV; U_{cg} = 100 – 200V

← **Long discharge**

U_{ga} = 2.4 kV; U_{cg} > 200V

← **Glow !!!**

Acquisition data system



Emission lines positions

A - strong, B – intermediate, C - weak

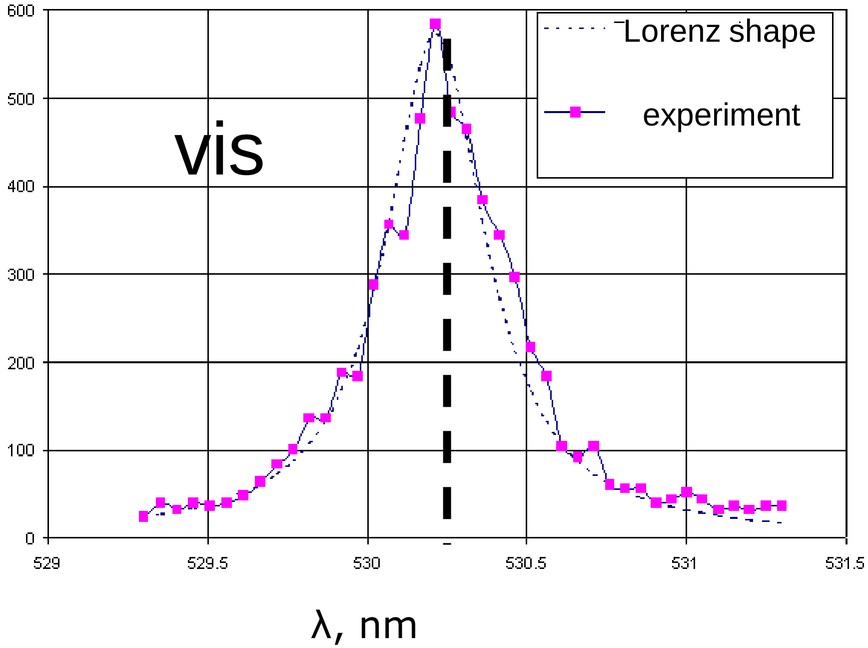
Line positions, nm our data	Intensity	Line positions, nm gas discharge [15]	Intensity	Line shift
		197,26	C	
203,712	C			
209,180	C			
210,750	C			
212,226	C			
225,294	C			
229,350	A	229,60	C	-0.25
231,364	B			
234,084	A			
234,342	B	234,45	C	-0.11
242,263	C	242,51	C	-0.25
247,446	A	247,59	C	-0.14
249,080	A			
250,927	B			
252,373	B			
253,163	B			
253,564	B			
260,353	A	260,69	C	-0.34
271,631	C			
273,250	C	273,41	C	-0.21
286,200	C	286,47	B	-0.32
290,583	C			
297,893	C	297,93	B	-0.08
		312,19	B	

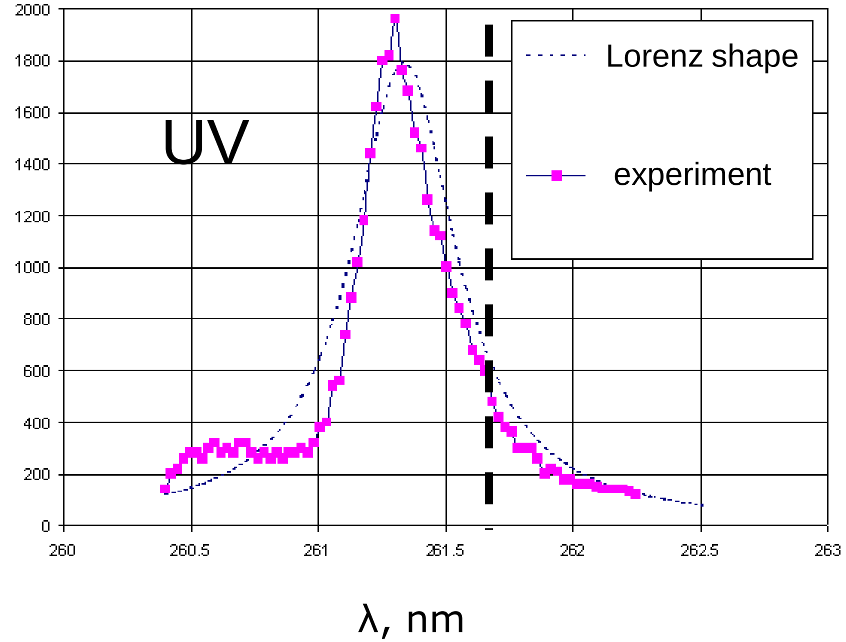
Line positions, nm our data	Intensity	Line positions, nm gas discharge [15]	Intensity	Line shift
361,39	B			
395,074	C			
403,927	C			
405,883	C			
416,154	C			
418,29	B	418,01	A	0.28
		420,85	B	
421,562	B	421,56	B	0.00
		423,83	B	
424,724	A	424,54	B	0.18
433,424	B	433,05	A	0.37
439,711	B			
446,5	A	446,22	A	0.28
—		**450,10**	B	
—		**452,47**	B	
		458,55	B	
—		**458,27**	B	
460,273	A	460,30	B	-0.03
—		**462,42**	A	
—		**467,12**	A	
484,447	A	484,43	A	0.017
487,7	C			
488,328	B	488,35	B	-0.02
492,137	A	492,15	B	-0.01
—		**492,32**	B	
519,1	C			
526,245	C			
529,265	A	529,22	A	0.05
534,025	B	533,94	A	0.09
		536,81	C	
537,367	C			
542,039	B	541,92	A	0.12
—		**582,39**	B	

Atomic lines (bold) are absent

Xe_2^+ lines are absent

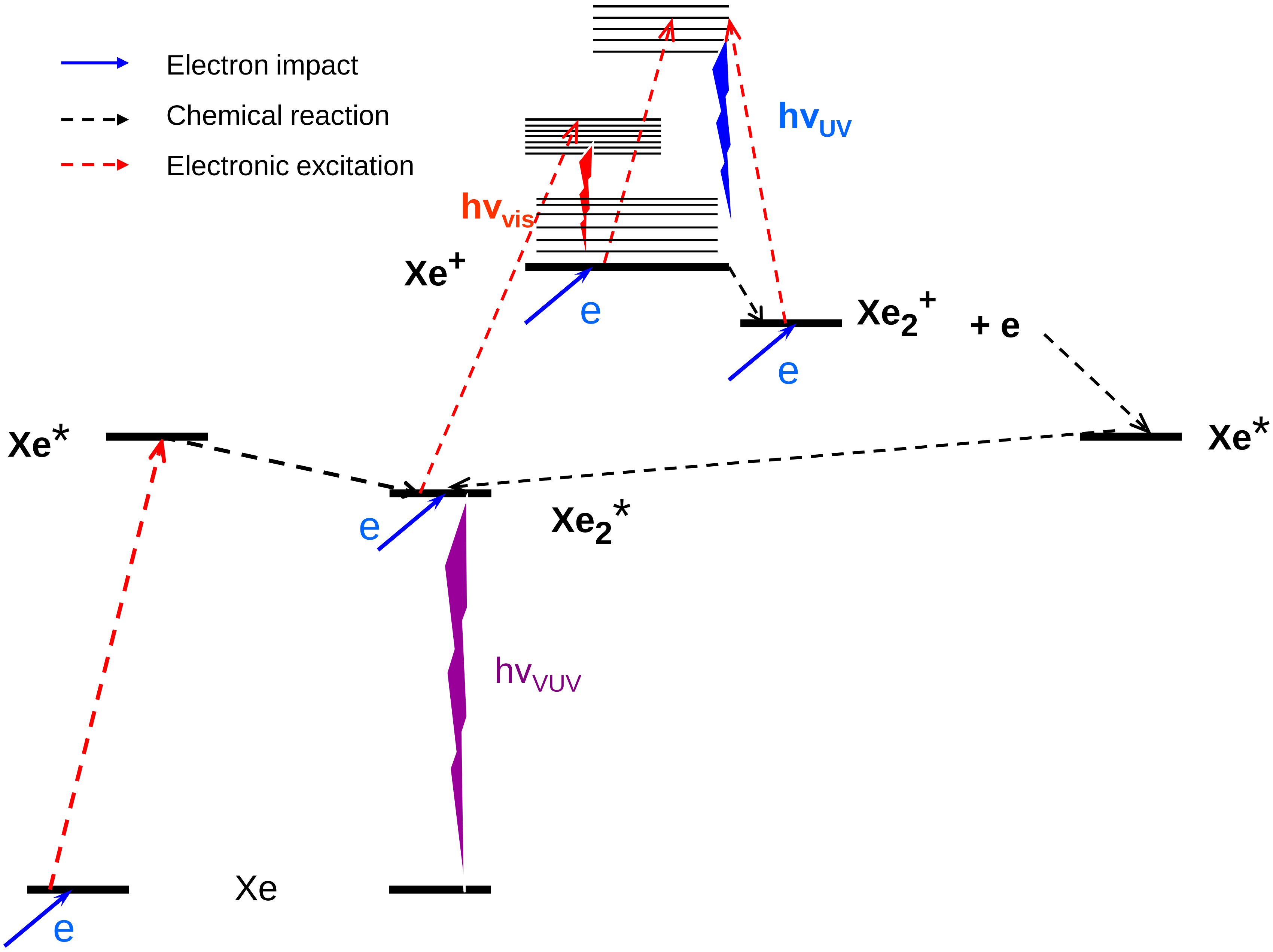
Spectral lines shapes in UV and visible





The line distortion grows with its deviation from gas position

Electron induced excitation and ionization in solid Xe



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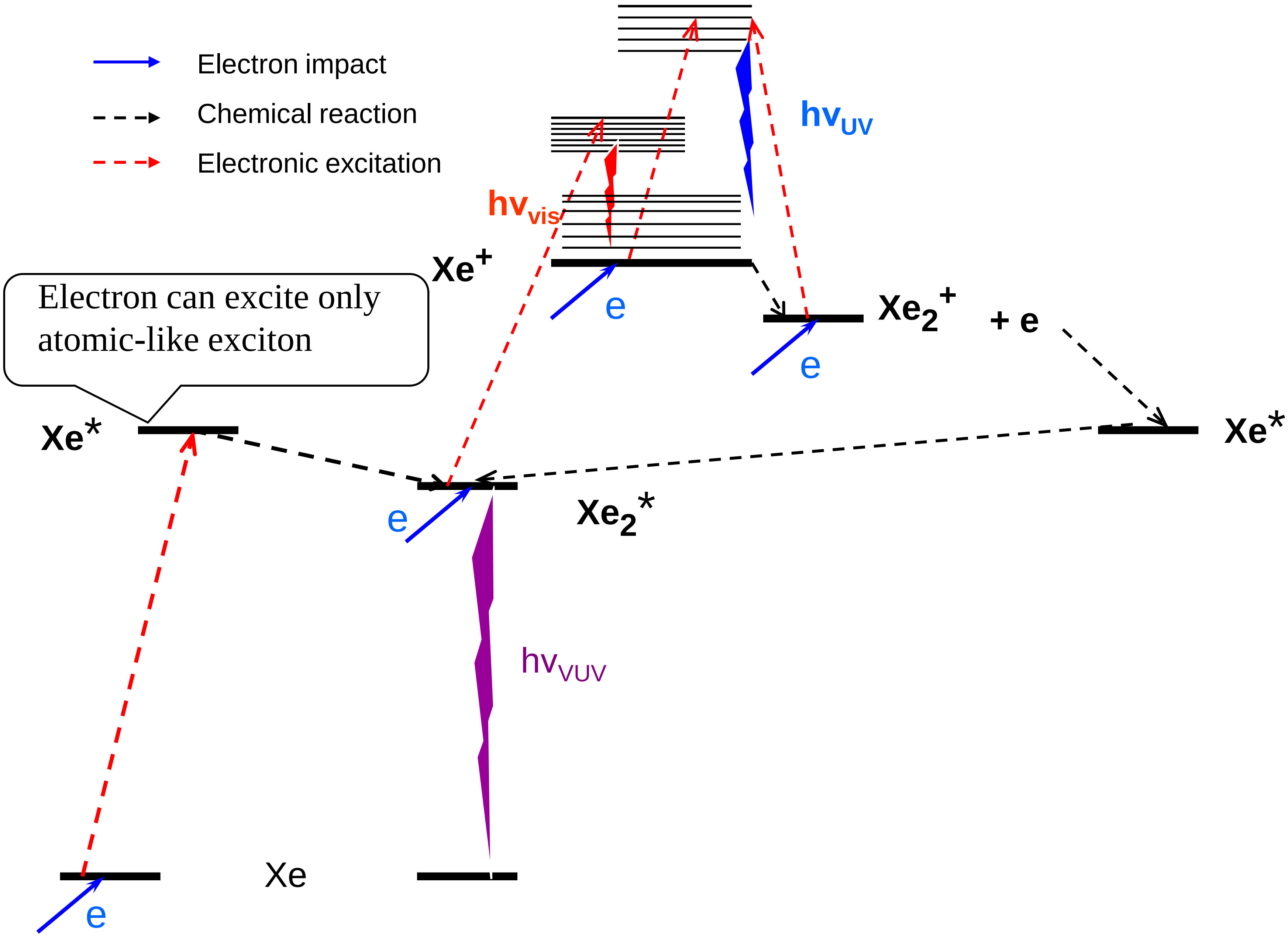

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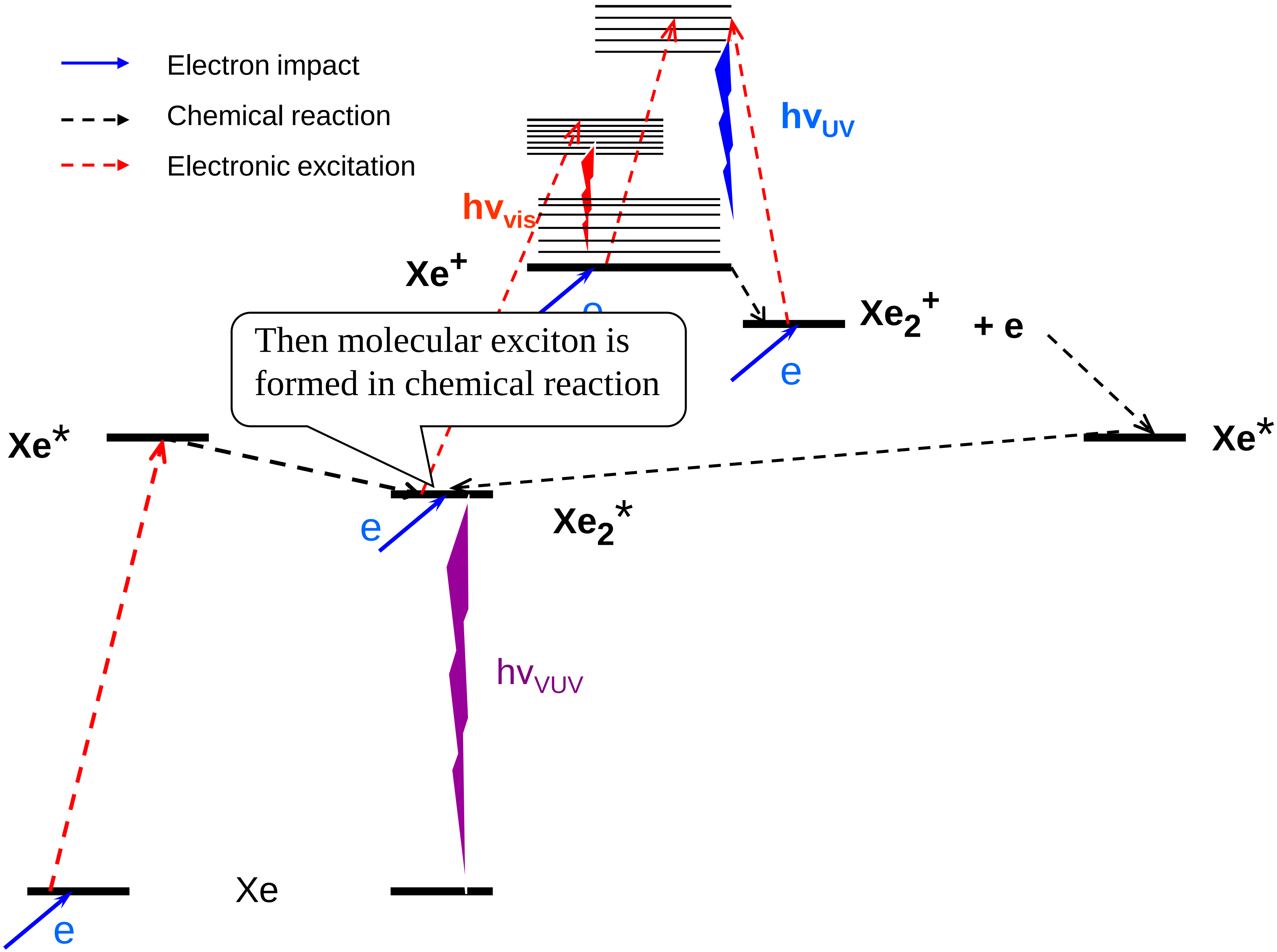

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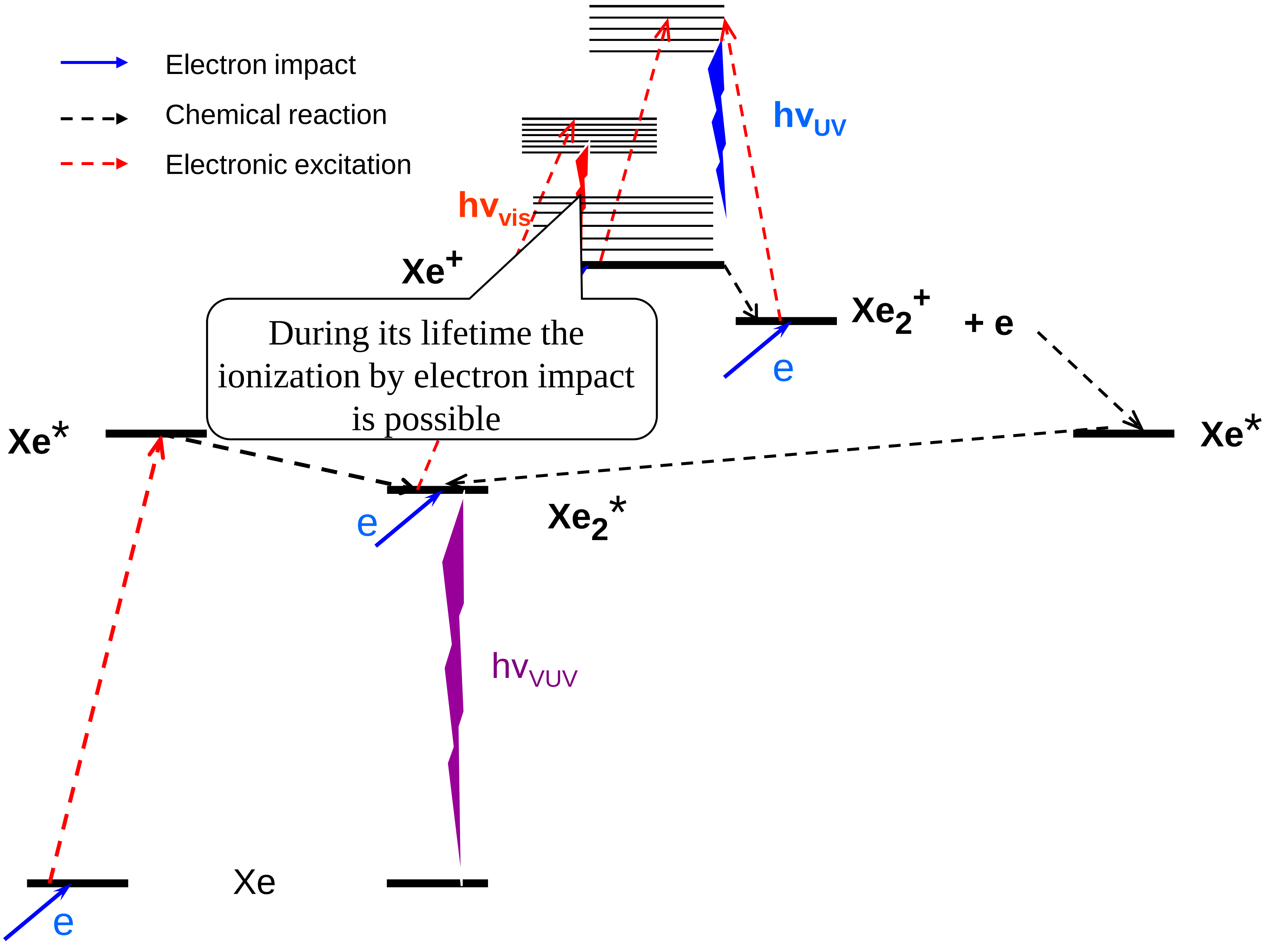

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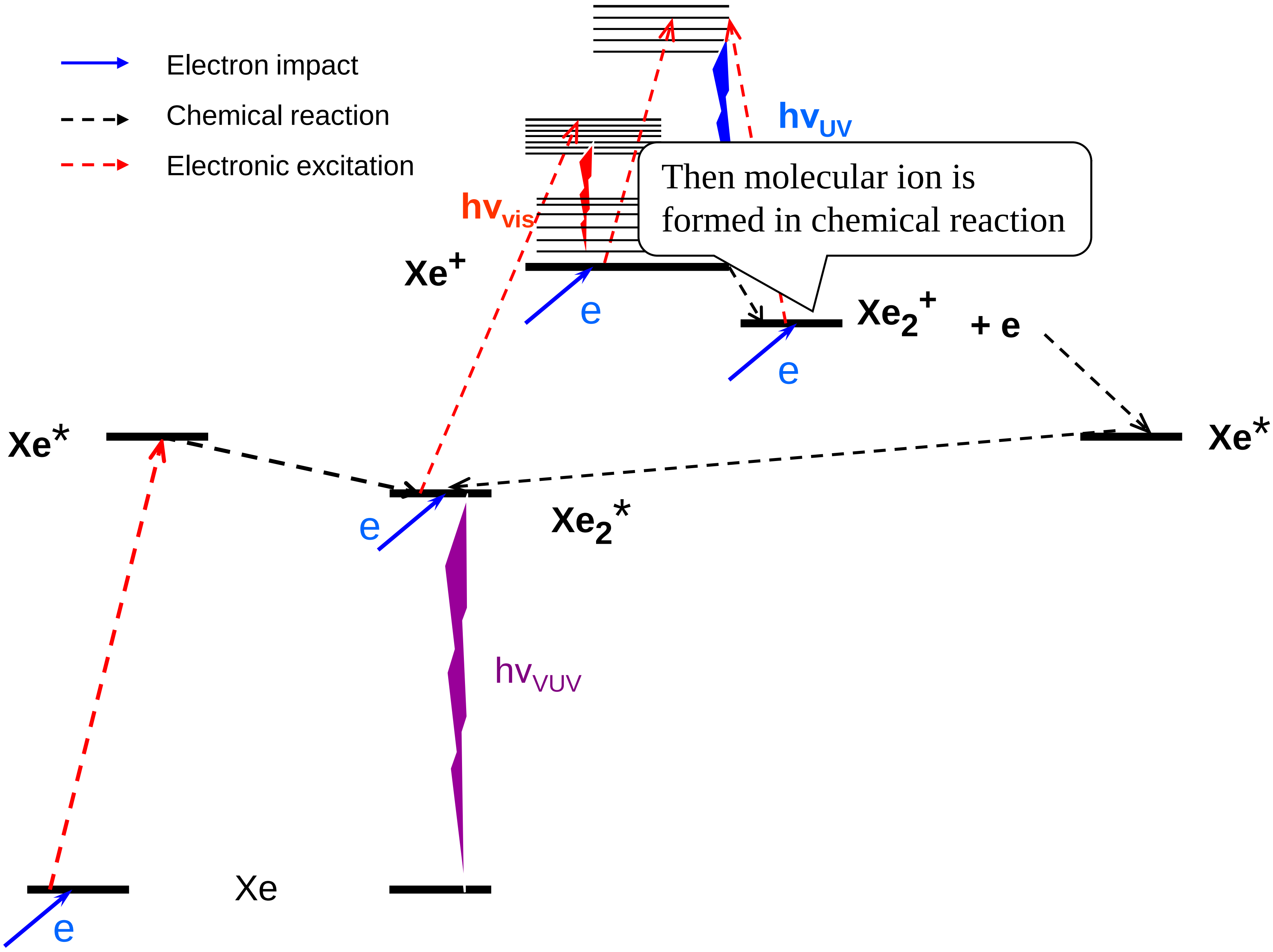

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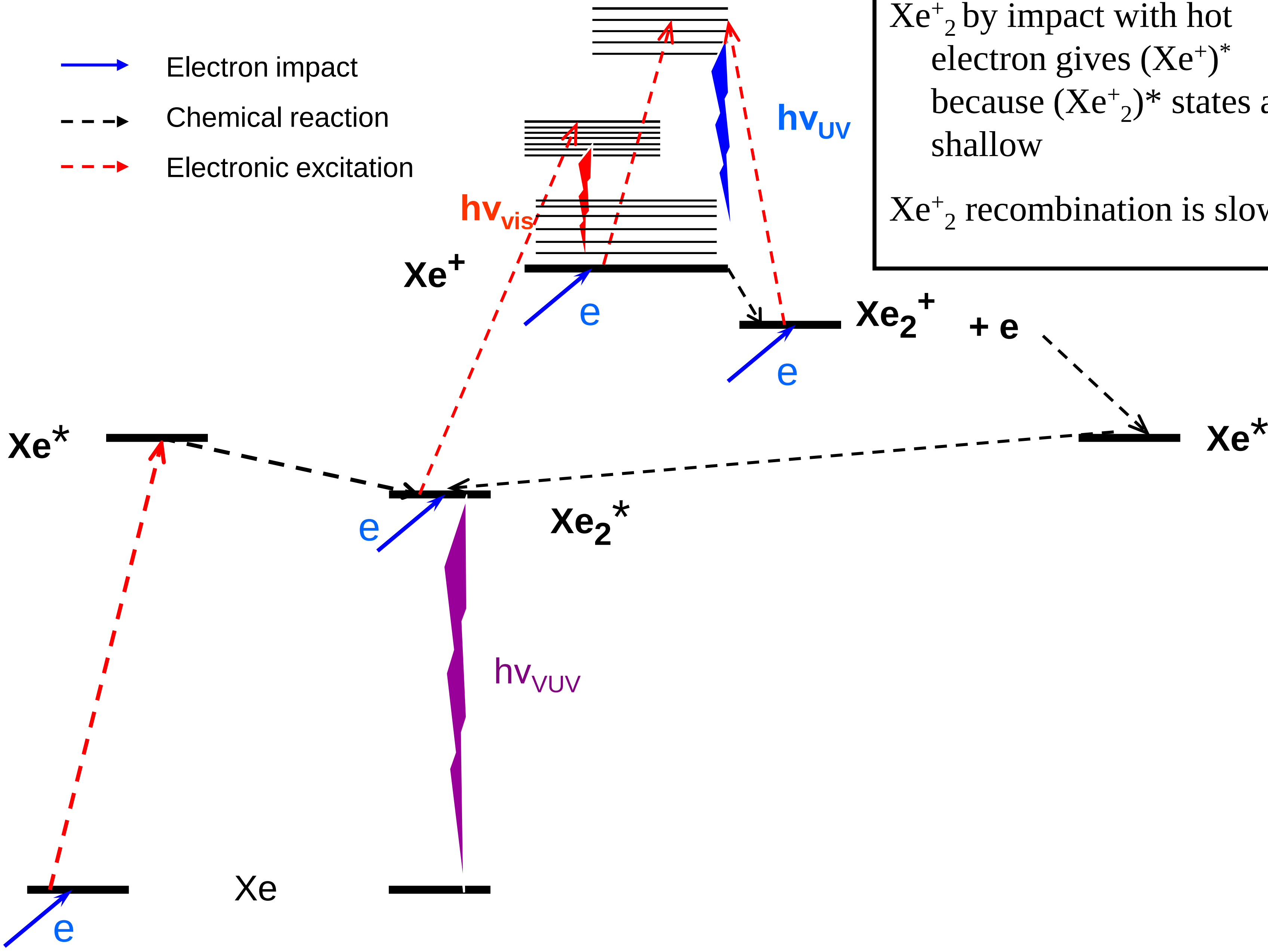
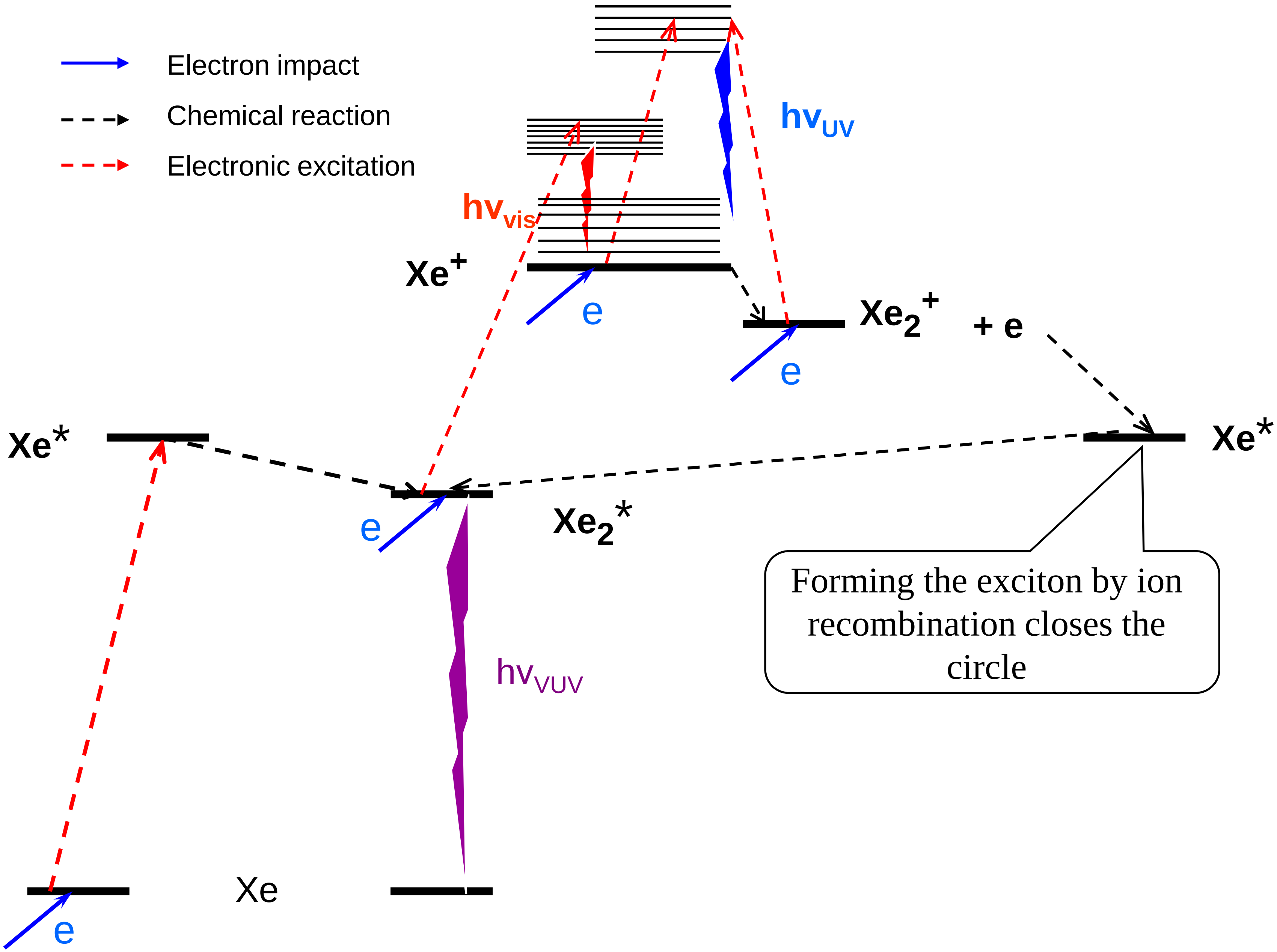


Xe^+_2 by impact with hot electron gives $(Xe^+)^*$ because $(Xe^+_2)^*$ states are shallow

Xe^+_2 recombination is slow

Electron induced excitation and ionization in solid Xe



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Thank you for attention

The Comparison of Inelastic Processes Probabilities for Beams and Drift Motion

$$\eta_p = \sigma_p n_X d$$

Beam or ray

$$\eta_e = \frac{v_T}{v_d} \sigma_e n_X d$$

Drift motion

The real electron pathway exceeds the sample thickness in

$$\frac{v_T}{v_d} \cong \sqrt{\frac{M}{m_e}} \approx 10^3$$ times