LABORATORIJA ZA FIZIKU ATOMSKIH SUDARA

SEMINAR

TEMA: ELECTRON LOSS FROM NEGATIVE IONS IN COLLISIONS WITH ATOMS AND MOLECULES

VREME: 20. APRIL 1990. 9:00

MESTO: SOBA 300

PREDAVAC: DR VLADIMIR A. ESAULOV

LABORATOIRE DES COLLISIONS ATOMIQUES
ET MOLECULAIRES
UNIVERSITE PARIS-SUD ORSAY

Electron detachment from negative ions in collisions with atoms & molecules

work done at:-

LAB. Collisions Atomiques + Moleculaires
ORSAY

Dept. of Physics, College of William + Mary
Williamsburg, USA
group of R. L. Champion

LAB. DE PHYSIQUE ET OPTIQUE
CORPUSCULAIRE, Univ. PARIS 6
PARIS

group of R. I. HALL

OBJECTIVE

STUDY OF IONISATION PHENOMENA AT **LOW ENERGIES.**

→ ⇒ MOLECULAR DESCRIPTION OF THE COLLISIONAL SYSTEM.

WHY NEGATIVE IONS ?

CHARACTERISTICS —

— LOW BINDING ENERGIES

$H^- \simeq 0,75\ eV$

$F^- \simeq 3.4\ eV$

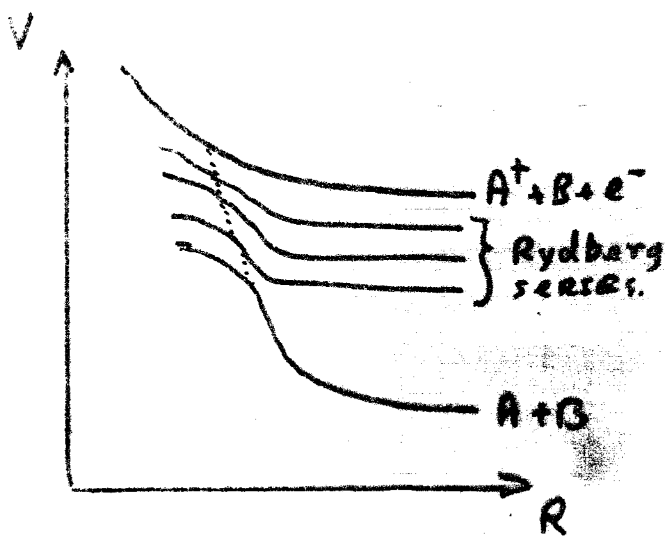
— THEY HAVE NO "SINGLY EXCITED" STATES. i.e.

$H^{-*} \cdots 1s\, n\ell$, $F^{-*} \cdots 2p^5\, n\ell$

BUT ONLY

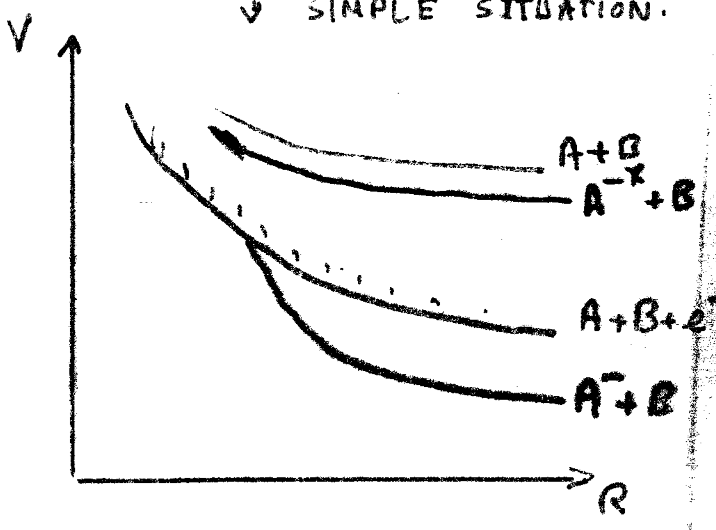
$H^{-*}\,(n\ell . n'\ell')$, $F^{-*}\ 2p^4\, n\ell, n'\ell'$

ATOM + ATOM



A^- + ATOM

↓ "SIMPLE" SITUATION.

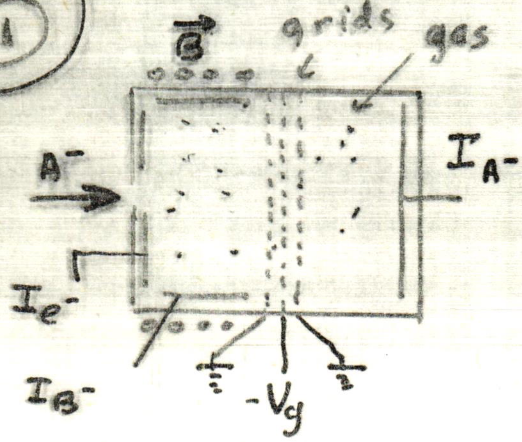


TYPES OF REACTIONS

$A^- + B$	$\longrightarrow$	$A^- + B$	elastic SCATTERING
		$A + B + e^-$	1 e^- detachment
		$A^* + B + e^-$	detachment + excitation.
		$A + B^{-*}$ $\hookrightarrow B(B^*) + e^-$	AUTODETACHING STATE EXCITATION.
		$A^+ + B + 2e^-$	ionisation
$A^- + BC$	$\longrightarrow$	$AB + C + e$	reactive detachment
		$AC + B^-$	ion production
		..... etc.	

TYPES OF EXPERIMENTS

(1) TOTAL cross sections. (WILLIAMSBURG)



$A^- + BC \rightarrow A + BC + e$

$AC + B + e$

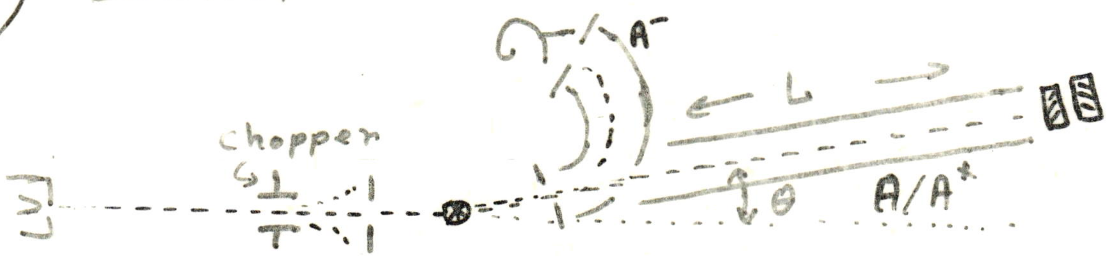
$AC + B^-$

I_{A^-}, I_{e^-}, I_{B^-}, Pressure → σ

- GLOBAL INFORMATION, CROSS SECTION MAGNITUDE, THRESHOLDS. YOU CAN ALSO GET SOME IDEA OF THE DYNAMICS (VELOCITY DEPENDE[NCE]) BY LOOKING AT ISOTOPIC EFECTS
  - H^-/D^- + TARGET
  - $A^- + H_2/D_2$

---

(2) ENERGY LOSS STUDIES (ORSAY).



ELECTROSTATIC ANALYSIC (A^-), TIME OF FLIGHT (TOF) ENERGY LOSS MEASUREMENTS FOR (A).

- ENERGY RANGE - 100 eV - 5 keV
- ANGULAR " - 0 ÷ 30 deg

ENERGY RESOLUTION ≈ 0,2 eV → 2 eV

TOF LENGTH L = 0.5 m ÷ 7.5 m

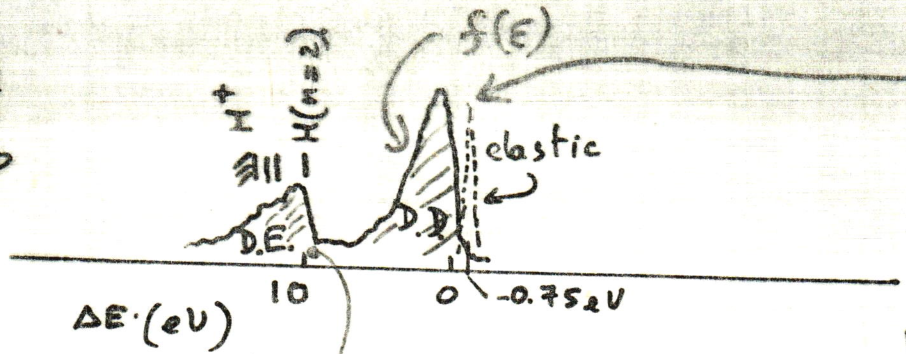
(1) → STUDY SEPARATELY DETACHMENT INTO GROUND & EXCITED STATES

(2). → DETERMINE DIFFERENTIAL CROSS SECTIONS WHICH GIVE INFORMATION ABOUT THE IMPORTANCE OF PROCESSES AS A FUNCTION OF INTERNUCLEAR SEPARATION.

TOF (contd.)

③ GIVE INDICATIONS ABOUT THE SPECTRA OF e^- emitted AND THEIR IMPACT PARAMETER (ANGULAR) DEPENDENCE.

$H^- + He$
750 eV
$\theta = 0.6^\circ$



→ $A^- + B \rightarrow A(-f(\varepsilon)) + B + e^- (+f(\varepsilon))$ FOR AN ANGLE Θ

$A^*(-g(\varepsilon)) + B + e^- (+g(\varepsilon))$

ATOM SCATTERING ANGLE ⇔ b, THE PARAMETER

$f(\varepsilon)$ - is a sum over all e^- ejection angles.

TOF → FAIRLY DETAILED INFORMATION,

BUT — THE ENERGY RESOLUTION IS NOT GOOD

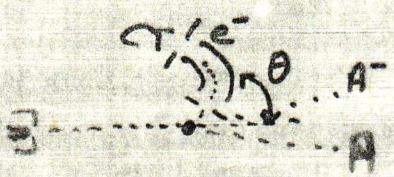
— DECAY CHANNELS FOR EXCITED STATES ARE NOT KNOWN

— COLLISION ENERGY RANGE IS FAIRLY HIGH

$E \gtrsim 100$ eV (detection EFFICIENCY FOR NEUTRAL ATOMS).

---

③ ELECTRON SPECTROSCOPY



Ⓐ WITHOUT COINCIDENCES.

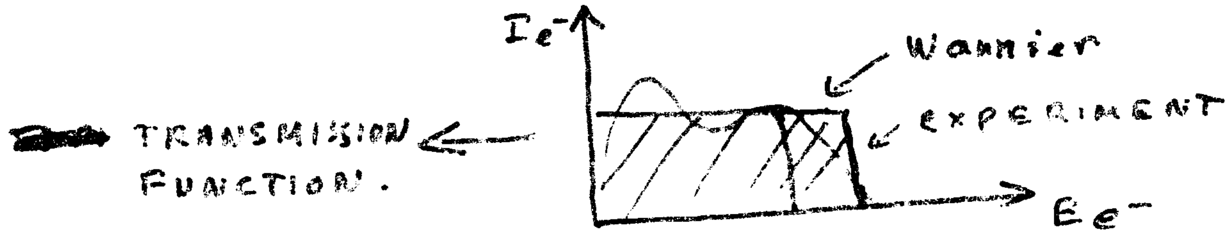
① → ELECTRON SPECTRUM SUMMED OVER IMPACT PARAMETERS BUT CORRESPONDS TO A GIVEN e^- ejection angle.

② → GET INFORMATION ABOUT EXCITED STATES PRODUCED AND THEIR DECAY CHANNELS.

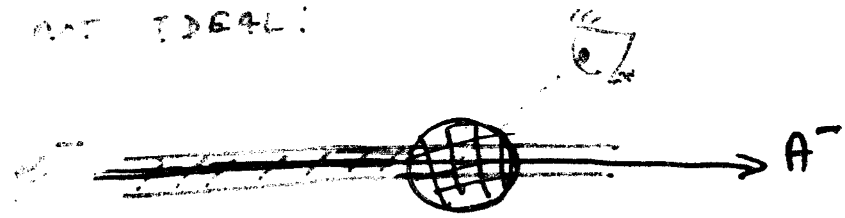
ELECTRON SPECTROSCOPY (CONTD.)

PROBLEMS :- TRANSMISSION FUNCTION OF THE ANALYSER + OPTICS.

METHOD → $e^- + He \rightarrow He^+ + 2e^-$



THIS IS NOT IDEAL:



THE COLLISION VOLUME MAY NOT BE THE SAME.

A BETTER WAY WOULD BE TO DO A e^- TIME OF FLIGHT SPECTRUM — NOT DONE EXTENSIVELY.

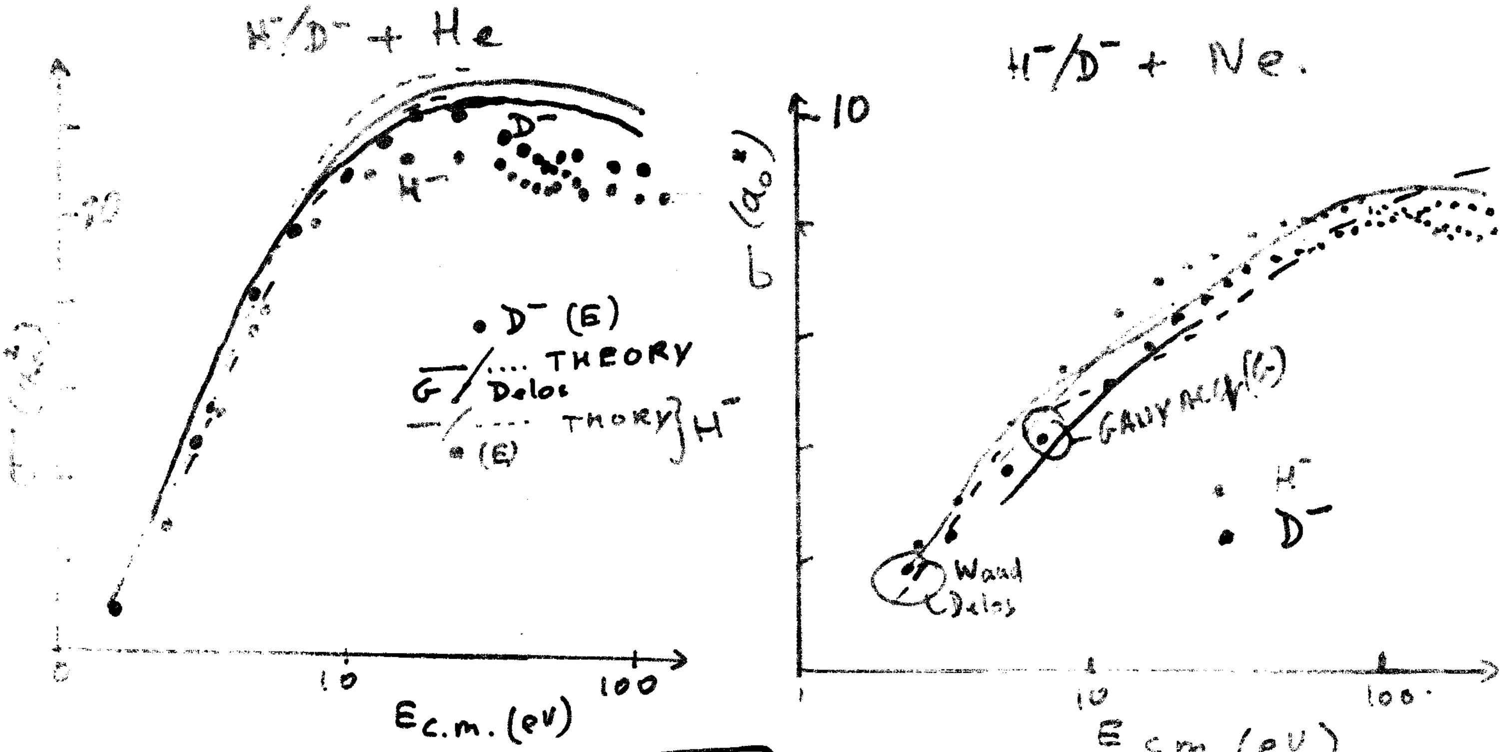
EXCEPTION — $H^- + He$ – some scattering angles of H. → Linder (Kaiserslautern)

RESULTS

SYSTEMS STUDIED — H^-, F^-, Cl^-, ... O^-, S^- ... Li^-, Na^- ... } + He, Ne ... Na, Li ... H_2, N_2, O_2 ...

HERE WE SHALL MAINLY LOOK AT (H^-).

① TOTAL CROSS SECTIONS..



N.B. [$\sigma_{H^-} < \sigma_{D^-}$] [STEEP RISE OF σ] [$\sigma_{H^-} > \sigma_{D^-}$] [SLOW RISE OF σ]

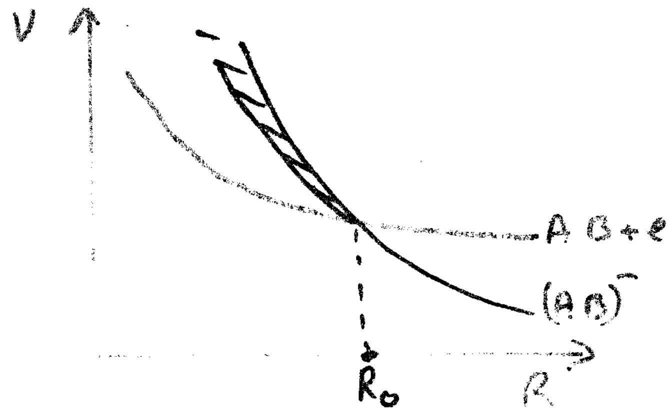
TWO DIFFERENT BEHAVIOURS. !!!

THE PLOT σ(E<u>c.m.</u>) → FOR THE SAME CENTER OF MASS (c.m) ENERGY (E_{cm}) THE IONS FOLLOW THE SAME TRAJECTOR (SAME DISTANCE OF CLOSEST APPROACH) BUT THE **RADIAL VELOCITIES** ARE DIFFERENT. AND THE TIME A SYSTEM SPENDS IN THE INTERACTION REGION IS DIFFERENT.

① $H^-/D^- + He$ → THE SLOWER D^- HAS A BIGGER σ

GOOD OLD DESCRIPTIONS.

LOCAL COMPLEX POTENTIAL MODEL. **STATIC DESCRIPTION.**
(RESONANT STATES).



$$V(R) = E(R) - \frac{i\,\Gamma(R)}{2}$$

$\Gamma(R)$ - width, which depends only on R, but not on velocity

$\Gamma(R) = 0$ FOR $R > R_0$

— Detachment probability

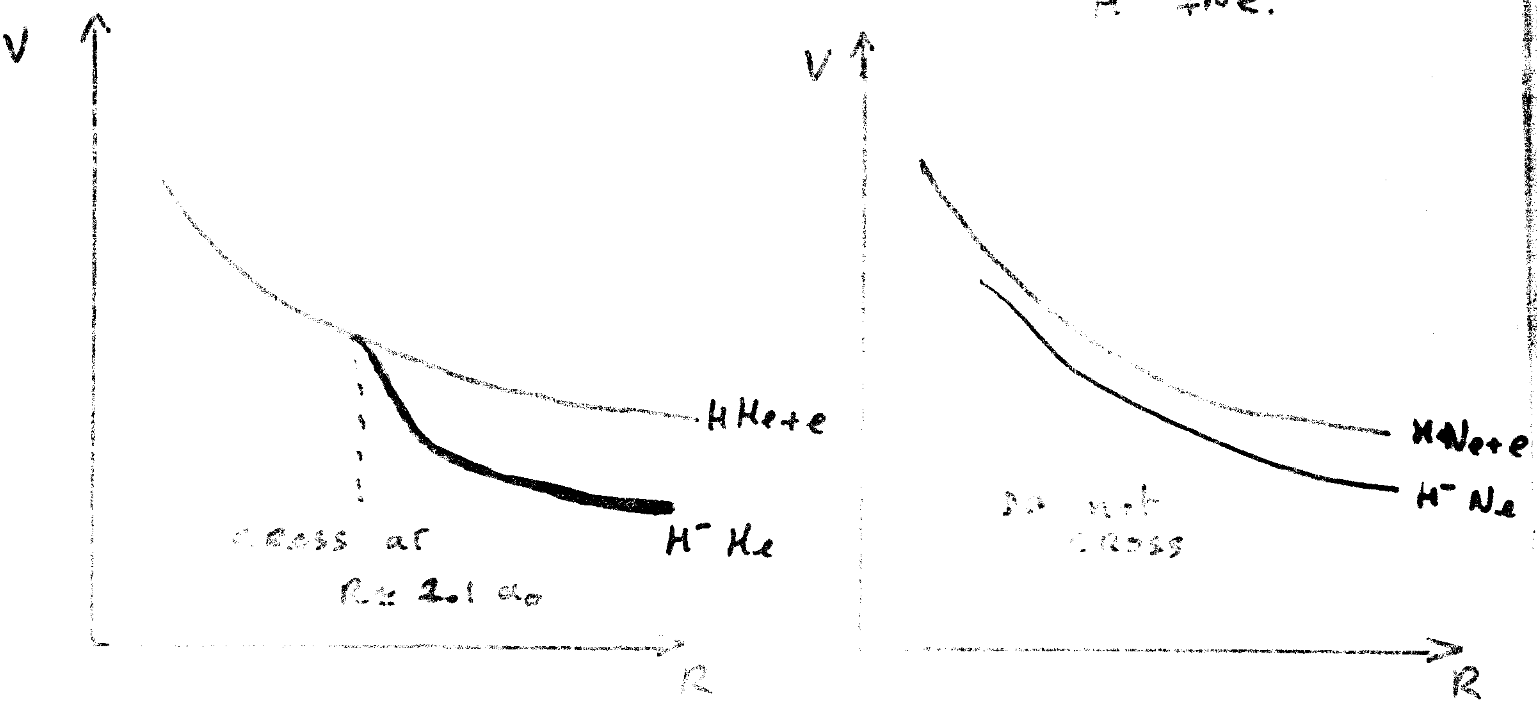
$$P_d = 1 - \exp(-\Gamma\, dt)$$
$$= 1 - \exp\left(-\int_{R_{min}}^{\infty} dR\, \frac{\Gamma(R)}{v(R)}\right),$$ v_R - radial velocity

R_{min} - distance of closest approach.

— Predictions :- FOR H^-/D^- — THE SLOWER ISOTOPE WILL SPEND A LONGER TIME IN THE CONTINUUM AND $\sigma_{D^-} > \sigma_{H^-}$.

THIS SEEMS OK FOR $H^- + He$ BUT IS NOT OK FOR $H^- + Ne$.

THERE EXIST MANY OTHER EXAMPLES WHERE THESE PREDICTIONS FAIL AND WHERE OBVIOUSLY COLLISION VELOCITY DEPENDENT EFFECTS (INCREASE OF σ WITH INCREASING VELOCITY) ARE OBSERVED.

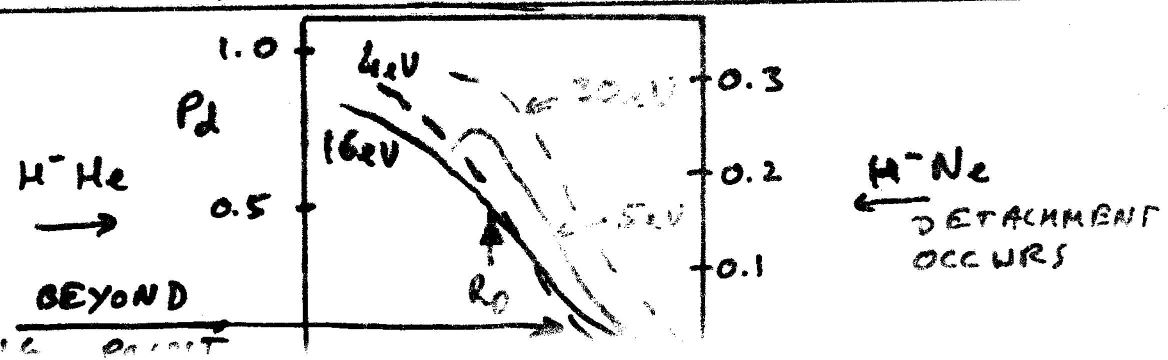


CLEARLY THE SITUATION FOR H^-Ne DOES NOT CONFORM TO THE LOCAL COMPLEX POTENTIAL DESCRIPTION.

ONE NEEDS OTHER DESCRIPTIONS WHERE <u>DYNAMIC</u> EFFECTS ARE TAKEN INTO ACCOUNT.

1. NON-LOCAL RESONANT STATE FORMALISMS.
   - W. DOMCKE — FRG
   - J. DELOS — WILLIAMSBURG
2. EFFECTIVE RANGE DESCRIPTIONS
   - "ZERO RANGE POTENTIAL MODEL" (ZRP.) <u>DEMKOV</u> — LENINGRAD
   - GAUYACQ — ORSAY

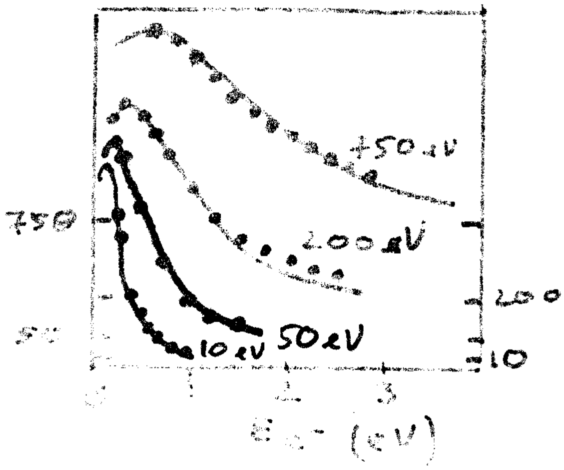
EXAMPLE.
ZRP



TRANSITIONS BEYOND THE ... POINT

APPLICATIONS: ① TOTAL CROSS SECTIONS → (GOOD AGREEMENT).

② ELECTRON SPECTRA [SUM OVER IMPACT PARAMETERS].

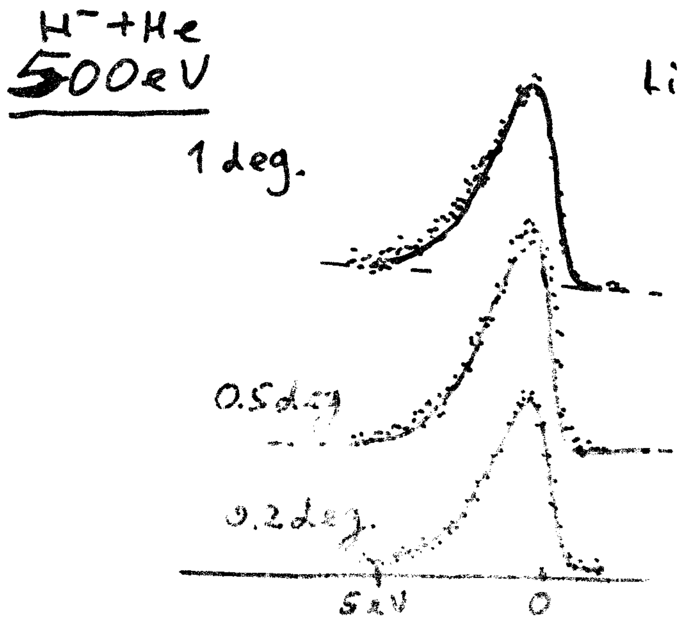


• EXPERIMENT (PARIS L.P.O.C.)

— THEORY – ZRP

③ Electron SPECTRA — IMPACT PARAMETER DEPENDENCE

TOF — ...



Line – Theory ZRP

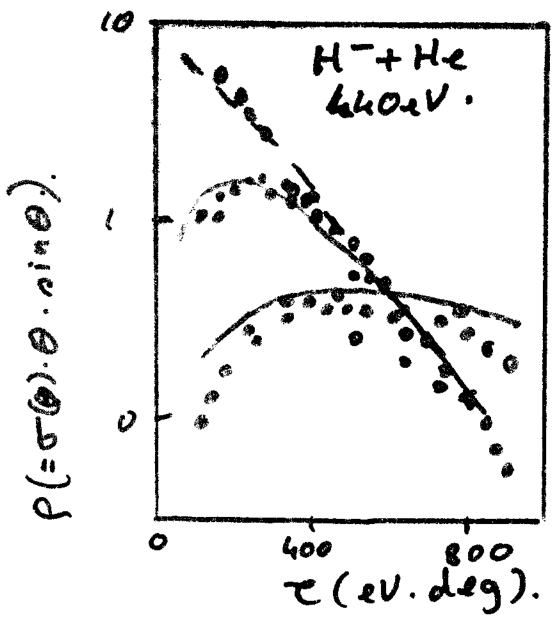
● – experiment.

THESE ARE NETRAL H atom TOF SPECTRA

THEORY is A CONVOLUTION FOR EJECTION KINEMATCS + APPARATUS EFFECTS – ($\Delta E = 0.5$ eV)

THERE EXIST SOME RECENT $e^- \leftrightarrow H$ COINCIDENCE MEASUREMENTS BY TOF of e^- – LINDER (KAISERSLAUTERN). THESE DATA ALSO AGREE WITH THE ZRP CALCULATIONS.

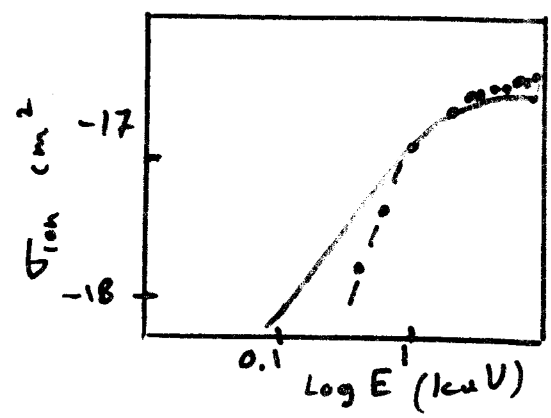
(4) - Differential cross sections. TOF - ORSAY.



ZRP does not take into account excitation processes.
THES were TAKEN INTO account IN a "hybrid" model.
assuming the outer H^- electron and the core (H + He) collision evolve independently.

(5) Ionisation $H^- + He \rightarrow H^+ + He + 2e^-$

ZRP
+
"hybrid"



• EXPERIMENT
— THEORY USING DIFFERENT SETS OF EXPERIMENTAL (H + He) data.

CONCLUSION A GOOD DESCRIPTION OF ELECTRON DETACHMENT IS OBTAINED WHEN DYNAMIC EFFECTS (NUCLEAR VELOCITY) ARE TAKEN INTO ACCOUNT.

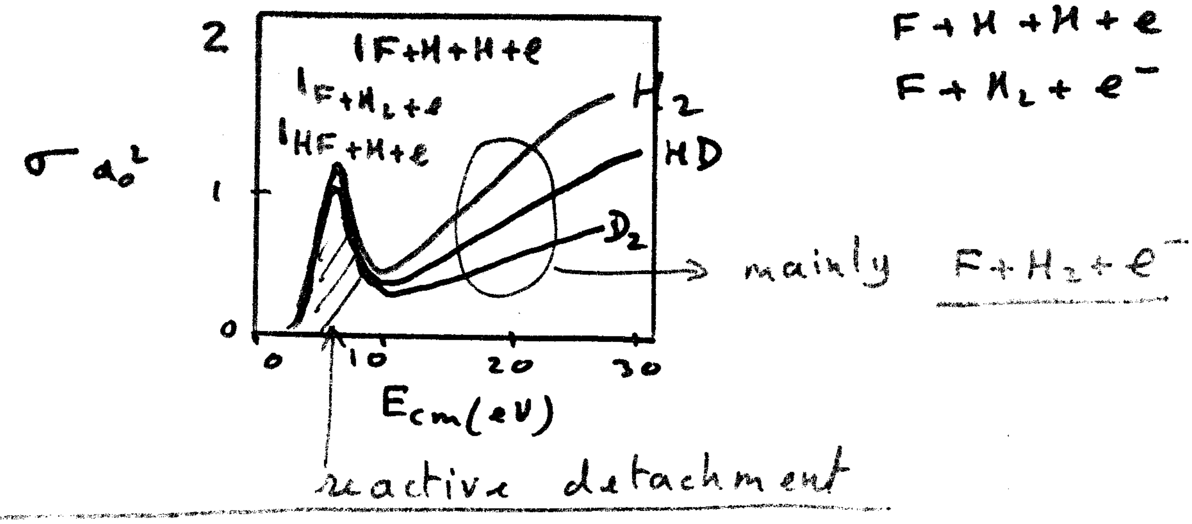
THIS IS NOT THE CASE OF LOCAL RESONANT STATE DESCRIPTIONS.

COLLISIONS WITH MOLECULES

THERE ALSO EXIST DYNAMIC EFFECTS:-

EXAMPLE :—

$F^- + \begin{matrix} H_2 \\ D_2 \\ HD \end{matrix} \rightarrow \begin{matrix} FH + H^- \\ FH + H + e \\ F + H + H^- \\ F + H + H + e \\ F + H_2 + e^- \end{matrix}$



THESE CROSS SECTIONS ARE DIFFERENT FOR THE SAME ← CENTER OF MASS ENERGY BUT ARE THE SAME FOR THE SAME LAB. ENERGY i.e. FOR THE SAME COLLISION VELOCITY.

OTHER PROCESSES.

$H^- + N_2$

TOTAL CROSS SECTION

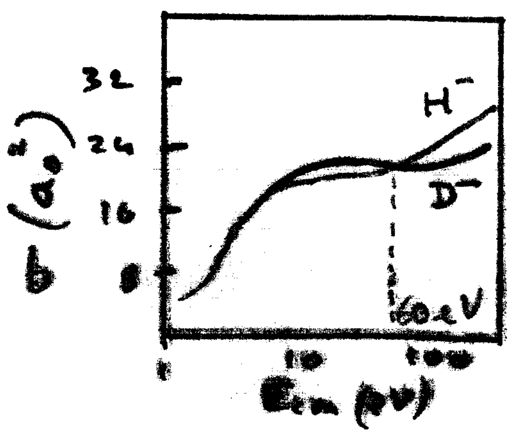
$E < 60\ eV$

$\sigma_{H^-} < \sigma_{D^-}$

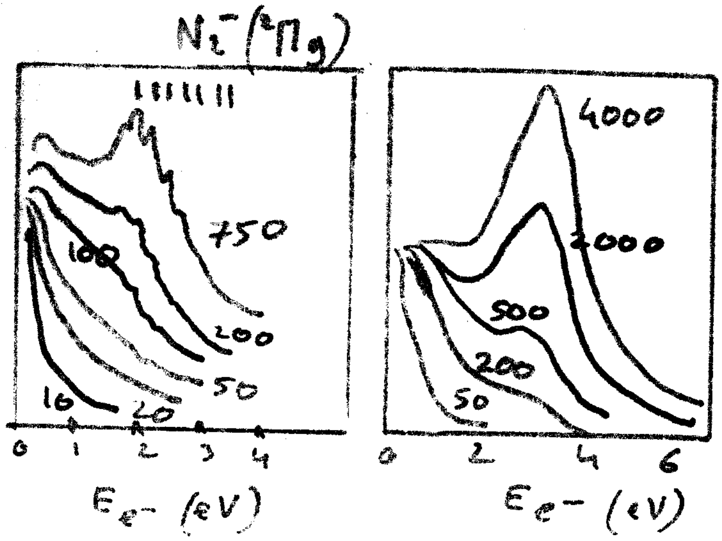
BUT $E > 60\ eV$

$\sigma_{H^-} > \sigma_{D^-}$

↳ ONSET OF SOMETHING ?



ELECTRON SPECTRA $H^- + N_2$, CO_2



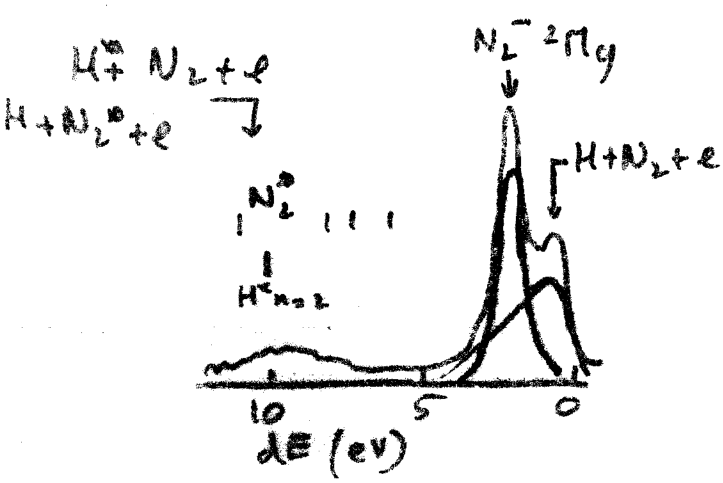
AT ABOUT 50 eV ONE SEES THE APPEARANCE OF STRUCTURES DUE TO THE DECAY OF N_2^- $^2\Pi_g$ RESONANCE.

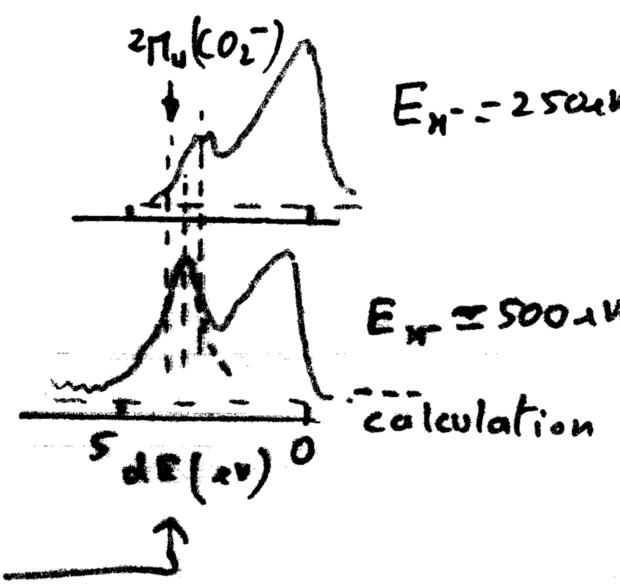
$$H^- + N_2 \rightarrow H + N_2^-(v')$$
$$\hookrightarrow N_2(v) + e^-$$

THIS MUST BE RESPONSIBLE FOR THE CHANGE IN THE ISOTOPE EFFECT.

TOF (H atom) spectra

FRANCK CONDON POSITION





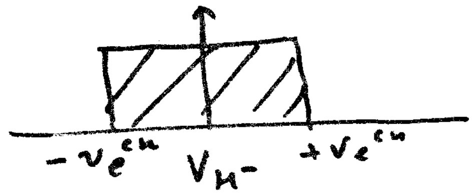
THE PEAK LIES <u>BELOW</u> THE FRANCK CONDON RESONANCE POSITION AT LOW COLLISION ENERGIES. STRANGE

CONSIDER FAST COLLISIONS of H^-

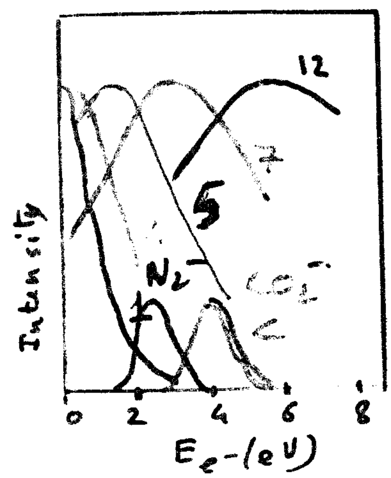
BINARY COLLISION APPROXIMATION.

CONSIDER THE SCATTERING OF THE OUTER e^- ON THE TARGET

$$\vec{v}_e^{\,lab} = \vec{V}_{H^-} + \vec{v}_e^{\,cm}.$$



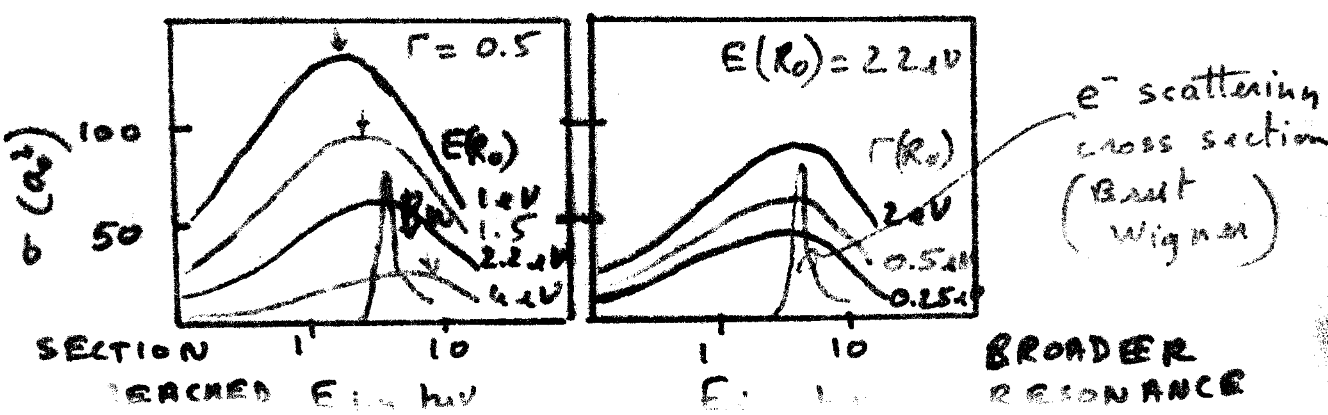
velocity distribution schematic



Energy distribution in the electron wave packet (calculated – Gauyacq – Herzenberg). for different H^- energies.

- Franck Condon envelope for the N_2^- and CO_2^- resonances.

For low collision energies the translational energy of the electron is not high enough and only the low energy tail of the [redacted] resonance is excited. At high energies the e^- energy is high enough so that the F.C. position is attained in the TOF spectra.



CROSS SECTION MAXI... REACHED E... keV

E...

BROADER RESONANCE

(16)

Two e⁻ loss in Negative Ion collisions

Case of open shell parent atoms.

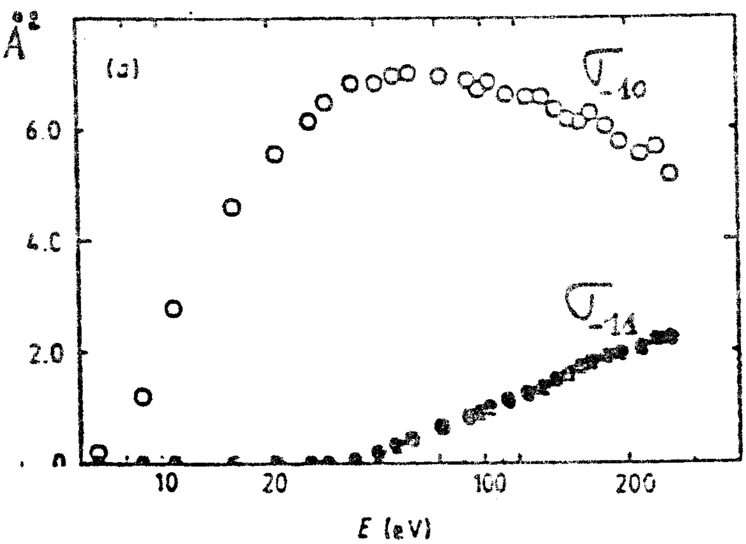
$F^- \rightarrow F \ 2p^5 \ (^2P)$

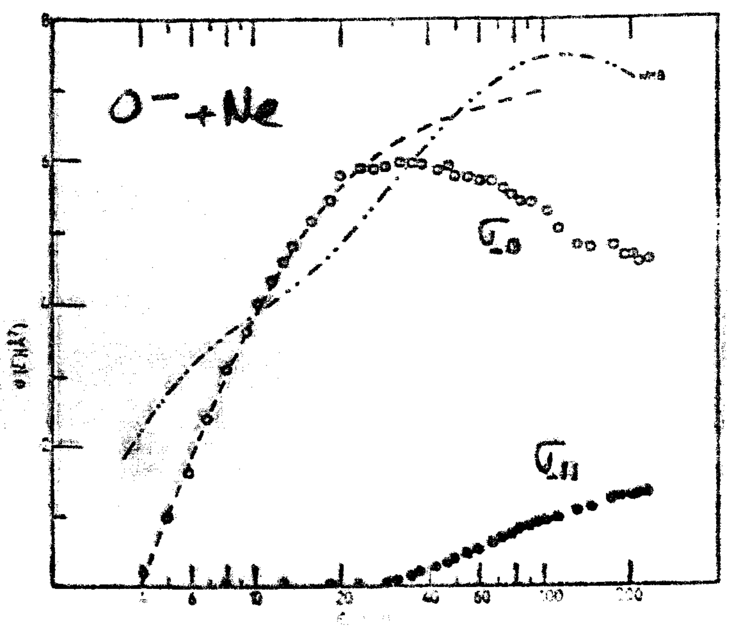
$O^- \rightarrow O \ 2p^4 \ (^3P, {}^1D, {}^1S)$

Total and differential cross section measurements show that in some cases the two e⁻ loss cross section may be very large and onsets at low energies.

F⁻/Ne

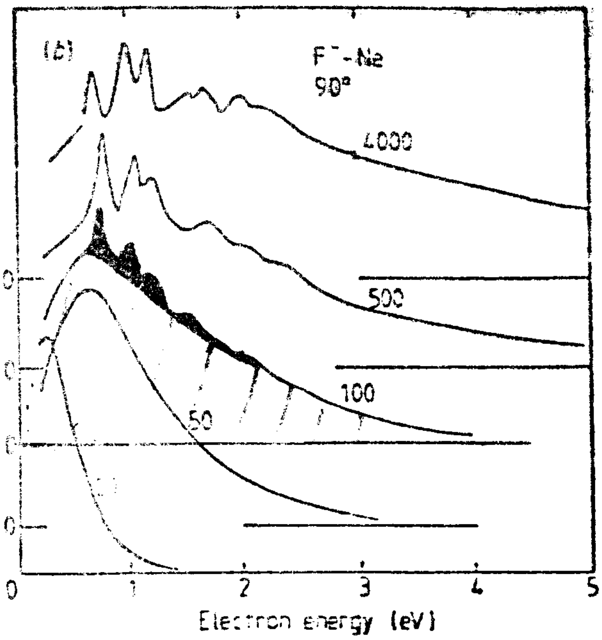
MECHANISM ?

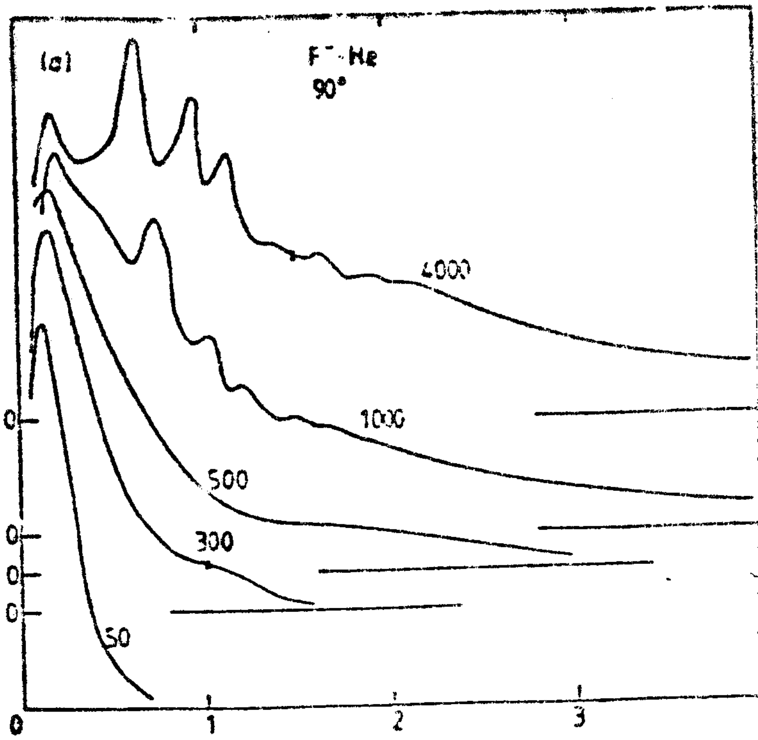




(17)

ELECTRON SPECTRA. → PEAKS THAT ARE DUE TO AUTOIONISING STATES.

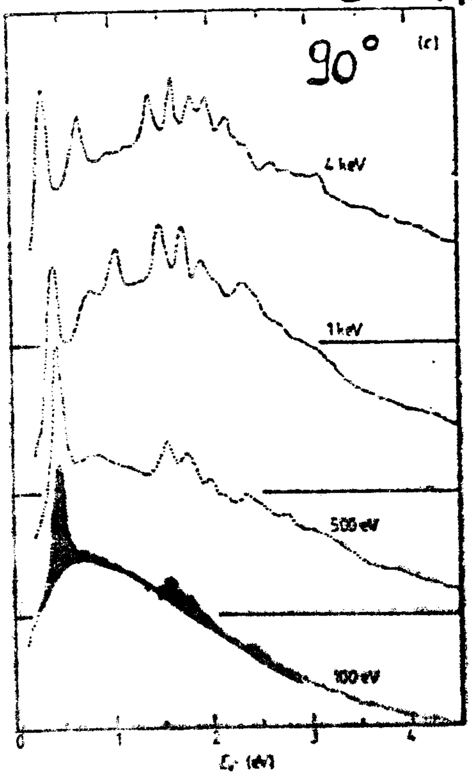




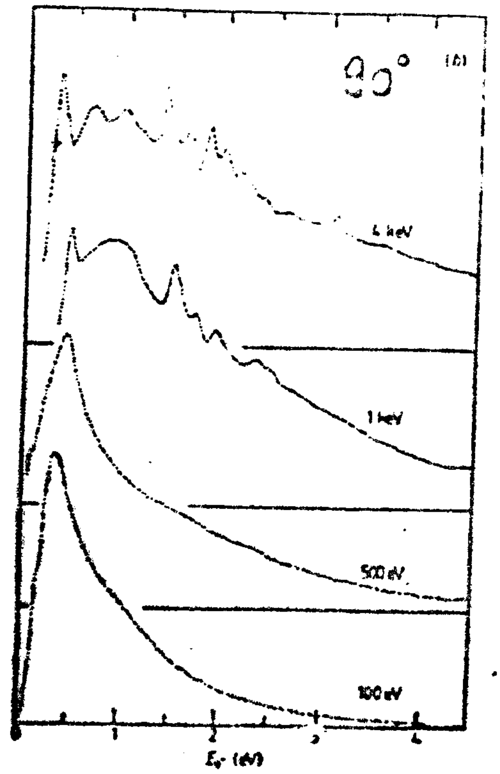
THRESHOLDS F^- Ne ~ 50 eV c.m.

$\frac{\sigma_{-11}}{\sigma_{-10}} \approx 3\%$	PEAK AREAS
$\frac{\sigma_{-11}}{\sigma_{-10}} = 4\%$	TOTAL CROSS SECTION

$O^- + Ne$

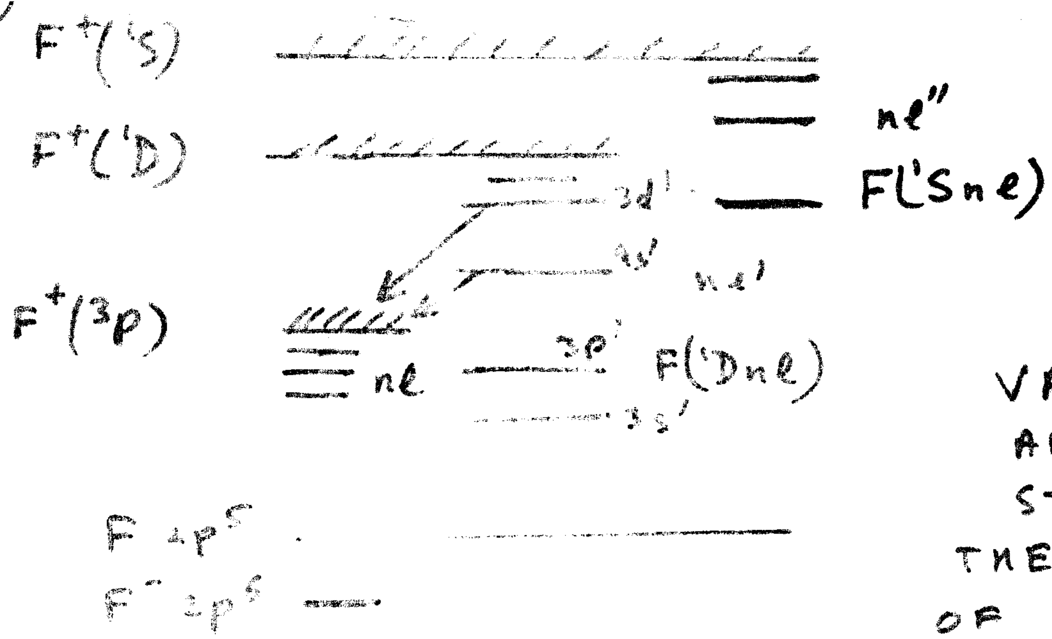


$O^- + He$



[illegible]ISATION AT THRESHOLD PROBABLY DUE

18



VALENCE AUTOIONISING STATES, DUE TO THE EXISTENCE OF SEVERAL STATES OF THE GROUND OF THE [redacted] PARENT ION CONFIGURATION

F^-H_e

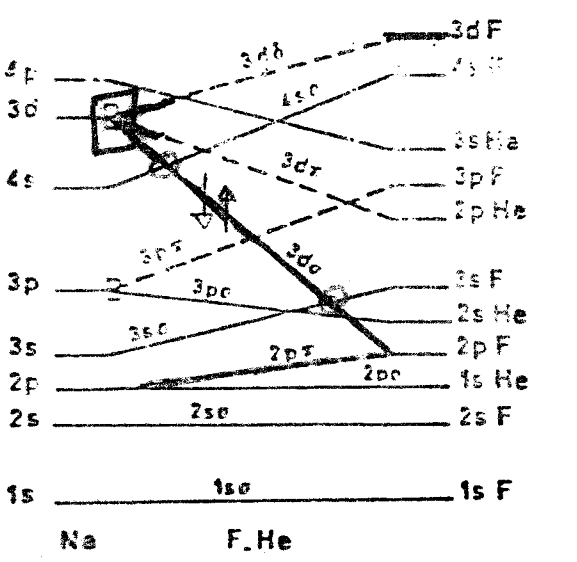


Diagramme de corrélation des orbitales.

Molecular orbitals correlations

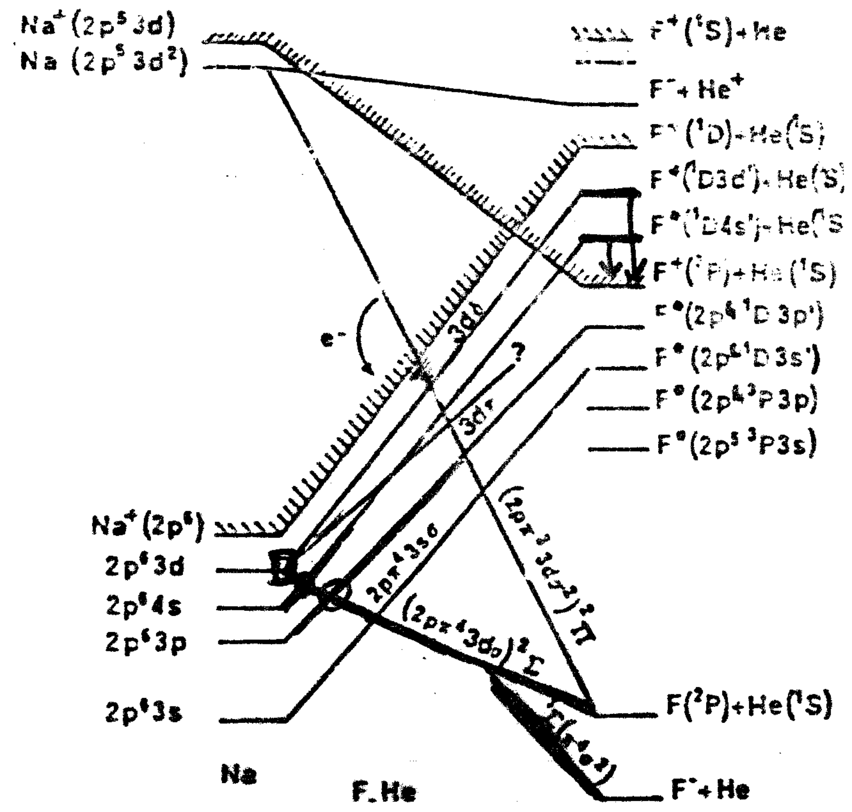


Diagramme de corrélation des États

Molecular states correlations

(step 1) $F^- He \rightarrow {}^1\Sigma\ \pi^4 \sigma^2$ $\xrightarrow{\text{REMOVE ONE } \sigma \text{ electron}}$ ${}^2\Sigma\ \pi^4 \sigma$ - FK

Excitation :- RADIAL COUPLING $3d\sigma - 3s\sigma, 4s\sigma$
ROTATIONAL " $3d\sigma - 3d\pi - 3d\delta$

RESULT $\rightarrow {}^2\Sigma(\pi^4\sigma) \rightarrow \pi^4 n\lambda$ eg. $3d\pi^4 3d\delta$
$(^1D)\ 3d'$

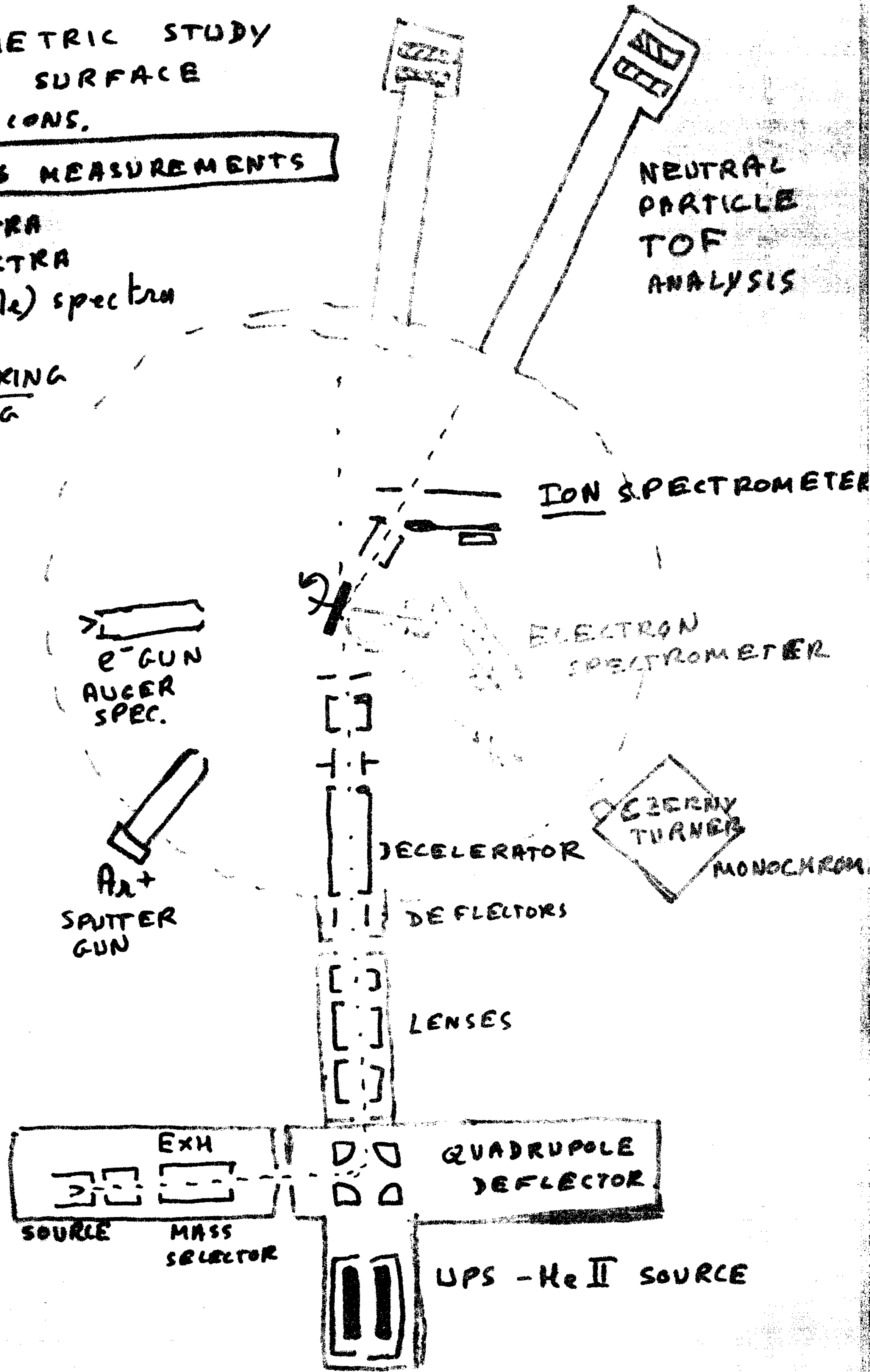
MULTIPARAMETRIC STUDY OF ION · SURFACE COLLISIONS.

SIMULTANEOUS MEASUREMENTS OF

e^- SPECTRA
ION SPECTRA
hν (visible) spectra

ALSO TOF SCATTERING AND RECOILING SPECTRA.

ANALYSIS
1) AES
2) UPS
3) TOF RECOIL
FUTURE
(??)



FUTURE PROSPECTS. – (OK>ITY – [illegible])

ION SCATTERING AT SURFACES. $(E \in 5\,eV \div 5\,keV)$

OBJECTIVES.

1. STUDY OF RELATIVE ROLES OF ONE (RESONANT) AND TWO (AUGER) ELECTRON NEUTRALISATION.

2. STUDY OF THE ROLE OF COLLISIONS AT VERY CLOSE INTERNUCLEAR SEPARATION WITH SURFACES ATOMS. – EXCITED STATE PRODUCTION AND IONISATION

3. INTERACTIONS OF LOW ENERGY ION BEAMS WITH SURFACES WITH CHEMISORBED GASSES. REACTIONS AND EXCITED STATE PRODUCTION.

4. INTERACTIONS OF MOLECULAR SPECIES WITH SURFACES, DISSOCIATION ETC.

APPLICATIONS.

i) MONITORING REACTION KINETICS

ii) DETERMINATION OF ADSORPTION SITES AND BINDING ENERGIES OF ADSORBATES

iii) MAKING OF THIN FILMS BY ION IMPLANTATION (e.g. DIAMOND FILMS FROM C^+ BEAMS)

iv) STUDIES OF INTERACTIONS OF LOW ENERGY BEAMS WITH SURFACES IN SPACE TECHNOLOGY :– PROBLEMS OF EROSION AND SPURIOUS LIGHT EMISSION (SHUTTLE GLOW PHENOMENA).