State-Resolved Cross Section Measurements in Low and Intermediate Energy Ion-He/H\(_2\) Collisions

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Outline

1. Introduction to the Institute
2. Introduction of the experimental facilities
3. Some differential results in ion-atom collisions
4. Experiments planned for the CRP
A Brief Introduction to IMP

- Funds: ~2500 MRMB
- Staff: ~744
- Students: ~280
Lanzhou locates almost in the geometric center of China
HIRFL: Beam Facilities

Heavy Ion Research Facility in Lanzhou

- **SFC**: ≤ 10 AMeV (H.I.), 17~35 MeV (p)
- **SSC**: ≤ 100 AMeV (H.I.), ≤ 110 MeV (p)
- **CSRm**: ≤ 1000 AMeV (H.I.), ≤ 2.8 GeV (p)

**RIBLL1**: RIBs at tens of AMeV
**RIBLL2**: RIBs at hundreds of AMeV
**CSRe**: storage ring with deceleration
Heavy Ion Research Facility in Lanzhou

1. Low energy site in general
2. Atomic physics exp. site
3. SHANS - Spectrometer for Heavy Atom and Nuclear Structure
4. Heavy ion irradiation exp. site
5. RIBLL1 – 1st Radioactive Ion Beam Line in Lanzhou

6. ETF – External Target Facility at CSR
7. CSRe – Experimental Ring
8. PISA
9. Tumor therapy site
There are three experimental areas at CSR in Lanzou. One area is at the internal gas target in CSRe, the other area is at the electron cooler (CSRm and CSRe). At the electron cooler, where the cooling electron can be used as a free electron target, dielectronic recombination, radiative recombination, and electron impact ionization of highly charged ions can be studied in detail.
A 320kV platform for researches with highly charged ions

320kV ECR platform for researches with highly charged ions, equipped with five experimental terminals for ion-atom/molecule, surface interactions.
A 320kV platform for researches with highly charged ions

\[ E_{\text{max}} = q (320 + 25) \text{ keV} \]
The experimental equipment. This figure shows recoil detector, electron detector, projectile detector, supersonic gas-jet by cooling of liquid nitrogen, and Helmholtz coils.
ReMiLa

Supersonic gasjet

Helmholtz coils

e - PSD

Ion beam

R - PSD

X

Y

Z
Momentum Imaging

\[ p_i = m \frac{\Delta x}{\Delta t} \]

\[ P_{\text{long}} = -\frac{Q}{v_p} - \frac{n_c}{2} v_p \]

\[ \theta \approx \tan \theta \approx -\frac{P_{\text{trans}}}{P_0} \]

\[ b = \frac{a}{2 \tan(\theta/2)} \approx \frac{a}{\theta} \approx -a \cdot \frac{P_0}{P_{\text{trans}}} \]

\[ Q = \sum \mathcal{E}_i - \sum \mathcal{E}_f \]

Large impact collisions

Collision distances

State-selective information
Systems being studied

- **Ion-atom collisions**
  - $\text{He}^{2+}+\text{He}$ collisions (10~125 keV/u)
  - $\text{O}^{3+}+\text{He}/\text{H}_2$ collisions (60 keV)
  - $\text{C}^{4+}+\text{He}$ collisions (200 keV)
  - $\text{C}^{5+}+\text{He}$ collisions (200 keV)

- **ion-H$_2$ collisions:**
  - (non-dissociative single electron capture NDSEC)
    - $\text{He}^{2+}+\text{H}_2$ collisions (40 keV)
    - $\text{O}^{3+}+\text{H}_2$ collisions (60 keV)
    - $\text{C}^{4+}+\text{H}_2$ collisions (40 keV)
    - $\text{C}^{5+}+\text{H}_2$ collisions (200 keV)
$P_{\text{trans}}$

2D coincidence spectrum of double captures for He$^{2+}$ on He collisions at 40keV
**He$^{2+}$+He collisions**  

He$^{2+}$+He$\rightarrow$He$^+$ (nl)+He$^+$ (n'l') at 40 keV
He$^{2+}$+He collisions  SC at different impact energies
Differential cross sections

Scattering angle $\theta$ (mrad)

10 keV/u $\times 10^{-1}$
17.5 keV/u $\times 10^{-2}$
25 keV/u $\times 10^{-3}$
40 keV/u $\times 10^{-4}$
50 keV/u $\times 10^{-5}$
100 keV/u $\times 10^{-6}$
125 keV/u $\times 10^{-7}$

$\sigma_d/\Omega \left(10^{-16} \text{cm}^2/\text{sr}\right)$
C⁴⁺ + He collisions at 200 keV
$C^{4+}(1s^2) + \text{He} \rightarrow C^{3+}(1s^2nl) + \text{He}^+(n''l')$ at 200keV

Counts

Longitudinal momentum of recoil ion $P_{//R}$ (a.u.)

$(n,n') = (2,1)$

$(3,1)\&(2,2s)$

$(\geq 4,1)\&(2,2p)$

$n' = 1$

$n' = 2$
C⁵⁺ + He collisions at 200 keV

\[ \text{C}^5(1s)^+ + \text{He}(1s^2) \rightarrow \text{C}^4(1snl)^+ + \text{He}^+(n'l') \text{ at } 200 \text{ keV} \]
\[ C^{5+}(1s) + \text{He} \rightarrow C^{4+}(1s) + \text{He}^+(n'') \text{ at } 200 \text{ keV} \]

The diagram shows the distribution of counts for different values of \( n \) and \( n' \) in a longitudinal momentum of recoil ion \( P_{//R} \) (a.u.). The peaks are labeled for specific transitions:

- \( n=2 \)
- \( n=3, 4, 5, \infty \)
- \( n'=1 \)
- \( n'=2 \)
- \( (3,1) \& (2,2) \)
- \( (n,n')=(2,1) \)
- \( (\geq 4,1) \)
He\textsuperscript{2+}+H\textsubscript{2} collisions at 40 keV

\begin{equation}
\text{He}^{2+} + \text{H}_2 \rightarrow \text{He}^{+}(n\ell) + \text{H}_2^+ \text{ at 40 keV}
\end{equation}

反冲离子纵向动量和横向动量二维谱
\[ \text{He}^{2+} + \text{H}_2 \rightarrow \text{He}^+(n) + \text{H}_2^+ \text{ at } 40\text{keV} \]

Recoil ion longitudinal momentum spectrum $P_{//R}(0.01\text{a.u.})$

Recoil ion longitudinal momentum spectrum $n=2$ dominant
C⁴⁺+H₂ collisions at 40 keV

C⁴⁺(1s²)+H₂ → C³⁺(1s² nl)+H⁺ at 40 keV

Transverse momentum of recoil ion (0.01 a.u.)

Longitudinal momentum of recoil ion (0.01 a.u.)
$C^5^+ + H_2 \rightarrow C^4^+ (1snl) + H^+ \text{ at 200 keV}$

- Counts
- Recoil ion longitudinal momentum $P_{long}$ (a.u.)
Branch ratios determined in $\text{H}_2^+ + \text{He}$ collisions for various processes

\[ DI1: H_2^+ + \text{He} \rightarrow H + p + \text{He}^+ + e \]
\[ DI2: H_2^+ + \text{He} \rightarrow H + p + \text{He}^{2+} + 2e \]
\[ DC1: H_2^+ + \text{He} \rightarrow H + H + \text{He}^+ \]
\[ DC1I1: H_2^+ + \text{He} \rightarrow H + H + \text{He}^{2+} + e \]
\[ EI2: H_2^+ + \text{He} \rightarrow p + p + \text{He}^+ + 2e \]
\[ EI3: H_2^- + \text{He} \rightarrow p + p + \text{He}^{2+} + 3e \]
4. Experiments planned for the CRP

We plan to determine experimentally the state-resolved charge exchange cross sections in the energy range of \((q/M)(15-300)\) keV/u, where \(q\) is the charge state of the projectile and \(M\) is its atomic mass number. The ion species are chosen to be of interest to the fusion plasma modeling. The processes to be studied are as follows:

1. \(H^+ + \text{He} \ (E_p = 15 - 300\) keV/u)
2. \(\text{He}^{q+} + \text{He} \ (q=1, 2; E_p = 5.0 - 150\) keV/u)
3. \(C^{q+} + \text{He}/\text{H}_2 \ (q=2, 3, 4, 5; E_p = 2 - 125\) keV/u)
4. \(\text{Ar}^{q+} + \text{H}_2 \ (q=2, 3, 4, 5, 6; E_p = 0.7 - 45\) keV/u)
Additionally, we carried out the experiment of neutral H colliding with He at impact energies of 50 keV and 100 keV.

\[ H + He \rightarrow \begin{cases} H^+ + He^+ + 2e \\ H^+ + He^{2+} + 3e \\ H^- + He^+ \\ H^- + He^{2+} + e \end{cases} \]

Interested? What to be expected?
The team

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Thank you for your attention

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