Energetic negative ion and neutral atom beams from intense laser-plasma interaction

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GIST Ultrashort Quantum Beam Facility

- PW Ti:Sapphire Laser
  - Beam line I: 30 fs, 1.0 PW @ 0.1 Hz
  - Beam line II: 20 fs, 4 PW @ 0.1 Hz
- 100-TW Laser: 30 fs, E = 3 J @ 10 Hz
exploration of Relativistic Laser-Matter Interactions

Atto/Zeptosecond Science

Relativistic Laser-Plasma

Lab. Astrophysics

Super-intense Laser

High Energy Protons

Laser Nuclear Physics

Relativistic Electrons

x-rays, γ-rays

New Plasma Regimes - highly relativistic plasma

Novel Applications
This work highlights another important aspect of ion acceleration study:

namely the capability of generation **high energy**

**Negative ion and Neutral atom beams**

Why the negative ions are interesting?

there is a strong fundamental interest in negative ions

- in screening of nucleus the inter–electronic interactions become relatively more important than the electron–nuclear interactions

- electron correlation plays an important role.

The interplay of these attractive and repulsive interactions allows better understanding of atomic physics.
Why the negative ions are interesting?

- High brightness beams of heavy negative ions are required for
  - high current tandem accelerators
  - for ion beam microscopy and
  - lithography

- Negative ions as an alternative to positive ions for heavy ion fusion drivers in inertial confinement fusion:
  - electron accumulation would be prevented and,
  - if desired, the beams could be photo detached to neutrals.

If sources of positive ions are widely available now, the negative ion source development has lagged behind due to different kind of technological complications.
laser acceleration of ions

Absolute calibrated MCP detector is capable for single particle detection

Ion spectra (Thomson parabola)

10 nm C, 10 J
I ~ 5 × 10^{20} \, \text{W/cm}^2

laser

I > 10^{18} \, \text{W/cm}^2
negative ion acceleration in water spray

$I \sim 5 \times 10^{19} \text{ W/cm}^2$, contrast $< 10^{-8}$ at 10 ps prior the peak

- $H^- \sim 150 \text{ keV}$
- $d_{\text{droplet}} \sim 150 - 180 \text{ nm}$
- Density $10^{18} - 10^{19} \text{ cm}^{-3}$

ethanol spray
- Electric deflection
- $O^{1+}, C^{1+}, O^{2+}, C^{2+}$
- $C^{1-}, O^{1-}$

water spray
- Electric deflection
- $O^-$, $O^+$
negative ion formation in charge-exchange

- positive ions are accelerated
- propagation through the spray is collisional
  
  \[ \text{mean free path for oxygen: } L \sim 50 \, \mu m, \text{ for protons: } L \geq d_{\text{spray}} \]

- charge-exchange in a spray can explain the formation of negative ions:

  \[ O^{n+} \leftrightarrow O^{(n-1)+} \]

  \textit{electron capture and loss}

These are resonant processes:
probability is max. if fast ion \( v_{\text{ion}} \sim v_{\text{bound el.}} \)

\[ (1\text{MeV} \, O^{1+} = 3.4 \times 10^6 \text{ m/s}) \]

\[ (\, \downarrow \rightarrow O^- \, ) \quad \sigma_{0-1} \sim 1 \times 10^{-16} \text{ cm}^2 \text{ (for 0.1–1 MeV)} , \]

- spray density distribution is modified by the laser
Artist's conception of electron capture by proton

- the angular spread is very narrow, of the order of 1°
- the interaction proceeds almost elastically, without energy exchange

The ion that captures or loses an electron propagates essentially in the same direction and with the same energy as before the collision.
to use the spray as a secondary target:

ions accelerated from the foil are propagating through the spray
spray as secondary target

\[ A^+ \rightarrow A^0 \rightarrow A^- \rightarrow A^+ \]

ions from Ti target

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chase for neutrals

\[ A^+ \rightarrow A^0 \rightarrow A^- \rightarrow A^+ \]

ions through \( \text{H}_2\text{O} \) spray
chase for neutrals

\[ A^+ \to A^0 \to A^- \to A^+ \]

Neutral particles beam

“zero” point on CR39 (1mm pinhole)

TOF of neutrals: H and O

Hydrogen pits

Oxygen pits
chase for neutrals
chase for neutrals
chase for neutrals
chase for neutrals

\[ C^-_{\text{max}} \sim 1 \text{ MeV} \]
\[ H^-_{\text{max}} \sim 300 \text{ keV} \]
- the brightness of negative ion source is extremely high:

\[ B > 10^8 \text{ A} \cdot \text{cm}^{-2} \text{sr}^{-1} \]

(mainly due to the ultrashort duration of the emission)
open problems

- what is the role of droplet in the processes responsible for negative ion creation

- H\(^-\) needs additional detailed investigations on:
  - spatial distribution
  - energy dependence on propagation length

- create other negative heavy ion species
  - to use other liquids