Cold Titanium - Helium Collisions
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Abstract

Fine-structure changing collisions (J-changing collisions) have long been of experimental and theoretical interest due to their role in the cooling of diffuse interstellar gas and planetary atmospheres. Typical rate coefficients for fine-structure relaxation for atoms such as oxygen, carbon, silicon, and aluminum with noble gases or atomic hydrogen range from $10^{-12}$ to $10^{-10}$ cm$^3$ s$^{-1}$. We have experimentally measured inelastic collisions in the 3d$^2$P$^0_{3/2}$ electronic ground state of atomic titanium, which has fine-structure levels J=2, 3, and 4. We produce atomic titanium by laser ablation and cool it with a cryogenic helium buffer gas. The cold atoms diffuse to the cell walls where they adsorb; we observe titanium lifetimes up to a few seconds. We first prepare the atomic internal state by optical pumping, and then watch the atoms return to thermal equilibrium by inelastic collisions. From the rate of return and the helium density, we determine collisional cross-sections.

The Ti fine-structure-changing rate coefficient is significantly smaller than for collisions of non-submerged shell atoms C, Si, and Al. We use laser ablation to introduce titanium atoms and buffer-gas cooling to cool atoms. Vices: It is not as cold as laser cooling. Virtue: It is general to be applied in all species.

Inelastic collisions in atoms with fine structure

- Typical rate coefficients for fine-structure-changing collisions in cold noble gases and atomic hydrogen:
  
<table>
<thead>
<tr>
<th>Temperature [K]</th>
<th>Rate coefficient [cm$^3$ s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>$1.0 	imes 10^{-10}$</td>
</tr>
<tr>
<td>10.0</td>
<td>$2.0 	imes 10^{-10}$</td>
</tr>
<tr>
<td>15.0</td>
<td>$3.0 	imes 10^{-10}$</td>
</tr>
<tr>
<td>20.0</td>
<td>$4.0 	imes 10^{-10}$</td>
</tr>
</tbody>
</table>

- Theoretical calculation:
  Predicted the inelastic rate coefficient $k_{J2-J3} = 10^{-10}$ cm$^3$ s$^{-1}$.

- Experimental difficulty:
  - Carbon transition probe required ultraviolet light.
  - We start with titanium-helium collisions as a test of theory.

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- The Ti fine-structure-changing rate coefficient is significantly smaller than for collisions of non-submerged shell atoms C, Si, and Al.

Typical rate coefficients for fine-structure relaxation for atoms in collisions with noble gases or atomic hydrogen:

- H: $10^{-12}$ cm$^3$ s$^{-1}$
- C: $10^{-11}$ cm$^3$ s$^{-1}$
- N: $10^{-10}$ cm$^3$ s$^{-1}$
- O: $10^{-10}$ cm$^3$ s$^{-1}$
- Al: $10^{-10}$ cm$^3$ s$^{-1}$

Spin-relaxation Ti-He collisions

- We use optical pumping to prepare polarized atoms and measure depolarization due to Ti-He inelastic collisions.
- From the linear dependence between the depolarization rate and helium density, we have measured the spin-relaxation rate coefficient $A_{J2-J3} = 2 \times 10^{-10}$ cm$^{-1}$.

Spin-dec coherences Ti-He collisions

- We use electromagnetically-induced transparency (EIT) to measure spin-decay Ti-He collisions.
- The spin-decay characteristic time is of the order 10$^{-10}$ cm$^{-1}$.

Future interests

- Buffer-gas system can generate atoms with large optical density which is important to the realization of quantum storage.
- Extrapolating from our current measurements, we expect to be able to measure inelastic collisions ranging from 10$^{-10}$ to 10$^{-17}$ cm$^{-1}$.
- Upgrade our apparatus to operate at lower temperatures (0.8 K) and higher fields (few Tesla).