Development of Slow Positron Beam lines and Applications

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Outline of the Talk

- Positron
- Slow Positron beam
- Slow positron beam facilities over the world
- Applications in different branches of Science
- Fundamental Research with Positron beams
- Production of high intense positron beam
- Detection of Positronium Bose-Einstein Condensation.
1. Positron

- Predicted by P. A. M. Dirac and experimentally found by Carl Anderson in a historic cloud chamber experiment in 1932.
- $\beta^+$-decay process in radio isotope:
  $$p \rightarrow n + e^+ + \nu$$

Half-life 2.6 Y, good for slow $e^+$ beam.
Fission reaction in Atomic Reactor:

\[ _0^1n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\, n + E_\gamma (177\, MeV) \]

Fusion Reaction in the Stars/reactor:

\[ ^1_1H + ^1_1H \rightarrow ^2_1H + e^+ + \nu + 0.42\, MeV \]

\[ ^2_1H + ^1_1H \rightarrow ^3_2He + \gamma + 5.49\, MeV \]

\[ ^3_2He + ^3_2He \rightarrow ^4_2He + 2^1_1H + 12.86\, MeV \]
2. Accelerator based $e^+$ Source

The Stanford University superconducting linear accelerator, housed on campus below the Hansen Labs until 2007. This facility is separate from SLAC.

Compact Cyclotron based $e^+$ Source @ SHI, Japan

KEK in Japan, Photon Factory $e^+$, $e^-$ beam lines

Curtsey: Google, Wikipedia
3. Radioisotope based Positron beam

- Cost effective
- Independent
- User friendly
- **Example: Tokyo Metropolitan University Polarized Positron Source**

- **Positron Source:** $^{22}\text{Na}$
- **Source Strength:** 150 mCi
- **Half-life:** 2.6 years
- **UHV system:** $10^{-9}$ torr
- **Moderator:** Single crystal W
- **Moderator efficiency:** $10^{-4}$
- **Positron pulsing and guiding System**
- **Time-of-Flight (TOF) Spectrometer**
- **Detectors:** NaI(Tl) scintillators
- **Target Chamber:** Ps+Laser scattering
- **Cr:LiSAF laser:** Wavelength-256 nm
No. of Detectors: 12
NaI(Tl): from BICRON
PMT: from HAMAMATSU
Pb Thickness: 4.6 cm
W Thickness: 2.5 cm

Slit gap: 2 mm
Positron beam intensity: $10^6$ e$^+$/s
Position resolution: 1.5 mm
Target sample: Single crystal W
### Slow positron beam facilities over the world (15 - 20 years back)

<table>
<thead>
<tr>
<th>Names &amp; Places</th>
<th>Contact persons</th>
<th>Positron Sources</th>
<th>Beam Energy</th>
<th>Beam I: e⁺/sec</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. EPOS, Dresden</td>
<td>Prof. Krause-Rehberg</td>
<td>40 MeV e⁻ Linac</td>
<td>0.2 – 100 keV</td>
<td>Moderated: 10⁹ and Bunched: 10⁶</td>
<td>Defects of materials, AMOC, CDBS, PACS etc.</td>
</tr>
<tr>
<td>2. LLNL, Livermore</td>
<td>Dr. W. Stoeffl</td>
<td>Pelletron, 3 MeV</td>
<td>1 – 50 keV</td>
<td>300, 20 MHz</td>
<td>Defects of materials, CDBS, PAS, etc.</td>
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<tr>
<td>3. KEK-B Factory, Tsukuba</td>
<td>Dr. T. Kurihara</td>
<td>2.5 GeV e⁻ Linac</td>
<td>10 – 100 keV</td>
<td>10⁸</td>
<td>2D-ACAR, TOF, Spin polarization</td>
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<tr>
<td>5. MRR-FRM-II, Munich</td>
<td>Prof. G. Kogel</td>
<td>Reactor based</td>
<td>100 eV</td>
<td>10⁷ – 10⁹</td>
<td>Positron microprobe, defect concentration</td>
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<tr>
<td>6. TOPS, Tokyo</td>
<td>Dr. T. Kumita, *Dr. N.N. Mondal</td>
<td>²²Na (150 mCi)</td>
<td>1 eV – 250 keV</td>
<td>10⁶</td>
<td>BEC, Laser cooling, TOF, defects, polarization</td>
</tr>
<tr>
<td>7. GU, Tokyo</td>
<td>Dr. I. Kanazawa</td>
<td>²²Na (3 mCi)</td>
<td>30 eV</td>
<td>10³</td>
<td>Vacancy-type defects</td>
</tr>
<tr>
<td>8. Bonn University</td>
<td>Dr. K. Maier</td>
<td>²²Na (10 mCi)</td>
<td>150 eV</td>
<td>10³</td>
<td>Surface and dislocation of materials</td>
</tr>
<tr>
<td>9. TUS, Tokyo</td>
<td>Dr. Y. Nagashima</td>
<td>²²Na (740 MBq)</td>
<td>100 eV</td>
<td>10⁵</td>
<td>Ps-, moderator, defects of materials.</td>
</tr>
<tr>
<td>10. SHI, Tokyo</td>
<td>Dr. M. Hirose</td>
<td>Compact Cyclotron</td>
<td>10 – 150 keV</td>
<td>10⁶</td>
<td>Commercial purpose, surface, interface, polarization.</td>
</tr>
</tbody>
</table>
4. Applications in different branches of Science

Defect studies of materials

Ref. : Prof. R. Krause-Rehberg

Alkali borosilicate glass

Positron source

Thermalize e^+

511 keV

Alkali borosilicate glass

VYCOR-Process

T: 530-710 °C

Extraction: HCl/NaOH

CPG (controlled pore glass)

CPG: It will be a good candidate for PsBEC
5. Fundamental Research with Positron beams

- The Ps work function: \( \varphi_{Ps} = -\mu_{Ps} + E_B - \frac{1}{2} R_\infty \)
  where \( \frac{1}{2} R_\infty = 6.8 \text{ eV} \). Ps formation potential:
    \( \varepsilon_{Ps} = \varphi_- + \varphi_+ - \frac{1}{2} R_\infty \),
  Where, \(-\mu_{Ps} = \varphi_- + \varphi_+\)
- \( E_B \): the binding energy of Ps
- Ps chemical potential: \( \mu_{Ps} \)

Measurement of Thermal and Work function Positronium @ TMU [App. Surf. Sci.]

Distribution of Ps (MC simulation)

- Thermal Ps
- Critical points for the particular measurement

Work functions:
- $E = 1.0 \text{ eV}$
- $E = 2.0 \text{ eV}$
- $E = 4.0 \text{ eV}$

$T = 300 \text{ K}$

Time-of-flight distribution of Ps

Mean Time-of-Flight vs. Target position

Simulation energy
- $E_{\text{sim}} = (0.70 \pm 0.30) \text{ eV}$
MC simulation for 1 eV and 3 eV Ps and their measurements

6. Production of high intense positron beam

- High intensity polarized positron source
- (a) Polarized $e^+$ source for JLC project

$CO_2$ Laser ($\lambda=10.6\ \mu m$, $E=0.117\ eV$

- $e^-$ beam
- 5.8 GeV

- $\gamma$-ray, $E_{max}=60\ MeV$

Thin target, $W$

- $e^-$ pair creation
- $e^+\ energy\ (MeV)$

Principle of polarized $e^+$ source:

- 6.67 msec ($\nu=150\ Hz$)
**Configuration of the polarized e+ Source for the JLC project**

- **3 GeV Linac**
- **2.8 GeV Linac**
- **3 GeV Linac**
- **1.98 GeV Pre-DR**
- **1.98 GeV DR**
- **BC**

**Requirements of the JLC beam**

- **95 bunches = a train**
- **1.1 \times 10^{11} e^+/bunch**

**Expected e+ intensity:** \(10^{13}/\text{train}; \text{best for the PsBEC}\)
7. Achievement of PsBEC

De Broglie wave length, $\lambda_D = \frac{h}{\sqrt{2\pi mKT}}$

Phase space density, $\rho = n\lambda_D^3$, Condition for occurring BEC, $\rho >> 2.617$
7. Detection of PsBEC

Laser Cooling @TMU

Prof. A.P. Mills
Riverside, USA, in 2010

Monte Carlo Simulation

Hydrogen

Plastronium

Lifetime distribution of Ps

TMU, Japan, 2002
Position-sensitive Gamma-ray detectors system is used to visualize the laser cooled ortho-Ps. Spatial resolution is 2 mm. It is an ideal system for imaging PsBEC.

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Thanks for your attention