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POSITRON SOURCES FOR ATOMIC PHYSICS EXPERIMENTS

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Abstract. We have demonstrated the possibility to produce strong and pointlike positron sources by collection of the ion beams from an on-line mass separator. At ISOLDE β^+ emission rates of 3.7×10^9 Bq were obtained from ^{81}Rb sources collected on an area $\leq 4.5 \text{ mm}^2$. When the activity is deposited on a transmission moderator, low energy positron beams with a high brightness can be produced. With a $6 \mu\text{m}$ thick polycrystalline tungsten transmission moderator a brightness per energy of $> 800 \text{ s}^{-1} \text{ mm}^{-2} \text{ rad}^{-2} \text{ eV}^{-1}$ was achieved. This value still can be considerably increased by optimization of the ion beam parameters and by means of a more efficient moderator.

For atomic physics experiments with intense low energy (eV) positron beams, positrons from radioactive decay or pair production are moderated in solids. The quality of the slow positron beam depends on the properties of source and moderator. The beam is characterized by current, brightness or brightness per energy. Source dimension and source/moderator geometry define the phase space of the low energy positron beam. Only those

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positrons that thermalise within about $1000 \text{ \AA}$ from the surface have a chance to be reemitted from the moderator instead of annihilating inside (Lynn and McKee 1979). With increasing end-point energy of the β^+ spectrum the stopping profile broadens and the number of positrons which thermalise per unit thickness decreases.

We investigated the possibility of using ISOLDE, the Isotope Separator On-Line at CERN (Hansen et al 1981) to produce suitable β^+ sources. In a first approach we studied ^{130}Cs and ^{81}Rb . These nuclei were chosen because their beams can be produced with intensities of above $10^{10} \text{ particles s}^{-1}$ (Ravn 1984). Their half lives of 29 min and 4.7 h and β^+ decay branches of 50% and 27%, respectively, allow sufficiently strong sources to be produced. The end-point energies of 2 and 1.1 MeV are not much higher than those of the commonly used ^{22}Na , ^{58}Co and ^{64}Cu sources (0.54, 0.47 and 0.65 MeV).

The probes were collected on 4 mm diameter 6 to 25 μm thick polycrystalline tungsten foils. The foils had been annealed at $\approx 2000^\circ\text{C}$ as recommended for efficient moderators (Dale et al 1980). Figure 1 shows the apparatus used to study the properties of the positron sources. The sources were mounted so that they faced the low energy positron beam transport system. It consists of four tube lenses which transport the beam from the moderator to a deflector. With an appropriate deflection voltage the beam is directed towards a channel electron multiplier (CEM). For some of the measurements the 10 mm diameter cone of the CEM was shielded with a $2 \times 10 \text{ mm}^2$ slit aperture. A separate moderator could be inserted between the collector foil (source) and the lenses. Relative measurements of the source activity were performed with a surface barrier detector and a dosimeter at a fixed position outside the apparatus.

Before depositions of the radioactive ions, we used a stable ion beam to check the beam transport and focussing. Oval beam spots of $1.5 \times 3 \text{ mm}^2$

were achieved without difficulty. The beam current in front of our collector was measured before and after each collection. It varied between 2 and 6 nA. About 80% of the ions passed a 4 mm diameter aperture and were collected on the foil.

Thirteen collections, six of ^{130}Cs and seven of ^{81}Rb , were made. The activity was calculated from the beam current and the collection time. We used the readings of the dosimeter in order to compare different sources of the same nuclide. From this comparison we estimated the uncertainty of the activity to be $\pm 20\%$. These calculated activities do not account for sputtering losses and fluctuations of the ion beam intensity. For one run the activity was checked with an intensity calibrated Ge-Li γ ray spectrometer. It was found to be 15% lower than calculated. The collected activities ranged from 2×10^8 to 1.4×10^{10} Bq. Positron emission rates of up to 3.7×10^9 Bq were obtained on a spot of less than 4.5 mm^2 , a source strength superior to that of the ^{58}Co and ^{22}Na sources presently in use. This source produced an e^+ beam of 30.000 s^{-1} .

The basic quantity studied was the number of low energy positrons per Bq of emitted β^+ ("normalised yield"). Table 1 shows the normalised yields from the ^{130}Cs and ^{81}Rb sources with different source-moderator configurations. These are average values from runs with different source activities and similarly but individually prepared foils. The errors arise from the uncertainty about the activity, they do not account for a possible systematic overestimate of the source activity. For comparison the result from a 3 mm diameter ^{22}Na source is also given.

The comparison between the different sources and configurations shows:

- The yield from ^{130}Cs sources is low. We attribute this to the high β^+ end-point energy. The highest value is achieved, when the source is implanted on the side of the moderator. As the source faces the beam optics directly, the signal-to-noise ratio is poor.

- ^{81}Rb sources are nearly as good as ^{22}Na sources when implanted on the backside of the moderator.
- When a separate moderator is used, the effective size of the source increases. In this configuration the ^{81}Rb sources are inferior to ^{22}Na .
- Due to insufficient shielding of the source the signal-to-noise ratio was lower for ISOLDE sources than for ^{22}Na .

Comparing our positron beam with other beams we refer to the brightness per energy, R_V (Canter et al 1986). This R_V ($\text{s}^{-1}\text{mm}^{-2}\text{rad}^{-2}\text{eV}^{-1}$) is a function of the β^+ emission rate (A_{β^+}), the moderation efficiency (ϵ), and the diameter (d), divergence (θ) and energy (E) of the slow positron beam:

$$R_V = A_{\beta^+} \epsilon (\pi (\theta d)^2 E)^{-1}$$

For a conservative estimate we insert $A_{\beta^+} \epsilon = 30000 \text{ s}^{-1}$, $d^2 = 4.5 \text{ mm}^2$ and $\theta^2 E = 2.5 \text{ eV rad}^2$ at the source. This yields $R_V \approx 8 \times 10^2$, which is about four times the value that can be achieved with a $1.9 \times 10^9 \text{ Bq } ^{22}\text{Na}$ source and an annealed polycrystalline W vane moderator (Canter et al 1986) and about a factor of 10 less than Frieze et al (1985) obtained from a $1.9 \times 10^{10} \text{ Bq } ^{58}\text{Co}$ source and a W(111) moderator under UHV conditions (10^{-8} Pa).

For the comparison with LINAC-based beams the brightness is not a good parameter because these beams are used in magnetic guiding fields. With a field of up to 500 G, Howell et al (1985) observe about $6 \times 10^7 \text{ e}^+ \text{ s}^{-1} \text{ mm}^{-2}$. With the slit aperture in front of the CEM we obtained up to $2.3 \times 10^4 \text{ e}^+ \text{ s}^{-1} \text{ mm}^{-2}$ in a field free region.

By reducing the beam size and extending the collection time it should be possible to increase the activity per mm^2 by more than a factor of five. Furthermore the ISOLDE ^{81}Rb intensity can be increased by a factor of four if the thicker Y-La molten alloy target is used, and a factor of two if the

target length is doubled. Thus sources with β^+ emission rates of above 2×10^{10} Bq with $8 \times 10^9 - 1.6 \times 10^{10}$ Bq mm⁻² can be achieved. For applications, where pointlike sources are required, the latter quantity is of interest. The value of 1.6×10^{10} Bq mm⁻² is as high as that obtained with the ⁶⁴Cu sources produced in the high flux reactor at Brookhaven (Lynn and Frieze 1984, Lynn et al 1985). The total β^+ emission rate would exceed that of most radioactive sources with the exception of the ⁶⁴Cu sources at Brookhaven.

With ⁸¹Rb implanted on the backside of annealed 6 μ m polycrystalline W foils we observed moderation efficiencies around 10^{-5} in transmission. Thinner single crystal foils should increase this value substantially. This method opens the possibility to produce intense positron beams without the use of a magnetic guiding field or the addition of brightness enhancement by multiple moderation.

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Table 1: Normalised yields [e^+ (s Bq $_{\beta^+}$) $^{-1}$], uncertainty: $\pm 20\%$,
 moderator: 6 μ m W foil, $E(e^+) \approx 150$ eV, in brackets: signal-to-noise ratio.

source	separate trans-	source implanted on foil		aperture in
	mission moderator	backside	front	front of CEM
^{130}Cs	0.68×10^{-5} (11)	0.53×10^{-5} (8)	0.92×10^{-5} (4)	no
^{81}Rb	0.73×10^{-5} (20)	1.27×10^{-5} (17)	- -	yes
for comparison:				
^{22}Na	1.51×10^{-5} (50)	-	-	yes

Figure 1 Schematic Diagram of the Apparatus
for the Study of Positron Sources