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MEASUREMENT OF THE LIFETIME OF PB^{52+}, PB^{53+} AND PB^{54+} BEAMS AT 4.2 MEV PER NUCLEON SUBJECT TO ELECTRON COOLING

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ABSTRACT

By measuring the lifetime of stored beams, the recombination of the ions with cooling electrons was investigated. Rates found are larger than expected for radiative electron capture and significantly higher for Pb^{53+} than for Pb^{54+} and Pb^{52+}. These results are important for the design of the lead ion injection system for the Large Hadron Collider and for recombination theories.

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By measuring the lifetime of stored beams, the recombination of the ions with cooling electrons was investigated. Rates found are larger than expected for radiative electron capture and significantly higher for Pb^{53+} than for Pb^{54+} and Pb^{52+}. These results are important for the design of the lead ion injection system for the Large Hadron Collider and for recombination theories.

When electron cooling [1] is applied to heavy ions, recombination - i.e. capture of cooling electrons into atomic levels resulting in losses of ions from the storage ring due to the change of their charge [2] - can become important. We have determined the recombination rates of partially stripped lead ions by storing and cooling beams from a recently commissioned linac [3] in the Low Energy Antiproton Ring (LEAR) (Table 1) to test its feasibility as a Low Energy Accumulator Ring for ions [4]. Rate coefficients were derived from the beam lifetime as a function of the electron current.

Table 1 - Parameters of the experiment

	E	[MeV/u]	4.2
ions and electrons)	$\beta = v/c$		0.094
circumference	$2\pi R$	[m]	78.54
vacuum pressure	P	[torr]	$\approx 2 \times 10^{-11}$ (85% H_2 and He)
gth/circumference	η		0.02
m radius	b	[cm]	2.5
tron current	I	[A]	- 0.2 (0.4)
cooling section	$n_e = I/e\pi b^2\beta c$	[cm^{-3}]	$1.1 \times 10^8 I$
lensity per turn	$n_{eff} = \eta n_e$	[cm^{-3}]	$2.2 \times 10^6 I$
it. B-field in cooler	B	[T]	0.06

The linac accelerates Pb^{27+} * which is further stripped by a foil after the exit. A "dogleg" arrangement of bending magnets and a "momentum defining slit" are used to select a single charge state. The transfer line and LEAR have also to be readjusted to inject and store different states. About equal intensities of Pb^{53+} and Pb^{54+} and a slightly (~20%) lower current of Pb^{52+} were found, in fair agreement with the results of Ref. [5].

The intensity of the circulating beam in LEAR (about 2 μA corresponding to $\approx 5 \times 10^5$ ions at injection) was monitored via the Schottky noise [6], observed with current pick-up electrodes. A typical scan, giving the evolution of the beam current, is shown in Fig. 1. The $1/e$ lifetime (τ) is obtained from an exponential fit. Decay rates ($1/\tau$) as function of the electron current are drawn in Fig. 2. From the slope of the curves, rate coefficients $\alpha = \langle \sigma v_{rel} \rangle = (1/\tau)/n_{eff}$ (i.e. the decay rates normalised to the effective electron density h_{eff}, Table 1) are derived. They are collected in Table 2.

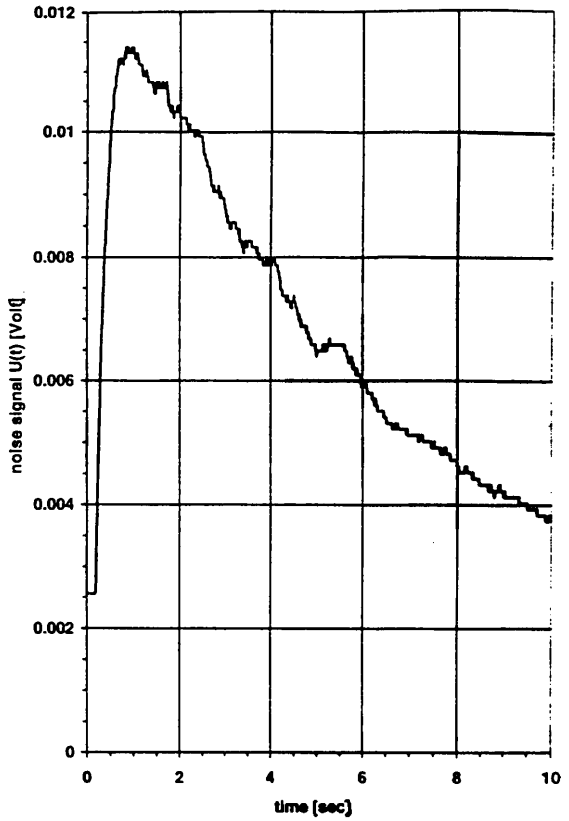

Fig. 1. Beam Schottky noise at the 100th harmonic ($f \approx 36$ MHz) of the revolution frequency, as displayed by a spectrum analyzer used in the receiver mode to record the time evolution of the signal induced on a beam current pick-up electrode. The resolution bandwidth (30 kHz) of the analyzer is chosen to cover the full frequency spread given by the momentum width of the cooled beam i.e. the total noise in the band is recorded. The scan is triggered to start 0.2 s prior to injection and the evolution of the signal is shown during about 10 s. The electronic noise (N) of the acquisition system adds in square to the Schottky signal (S). Thus the voltage recorded by the analyzer is $U(t) = \sqrt{S^2(t) + N^2}$. The decay rate is deduced from an exponential fit of the Schottky power $S^2(t)$, which is proportional to the ion beam current. In this example the measurement for a Pb^{53+} beam at 120 mA electron cooling current is displayed.

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* We use Pb^{Q+} to denote lead ions (atomic charge number $Z = 82$) of charge state Q, i.e. with Z-Q remaining electrons.

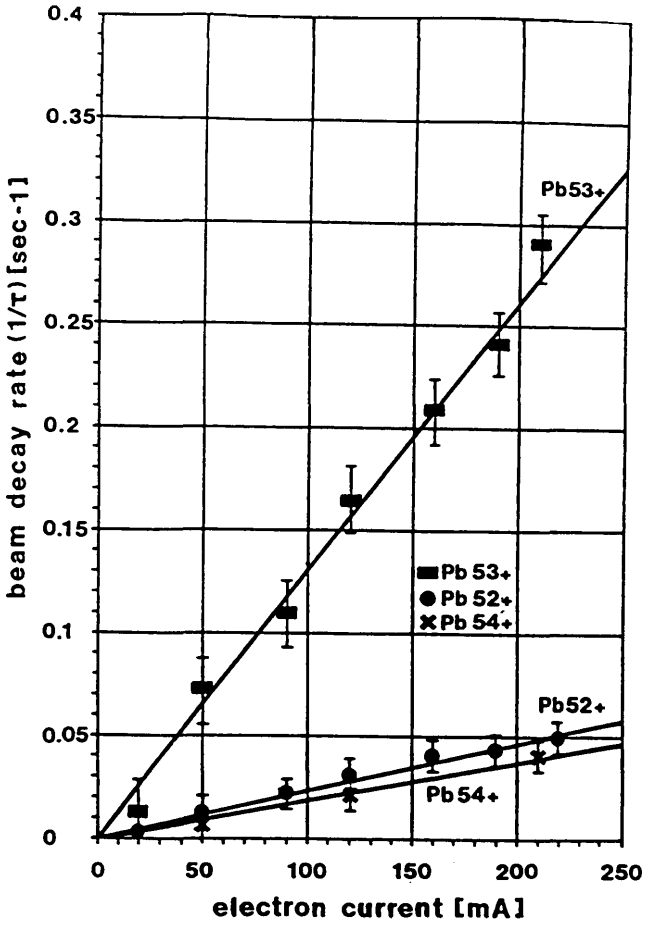

Fig. 2. Beam decay rates $1/\tau$ as a function of the electron cooling current. A constant "background" of $1/\tau \approx$ 1/20 s, corresponding to charge exchange with the residual gas, has been subtracted from the data. The rate coefficients given in Table 2 are deduced from the slope of the curves.

Table 2 - Rate coefficients. Present results and values reported in the literature for partially stripped uranium and gold ions. Included for comparison are the rates calculated for radiative capture from Bell's formula [7] taking an electron temperature $T_{e\perp} = 0.2$ eV and an effective ion charge $Q_{eff} = (Q+Z)/2$ [8].

Ion	Measured rate coefficient α [10^{-8} cm^3s^{-1}]	Reference	Calculated from Bell's formula for radiative capture α [10^{-8} cm^3s^{-1}]
Pb^{52+}	11	present results (June 95)	2.25
Pb^{53+}	60	"	2.29
Pb^{54+}	9	"	2.32
U^{28+}	10	[8, 9, 11]	1.8
Au^{25+}	10	[9]	1.3

Two interesting facts emerge from this table: The rate coefficients are larger than calculated for radiative electron capture (using e.g. Bells' formula [7]) and the contrast between Pb^{53+} and the neighbouring charge states is very striking. The difference between Pb^{52+} and Pb^{54+} is not very significant given the error (±15%) of the measurement.

"Anomalously" high recombination rates have recently been found [8-11], with electron cooling or in a single pass technique with a co-moving "electron target", for a few special ions (Table 2). But this is the first time that neighbouring charge states of the same element were investigated with electron cooling showing a marked difference in the capture cross section.

Attempts reported in the literature to explain the "anomalous" recombination by dielectronic capture [2, 8-11] are so far only partially successful. Thus after a careful examination of the possible resonances Ref. [11] concludes that the "... recombination rate of U^{28+} ions... still remains a mystery." We have no explanation to offer for the higher rate of Pb^{53+} except the observation that Pb^{54+} and Pb^{52+} can perhaps arrange their remaining 28 and 30 electrons in closed shell structures (e.g. K, L, M shells for Pb^{54+}, K, L, M plus N, s-subshell for Pb^{52+}) whereas Pb^{53+} with its odd number of electrons does not have this possibility.

The motivation for the present study is the need for dense bunches of lead ions for the future Large Hadron Collider (LHC) [12]. Our results indicate that Pb^{54+} (or Pb^{52+}) is well suited for accumulation and electron cooling during a few seconds at 4.2 MeV/u, as proposed for the lead injection system of the LHC [4], whereas Pb^{53+}, originally foreseen, has an uncomfortably short lifetime in the presence of strong electron cooling.

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REFERENCES

[1] H. Poth, Physics Reports 196, (1990) 135.

[2] H. Beyer, D. Liesen and O. Guzman, Part. Acc. 24 (1989) 163,

A. Müller, Electron-ion recombination phenomena, in: Proc. Workshop on Recombination of Atomic Ions (Newcastle, 1991), eds. W. Graham et al. (Plenum Press, New York, 1992) p. 155.

[3] D.J. Warner, Heavy Ion Linac for the CERN lead ion facility, in: Proc. 1994 Linac Conf. (Tsukuba), Vol. 2, eds. T. Takata, W. Yamazaki and K. Nakahara, p. 654.

H. Haseroth, The CERN heavy ion accelerating facility, in: 1995 Part. Acc. Conf. (Dallas), to be published.

[4] P. Lefèvre and D. Möhl, Lead ion accumulation scheme for LHC, in: Proc. Workshop on Beam Cooling and Related Topics (Montreux, 1993), ed. J. Bosser (Report CERN 94-03, 1994) p. 411, see also Report CERN-PS 93-62/LHC Note 259 (1993), unpublished, and

S. Baird et al., CERN PS/AR/Note 95-06 (MD) (1995), unpublished.

[5] E. Baron, M. Bajard and C. Ricaud, Nucl. Instr. Methods A238 (1993) 117.

[6] D. Boussard, Schottky noise and beam transfer function diagnostics, in: Proc. CERN Accel. School (Oxford, 1985), Vol. 2, ed. S. Turner (Report CERN 87-03, 1987) p. 416.

[7] K. Kilian and D. Möhl, Lecture Notes in Phys. 178 (1983) 163.

[8] A. Müller et al., Physica Scripta T37 (1991) 62.

[9] A. Müller et al., Radiative and dielectronic recombination, in: Proc. Symposium on Cooler Rings (Tokyo, 1990), eds. T. Katayama and A. Noda (World Scientific, London, 1991) p. 248.

[10] A. Wolf et al., Electron-ion recombination in merged beams, in: Proc. 13th Int. Conf. on Atom. Phys. (Munich, 1992), eds. H. Walther et al. (AIP Conf. Proc. Vol. 275, Am. Inst. Phys., New York, 1993) p. 228.

[11] O. Uwira et al., in: GSI Scientific Report 94, ed. U. Grundiger, (Report GSI 94-1, March 1995, p. 137).

[12] The LHC Study Group, eds. Y. Baconnier et al., Report CERN/AC/93-03 (LHC) (1993).

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A : Susan
TO :

Veuillez/Please

- ◯ Donner suite/Take action
- ⊗ Noter/Note
- ◯ Approuver/Approve
- ◯ Payer/Pay
- ◯ Commenter/Comment
- ◯ Classer/File
- ◯ Signer/Sign
- ◯ Retourner/Return

Bien qu'il ne sort pas encore publié dans Physics Letters B, Dieter et Stéphan m'ont obligée à sortir ce rapport. Il paraît que tu es très mal informée (disait Dieter), comme sans doute la plupart des secrétaires -

SIS/RD/53

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De : From: Méder	No. Tel.	Date

on jette les os aux chiens, on me
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