Solid neon moderator for positron-trapping experiments

R.G. Greaves and C.M. Surko

Abstract: A solid neon moderator using a two-stage, closed-cycle refrigerator was installed in an experiment to accumulate positrons in a Penning trap. This moderator replaced a single-crystal tungsten film moderator and yielded an approximate 20-fold improvement in the positron-trapping rate. Experience with the new moderator in a relatively poor vacuum environment of $p \sim 1 \times 10^{-7}$ Torr is discussed.

Résumé : Un modérateur de Ne solide, utilisant un réfrigérateur en circuit fermé, a été installé sur notre montage pour capturer des électrons dans une jauge Penning. Ce modérateur améliore par un facteur 20 les performances précédentes qui utilisaient un modérateur fait d'un film de W monocristallin. Nous discutons de l'utilisation de ce modérateur pour des expériences dans un environnement dont le vide est médiocre ($<10^{-7}$ Torr).

[Traduit par la rédaction]

1. Introduction

Since rare-gas solid (RGS) moderators were discovered [1], they have been the subject of a number of experimental studies, using various geometries, gases, and positron sources [2–7]. In general, the highest moderation efficiencies are obtained with neon, although good efficiencies have been obtained recently with krypton [8] using an annealing procedure. One of the main disadvantages of solid neon is that the low temperatures require an expensive three-stage refrigerator, as opposed to the relatively low-cost two-stage refrigerator technology adequate for the other rare gases. However, a recent improvement in two-stage refrigerator technology now makes it possible for these devices to reach 6.5 K routinely. This was accomplished by replacing the lead shot used in the second stage regeneration matrix with Er_3Ni, which has a higher specific heat at cryogenic temperatures [9]. This paper describes a solid neon moderator based on one of these improved two-stage refrigeration units.

2. Description of the moderator

The positron source described here is used in a magnetic beam line that supplies positrons for accumulation and cooling to room temperature in a Penning trap [10, 11]. The stored positrons are used for electron–positron plasma experiments [12] and for positron annihilation studies, such as the measurement of annihilation cross sections [13–15], γ-ray annihilation line widths [16, 17], and positron ionization mass spectrometry [18, 19]. Other uses that have been proposed for positrons in Penning traps, but not yet demonstrated experimentally, include the production of antihydrogen [20], pulsed beams of positronium atoms as a diagnostic of plasma transport in Tokamaks [21], and the cooling of highly charged ions [22].

The positrons are obtained from a ^{22}Na radioactive positron emitter (~65 mCi; (1 Ci = 37 GBg)) supplied by Dupont Pharma. This source is sealed behind a 13 μm tantalum window and emits positrons with energies up to 540 MeV. We had previously used a single crystal tungsten film in a transmission geometry [23, 24], with which we achieved a maximum trapping rate of 4×10^5 positrons s^{-1} from a 150 mCi source. The decision to install the RGS moderator was based on the dramatic improvement in moderation efficiencies that had been reported by other groups.

As shown in Fig. 1, the source is recessed into a parabolic copper cup mounted on an Elkonite rod, which is attached to the second stage of a two-stage closed-cycle refrigerator (APD model DE-204SLB). The Elkonite rod is electrically isolated from ground by a sapphire washer, to allow electrical biasing of the source. Indium gaskets are inserted between all surfaces in contact. The entire assembly is enclosed in a copper heat shield, which is attached to the first stage of the refrigerator. The heat shield extends 6 cm beyond the source to minimize the heat load on the source. The interior surface of this extension is coated with a layer of commercial spray-on colloidal graphite to minimize reflection of incoming infrared radiation towards the source.

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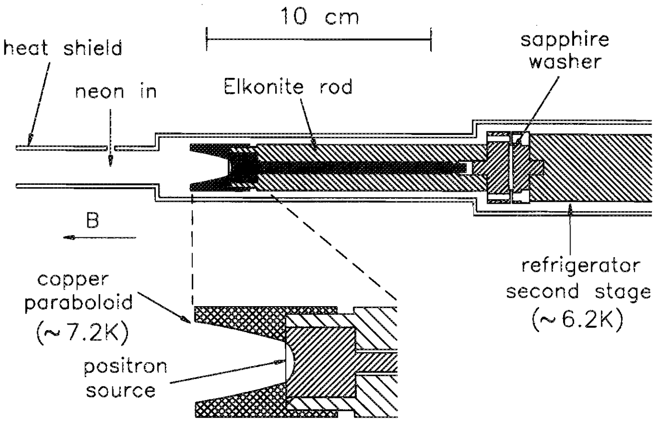
Fig. 1. Schematic diagram of the source and cold-head assembly.



stage of the cold head are monitored by silicon diodes using a Lakeshore temperature controller, which controls the temperature over a wide range by means of heater coils attached to the second stage. The second-stage temperature is typically 6–6.5 K, while the source itself is about 1 K warmer.

The source/cold-head assembly is installed in an all-metal UHV system pumped by an ion pump. The base pressure of the system is $\sim 2 \times 10^{-8}$ Torr (1 Torr = 133.32 Pa) after bakeout at 150°C and rises to about 5×10^{-8} Torr after neon has been frozen onto the source, presumably because of neon subliming from the warmer parts of the source/cold-head assembly.

3. Experimental results

Before a new moderator is grown, the source is slowly heated to 30 K, and the sublimated neon from the previous moderator is pumped out of the system using a turbo pump backed by an oil-free molecular drag pump. During the pump-out phase, the cold-head temperature is regulated so that the neon pressure does not rise above 1×10^{-2} Torr.

The moderators are grown with a slightly elevated source temperature (7.8–8.2 K). Neon is admitted at a pressure of 1–3 $\times\ 10^{-4}$ Torr. This pressure is too high for operation of the ion pump, which is therefore shut off during this neon admission phase. Figure 2 shows the growth of a typical moderator: after neon is admitted at $t = 0$, the number of slow positrons begins to rise and eventually saturates after $t \simeq 3$ h, at which time the neon gas feed is shut off. While neon is being admitted, some of the slow positrons annihilate on the neon filling gas before they strike the target. As soon as the neon gas feed is switched off, this effect disappears, leading to the rapid rise in the slow positron count that can be seen at $t = 3.2$ h. As soon as the neon gas is switched off, the moderator is annealed by raising its temperature to 10 K for a few minutes.

The characteristics of the RGS moderator, the earlier tungsten moderator, and the positrons trap are summarized in Table 1. The trapping rate was measured directly by dumping the trapped positrons onto a collector plate and measuring the charge using an electrometer. The beam strength was measured at installation of the cold-head against a calibrated ^{68}Ge test source as 7.5×10^{6} positron s^{-1}. The trapping rate has improved since installation, partly from improved vacuum conditions in the source region and partly from refined protocols for growing moderators. The value of the beam strength quoted in Table 1 was not measured directly but is based on the present measured trapping rate and the assumption that the trapping efficiency has not changed.

Fig. 2. Growth and decay of a neon moderator. Neon is admitted at $t = 0$ at a pressure of 2×10^{-4} Torr and shut off at $t = 3.2$ h. At $t = 22$ h, nitrogen buffer gas is admitted to the trap, increasing the pressure at the moderator to 1×10^{-7} Torr.

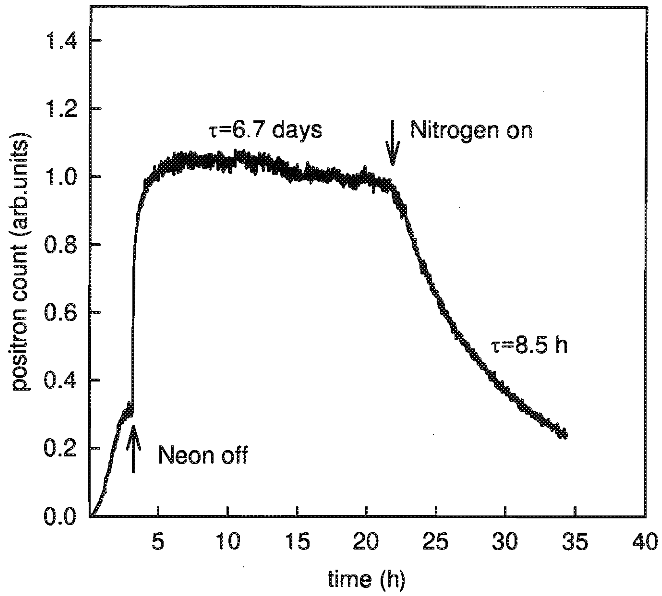
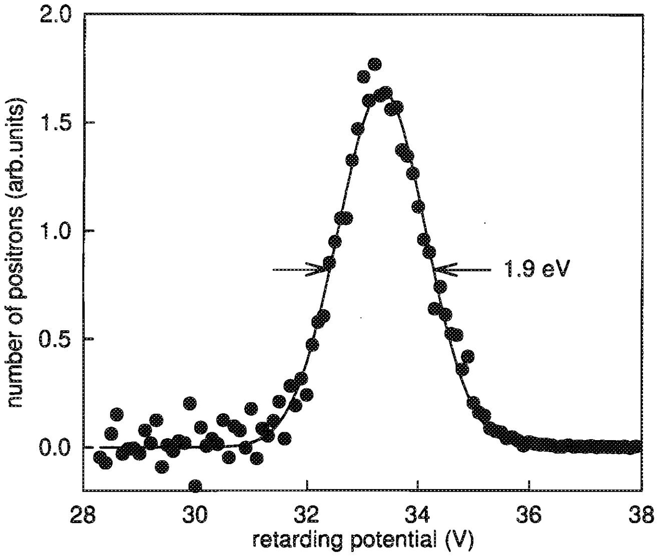


Fig. 3. Energy distribution of moderated positrons, measured in the trapping region of the Penning trap where the magnetic field is 1260 G, compared with a field of 150 G at the moderator.



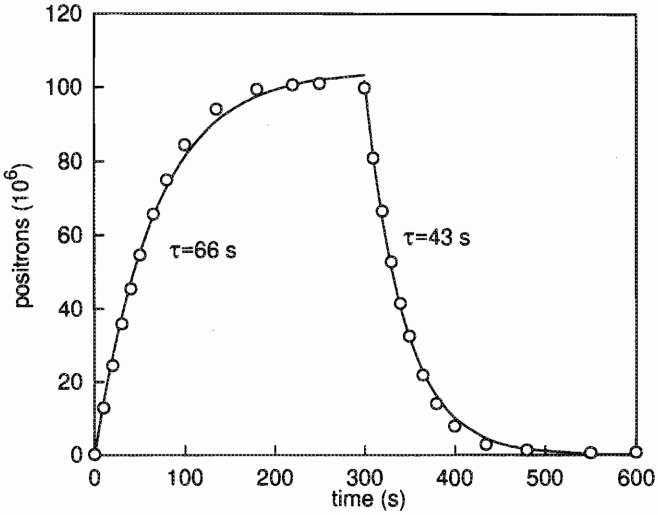
One of the disadvantages of RGS moderators is that the energy spread of the moderated positrons is substantially larger than that of positrons from metal film moderators. Figure 3 shows the energy distribution of positrons obtained from our solid neon moderator. For these measurements, the positrons were guided by the magnetic field from the source into the trap, where the energy spread was measured by apply-

Table 1. Parameters of the neon and tungsten moderators and the positron trap.

Parameter	Neon moderator	Tungsten moderator
Source strength (mCi ^{22}Na)	65	150
Source efficiency (%)	19	19
Fast e^+ flux (s^{-1})	4.6×10^8	1.0×10^9
Moderated e^+ flux	1.2×10^7	1.0×10^6
Efficiency[a]	0.005	2×10^{-4}
Efficiency[b]	0.026	1×10^{-3}
Energy spread (FWHM) (eV)	~ 1.8	~ 0.6
Trapping rate (s^{-1})	3.9×10^6	$4. \times 10^5$
Trapping efficiency (%)	~ 30	~ 40
Positron lifetime (s)[c]	45	45
Positron lifetime (h)[d]	0.5	0.5
Total trapped positrons	1×10^8	1.6×10^7

[a] Relative to source strength.
[b] Relative to emitted positrons.
[c] With buffer gas, $p \sim 5 \times 10^{-7}$ Torr.
[d] At base pressure, $p \sim 5 \times 10^{-10}$ Torr.

Fig. 4. Accumulation of positrons from a 65 mCi ^{22}Na source. The positron beam is switched off at $t = 300$ s. The positron lifetime of 43 s is due to the annihilation on the nitrogen buffer gas at a pressure of $\sim 6 \times 10^{-7}$ Torr in this stage of the positron trap.



ing a retarding potential to the trap electrodes. The magnetic field in the trap is 1260 G, i.e., about a factor of 8 higher than the field at the source. The passage of the positrons from the low to the high magnetic field leads to an exchange of the parallel and perpendicular momentum and a consequent broadening of the axial energy spread.

The energy spread of positrons from the solid neon moderator is at least a factor of 2 higher than those obtained from tungsten films. For positron trapping, the energy spread is an important factor determining the trapping efficiency, because the trap potentials are tuned optimally for a narrow range of energies [11]. The new moderator has enabled us to increase the number of positrons that we are able to trap substantially. Figure 4 shows the accumulation of 1×10^8 positrons from a 65 mCi source using a solid neon moderator. Previously we obtained 1.6×10^7 positrons using a 150 mCi source and a tungsten moderator. The trapping efficiency is reduced from about 40% to about 30% by replacing the tungsten moderator with solid neon, but the improved efficiency of the moderator more than compensates for this slight reduction. Therefore, we observed an approximate 20-fold overall increase in trapping efficiency by changing from tungsten moderators to Ne.

Once a moderator has been grown, its lifetime depends mainly on the temperature and vacuum conditions in which it is operated. The decay of a typical moderator is shown in Fig. 2. The base pressure at the source is $\sim 5 \times 10^{-8}$ Torr when isolated from the trap. Under these conditions, the moderator decays with a half-life of about 7 days, as shown in Fig. 2.

During normal operation of the trap, nitrogen is admitted as a buffer gas for trapping positrons by inelastic scattering collisions. This leads to an elevated pressure ($\sim 1 \times 10^{-7}$ Torr) at the moderator, which therefore decays more rapidly, usually with a half-life of less than 24 h. Figure 2 shows this effect, beginning with the admission of nitrogen at $t = 22$ h. Because of the rapid decay of the moderator when the trap is operated, we typically grow a new moderator every 24 h. Sublimation of the spent moderator, admission and freezing of neon, and the annealing of the new moderator are carried out overnight under computer control.

4. Discussion and summary

As summarized in Table 1, the RGS moderator functions very well in its present configuration. However, we have planned a number of modifications to improve its performance significantly. The major drawback of the present design is the relatively high pressure of nitrogen at the moderator when the trap is operated. At present, the trap is connected to the source by a magnetic beam tube 130 cm long and 3.5 cm in diameter. Since the positron beam is only 1 cm in diameter, and its diameter could be even further reduced by increasing the magnetic field, the beam tube could be reduced by at least a factor of 2, giving an eightfold reduction in its conductance and leading to a significant reduction in pressure at the moderator. In general, we have found that the added complexity of RGS moderators is more than compensated for by the dramatic improvement in moderation efficiencies.

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