磁镜辅助正电子慢化

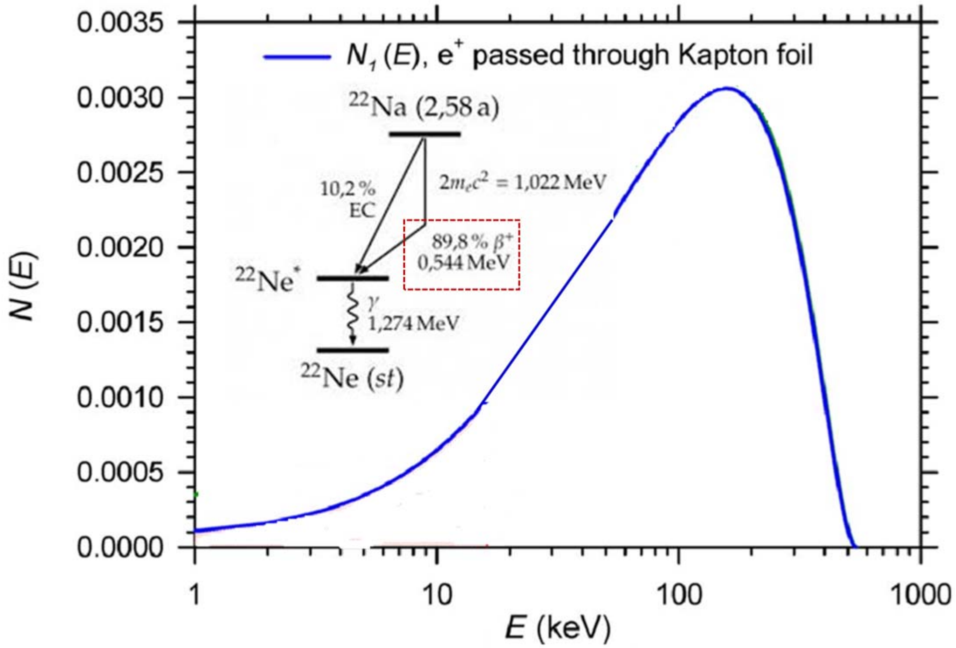
正电子源：^{22}Na

慢化材料：钨箔

辅助慢化：磁镜

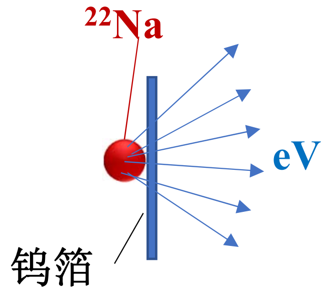
评估慢化效率：

$$\eta = \frac{N_{慢正电子}}{N_{总正电子数}}$$



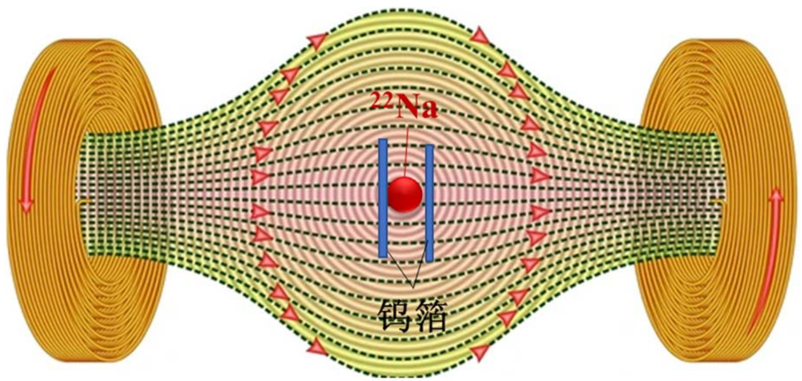
从正电子源发射出的正电子能谱

常规慢化方法



从放射源发射的正电子（能量连续分布）进入到钨箔，能量损失，一部分低能正电子（能量eV量级）从钨箔表面发射，收集正部分慢正电子。
这种慢化效率极低，约为10^{-3}–10^{-4}

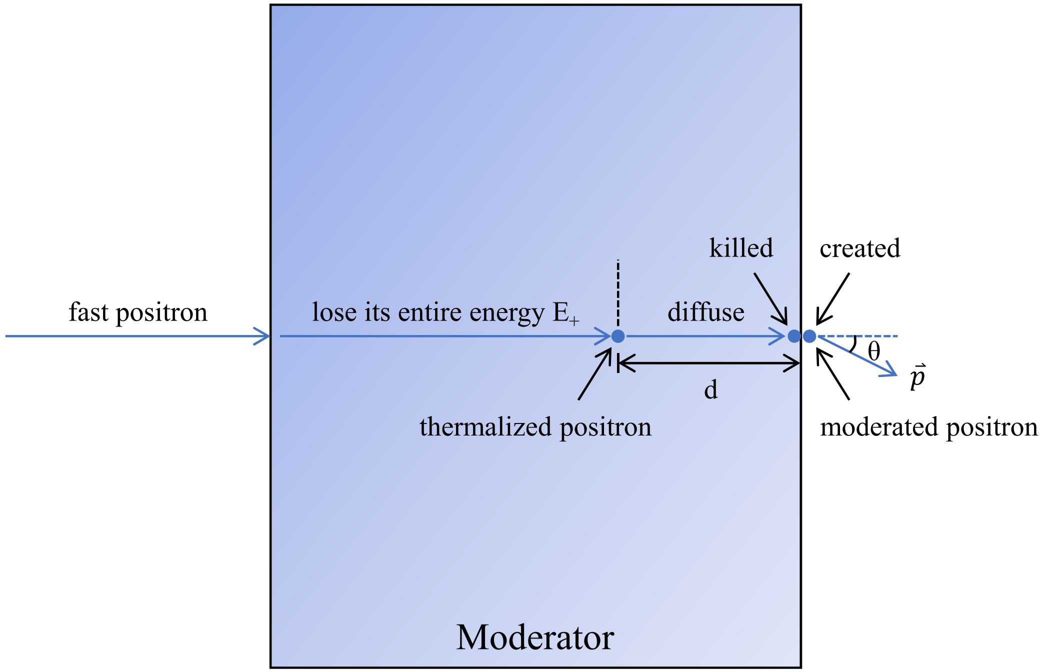
磁镜辅助慢化方法



把放射源和钨箔放置在磁镜中心处，从^{22}Na发射的正电子进入到钨箔，一部分低能正电子从钨箔表面发射，大部分直接穿透钨箔而损失掉，利用磁镜系统把没有被钨箔慢化的正电子约束在磁镜的中央，使之多次穿过钨箔，这样就可以提高慢化效率（10^{-2}）。

用于理论估算的正电子慢化过程的物理模型

慢化体材料：钨



Number of moderated positrons / number of thermalized positrons = $Y_0 \times p$

$p = \exp(-d/L_+)$ is the probability for a thermalized positron to diffuse to the surface

d is the distance to the nearest surface

L_+ is the positron diffusion length

Y_0 is the positron re-emission branching ratio

the momentum direction $\frac{\vec{p}}{|\vec{p}|}$ is randomized

$\theta_m = \sqrt{(k_B T)/|\Phi^+|}$ is the maximum angular deviation

($\theta_m \approx \tan\theta_m$ when $\theta_m \ll 1$)

Φ^+ is the positron workfunction

$k_B T = 0.025$ eV at room temperature

$\Phi^+ = -(3.00 \pm 0.15)\ eV, L_+ = 135\ nm$ for well-annealed single crystalline W(100)

$Y_0 \approx 0.33$

[2] N. Djourelov, A,B. Serban. Optimization of a device for positron moderation based on a magnetic bottle. Nuclear Instruments and Methods in Physics Research Section A, 2021, 1014:165699. https://doi.org/10.1016/j.nima.2021.165699

磁镜原理 & 磁镜辅助正电子慢化装置图

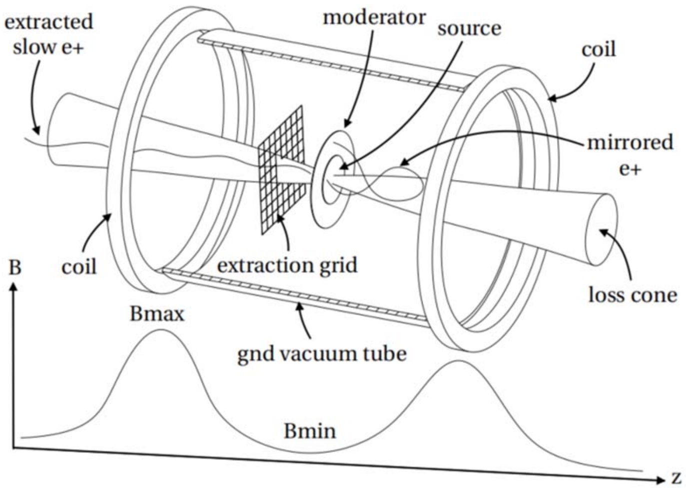


Figure 1. Scheme of the cyclotron assisted moderator principle. Two thin Ti activated foils (^{48}V), indicated as "source", and the W(110) foil, indicated as "moderator", placed inside a cyclotron trap act as a positron emitter, energy degrader and moderator. The confined positrons emitted from the source (kept at +100 V) lose energy passing through the foils until they are moderated. The use of a grid at ground potential maximizes the efficiency of the extraction of the moderated positrons.

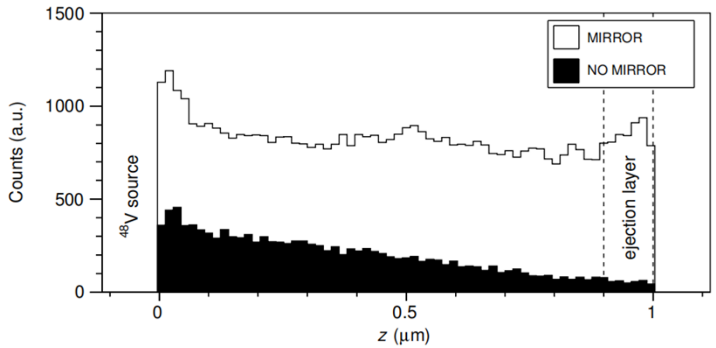


Figure 5. Simulated axial stopping position z split into mirrored (white area) and not mirrored (black area) events. The W moderator foil range from 0 to 1 µm. The ^{48}V source sits on the $-z$ side of the moderator. The ejection layer ranging from 0.9 to 1 µm is marked by the dashed lines.

$\sin^2\theta = 1 / R_m$

Θ is the pitch-angle,

$R_m = B_{max} / B_{min}$ is the magnetic mirror ratio

[1] Gerchow L, Braccini S, Carzaniga TS, Cooke D, Döbeli M, Kirch K, Köster U, Müller A, Van der Meulen NP, Vermeulen C, et al. High Efficiency Cyclotron Trap Assisted Positron Moderator. Instruments, 2018, 2(3):10. https://doi.org/10.3390/instruments2030010

研究目标

- 正电子的慢化效率=最终能得到的慢正电子数/从源出射的总正电子数
- 磁镜的作用是约束正电子，使得未被慢化的正电子能再次穿过慢化体，进而提高最终得到的慢正电子数
- 可以使用**G4beamline**软件进行模拟，正电子源采用^{22}**Na**，慢化体材料采用**W**，磁镜装置内部设置为真空状态。通过改变磁镜配置（线圈尺寸、距离、电流等）、慢化体厚度、慢化体边长甚至慢化体几何结构（正方形或百叶窗式等）等，实现尽可能大的正电子慢化效率（初步目标是达到**1%**左右的慢化效率）。
- 尽管**G4beamline**整合了**Geant4**的物理过程，但仍无法模拟热化正电子的扩散和表面再发射过程。为简化模拟过程，可认为从慢化体表面出射的慢正电子数等于模拟中停留在慢化体表面**135 nm**层的正电子数乘上**0.33**，模拟中可不设置电极提取网。