K 225 Positron Lifetime in Metals and Insulators

K 225.1 Aim of the Experiment

The aim of this experiment is to investigate the vacancy formation in solid state materials. Therefore the temperature dependence of the positron lifetime is measured using a fast-slow-coincidence setup. The formation of positronium is investigated by measuring a positron lifetime spectrum in acrylic glass.

K 225.2 Required Knowledge

- metals
  - lattice defects in metals
  - trapping model, positron lifetime spectrum
  - vacancy concentration in thermal equilibrium, formation enthalpy of vacancies
- positrons
  - positron sources, decay scheme of ^{22}Na (γ-energy spectrum)
  - positron annihilation
  - positronium formation, pickoff-decay
- measurement technique
  - LYSO scintillator, ^{176}Lu decay scheme, LYSO spectrum
  - photomultiplier (PM), dynode pickup
  - single channel analyzer (SCA), constant-fraction-discriminator (CFD)
  - time-to-amplitude converter (TAC), multichannel-analyzer (MCA)
  - fast-slow coincidence curcuit
  - prompt curve, resolving power, detector response function

K 225.3 Literature

- Schatz/Weidinger: "Nuclear Condensed Matter Physics"
- Leo: "Techniques for Nuclear and Particle Physics Experiments"
- Kittel: "Introduction to Solid State Physics"
- **The supplementing literature has to be borrowed from the assistant in charge of this experiment 1–2 weeks before the experiment**

K 225.4 Assignments

1. Measure one intrinsic energy spectrum of each LYSO detector.
2. Register one energy spectrum of the ^{22}Na source for each detector.
3. Tune the gain of the main amplifiers according to the 1275 keV lines.
4. Adjust the CFD thresholds and set up the TAC input signals.
5. Set the windows of the single channel analyzers on the low energy lines in the LYSO spectrum. For the time calibration take prompt curves in steps of 4 ns.
6. Determine the time resolution.
7. Set the SCA window of the start detector on the 1275keV line (start of the TAC) and the stop detector on the 511 keV Peak.
8. A lifetime spectrum in acrylic glass is measured during night. From this determine all possible lifetimes and interpret them.
9. Measure the positron lifetime in indium (metal) at eight temperatures from room temperature to 140^{o}C. **ATTENTION: Do not heat close to the melting point of indium (156^{o}C)!**
10. Calculate the positron lifetimes using the measured spectra and deduce the vacancy formation enthalpy.
11. All spectra collected during the experiment have to be saved for documentation. The data will be stored in ASCII-form. Therefore provide a USB storage device.

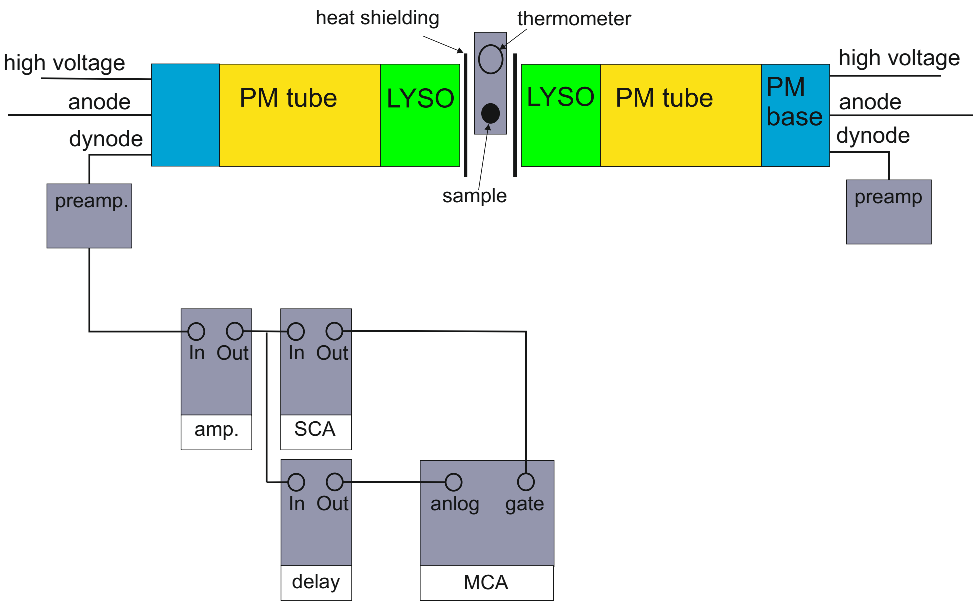

Figure K 225.1: *Adjustment of the SCA windows.* Here just one side is shown. The adjustments have to be done for each side separately, after each step watch the signal using an oscilloscope.

K 225.5 Procedure and analysis

K 225.1.1 Setting up the slow circuit

At first the gain of the main amplifiers has to be adjusted. Therefore each detector is set up separately as shown in Figure K 225.1. The SCA should be opened completely to get a full energy spectrum on the MCA. The output of the SCA is used as a gate for the MCA. Therefore the signals have to be checked for simultaneousness so that the analog signal peak is located inside of the gate signal. Start with the measurement of an intrinsic LYSO energy spectrum and identify the structures visible with the lines in the decay scheme. Insert the ^{22}Na source and while acquiring the spectrum adjust the gain of the main amplifier in order to cover the 1275 keV line. Do not modify the gain after this point.
In order to be able to determine the lifetime one needs to calibrate the time scale first. To prepare the time calibration measurement the setup has to be adjusted to detect the γ cascade decays of the LYSO material. For this both SCAs have to be set to the low energy lines in the LYSO Spectrum. This way one detector will measure γs originating from a cascade decay in the other detector and vice versa. To adjust the SCA windows acquire a raw LYSO spectrum and put the cursor of the MCA to the wanted position in the energy spectrum and raise the lower level above this position. Start a new measurement and decrease the lower level until the desired channel is reached. Proceed analogously with the SCA window width.
After setting up the first detector, repeat the procedure with the other side.

K 225.1.2 Adjustment of the fast circuit

The adjustment of the CFD thresholds is carried out by observing the **slow** signal while triggering on the CFD output of the same detector. Lower the threshold until a zero line in the slow signal is visible. Now raise the threshold until this line vanishes. After the CFD thresholds of both detectors have been adjusted, the time delay between the start and stop signal has to be set. Therefore connect the CFD outputs with the oscilloscope and use the ns delay to adjust the time delay to 20 ns. Now connect the start and stop signals to the TAC, and set the time range of the TAC to 50 ns. Use the same cables to connect to the TAC as used on the osciloscope (Why is that important?). If the TAC provides an output signal, the fast circuit is prepared.

K 225.1.3 Time calibration measurement

To be able to measure prompt events the setup has to be wired as shown in figure K 225.2. First the outputs of the SCA's have to be checked with the oscilloscope for simultaneousness. Do the same with the outputs of the TAC and the coincidence. Tune the SCA output delays simultaneously if necessary and recheck SCA overlap on the oscilloscope. Thereafter prompt curves can be measured. The time calibration is done by using the prompt setup and modifying the stop delay in steps of 4 ns. Acquire at least five prompt peaks measuring for 2 minutes at each position. A prompt peak also allows to determine the time resolution of the experimental setup. Therefore perform a seperate 20 minutes prompt peak measurement.

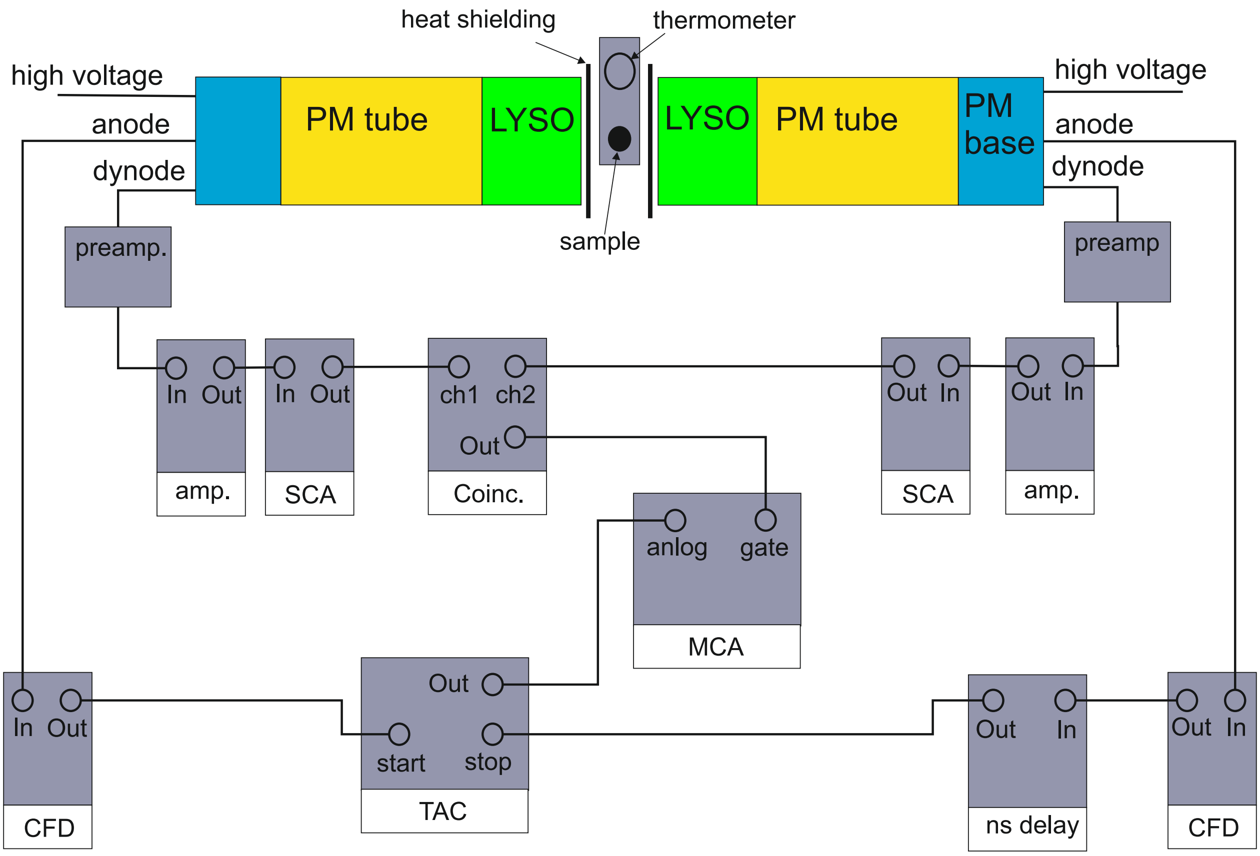

Figure K 225.2: Wiring scheme of the fast-slow-coincidence circuit.

K 225.1.4 Adjustments for Lifetime Measurement

To measure the positron lifetime spectra, one of the SCAs (wich one?) has to be set on the 1275 keV line to provide a start pulse, the other to the 511 keV annihilation line to deliver a stop signal. Therefore acquire a ^{22}Na spectrum and adjust the SCA windows using the same procedure as in K 225.1.1. Rewire the setup as shown in K 225.2. Check the SCA outputs and the fast-slow coincidence for simultaneousness again (why?). Now the temperature dependent measurements using the indium sample and the overnight run using acrylic glass can be started.

K 225.1.5 Lifetime Measurement with the indium sample

The indium sample is heated inside an aluminum block by a soldering iron. The temperature is adjusted with a potentiometer. Place the sample holder inbetween the heat shielding aluminium sheets and ensure that there is no contact. Place the detectors near to the heat shielding leaving a gap to avoid thermal contact. Optimise the position of the sample by observing the coincident count rate. When done start with the lifetime measurement at room temperature. After a reasonable number of events has been acquired (≈30 min), stop the MCA and heat the sample. Set a certain potentiometer value and wait until the temperature stabilises. Note the temperature

value when starting and stopping the measurement in order to be able to estimate the mean temperature.
For taking into account that the detector system has a limited time resolution, the measured spectra have to be fitted with a convolution of the resolution function and the lifetime distribution function. Which part of the time distribution will show the temperature dependence? Use the parameters obtained by the fit to show the temperature dependence of the formation of vacancies in the sample and determine the vacancy formation enthalpy.

K 225.1.6 Lifetime Measurement with acrylic glass

To acquire as much statistics as possible, perform an overnight measurement using the acrylic glass sample. The sample holder and the heat shielding can be removed. Use a convolution of two lifetime curves and the resolution function in order to analyse all relevant contributions to the spectrum. Which lifetimes are accessable with this setup?

K 225.2 Appendix

K 225.2.1 Decay schemes

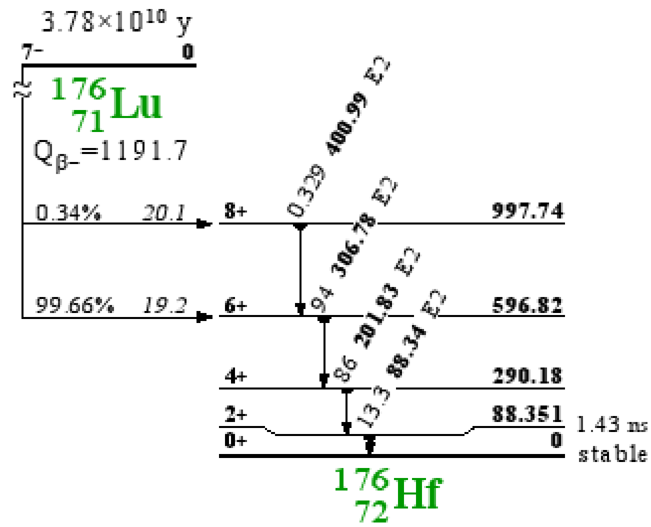

Figure K 225.3: Decay scheme of ^{176}Lu, from A. Adolphs, bachelor thesis, 2012.

Best wishes for a successful experiment! Date: July 2014

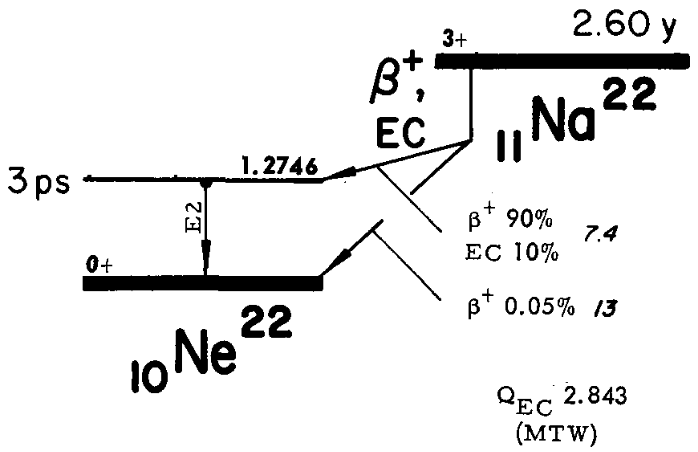

Figure K 225.4: Decay scheme of ^{22}Na, from Lederer, Table of Isotopes, 6th. edition, 1967.