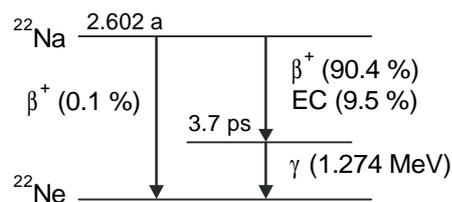


## Positron Sources

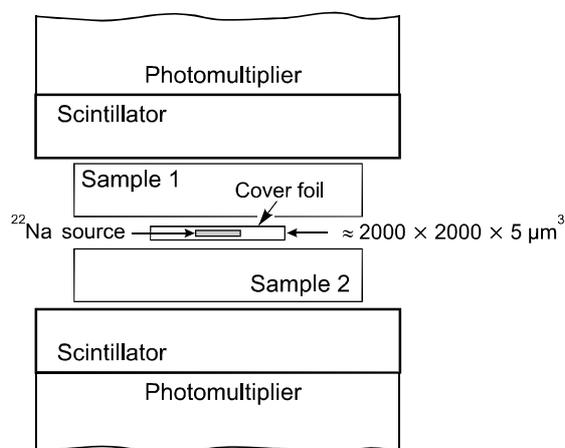
Positrons can be obtained from the  $\beta^+$ -decay of radioactive isotopes, e.g. from  $^{22}\text{Na}$  according to the decay reaction  $^{22}\text{Na} \rightarrow ^{22}\text{Ne} + \beta^+ + \nu_e + \gamma$ . The  $^{22}\text{Na}$  isotope gives a relatively high positron yield of 90.4 % (Fig. 1) and has several other advantages. First of all, the appearance of a 1.27-MeV  $\gamma$ -quantum almost simultaneously with the positron enables positron lifetime measurement by a start–stop coincidence  $\gamma$ -spectrometer. Moreover, the manufacture of laboratory sources is simple, due to the easy handling of different sodium salts in aqueous solution, such as sodium chloride or sodium acetate. The half-life of 2.6 years and a reasonable price make this isotope the most used source material in positron research. The accidental contamination of laboratory personnel is less harmful, since the biological half-life is only a few days. In addition to  $^{22}\text{Na}$ , other isotopes ( $^{64}\text{Cu}$ ,  $^{58}\text{Co}$ , etc.) can be used, but are less common. The generation of electron–positron pairs from high-energy photons is an alternative way to obtain positrons for use in beam systems. No broad application has been reported so far for applications in semiconductor research due to the need for appropriate accelerators.

The positrons generated in the  $\beta^+$ -decay reaction mentioned above exhibit a broad energy distribution up to an energy of 540 keV and can penetrate deep into a sample. In electron-irradiation experiments, a particle energy of 0.5 MeV may be sufficient to generate irradiation defects such as Frenkel pairs in many materials. This should be similar for positrons. However, the dose amounts only to  $\sim 1 \times 10^{11} \text{ cm}^{-2}$  for a rather long positron experiment of several days. Supposing a defect introduction rate of  $1 \text{ cm}^{-1}$ , the density of introduced defects is  $\sim 1 \times 10^{11} \text{ cm}^{-3}$  and thus several orders of magnitude lower than the sensitivity limit of positron annihilation.



**Fig. 1.** Decay scheme of the radioactive isotope  $^{22}\text{Na}$ . 90.4 % decays by emission of a positron and an electron neutrino to the excited state of  $^{22}\text{Ne}$ . The ground state is reached after 3.7 ps by emission of a  $\gamma$ -quantum of 1.274 MeV. Competitive processes with lower probabilities are electron capture (EC) and direct transition to the Ne ground state.

Sources of weak activity are needed for conventional positron lifetime and Doppler-broadening measurements. Even activities as low as  $8 \times 10^5$  Bq (20  $\mu$ Ci) are sufficient. The sources are usually prepared by evaporating a solution of a  $^{22}\text{Na}$  salt on a thin metal or polymer foil. The most common foil materials are Al, Ni, and mylar or kapton. In order to ensure the almost complete annihilation of positrons in the specimen volume, the foil source is placed between two identical samples ("sandwich arrangement", Fig. 2). A minimum sample thickness is required to ensure that the essential fraction of positrons annihilates in the sample pair. The scintillators should be placed as close as possible to the sample-source sandwich. If cooling of the sample is required, the design of the cryostat should allow the separation between the scintillators to be as small as possible in order to avoid a considerable reduction in the counting rate. A small fraction of the positrons annihilates in the source. This amounts to 2 to 15 % depending on the foil thickness and the atomic number of the sample, which determines the backscattering and, thus, the multiple passing of positrons through the source. For the analysis of positron lifetime spectra, this fraction must be carefully determined and subtracted. The so-called source correction is an essential task of the lifetime spectra evaluation. Details can be found e.g. in the paper of Staab et al. (1996). To reduce the source contribution, the isotope solution can be directly deposited onto the sample surface. The disadvantage of this procedure is radioactive contamination of the samples, which can thus hardly be used for further



**Fig. 2.** Scheme of the sample-source sandwich arrangement for the registration of the birth and annihilation  $\gamma$ -rays as start and stop signals in the conventional positron lifetime experiment. The  $\gamma$ -quanta are detected as light flashes in the scintillators. These photons are converted into electrical pulses in fast photomultipliers.  $^{22}\text{NaCl}$  is typically used as the source material.

investigations.

The positron beam and angular correlation techniques require much stronger sources. Source capsules of about 4 GBq (100 mCi) are commercially available, but are sometimes also prepared in the laboratory (see e.g. Huomo et al. 1989). In contrast to the weaker foil sources of lifetime and Doppler-broadening measurements, radiation protection becomes more important. Carefully arranged lead shielding is necessary.

Another possibility for strong positron sources is to generate positrons by pair production (Schultz and Lynn 1988). In this case, an electron beam is stopped in an absorber of high atomic number creating bremsstrahlung  $\gamma$ -rays. Provided that the energy of the primary electron beam is high enough, the generation probability of electron-positron pairs is sufficiently high. The bunching of the primary electrons leads to a pulsed positron beam.

Furthermore, positrons may be obtained from nuclear reactions. It was proposed by Stein et al. (1974) to direct high-energy protons at a boron target in order to obtain an intense flux of positrons. Another concept for positron production is to be realized in the Munich research reactor (Triftshaeuser 1995). During the  $^{113}\text{Cd}(n, \gamma)^{114}\text{Cd}$  reaction, three  $\gamma$ -quanta with a total energy of 9.041 MeV are released and can be used for pair production. The advantage of this technique is the formation of a continuous positron beam of high intensity.