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Positron Mean Lifetimes in Annealed Metals

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Centroid shift analysis of time spectra show that mean lifetimes range from 106 psec in Fe to 415 psec in Cs and have a systematic dependence on atomic number.

The lifetimes of positrons in simple metals, such as the alkalis, change with valence-electron density in a manner which is now understood on the basis of many-body theory.[1] There is some uncertainty about the numerical agreement of theory with experiment because of an approximate treatment of core-electron contribution.[2] Attempts to find similar order in the lifetimes in other metals have usually sought a correlation with the valence annihilation rate after estimating the core fraction from angular correlation. Such attempts have had only limited success.[3] We find that a remarkable correlation exists between the atomic number of the target material and the total annihilation rate (the reciprocal of the mean lifetime) as shown in Fig. 1.

The correlation has escaped detection previously because of the confusion introduced by varying degrees of positron trapping in lattice defects. The last extensive lifetime catalog was that of Weisberg and Berko[4] which was completed prior to the recognition that defects such as vacancies or edge dislocations could trap positrons and extend their lifetime.[5] Our measurements agree closely with theirs for the low-melting-point metals which anneal at room temperature but substantial disagreements are the rule for metals with melting points above 600°C. There have, of course, been numerous published lifetimes since the recognition of trapping, but subtleties in both measurement and analysis have caused sufficient disagreements among various laboratories to mask the correlation.

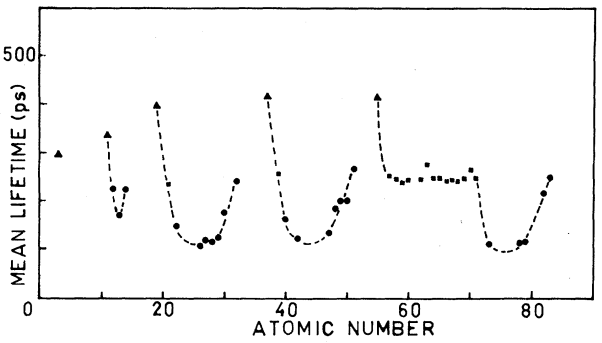

FIG. 1. The lifetimes of positrons in annealed metal specimens as a function of atomic number. Estimated errors are less than 5 psec in all cases. Triangles represent data from Ref. 7, squares from Ref. 9, and circles from our own work.

Our measurements were done with a routed, digitially stabilized spectrometer,[6] and analyzed by the centroid shift of the delayed spectrum relative to the centroid of the stabilized, symmetric peak (time zero). The source, which was used for all specimens, was prepared by drying $^{22}NaCl$ on a 1.8-mg/cm^2 Ni foil, coated with an evaporated Au layer on the side in contact with the salt. A similar Ni + Au layer covered the source and, since this sandwich was not sealed, all measurements were made in a sealed container containing a dessicant. All of our new data have only minor errors of purely statistical origin and the uncertainties, which are less than 5 psec, arise from the corrections for annihilations in the source.

We include older results on the alkali metals which, because of their long lifetimes and freedom from trapping effects,[7] have yielded consistent values from several groups.[4,7,8] We have

also included data on Sc, Y, and the rare-earth metals from Rodda and Stewart[9] who used a centroid shift analysis with Al as a reference. Following advice in a footnote to their paper, we have reduced their centroid shifts by 15% to correct an error in their time scale and have applied the same correction to their recommended value for the mean lifetime of Al. It is certainly controversial to include such data since the rare-earth metals have sufficiently high melting points to prevent annealing at room temperature. The consistency of the data suggests either that these metals do not exhibit trapping effects or, more likely, that annealing and etching was used as a routine in sample preparation.

The systematic dependence of the mean lifetime on the atomic number, and hence on some details of atomic structure, suggests that the data may prove useful in estimating the extent of positron overlap with core electrons. Lack of independent experimental data bearing on this point has long been a cause of serious concern in the analysis of angular correlation data. The remarkable insensitivity of the positron to the filling of the inner shell in the rare-earth metals is a particularly suggestive indicator of the extent of positron penetration of the core—a fact drawn to our attention by G. Karl.

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Thermal-Expansion Coefficient and Universality near the Superfluid Transition of ^{4}He under Pressure

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High-resolution measurements of the thermal-expansion coefficient of pressurized ^{4}He (5 bar $\leq P \leq$ 29 bar) near T_λ ($2\times10^{-5} \lesssim |t| \lesssim 0.07$; $t \equiv T/T_\lambda - 1$) by a new technique yielded a universal (pressure-independent) critical exponent $\alpha = \alpha' = -0.026 \pm 0.004$, a universal amplitude ratio $A/A' = 1.11 \pm 0.02$ for the leading singularity, and a universal ratio $D/D' = 1.27 \pm 0.2$ for the amplitudes of the confluent singularity. These results agree with renormalization-group theory, but are in part contrary to previous experiments.

Certain dimensionless parameters which describe the singularities of various properties near critical points were predicted to be universal[1] in the sense that they depend only upon a small number of very general symmetry properties of the system. This prediction was confirmed by the more recently developed renormalization-group theory,[2] and received strong support from a variety of experiments. Nonetheless, recent measurements of the specific heat C_p of ^{4}He near the superfluid transition temperature T_λ yielded an amplitude ratio A/A' of the singular part above and below T_λ which appeared to depend upon the pressure P.[3] A pressure-dependent