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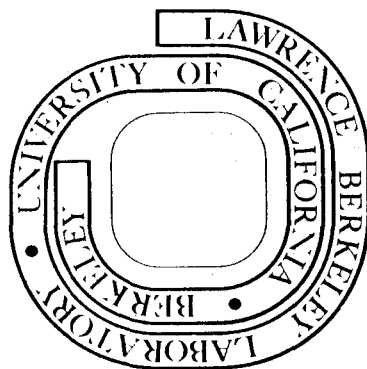
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Atomic K-Vacancy Production with 3 GeV Carbon Ions*

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ABSTRACT

We report measurements of K-vacancy production cross sections for 3 GeV¹²C ions on targets ranging from Ti to Pb. The cross sections lie below values from PWBA, BEA, and relativistically modified PWBA and BEA theories.

Atomic K-Vacancy Production with 3 GeV Carbon Ions

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K-vacancy production by relativistic heavy charged particles is a completely unexplored field. Jarvis et al.¹ and Anholt et al.² have made measurements with relativistic protons. The measurements indicated that an additional term must be added to the cross section given by the Plane Wave Born³ (PWBA) and Binary Encounter⁴ (BEA) Approximations. Those theories only account for the interaction between the static Coulomb fields of the projectile and electron. This contribution is called longitudinal excitation because the interaction exerts a force parallel to \vec{q} , the momentum transfer. At relativistic energies, the current-current interaction between the two particles is also important and gives rise to transverse (force perpendicular to \vec{q}) excitation⁵. For projectile energies greater than approximately

2 GeV/a.m.u. (v_1 constant $\approx c$), the PWBA and BEA cross sections no longer change with projectile energy. The transverse contribution, however, causes the total cross section to rise as the $\ln \gamma^2 + C$ where $\gamma = [1 - \beta^2]^{-1/2}$, $\beta = v_1/c$, and C is a constant.

The experimental procedure was identical to the procedure described earlier.² The K-vacancy cross sections are measured relative to the 70 mb cross section for the nuclear reaction $^{12}\text{C}(^{12}\text{C},X)^{11}\text{C}$. Although the $^{12}\text{C}(^{12}\text{C},X)^{11}\text{C}$ cross section has not been directly measured at 250 MeV/a.m.u., it is possible to extrapolate with confidence from extensive proton production⁶ and higher energy carbon ion production⁷ cross sections.

The measured cross sections are compared with various theories in Fig. 1. The BEA and PWBA cross sections were obtained from universal curves given by Garcia et al.³ and Basbas et al.⁸ The reduced ion velocity was taken as $\beta c/v_K$ where $v_K = (2U_K/m)$ and U_K is the K binding energy.

Two relativistic modifications to these theories should be made. For large v_1/v_K , the PWBA and BEA cross sections approach (but never equal) the integrated Rutherford cross section (σ_R) for scattering an initially stationary electron with an energy

transfer $\epsilon \geq U_K$. For relativistic heavy ions σ_K should approach the integrated McKinley-Feshbach cross section (σ_{MF}) for relativistic electrons on nuclei. We therefore define a correction factor to the PWBA and BEA theories as:

$$R = \frac{\int_{U_K}^{\epsilon} \frac{d\sigma_{MF}}{d\epsilon}}{\int_{U_K}^{\epsilon_m} \frac{d\sigma_R}{d\epsilon}} \quad (1)$$

where ϵ_m is the maximum energy transfer $2mc^2\beta^2\gamma^2$. Eq. (1) is easily evaluated using formulas in ref. 9.

The second relativistic correction factor comes from the inclusion of the transverse term.² We have evaluated this contribution using the PWBA dipole approximations:

$$\sigma_K^t = \frac{143 Z_1^2}{\beta^2 U_K} [\ln\gamma^2 - \beta^2] \text{ barns} - \text{keV} \quad (2)$$

The dipole approximation is only valid when $2 v_1/v_K \gg 1$. In these cases $2 v_1/v_K$ lies between 1.6 and 10.

The relativistically corrected PWBA or BEA cross sections shown in Fig. 1 are given by:

$$\sigma_K = R\sigma_K^0 + \sigma_K^t \quad (3)$$

where σ_K^0 is either the PWBA or BEA cross section. The measured cross sections generally lie lower than the predictions of the PWBA, BEA, and relativistically corrected theories. For lower

atomic numbers, the BEA theory works best; for higher atomic number all theories fail. The relativistic correction given by Eq. (1) becomes important at higher atomic numbers, lowering the cross sections, bringing them closer to experiment. The additive transverse contribution is not very important at these velocities.

We have considered whether the polarization,¹⁰ binding,⁸ and charge-exchange effects might account for the discrepancy between experiment and theory. For $2v_1/v_K > 1$, the polarization effect is expected to be more important than the binding correction and should give a positive contribution to the K-vacancy cross section. We used Eq. (1) of ref. 5 to evaluate the polarization contribution and found it adds only 2, 4, and 12%, respectively, for the Ni, Ag, and Pb targets. There are also negative contributions from the binding effect, so the net polarization plus binding correction is liable to be smaller than these factors. Charge-exchange contributions are expected to give a positive contribution to σ_K also. Raisbeck et al.¹¹ have studied charge exchange phenomena using relativistic protons and, recently, heavy ions. His work allows us to establish the upper limit to the charge-exchange contribution to the K-vacancy cross section as 0.7% (in Pb).

Thus, while the measured cross sections clearly lie lower than the predictions of the first order PWBA and BEA theories, the polarization and charge exchange contributions to these cross sections appear to be negligible and, in any case, in the wrong direction to explain the discrepancy.

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REFERENCES

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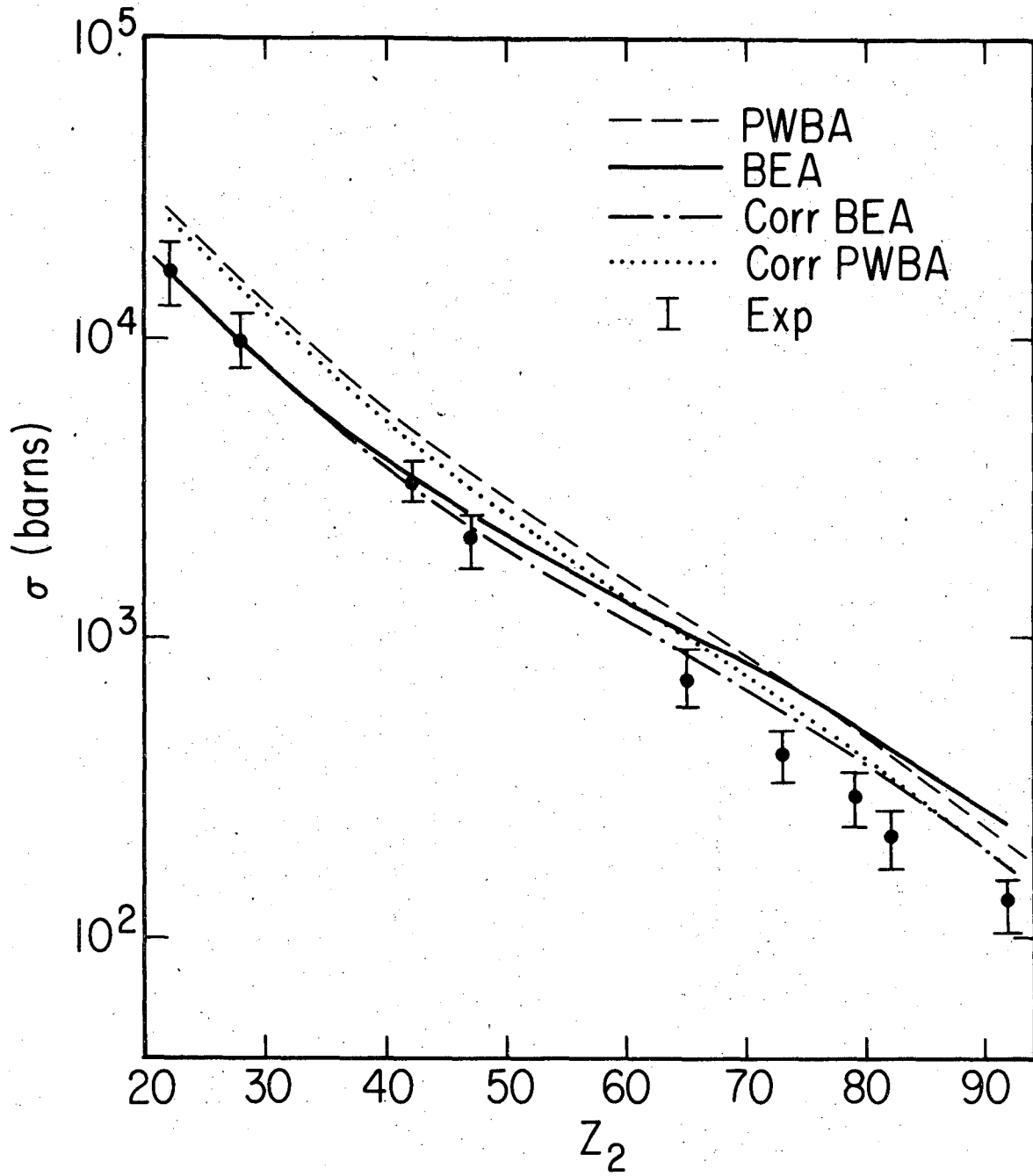
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1. O.N. Jarvis, C. Whitehead, and M. Shah, Phys. Rev. A5, 1198 (1972).
2. R. Anholt, S. Nagamiya, J.O. Rasmussen, H. Bowman, J.G. Ioannou-Yannou, and E. Rauscher, submitted to Phys. Rev. A (1976).
3. J.D. Garcia, R.J. Fortner, and T.M. Kavanagh, Rev. Mod. Phys. 45, 11 (1973).
4. E. Merzbacher, and H. Lewis, Handbuch der Physik 34, 166 (Springer-Verlag, Berlin, 1958).
5. U. Fano, Ann. Rev. Nuc. Science 13, 1 (1963).
6. J.B. Cummings, Ann. Rev. Nuc. Science 13, 261 (1963).
7. P.J. Lindstrom, D.E. Greiner, H.H. Heckman, B. Cork, and F.S. Bieser, unpublished report LBL-3650, Berkeley (1975).
8. G. Basbas, W. Brandt, and R. Laubert, Phys. Rev. A7, 983 (1973).
9. J.D. Jackson and R.L. McCarthy, Phys. Rev. B6, 4131 (1975).
10. G. Basbas, W. Brandt, and R. Laubert, Physics Letters 34A, 277 (1971).
11. G. Raisbeck and F. Yiou, Phys. Rev. A4, 1858 (1971).

FIGURE CAPTION

K-vacancy production cross sections versus target atomic number. Comparison is made with the PWBA and BEA theories and relativistically corrected PWBA and BEA theories.



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Fig. 1

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