Radiative Single (REC) and Double (RDEC) Electron Capture in 10 A MeV Ar^{18+} + C Collisions

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Radiative electron capture (REC)[1], is a process which occurs in an ion-atom collision when electron capture is accompanied by simultaneous x-ray emission. REC is completely analogous to radiative recombination (RR) involving a similar interaction with a free electron, which is simply the inverse of the photoelectric effect. In an ion-atom collision, however, the electrons to be captured are not free but are bound to the target nucleus, and therefore have a momentum distribution. If the velocity of the ion is considerably greater than the orbital velocity of the target electron to be captured, then, based upon the impulse approximation, the cross section can be written [2] as:

$$\frac{d^2\sigma}{d\Omega\, dE_{REC}} = \int d^3p \frac{d\sigma_{RR}}{d\Omega} |\psi_i(p-p_0)|^2 \delta(E_f - E_i) \quad (1)$$

The delta function guarantees energy conservation and $|R_i(p\text{-}p_0)|^2$ is the initial electronic momentum distribution, which is peaked around $p_0 = mv_P$ because the electron is moving with this average momentum towards the projectile, which is considered to be at rest. If the projectile ion is much heavier than the target then the energy centroid of the emitted x rays is given by:

$$E_{REC} = \epsilon_P - \epsilon_T + 1/2mv_P^2 \simeq \epsilon_P + \frac{m}{M}E \qquad (2)$$

assuming that the initial binding energy of the electron to the target ($,_T$) is negligibly small for a light target. In the above equation, m, v_P, $,_P$, E, and M are the electron mass, the velocity of the projectile, the binding energy of the electron to the projectile ion, the beam energy, and the projectile mass respectively. A similar expression can be derived for radiative double electron capture (RDEC) (i.e., double electron capture accompanied by simultaneous x-ray emission) mechanism:

$$E_{RDEC} \simeq \epsilon_P' + 2\frac{m}{M}E \qquad (3)$$

where $\in_p'$ is the binding energy of the two electrons to the projectile ion, considered as one "quasiparticle". The factor of 2 is introduced since two target electrons are captured by the projectile during the RDEC process. For the collision system investigated in this work (10A MeV Ar^{18+} +C) the corresponding calculated x-ray energies for both the REC and RDEC mechanisms were found to be 9.91 keV and 19.52 keV respectively.

An attempt [3] to observe the RDEC photons for bare Ar ions in collisions with thin solid carbon targets was made at GSI but no evidence for the RDEC mechanism was found. In order to investigate RDEC for this system more completely, we undertook similar measurements at TAMU using the cyclotron facility. A projectile beam composed of 10 A MeV bare Ar ions was accelerated and directed to a thick solid carbon target placed at a 45^0 angle with respect to the beam axis. The choice of carbon as a target was dictated by the desire to obtain as high as possible rates for double charge exchange in one collision. For x-ray detection, a Si(Li) detector was mounted next to the target at 90^0 to the beam axis. The estimated ratio F_{REC}/F_{RDEC} is of the order of 10^5. Thus, in order to avoid pileup effects, an x-ray absorber (0.255 g/cm^2 Aluminum) was inserted between the target and the Si(Li) detector. The absorber material and thickness chosen guaranteed a strong suppression (by a factor of 1000) of REC photons while the number of RDEC x rays were only reduced by a factor of 2.5.

A typical x-ray spectrum is shown in Fig. 1. The REC peak-energy position is near the calculated value (9.91keV) obtained by equation (2) but the precise absolute REC peak energy observed is shifted from the simple value one might expect by mechanisms (see below) which lead to a reduction in the measured value. The most important REC peak shift and uncertainty occurs because of ion energy loss in the solid target. The next most significant effect is the relativistic Doppler shift. There are additional effects that may contribute to this energy shift: REC to excited states (n REC) which produces x rays lying below the K REC peak energy, and multiple REC events experienced by a single ion as a result of multiple collisions with the target atoms. In this later case the REC x-ray energy decreases as a result of the continuing screening of the ion's nuclear charge.

It is seen that the spectrum in Fig. 1 is dominated by the single REC peak even though it was strongly suppressed by the applied x-ray absorber. This dominance is mainly due to intense double collision processes in the solid target, producing single REC photons at a very high rate. In the RDEC region of the spectrum no structure is observed which could be attributed to the process of interest. The smooth background in this spectral region is mostly due to the high energy tail of single REC photons as well as to secondary electron bremsstrahlung [3].

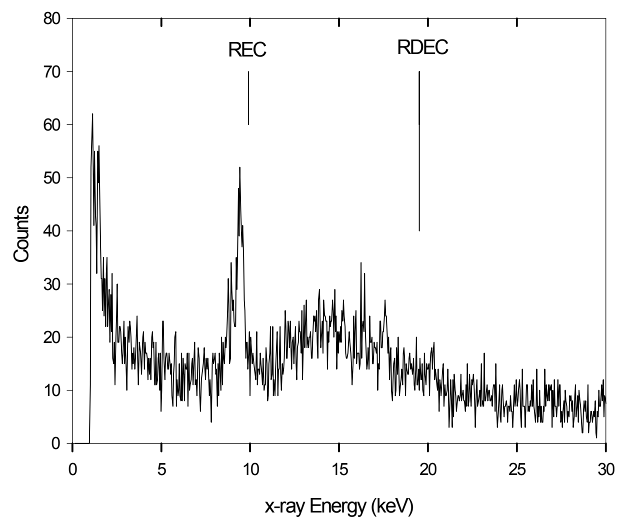

Figure 1: X-ray spectrum for 10 A MeV Ar^{18+} + C.

It is evident that although RDEC is a mechanism that probably does occur in an ion atom collision, its experimental investigation requires more sensitive techniques in order to distinguish it from the competing REC process and background radiation.

References

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