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NEUTRON INDUCED X-RAYS

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Atomic excitations are traditionally obtained through electromagnetic interactions. In particular X-ray excitations have been studied through the Coulomb interaction with charged projectiles. Here we examine the use of the strong interaction as mediated by the scattering of 30 MeV neutrons to obtain collective excitations of atoms in which only the nucleus recoils suddenly i.e. with time constants related to the short range of nuclear forces.

The excitation energy within atoms recoiling after neutron scattering can be calculated from momentum conservation. Let P be the momentum imparted to the nucleus during the neutron scattering, which occurs in a time equal to the ratio of nuclear force range to projectile velocity ($\sim 10^{-23}$sec). At this stage the energy associated with the recoiling atom resides in the nucleus motion only and is given by

$$E_i = P^2/2Am_N$$

where A is the atom's mass number and m_N the nucleon mass. Subsequently the electrons are accelerated in the Coulomb field, thereafter performing collective vibrations about the moving nucleus. After photon deexcitation the final energy of the recoiling atom will be

$$E_f = P^2/2(Am_N+Zm_e)$$

so that the collective photon energy is given by

$$h\nu = E_i - E_f = \tfrac{1}{2}Zm_eV^2/(1+Zm_e/Am_N) \approx \tfrac{1}{2}Zm_eV^2$$

where V is the initial nuclear recoil velocity. Neglecting relativistic effects one obtains in the case of neutrons of initial energy E_n which are backscattered through 180°

$$h\nu \approx 4E_n \frac{m_e}{m_N} Z/(A+1)^2$$

The time constant associated with recovery to spherical symmetry within the atom is of order

$$\tau = \frac{m_e a_o^2}{Ze^2(A+1)} (8E_n/m_N)^{\frac{1}{2}}$$

$$\sim 10^{-17} \text{ sec for light nuclei and 30 MeV neutrons.}$$

This corresponds to the traversal by the recoiling atom of one mean free path in a gas at one tenth atmospheric pressure.

Of particular interest is the observation of the modes of deexcitation of the recoil atom. Using neutrons, in contrast to the adiabatic excitation processes associated with charged projectiles, we create in a controlled way a deformed potential which sets the otherwise unperturbed (except for the negligible magnetic moment coupling) electron shells into vibration. If collective single photons are emitted one might expect this to occur in times not substantially larger than τ, whereas the emission of characteristic X-rays would be expected to be much slower, requiring complicated internal rearrangement to transfer the energy to single electrons.

In order to exploit experimentally the controlled excitation mode afforded by neutron scattering, it is necessary to use a gas target so that deexcitation can occur before the recoil atom undergoes ionizing collisions. However, the subsequent ionization signal serves to define the momentum transfer associated with each event and provides a coincidence signal (essential for survival in a Compton scattered γ background). Suitable neutron energies are defined by the requirement that the impulse imparted to recoil atoms should not excite electrons above the ionization potential. Carbon dioxide and the noble gasses provide suitable targets for an intrinsic detector. Using neutrons up to 30 MeV from $^3H(d,n)^4He$ these targets would yield X-rays in the range .2 to 2 KeV, where strong absorption precludes the use of windows.