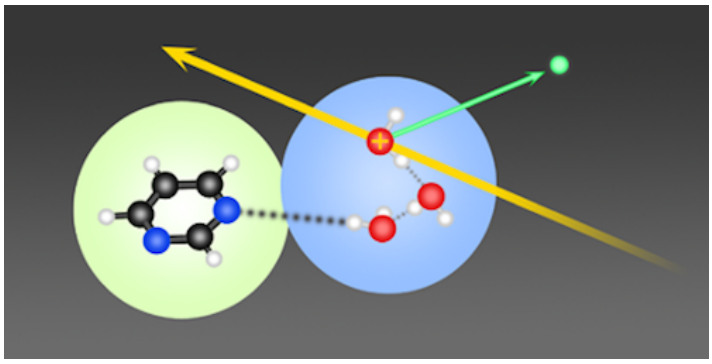
The Effectiveness of Carbon-Ion Cancer Therapy

Experiments have shown that heavy-ion irradiation of biomolecules in aqueous environments efficiently triggers DNA-destroying cascades.

By **Marric Stephens**

Ion beams are especially effective in treating cancer in part because heavy particles deposit their energy over shorter distances within the target volume than lighter ones do. Yue Gao at the Institute of Modern Physics of the Chinese Academy of Sciences and colleagues have now discovered another reason for the enhanced biological effectiveness of carbon ions in particular: Heavier particles are significantly more likely to trigger intermolecular Coulombic decay (ICD), a process that damages DNA by generating secondary particles such as electrons and molecular ions [**1**].

ICD occurs when ionizing radiation strikes one molecule in a weakly bound cluster. Through electronic interactions, the energy delivered to the target molecule is shared with a neighbor, causing both molecules to emit low-energy electrons and then to fly apart. Gao and colleagues studied what happens when the ionizing radiation consists of either carbon or iron ions and when the target, a simplified stand-in for human tissue, consists of hydrated biomolecules—specifically, pyrimidine, which resembles two of the bases that make up DNA. They also modeled the process using quantum chemical calculations.



Credit: Y. Gao *et al.* [**1**]; adapted by APS

The researchers observed dramatically enhanced emission of low-energy electrons with respect to x rays or other light particles. This emission was accompanied by positively charged pyrimidine and water molecules—the fingerprint of ICD. They also found that, upon ionization, clusters of water molecules would split into hydrated proton and hydroxyl radicals. These additional species add to the biological effect of the usual ICD-induced electron emission, the researchers say. Next, they intend to investigate whether ICD in DNA base pairs damages both strands simultaneously, thereby causing fatal damage to cells.

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REFERENCES

1. Y. Gao *et al.*, "Damaging intermolecular relaxation processes initiated by heavy-ion irradiation of hydrated biomolecules," **Phys. Rev. X 15, 011053 (2025).**