Exotic nuclear decay discovered

The discovery, nearly a century after Becquerel, of a novel mode of radioactive decay is a surprise, but one that confirms α decay as the chief means by which heavy nuclei shed mass.

THOSE who decorate their offices with wall charts showing the isotopes, stable and otherwise, of the elements are in for trouble. As things are, these elaborate diagrams usually show by means of a colour scheme of some kind which radioactively unstable nuclei decay by which means. Decays in which the α– or β-particles (electrons) are emitted predominate, but the diagrams must also make room for other less common processes — positron emission, internal conversion (of an electron in an inner shell) and even fission. Now the same wall charts will have to accommodate radioactive decays in which unstable nuclides emit substantially heavier nuclear fragments than the familiar α–particle.

That is the burden of the discovery (see p.245) reported this week from the University of Oxford by H.J. Rose and G.A. Jones of a handful of unmistakable carbon nuclei among the decay products of radium-223 (^{223}Ra), hitherto marked in the charts as a simple α–emitter with a half-life of 11.2 days. What they have shown is that ^{223}Ra nuclei occasionally, but significantly, decay with the loss not of an α–particle but of a carbon-14 (^{14}C) fragment. Anthropomorphically, from the point of view of the nucleus so to speak, this novel arrangement has obvious advantages. The decay scheme of ^{223}Ra involves the successive emission of three α–particles (to give radon-219, polonium-215 and lead-211) followed by an electron, to give bismuth-211. (This decay scheme, which begins with uranium-235, predominantly leads to lead-207 by the further emission of two α-particles and an electron.) So why should not an unstable ^{223}Ra nucleus shorten this tortuous process by eliminating a substantial part of the charge and mass that must ultimately be lost in a single package? What now emerges is that that option is not as rigorously forsworn as the conventional wall charts suggest.

So how can it be that the best part of 90 years has passed since Becquerel's discovery of radioactivity before it has been recognized that α- and β-emission are not the whole of radioactivity? That is the obvious question that will now arise. The proper response, as a glance at the article by Rose and Jones will show, is that the discovery of ^{14}C emission from ^{223}Ra, important though it is, serves chiefly to emphasize that α-particle emission is the chief means by which radioactively unstable nuclei lose mass. Indeed, in the observations now reported, there are roughly 1,000 million times as many α-particles and ^{14}C nuclei in the decay of ^{223}Ra, perhaps as vivid a proof as there could be of the dominance of the familiar mechanisms of decay.

The rarity of these events is also the explanation why this novel form of radioactivity has not previously been found. So much can be told from the account by Rose and Jones of their observations, which entailed more than half a year of running time with detectors arranged so as to distinguish between single ^{14}C fragments and more frequent occurrence of groups of three α-particles from the nearly simultaneous decay of separate ^{223}Ra nuclei. (The fact that one of the two detectors seems at one stage to have been put out of action by accumulated radiation damage is a telling measure of the numbers of α-particles involved, even if the fault appears to have been an ambition to avoid buying new material for this purpose.) In the circumstances, there is no reason to think that the discovery that ^{223}Ra can decay with the emission of a ^{14}C particle will quickly be followed by similar observations in respect of other nuclei. Rose and Jones say they are looking at another candidate nucleus, but there will be few groups with the stamina that compels competition.

Some, no doubt, will even ask whether this search for exotic and necessarily rare mechanisms of decay can be worth the trouble, now at least that it has been demonstrated that such mechanisms are not entirely excluded. The simple answer, as always, is that the neglect of phenomena on the simple grounds that they are only rare, or that their effects are small, is never justified. On this occasion, several important questions arise, not the least of which is why the first exotic fragment to have been found in the decay of a radioactive nucleus should have been the unstable ^{14}C nucleus and not the stable ^{12}C, itself simply a combination of three α-particles.

Superficially, the calculation of the rate of some specified radioactive decay is a simple problem in elementary quantum mechanics, often found in introductory textbooks. An α-particle, for example, can escape from an unstable nucleus only if it can tunnel through the potential barrier against disintegration caused by the nuclear forces that hold even unstable nuclei together. The chance that if such a particle exists within the nucleus it will then escape, or the rate of the corresponding disintegration process, is thus a function of the height of the potential barrier, its width and of the total decrease of the potential energy of the system once the disintegration has taken place.

This calculation, first made in simple form by Gamow, has more recently been much refined and accounts for the "Gamow factors" used by Rose and Jones as part of their reason for believing that their disintegration products are ^{14}C and not some other isotope of carbon. But even on this simple picture, one huge uncertainty persists — the chance that a particle of the kind that eventually tunnels successfully through the barrier can be held, if only momentarily, to exist. What emerges from what Rose and Jones now say is that the "preformation probability" of ^{12}C would have to be comparable with that of the much simpler α-particle if it were to be produced in a distintegration. That cannot be the case, at least on this simple picture. It is relevant, but sobering, also to recall that the preformation probability of ^{14}C inferred from the results now reported is substantially greater than might have been expected from simple considerations, which is a reminder that the calculation of the absolute rates of even α decay, for example, is still not feasible.

What, in these circumstances, may be made of the discovery now reported? If, in the years ahead, there should accumulate a handful of examples of exotic kinds of radioactive decay in unstable heavy nuclei, it should at least be possible to glean some empirical information on the chance that various groups of nucleons will assemble into different potential disintegration fragments in neutron-rich heavy isotopes such as ^{223}Ra.

Hopes that exotic disintegration routes may have some practical value in other fields, perhaps in some novel technique of geochronology, seem, however, to be slim. Exotic disintegrations of the kind now identified are simply too few compared with the more familiar α disintegrations for their daughter nuclei and their products to be recognizable among the end products of the three principal radioactive series. (And ^{14}C is in any case unstable.) But at this stage it would be rash to rule out such possibilities. Too many confident predictions that new phenomena have no practical significance have too often been falsified for that course to be wise. **John Maddox**

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