strain of mice was determined in 20 normal animals to be $10.6\% \pm 0.2\%$. Brecher *et al.* (*2*) found somewhat higher values, reporting total nucleated red cells.

The experimental group was maintained in the evacuated chamber until samples showed the erythroid cell level to have increased to $18.6\% \pm 1\%$. At this time both groups were exposed to 500 r of total-body X radiation and thereafter maintained at sea level pressure. The mice were placed 20 at a time in a paper box, $10 \times 10 \times 1.5$ cm, and irradiated with a 200-kv machine filtered with 1 mm of aluminum and 0.5 mm of copper, and calibrated with a Victoreen r-meter.

The data are presented in Fig. 1.

The control group responded as would be expected from previous studies (*1*) and (*2*). There was a rapid fall in percentage of erythroid cells in the first two days, followed by a rise from the fourth to the sixth day. This apparent recovery coincided with the loss of myeloid elements, the percentage of erythroid cells falling off again as the myeloid series recovered.

The group which had been subjected to anoxia showed the same pattern to the sixth day. However, the sharp fall noted in days 6–9 in the control group was absent. The probability that the differences between groups on days 7, 8, and 9 were due to chance alone is 1/250. It therefore appears that the hyperplasia of the red marrow produced by exposure to low oxygen tension enhances the resistance of the erythroid elements of the mouse subsequently exposed to 500 r total-body X radiations.

References

1. Bloom, M. A. and Bloom, W. *J. Lab. clin. Med.*, 1947, **6**, 654.
2. Brecher, G. *et al.* *Blood*, 1948, **3**, 1259.
3. Jacobson, L. O. *et al.* *Science*, 1948, **107**, 248.

Comments and Communications

The System of Stable Nuclei

For some time it has been known that certain preferred numbers, N or $Z = 20$, 50, 82 or 126 give exceptional stability to a nucleus (Elsasser, W. *J. Physique Rad.*, 1933, 4, 549; 1934, 5, 389, 635; Mayer, M. G. *Phys. Rev.*, 1948, 74, 235). Just recently it has been pointed out that in the neighborhood of $Z = 82$ and of $N = 126$, nuclei with a number of protons or neutrons only approximately equal to these numbers have abnormally high binding energies, too (Way, K. *Phys. Rev.*, 1949, 75, 1448). The same conclusion had been reached independently by Mr. Wapstra of this laboratory in connection with his calculations of nuclear masses of natural radioactive elements (Rosenfeld, L. *Nuclear forces* I, Netherlands: North-Holland Pub.; New York: Interscience, 1948, pp. 525–529 and plate II).

As an example we shall give an approximative sketch of a series of isotopes of a single element with neutron numbers between 120 and 132. Nuclei with $N = 120$ and 121 will have roughly normal energy contents. The binding energy of the 122nd neutron is slightly enlarged, which brings the energy content of this nucleus somewhat below normal. The following neutrons are again added with binding energies larger than normal till the nucleus with the preferred number $N = 126$ has been reached. This is the isotope in which the energy content of the nucleus lies deepest below the normal level. The 127th neutron is bound with an exceptionally small energy effect, but the nucleus as a whole still has a lower energy content than it would have had under normal circumstances. It takes about four more neutrons, which are bound less tightly than the average, to bring the energy content of the nucleus back to normal, around $N = 132$. A diagram of the difference between the actual energy content of the nuclei and its interpolated normal value shows a horizontal line $= 0$ below about $N = 122$ and above about $N = 132$. Between these values a dip is observed with its lowest point at $N = 126$. It is difficult to say anything definite both about the actual width and about the shape of this dip, but it seems likely that it is steepest near $N = 126$ and flattens out on both sides.

Thus the stabilizing influence is not restricted to the exact preferred numbers but it is also active, though to a lesser extent, in nuclei containing a number of nucleons smaller or larger by a few units. These near-preferred numbers make a nucleus more stable than normal compared to ordinary nuclei but they decrease their stability towards nuclei containing a preferred or a nearer preferred number of nucleons. It can be demonstrated that a similar state of affairs occurs also in the neighborhood of other preferred numbers below $N = 126$ and $Z = 82$ and that it explains the majority of the apparent irregularities in the system of stable nuclei.

First it may be pointed out that, contrary to an occasional suggestion (Suess, H. E. *Zeitschrift für Naturforschung*, 1947, **2A**, 604), the excess binding energy is very nearly equal in a proton and in a neutron of the same preferred number. Proof of this fact is to be found in the perfectly regular series of half-lives of the $Z = N + 1$ nuclei and in the agreement of the positron energy limit of Sc^{41} with the value calculated from the liquid drop model (Rosenfeld, L. *Loc. cit.*, p. 383).

If the increased binding energy had occurred only in nuclei with "preferred numbers," only the stability of these nuclei and that of the adjoining odd-mass nuclei would have been affected. As it is, the extra stability of near-preferred numbers of nucleons is expressed in the nuclear energy diagram as additional local valleys superimposed on the main surface, which have an axis coinciding with a line indicating one of the preferred numbers. This means that the line of maximum stability shows exceptionally high values of dZ/dN at $N=50$ and $N=82$ and an abnormally low value at $Z=50$.

The course of the energy valley is seen easily from the $Z=f(N)$ representation of stable odd-mass nuclei. In this scheme, different nuclei with a constant neutron excess lie on diagonals, straight lines making an angle of 45° with both axes. Above $N=82$, from gadolinium onwards, the course of this line is very regular. It is almost unaffected by the preferred numbers $Z=82$ and $N=126$, as it passes very near their intersection. The average number of nuclei with constant neutron excess is somewhat less than 4, at lower masses it should be slightly higher. The actual number of nuclei varies to a certain extent (3,5,3,5,2,4,2. . . .) possibly due to irregularities of the energy levels in individual nuclei. The steepness of the $Z=f(N)$ curve in the region of $N=50$ is seen from the fact that here nine nuclei have the same neutron excess 11, whereas the preceding neutron excess is represented by five nuclei only, and the neutron excess 7 by three. It is equally satisfactory to find very short series at $Z=50$, two nuclei with neutron excess 17 and $2\frac{1}{2}$ nuclei with an excess of 19. (Members of isobar pairs of unknown stability are counted as $\frac{1}{2}$.) In the neighborhood of $N=82$ the situation is somewhat more complicated. It will be discussed presently, but here also the number of 11 nuclei occupying two adjoining diagonals is strikingly high. J. H. D. Jensen and H. E. Suess (*Naturwiss.*, 1947, 34, 131) have stressed the fact that apart from the elements missing in nature ($Z=43$ and $Z=61$), there are also two even elements, which do not have an odd-mass isotope (argon with $Z=18$ and cerium with $Z=58$). In these elements the reason is easily understood, as the odd-mass isotopes which would normally have been stable, have adjoining isobars, with energies lowered by $N=20$ and $N=82$. In argon, A^{37} decays to Cl^{37} and A^{39} to K^{39}. In cerium, the situation is analogous, Ce^{139} being unstable towards La^{139} and Ce^{141} towards Pr^{141}. (These transitions are included in Elsasser's and M. G. Mayer's considerations.) In the region of $N=82$, the nuclei with near-preferred numbers are stabilized sufficiently to cause a more extensive irregularity. Either La^{137} ($N=80$) or Pr^{143} ($N=84$) should normally have been stable, but because the stability is increased to a greater extent at $N=81$ or at $N=83$ than at $N=80$ or 84, the nucleus has decayed to an adjoining isobar with a nearer-preferred nucleon number.

The absence of the elements $Z=43$ and $Z=61$ is much more difficult to explain. The only point which can be made is that if elements are lacking in nature their nuclear charges 43 and 61 are among the values where this type of anomaly is not unlikely to occur. The choice is governed by three considerations. First, the energy valley should not be too narrow; therefore light masses are excluded. Then, dZ/dN should be as high as possible—we must be in a steep part of the curve. (Otherwise a heavier odd-mass nucleus will always have a strong tendency towards a higher neutron excess.) Finally, the anomaly should be near the transition point between two diagonals.

The system of stable nuclei of even mass can be fully described by the stability of the lightest and the heaviest isotope of each element, as all even isotopes between are stable too. The only exception, samarium, is easily explained by the theory of M. G. Mayer. Sm^{144} is stable because of its 82 neutrons, whereas Sm^{146} has not been found. It is probably β-stable, but it is almost certainly an α-emitter, decaying to Nd^{142}, because the α-energy is increased by the latter's number of 82 neutrons.

According to E. Feenberg (*Rev. mod. Phys.*, 1947, 19, 239) single even isobars are to be expected among masses > 150. These are indeed observed at regular intervals in and above erbium, and also in and below germanium. Between these elements the only single isobars found—apart from Nd^{146}, which should have had Sm^{146} as its isobar—are Sr^{88} ($N=50$), Zr^{90} ($N=50$), Sn^{118} ($Z=50$), and Ce^{140} ($N=82$). These four are preferred-number nuclei, but this does not in itself provide an explanation of the absence of isobars. The real reason is that the adjoining odd-odd isobars have an increased binding energy too. This makes possible the decay, via this nearest-preferred nucleus, of the unstable even-mass isobar, in which the stability is increased to only a smaller extent. From the general course of the observed limits of β-stability one can easily see which isobars of the nuclei mentioned would have been stable if near-preferred nuclei had had normal energy contents: Zr^{88} (decays through Y^{88}), Sr^{90} (through Y^{90}), Te^{118} (through Sb^{118}), and Nd^{140} (through Pr^{140}) or Ba^{140} (through La^{140}). Ce^{144}, too, would have been a stable nucleus under normal conditions. As it is, Pr^{144}, with $N=85$, has an energy content sufficiently decreased to make possible the β-decay of Ce^{144}. The instability of the even isotopes mentioned explains why in these elements the odd-mass isotopes lie quite asymmetrically between the even ones. An additional reason is the shift of stability in odd-mass nuclei towards $N=82$.

Whereas the limits of β-stability are narrowed where a preferred number lies between them, they are widened in cases where the line indicating such a number runs near but outside one of the limits. In this case an extra even nucleus may be stabilized by the fact that it is nearer-preferred than the odd-odd nucleus through which it would have decayed under normal circumstances. This effect is seen in the triple isobars, of which four sets exist, at masses 96, 124, 130 and 136. Of these Sn^{124} ($Z=50$) and Xe^{136} ($N=82$) are stabilized by preferred numbers but Ru^{96} ($N=52$)—though it is difficult to say whether this nucleus is outside the normal β-stability limits or not—and Te^{130} ($Z=52$, $N=78$) owe their increased stability to near-preferred numbers. There can be little doubt that the exceptionally high abundances in ruthenium of the lightest isotopes—which are much rarer in other elements heavier than arsenic (FRANK, F. C. *Proc. phys. Soc.*, 1948, 60, 211)—and in tellurium of the heaviest isotopes are due to the same stabilizing influence.

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