SUPER HEAVY NUCLEI

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INTRODUCTION:

There are 92 naturally occurring elements with uranium having atomic number 92. The elements occurring after uranium are known as “transuranic elements”. A few numbers of these elements have been manufactured so far & these have life times in various ranges. Now there is a search for the possible existence of nuclei which are much heavier than already observed. These nuclei are known as “super heavy nuclei”

In nuclear structure physics, now it is a fascinating challenge to find the maximum atomic number Z -the number of protons for which a relatively stable nucleus can exist. The question is just how many stable elements is it possible to make.

The creation of three new elements last year, Z= 114, at the Joint institute for nuclear research at Dubna, Russia &Z=118, and Z=116 at Lawrence Berkeley, National laboratory, in US are momentous events in the field of super heavy nuclei production. This has opened a new, exciting area of research in nuclear physics.
Nuclear stability:

To know about the stability of various nuclei a nuclear chart is used which is plot between no of neutrons & no of protons. The chart shows that there are about three hundred nuclei present which are very much stable and form a valley of stability. Yet there are abut two thousand nuclei discovered up to now with various life times.

The existence of valley of stability is well explained by nucleon separation energy. Neutron separation energy: The energy required to separate one neutron from the nucleus.

Mathematically,

$Sn(N,Z) = B.E(N, Z) - B.E(N-1, Z)$
Proton separation energy: Energy required to separate one proton from the nucleus.
$Sp(N,Z) = B.E(N, Z) - B.E(N, Z-1)$

When we go on adding neutrons (say) to a nucleus with fixed z, after a certain no. the nucleus does not accept any neutrons. Then at that point Sn=0. Similar is the case for protons.

So we can then draw two lines on the sides of valley of stability along which the proton and neutron separation energy is zero. These are called proton and neutron drip lines.

Hence for a particular value of Z, we can create a no. of relatively stable nuclei by adding neutrons to it up to a certain limit. Similarly for a particular value of N, a no. of isobars can be created.

All these discussions infer that if there exists a super heavy nucleus somewhere in the stability region, then there can actually be a no. of nuclei in its neighborhood which are also relatively stable.

SHELL STRUCTURE OF SUPER HEAVY ELEMENTS:

The stability of a nucleus is better understood by its shell structure, where nucleons are assumed to occupy certain energy levels. Rather than being evenly distributed, there occur 'shell gaps' because of splitting of orbits. A magic no. of nucleons, e.g. 2, 8,20,50,82,126 ...arise when they fill up the levels just below the shell gap. This compression in energy levels leads to significant increase in B.E and hence stability of a nucleus. This shell effect persists over a range of nucleon numbers around the magic number. Clearly, nuclei with both N, Z being magic are called 'doubly magic' and are extra-stable.

The heaviest closed shell nucleus known so far is $^{126}Pb^{82}$ with Z=82 and N=126. Calculations indicate that the next stable nucleus should have Z=114 because of the large separation between proton orbits $3p^{3/2}$, $2f^{5/2}$ and $1h^{9/2}$, $1i^{3/2}$, $2f^{7/2}$. Similarly there is a shell closure at N=184 for the neutrons. Thus the next stable super heavy element has Z=114, N=184.

Since Z=114 is not very far from the actinide series at Z=103, there is some possibility that this super heavy nucleus can be created in the lab.

ISLAND OF STABILITY:

As discussed earlier there should be a no. of nuclei around the next close shell super heavy nucleus Z=114, N=184, which will also be relatively stable. This group of nuclei constitutes an island of stability in the sea of instability on the nuclear chart.

Similarly we can have another island of stability around Z=184, the next shell closure. These nuclei may have life times varying from few milliseconds to several years.

After this prediction many experimental attempts were made to create super heavy elements and to discover the island of stability.

SYNTHESIS OF SUPER HEAVY NUCLEI:

Since the nuclei to be synthesized are very heavy, we have to choose the target and projectile accordingly. To fuse the target and projectile, they must be launched with a relatively high K.E to overcome the repulsive or coulomb energy between their positive charges. Below this coulomb barrier the probability of fusion drops drastically and even at this energy the compound nucleus is formed at a temperature at which such a heavy system is unlikely to survive fission. So though the fusion probability increases gradually above the coulomb barrier the survival probability falls off steeply. Hence the projectile and targets are so chosen that when they fuse just at the coulomb barrier, the compound nucleus formed should not be excited to much higher energy so that spontaneous fission to smaller nuclei are avoided by the evaporation of just a few no. of neutrons. Pb^{208}, U^{234}, $Pu^{242,244}$, Kr^{86}, Ca^{48} are some of the targets and projectiles used in the recent experiments on super heavy elements. Particularly Ca^{48} plays a very important role there. Being doubly magic it has a significant mass defect and compound nucleus formed with this as a projectile has a lower excitation energy.

RECENT DISCOVERIES:

To bridge the gap between the stable or long-lived nuclei and the putative island of stability many experimental attempts are being made. The most recent discoveries are tabulated below:

Year	Place	Element Discovered	Reactions involved
1994-96	G.S.I, U.S.A	110,111	112, $^{208}Pb_{82}$+a suitable projectile$\rightarrow$(( )$_{110}$, ( )$_{111}$,( )$_{112}$
Mid 1998	Dubna, Russia	112	$^{238}U_{92}+^{48}Ca_{20}\rightarrow$ ^{286}( )$_{112}$, ^{3n} ^{283}( )$_{112}$
End of 1998	-Do-	114	$^{244}Pu_{94}+^{48}Ca_{20}\rightarrow^{292}$( )$_{114}$ $^{(3n}$ ^{289}( )$_{114}$
5thApril 1999	-Do-	114	$^{242}Pu_{94}+^{48}Ca_{20}\rightarrow$ ^{290}( )$_{114}$$^{(3n}$ ^{287}( )$_{114}$
June 1999	LBNL, Germany	118,116	$^{208}Pb_{82}+^{86}Kr_{36}\rightarrow$(( )$_{118}$ ((( )^{116}((( )$_{114}$ (......

CONCLUSION:

The group of scientists in Dubna were able to create the two isotopes of Z=114. The predicted stable super heavy nuclei has Z=114, N=184. Thus we have reached the island in terms of proton number and we are getting closer towards it in terms of neutron number.

The life time of 287( ) 114 against fission = 1.32 seconds.

The life time of 289( ) 114 against fission = 30.4 seconds.

So it is clear that as the no of neutrons increases, the stability also increases. Such a trend was expected because according to our prediction, at N = 184 we will get the most stable nucleus in that island. Hence this increase in life time gives an experimental proof of the existence of the island.

Among the groups working on the synthesis of super heavy nuclei all over the world, the Dubna group is found to be the closest in terms of reaching the island. And we hope that we will parachute over the beach of this island in near future.

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Seminar delivered on

<u>REFERENCES</u>

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