The Meson Bond Barrier to Nuclear Fission

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SUMMARY. The Coulomb barrier to nuclear fusion is sometimes described as a barrier to nuclear fission. In this paper it will be shown that it is more meaningful to describe the repulsive Coulomb force between the daughters of fission as the cause of fission rather than a barrier. In fact it is this force which breaks the meson bonds between the daughters and imparts kinetic energy to them. This process may therefore be described as a quantum jump rather than a 'tunneling'. The Bernal liquid drop layered alpha particle model of a heavy nucleus shows that the sixth layer of alpha particles is not closed and is inherently unstable. This nucleus therefore either gradually decays by radiating alpha and beta particles until most of the sixth layer has been shed or it undergoes spontaneous fission to form a heavy daughter rarely containing less than four closed layers and a lighter daughter never containing less than three closed layers. It will be shown how each alpha decay involves the breaking of five or six meson bonds and each spontaneous fission breaks about thirty bonds.

1. Introduction

The underlying nuclear structure of heavy elements may be visualized as 6 concentric layers of alpha particles. This structure is based on Bernal's [1] model of a drop of a monatomic liquid in which hard spheres representing atoms are densely packed. This model successfully explained many properties of such liquids as well as those of metallic glasses. Norman [2]-[7] showed how Bernal's model may be used to account for the size, density, quadrupole moment and binding energy levels of many nuclei if the hard spheres are alpha particles. Accordingly an oxygen 16 nucleus is modeled as a single tetrahedral layer of 4 alpha particles. A second layer of 4 alpha particles models sulfur 32, a third layer of 6 alphas models nickel 56; a fourth closed layer of 12 alphas forms the core of all nuclei containing at least 52 protons, and a fifth layer of 12 additional alphas forms a basis for those nuclei with 76 or more protons. Norman [3],[4] has also shown that this latter structure of 38 alphas constitutes the stable end point of the radioactive decay of heavy nuclei such as uranium. Furthermore, when a uranium nucleus undergoes fission induced by thermal neutrons it forms a light fragment with a core of no less than 3 alpha layers and a heavier daughter with a core of rarely less than 4 alpha layers.

2. Meson Bonds

If the inter-nucleon bond between two adjacent nucleons in a nucleus is mediated by the exchange of virtual mesons then the time averaged meson bond (MB) energy, E_m may be calculated in the following way. Because of isospin it is assume that 6 equal meson bonds strongly bind the 2 protons and 2 neutrons of a ^{4}He nucleus (alpha particle) into a tetrahedral structure. The total meson bond energy, E_m, of the ^{4}He nucleus is defined as the empirically determined binding energy, E_b, of this nucleus corrected for the Coulomb repulsive energy, Ec, so that: $E_m = 6\ \text{MB} = E_b + E_c$ where $E_b = 28.3$ MeV and $E_c = 0.8$ MeV. Therefore 1 MB = 4.84 MeV. The total number of meson bonds in any nucleus is equal to the value of Em for that nucleus divided by 4.84 MeV.

A table of the values of E_b, E_c, E_m and the number of MB for the decay products of U235 is provided in Appendix 1. The data that is provided in Table 3 indicates the manner in which the number of meson bonds between successive layers increases in order to balance the increasing Coulomb repulsion.

3. Alpha Decay

The net energy balance of an alpha decay may be written as follows:

$$\Delta E_b = E_k \qquad (1)$$

where ΔE_b is the difference between the sum of the binding energies of the two daughter nuclei and the b0inding energy of the mother nucleus. E_k is the kinetic energy of the alpha particle. This is exemplified by the alpha decay of ^{235}U where

$$\Delta E_b = 4(\text{MeV}) \text{ and } E_k = 4(\text{MeV}).$$

However, equation (1) takes no account of the difference ΔE_c between the powerful repulsive Coulomb energy of the mother nucleus and the sum of the Coulomb energies of the daughter nuclei. Adding ΔE_c to both sides of (1) gives:

$$\Delta E_b + \Delta E_c = \Delta E_c + E_k \qquad (2)$$

Subtracting ΔE_b from both sides of (2) gives:

$$\Delta E_c = \Delta E_c - \Delta E_b + E_k \qquad (3)$$

In all alpha decays $\Delta E_c - \Delta E_b = \Delta E_m$ where ΔE_m is the meson bond barrier being the difference between the meson energy of the mother nucleus and the sum of the meson energies of the two daughters. It can be seen in Table 1 that this difference is approximately equivalent to 6 meson bonds (namely 29.1MeV). Equation (3) may be rewritten as: $\Delta E_c = \Delta E_m + E_k$ (4)

This equation was previously used in reference [4] to describe alpha decay in ^{238}U as Coulomb breaking of the 6 meson bonds between the two daughter nuclei.

In this way an alpha particle 'tunnels' through the so-called Coulomb barrier. The total energy balance (in MeV) is indicated in Figs.1and 2 for the initial decay of ^{235}U and in Table 1 for all 10 alpha decays in the decay chain of ^{235}U.

^{235}U	→	^{231}**Th + alpha**
$E_c = 909$		
	$\downarrow \Delta E_c = -33$	$E_c = 876$
0	**0**	**0**
$E_b = -1784$		
	$\downarrow \Delta E_b = -4$	$E_b = -1788$
		$E_m = -2664$
$E_m = -2693$	$\uparrow \Delta E_m = 29$	
	$\uparrow E_k = 4$	

Fig.1 Schematic energy balance of ^{235}U alpha decay

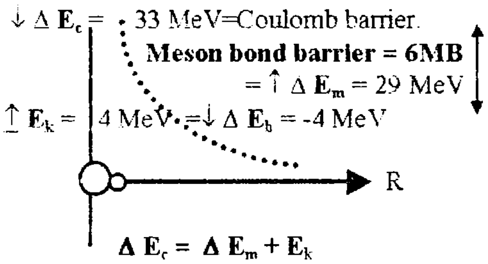

Fig.2 The meson bond barrier, ΔE_m, to the alpha decay of ^{235}U.

Alpha Decay	**ΔE_c (MeV) Released**	**$\Delta E_m + E_k$ (MeV) Absorbed**
$^{235}U \rightarrow {}^{231}Th + \alpha$	33	29 + 4 = 33
$^{231}Pa \rightarrow {}^{227}Ac + \alpha$	33	28 + 5 = 33
$^{227}Ac \rightarrow {}^{223}Fr + \alpha$	32	28 + 5 = 33
$^{227}Th \rightarrow {}^{223}Ra + \alpha$	33	27 + 6 = 33
$^{223}Ra \rightarrow {}^{219}Rn + \alpha$	32	27 + 6 = 33
$^{219}Rn \rightarrow {}^{215}Po + \alpha$	32	25 + 6 = 31
$^{215}Po \rightarrow {}^{211}Pb + \alpha$	31	24 + 7 = 31
$^{215}At \rightarrow {}^{211}Bi + \alpha$	32	24 + 8 = 32
$^{211}Bi \rightarrow {}^{207}Tl + \alpha$	31	25 + 6 = 31
$^{211}Po \rightarrow {}^{207}Pb + \alpha$	32	24 + 8 = 32

Table1. Energy balances for ^{235}U alpha decay chain

4. Fission Energy Balance

The fission of a ^{235}U nucleus into 2 daughters each larger than an alpha particle has previously been discussed by Norman [3],[5] in terms of the layered alpha particle models of nuclear structure. In those papers it was shown that the lighter daughter never has a core of less than 14 alpha particles whereas the heavier daughter rarely has a core of less than 26 alphas.

An example of the energy balance (in MeV) involved in the fission of ^{235}U is illustrated in Figures 3 and 4.

^{235}U	→	**2n +** ^{141}**Ba +** ^{92}**Kr**
$E_c = 909$		
	$\downarrow \Delta E_c = -325$	$E_c = 584$
0	**0**	**0**
$E_b = -1784$		
	$\downarrow \Delta E_b = -173$	$E_b = -1957$
		$E_m = -2541$
$E_m = -2693$	$\uparrow \Delta E_m = 152$	
	$\uparrow E_k = 173$	

Fig.3 Schematic energy balance of a ^{235}U fission.

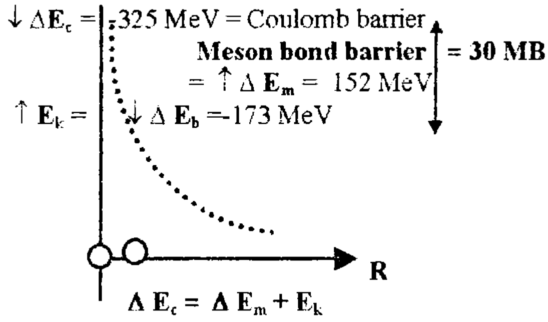

Fig.4 The meson bond barrier, $\uparrow \Delta \mathbf{E_m}$, to the fission of a ^{235}U nucleus.

It will now be shown that in each of these fission processes the separation of the 2 initial unstable daughters involves the breaking of approximately 30 meson bonds. This will be indicated in Table 2 by a number of examples of fission ranging across the bi-modal fission spectrum of ^{235}U. In this Table the numbers refer to the meson bonds associated with the terms of the equations. The derivation of the bonds in each nucleus is to be found in Appendix 2.

^{235}U:	Neutrons:	2 Daughters:		Broken Bonds between daughters:
$^{235}U \rightarrow$	n +	^{157}Sm +	^{77}Zn	
556		363	164	29
$^{235}U \rightarrow$	2n +	^{144}Ba +	^{89}Kr	
556		327	198	31
$^{235}U \rightarrow$	2n +	^{141}Ba +	^{92}Kr	
556		325	201	30
$^{235}U \rightarrow$	n +	^{140}Xe +	^{94}Sr	
556		316	210	30
$^{235}U \rightarrow$	2n +	^{132}Sn +	^{101}Mo	
556		294	230	32
$^{235}U \rightarrow$	n +	^{128}Sn +	^{106}Mo	
556		290	236	30
$^{235}U \rightarrow$	3n +	^{116}Pd +	^{116}Pd	
556		261	261	34

Table 2 Meson bonds involved in the creation of the initial products of ^{235}U fission.

The effective source of energy in breaking the bonds and imparting kinetic energy to the daughters is the excessive Coulomb repulsion energy, ΔE_c, in the metastable ^{235}U nucleus just as in alpha decay.

Each of the daughters listed in Table 2 is intrinsically unstable due to an excess of neutrons. Stability is quickly restored in each nucleus as several neutrons are converted into protons by successive β decays. The release of energy occurs as new meson bonds complete the formation of new alpha particles in each daughter nucleus.

5. A Fission Mechanism

From this analysis it can be seen that very little, if any, energy is needed to destabilize a ^{235}U nucleus in order for either alpha decay or fission to occur. In both cases the so-called 'Coulomb Barrier' is the cause of fission rather than a barrier. Furthermore it is more appropriate in each case to describe the process of 'tunneling' as a quantum jump in a manner analogous to the process of a gamma decay in an excited nucleus or of ionization of an atom. In alpha decay and fission the fundamental difference between the concepts of tunneling and jumping arises from the decision to either ignore or consider the Coulomb force and energy inside the nucleus.

The mechanism for fission consistent with the layered alpha particle model is based on the bond structures of closed layer nuclei as first outlined in reference [6] and as listed below in Table 3. Noting that there is a total of 60 meson bonds between layers 4 and 5 it appears that in the fission process about 30 of these bonds are broken after the uranium nucleus is destabilized either by deformation or the absorption of a thermal neutron.

Layer	**1**	**2**	**3**	**4**	**5**	**6**
Alphas/ Layer	4	4	6	12	12	16
MB in Layer	4x6 =24	4x6 =24	6x6 =36	12x6 =72	12x6 = 72	16x6 = 96
MB ex Layer	4x3/2 =6	4x3 =12	6x4 =24	12x4 = 48	12x5 = **60**	16x**6** =96
MB in + ex	24+6 =30	24+12 =36	36+24 =60	72+48 =120	72+60 =132	96+96 =192
Closed Nucleus	$_8O_8$	$_{16}S_{16}$	$_{28}Ni_{28}$	$_{52}Te_{76}$	$_{76}Os_{116}$	$_{108}Hs_{157}$
MB N-Z	-	-	-	24x2 =48	40x2 =80	49x1 =49
MB Core	30	30+36 =66	66+60 =126	126+120 =246	246+132 =378	378+192 =570
MB Total (Model)	30	66	126	48+246 =294	80+378 =458	49+570 =619
MB Total (Data)	29	67	127	296	456	646

Table 3. The bond structure of the layered models of nuclei with closed layers compared with the total number of bonds based on calculations of E_m.

According to the liquid drop model of fission triggered by the absorption of a thermal neutron the nucleus undergoes oscillations until the nucleus becomes elongated like an egg rather than spherical. According to the layered alpha particle model it is at this stage that part of the outer 2 layers (the egg white) separates from the inner core of 4 layers (the egg yolk) when 30 meson bonds are broken by the Coulomb force acting between the 2 daughters as illustrated in Fig.5.

6. Conclusion

The Bernal liquid drop alpha particle model of a heavy nucleus shows that the sixth layer of alpha particles is not closed and is inherently unstable so that the nucleus either gradually decays or undergoes spontaneous fission. It decays by radiating alpha and beta particles until most of the sixth layer has been shed. The alpha decay may be construed as the release of repulsive Coulomb energy that breaks six meson bonds and imparts kinetic energy to the alpha particle. In this way the alpha particle jumps rather than 'tunnels' through the Coulomb barrier. By contrast, in beta decay energy is released when a neutron decays to form a proton and electron at the same time as four new meson bonds are formed. Together these two sources of energy balance the additional repulsive Coulomb energy generated by the new proton in the daughter nucleus and impart kinetic energy to the beta particle and anti-neutrino as explained in reference [4]. Uranium fission is similar to alpha decay and involves the Coulomb breaking of about 30 meson bonds to separate at least 14 alphas simultaneously as a light daughter. Both daughters subsequently become more stable by a sequence of beta decays.

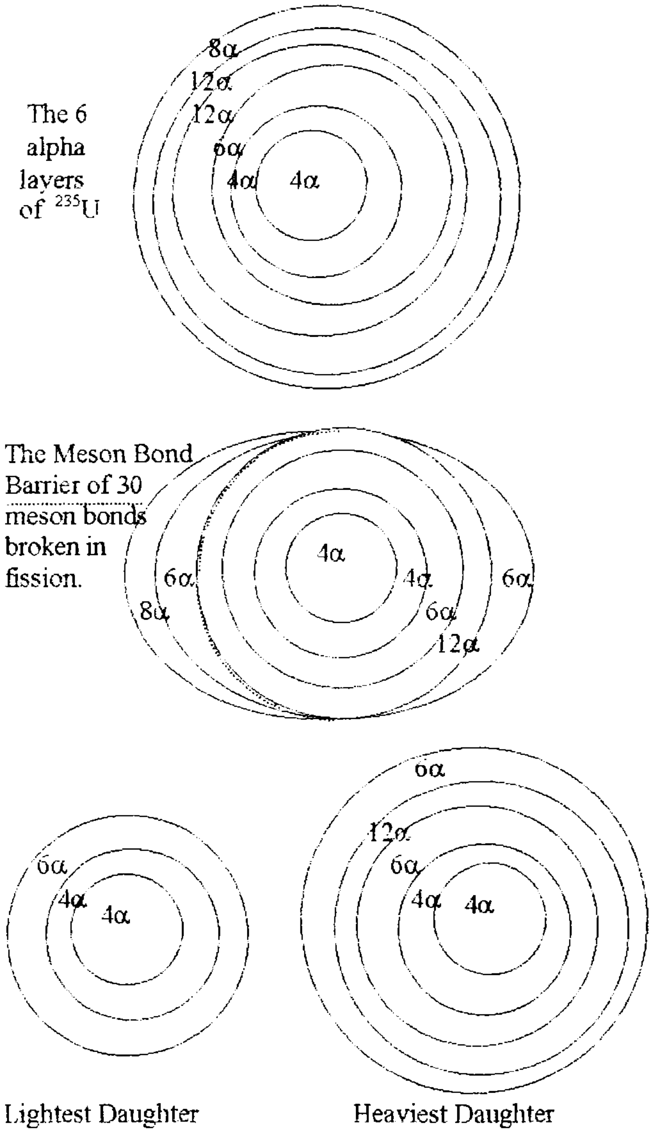

Figure 5. An illustration of the fission of a ^{235}U nucleus modeled as a liquid drop of 6 layers of alpha particles.

7.Appendix 1.

Binding, Coulomb and Meson Bond Energies (in MeV) of decay products of ^{235}U

A	P	N	E_b	E_c	E_m	MB
^{235}U	92	143	1784	909	2693	556
^{231}Pa	91	140	1760	894	2654	548
^{231}Th	90	141	1760	875	2635	544
^{227}Th	90	137	1736	880	2616	540
^{227}Ac	89	138	1737	860	2597	537
^{223}Ra	88	135	1714	846	2560	529
^{223}Fr	87	136	1713	827	2540	525
^{219}Rn	86	133	1691	813	2504	517
^{215}At	85	130	1670	799	2469	510
^{215}Po	84	131	1670	780	2450	506
^{211}Po	84	127	1650	785	2434	503
^{211}Bi	83	128	1650	766	2416	499
^{211}Pb	82	129	1649	748	2397	495
^{207}Pb	82	125	1629	752	2381	492
^{207}Tl	81	126	1628	734	2362	488

8. Appendix 2.

Binding, Coulomb and Meson Bond Energies of some fission products of ^{235}U.

A	P	N	E_b (MeV)	E_c (MeV)	E_m (MeV)	MB
^{235}U	92	143	1784	909	2693	556
^{157}Sm	62	95	1286	469	1755	363
^{144}Ba	56	88	1190	394	1584	327
^{141}Ba	56	85	1174	397	1571	325
^{140}Xe	54	86	1161	370	1530	316
^{132}Sn	50	82	1103	323	1424	294
^{128}Sn	50	78	1072	326	1403	290
^{116}Pd	46	70	980	284	1265	261
^{106}Mo	42	64	899	244	1143	236
^{101}Mo	42	59	866	248	1113	230
^{94}Sr	38	56	808	207	1015	210
^{92}Kr	36	56	783	187	970	201
^{89}Kr	36	53	767	189	956	198
^{77}Zn	30	47	657	137	794	164

9. References

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