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# Meson Bonds and Radioactive Decay

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**SUMMARY**. The Bernal liquid drop alpha particle model of a heavy nucleus shows that the fifth layer of alpha particles is not closed and is inherently unstable so that the nucleus gradually decays by radiating alpha and beta particles until most of the fifth layer has been shed. It will be shown how 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 'tunnels' through the Coulomb barrier. By contrast, in beta decay energy is released when a neutron decays into 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

## 1. Introduction

The underlying nuclear structure of heavy elements may be visualized as 5 concentric layers of alpha particles. This structure is an extension of layered alpha particle models of common nuclei 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) 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 10 alpha particles models nickel 56; a third closed layer of 12 alphas forms the core of all nuclei containing at least 52 protons, and a fourth 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 2 alpha layers and a heavier daughter with a core of rarely less than 3 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 meson bond (MB) energy may be calculated in the following way. Assume that 6 equal meson bonds strongly bind the 2 protons and 2 neutrons of a He4 nucleus (alpha particle) into a tetrahedral structure. The total meson bond energy, Em, of the He4 nucleus is defined as the empirically determined binding energy, Eb, of this nucleus corrected for the Coulomb repulsive energy, Ec, so that: Em = 6 MB = Eb + Ec where Eb = 28.3 MeV and Ec = 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 Eb, Ec, Em and the number of MB for the decay products of U238 is provided in the Appendix.

## 3. Alpha Decay

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

$$\Delta Eb = Ek \qquad (1)$$

where ΔEb is the difference between the sum of the binding energies of the two daughter nuclei and the binding energy of the mother nucleus. Ek is the kinetic energy of the alpha particle. This is exemplified by the alpha decay of U238 where

$$\Delta Eb = 4.27(\mathrm{MeV}) \text{ and } Ek = 4.19(\mathrm{MeV}).$$

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

$$\Delta Eb + \Delta Ec = \Delta Ec + Ek \qquad (2)$$

Subtracting ΔEb from both sides of (2) gives:

$$\Delta Ec = \Delta Ec - \Delta Eb + Ek \qquad (3)$$

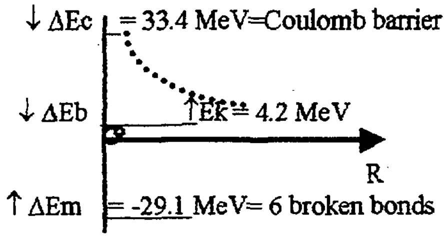
In all alpha decays $\Delta Ec - \Delta Eb = \Delta Em$ where ΔEm is the difference between the meson energy of the mother nucleus and the sum of the meson energies of the two daughters. It can be seen in Table 1 that this difference is approximately equivalent to 6 meson bonds (namely 29.1MeV). Equation (3) may be rewritten as:

$$\Delta Ec = \Delta Em + Ek \qquad (4)$$

This equation describes an alpha decay as the Coulombic breaking of the 6 meson bonds between the two daughter nuclei. In this way an alpha particle 'tunnels' through the so-called Coulomb barrier. This total energy balance is indicated in Figs.1and 2 for the initial decay of U238 and in Table1 for all 8 alpha decays in the decay chain of U238 as illustrated in Fig.5.

| **U238** | → | **Th234 + α** |
|---|---|---|
| Ec = 905.1 | | |
| | ↓ΔEc = -33.4 | Ec = 871.7 |
| **0** | **0** | **0** |
| Eb = -1801.6 | | |
| | ↓ΔEb = - 4.3 | Eb = -1805.9 |
| | | Em = -2677.6 |
| Em = -2706.7 | ↑ΔEm= 29.1 | |
| | ↑Ek = 4.2 | |

Fig.1 Schematic energy balance of U238 alpha decay



**ΔEc = ΔEm + Ek**

(Note: ΔEb is included in ΔEm)

Fig.2 The Coulomb barrier to α decay of U238

| **Alpha Decay** | **ΔEc (MeV) Released** | **ΔEm + Ek (MeV) Absorbed** |
|---|---|---|
| U238 → Th234 + α | 33.4 | 29.1 + 4.2 = 33.3 |
| U234 → Th230 + α | 33.6 | 28.8 + 4.8 = 33.6 |
| Th230 → Ra226 + α | 33.0 | 28.2 + 4.6 = 32.8 |
| Ra226 → Rn222 + α | 32.4 | 26.9 + 4.8 = 31.7 |
| Rn222 → Po218 + α | 31.9 | 26.3 + 5.5 = 31.8 |
| Po218 → Pb214 + α | 31.4 | 25.7 + 6.0 = 31.7 |
| At218 → Bi214 + α | 31.7 | 24.8 + 6.7 = 31.5 |
| Po214 → Pb210 + α | 31.5 | 22.7 + 7.7 = 30.4 |

Table1. Energy balances for U238 alpha decay chain

## 4.Beta Decay

The net energy balance of a beta decay is:

$$En - \Delta Eb = Ek \qquad (5)$$

where ΔEb is the difference between the binding energies of the mother and daughter nuclei, and Ek is the maximum kinetic energy of the radiated β particle. En is equal to 0.78 MeV being the difference between the rest mass energies of the decaying neutron and the sum of those of the new proton and radiated β particle. Equation (5) is exemplified by the beta decay of Th234 to Pa234 as follows: 0.78 – 0.5 ~ 0.19 MeV

Adding ΔEc to both sides of (5) gives:

$$En + \Delta Ec - \Delta Eb = \Delta Ec + Ek \qquad (6)$$

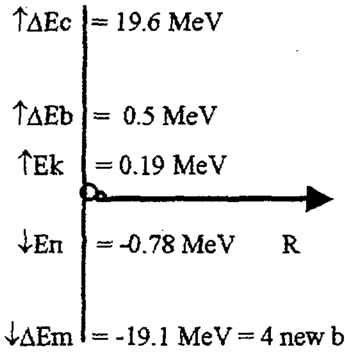
By replacing $\Delta Ec - \Delta Eb$ wtth ΔEm (6) becomes:

$$En + \Delta Em = \Delta Ec + Ek \qquad (7)$$

It can be seen in Table2 that ΔEm represents the energy released as approximately 4 new meson bonds are formed (19.4 MeV). Equation (7) effectively says that β decay occurs when a neutron in the mother nucleus decays and 4 new meson bonds form in order to counteract the increased Coulomb repulsion generated by the newly formed proton. This total energy balance is graphically indicated in Figs 3 and 4 for the beta decay of Th234. Table 2 gives the relevant data for 5 beta decays in the U238 series.

| **Th234** | → | **Pa234 + β** |
|---|---|---|
| | | Ec = 890.5 |
| Ec = 870.9 | ↑ΔEc = 19.6 | |
| **0** | **0** | **0** |
| | | Eb = -1777.1 |
| Eb = -1777.6 | ↑ ΔEb = 0.5 | |
| Em = -2648.5 | | |
| | ↓ΔEm= -19.1 | Em = -2667.6 |
| | ↓ En = -0.78 | |
| | ↑ Ek = 0.19 | |

Fig.3 Schematic energy balance of Th234 beta decay



**ΔEm + En = ΔEc + Ek**

(Note: ΔEb is included in ΔEm)

Figure 4. Energy balance for β decay of Th234

| Beta Decay | ΔEm + En Released | ΔEc + Ek Absorbed |
|---|---|---|
| Th234→Pa234 +β | 19.1+ 0.78 = 19.88 | 19.6+ 0.19 = 19.79 |
| Pa234→U234 + β | 20.9+ 0.78 = 21.68 | 19.7+ 0.5 = 20.2 |
| Po218 →At218+ β | 18.2+ 0.78 = 18.98 | 18.7+ 0.3 = 19.0 |
| Pb214→Bi214+ β | 19.1 + 0.78 = 19.88 | 18.4 + 0.7 = 19.1 |
| Bi214→Po214+ β | 20.1+ 0.78 = 20.88 | 18.6+ 0.4 = 19.0 |

Table2. Energy balances for U238 beta decay.

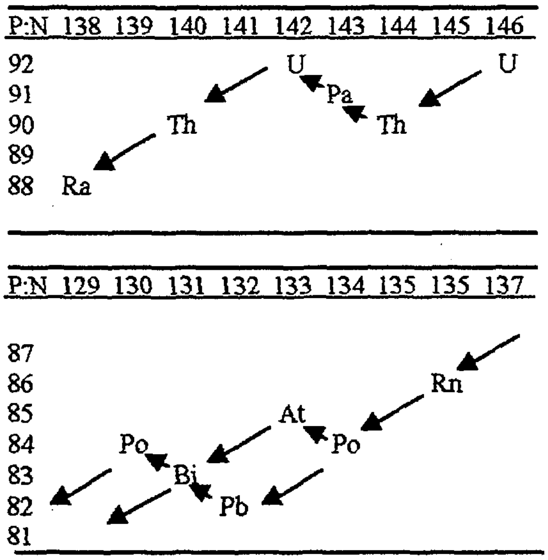


Fig. 5 The radioactive decay chain of U238
In each **α decay** (↙) the energy released by the decrease in the total Coulomb repulsion energy breaks 6 meson bonds and imparts kinetic energy to the α particle.

In each **β decay** (↘) the increased Coulomb repulsion energy is counteracted by the formation of 4 additional meson bonds and the energy released by the decaying neutron.

## 5. Conclusion

The Bernal liquid drop alpha particle model of a heavy nucleus shows that the fifth layer of alpha particles is not closed and is inherently unstable so that the nucleus gradually decays by radiating alpha and beta particles until most of the fifth layer has been shed. It has been shown how 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 'tunnels' through the Coulomb barrier. By contrast, in beta decay energy is released when a neutron decays into 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

## 6. Appendix.

Binding, Coulomb and Meson Bond Energies of Decay Products of U238

| A | P | N | $E_b$ | $E_c$ | $E_m$ | MB |
|---|---|---|---|---|---|---|
| U238 | 92 | 146 | 1802 | 905 | 2707 | 559 |
| U234 | 92 | 142 | 1779 | 910 | 2689 | 555 |
| Pa234 | 91 | 143 | 1777 | 891 | 2668 | 551 |
| Th234 | 90 | 144 | 1778 | 871 | 2649 | 547 |
| Th230 | 90 | 140 | 1755 | 876 | 2631 | 544 |
| Ra226 | 88 | 138 | 1731 | 842 | 2574 | 532 |
| Rn222 | 86 | 136 | 1708 | 809 | 2517 | 520 |
| Po218 | 84 | 134 | 1685 | 776 | 2462 | 508 |
| At218 | 85 | 133 | 1685 | 795 | 2480 | 512 |
| Po214 | 84 | 130 | 1666 | 781 | 2446 | 506 |
| Bi214 | 83 | 131 | 1664 | 762 | 2426 | 501 |
| Pb214 | 82 | 132 | 1663 | 744 | 2407 | 497 |
| Pb210 | 82 | 128 | 1646 | 749 | 2394 | 495 |

## 7. References

(1) Bernal,J.D.(1960) Nature, (London),185,68.
(2) Norman,P.(1993)Eur.J.Phys.,(Bristol),14,36.
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(4) Norman,P.(1998)Proc.Nat.Cong.AIP, (Freemantle), 25,365.