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LETTER TO THE EDITOR

# Uniqueness of $^{56}$Fe as a primary standard for atomic masses

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**Abstract.** A recent evaluation of atomic masses confirms that $^{56}$Fe has uniquely the 'least' atomic mass per baryon, ${}^{A}_{Z}M/A$. Thus, with $^{56}$Fe as the primary standard (${}^{56}_{26}M = 56$) all other atomic masses would be greater than the mass number $A$ and the corresponding 'mass excesses' would be not only 'positive' but also 'maxima'. Moreover, a mass excess relative to $^{56}$Fe is potentially the largest 'portion' of the atomic mass that can be transformed into energy (assuming conservation of baryon number); it therefore has a unique physical significance. Accordingly, a plot of the mass excesses against $A$ and $Z$ would provide a unique 'potential-energy surface' which should be useful in the representation of nuclidic transformations that involve a change in $A$ (eg $\alpha$ decay) as well as those with $A$ = constant.

Initially, atomic masses were determined with $^{16}$O as the primary standard and the empirical values differed from an integer by a very small amount. Accordingly, it was convenient to express the mass of an atom as $\{A+(\Delta)\}$ atomic mass units, where $A$ is an integer and $(\Delta)$ is a small proper fraction $(\pm)$. The integer $A$ was referred to as the 'mass number' and $(\Delta)$ has been referred to as the 'mass fraction' (Durnford 1965).

For various reasons (Wichers 1959, Kohman *et al* 1959), the primary standard was changed in 1960 to $^{12}$C and the atomic mass unit became one twelfth the mass of the neutral $^{12}$C atom; the latter is represented by $u$ (Duckworth 1961). Although this altered the values of $(\Delta)$, with the decrease being approximately proportional to $A$, the values of $A$ were not affected. Thus the mass of an atom has been represented (Durnford 1965) by the formula ${}^{A}_{Z}M = \{A + {}_{Z}(\Delta)^{A}\}u$, where $Z$ represents the 'atomic number'. The quantity ${}_{Z}(\Delta)^{A}u$ is called the 'mass excess' and, being dependent on both the mass number and the atomic number, is represented by the symbol ${}_{Z}\Delta^{A}$, without parentheses. Alternatively, the mass excess can be expressed in energy units but it should be noted that this does not render it independent of the choice of primary standard. Furthermore, the majority of the mass excesses relative to $^{12}$C have 'negative' values.

It has been pointed out (Durnford 1965) that having adopted a particular atom as the primary standard for empirical purposes, it is a simple matter to determine the atom that must be used as the primary standard in order that all mass excesses be 'positive'. Employing 1960 values of atomic masses (Everling *et al* 1960), it was shown that $^{56}$Fe uniquely satisfied the required condition (Durnford 1965). Additional advantages attendant on this choice of primary standard were discussed in the same communication (eg absolute energy diagram). Furthermore, other investigators (Harrison *et al* 1965) have found it convenient to adopt $^{56}$Fe as a standard, on the assumption that it represents the most stable nuclide in the atomic system. Accordingly, with 'the 1971 atomic mass evaluation' by Wapstra and Gove (1971) now at hand, it would appear to be desirable to check the validity of the above findings.

The justification for the criterion that led to the 1965 selection of $^{56}$Fe, follows quite simply if we express the mass of an atom in the form

$$M(\text{relative to } ^{12}\text{C}) = A\{1+(\Delta)/A\}u \equiv A(1+f)u$$

where $f$ is the so called 'packing fraction'. Thus $(1+f)u \equiv M/A$ which equals the mass per baryon (Harrison *et al* 1965, Klepp 1966); this can be regarded as a 'natural' unit of mass that varies from atom to atom. It follows that the most stable atom corresponds to that with the smallest packing fraction. Furthermore, if an integral mass $A$ is assigned to this particular atom, all other atoms will have 'positive' mass excesses. Accordingly, packing fractions† corresponding to the isobar with the 'least mass-excess', as given by Wapstra and Gove (1971), have been calculated and a selection with the range $48 \leqslant A \leqslant 72$ is given in table 1 along with estimates of error. Table 1 includes all cases where the 'least mass-excess' for a particular $A$ is less than $-A$ MeV.

**Table 1.** Values of (mass excess)/$A$ and its error for atoms with the least mass-excess† for each mass number from 48 to 72

| Element | $A$ | (Mass excess)/$A$ (keV) | | Element | $A$ | (Mass excess)/$A$ (keV) | |
|---|---|---|---|---|---|---|---|
| Ti | 48 | −1010·117 | ±0·031 | Ni | 61 | −1052·902 | ±0·051 |
| Ti | 49 | − 990·965 | ±0·031 | Ni | 62 | −1076·644 | ±0·052 |
| Ti | 50 | −1028·672 | ±0·052 | Cu | 63 | −1041·070 | ±0·052 |
| V | 51 | −1023·478 | ±0·031 | Ni | 64 | −1048·583 | ±0·059 |
| Cr | 52 | −1065·673 | ±0·042 | Cu | 65 | −1034·843 | ±0·055 |
| Cr | 53 | −1043·090 | ±0·042 | Zn | 66 | −1043·856 | ±0·055 |
| Cr | 54 | −1054·302 | ±0·043 | Zn | 67 | −1013·085 | ±0·054 |
| Mn | 55 | −1049·273 | ±0·047 | Zn | 68 | −1029·475 | ±0·052 |
| Fe | 56 | −1082·311 | ±0·045 | Ga | 69 | −1004·681 | ±0·042 |
| Fe | 57 | −1055·856 | ±0·044 | Ge | 70 | −1007·993 | ±0·024 |
| Fe | 58 | −1071·640 | ±0·045 | Ga | 71 | − 987·861 | ±0·037 |
| Co | 59 | −1054·842 | ±0·049 | Ge | 72 | −1008·065 | ±0·024 |
| Ni | 60 | −1074·653 | ±0·050 | | | | |

† Values relative to $^{12}$C from Wapstra and Gove (1971).

An examination of table 1 reveals that $^{56}$Fe can still be regarded as uniquely having the smallest packing fraction. Thus the choice of $^{56}$Fe as the primary standard would render all mass excesses 'positive' and the corresponding 'mass surface' would possess the unique characteristics referred to previously (Durnford 1965). It is noteworthy that the mass excesses relative to $^{56}$Fe are 'maxima' and that the equivalent 'energy surface' ($_Z\Delta^A$ (keV) against $A$ and $Z$) is therefore 'absolute' in character. This 'potential-energy surface' should be useful in the representation of nuclidic transformations that involve a change in $A$ (eg $\alpha$ decay) as well as those with $A$ = constant.

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† Since Wapstra and Gove present the mass excess in keV, the quantity (mass excess)/$A$ is used in *lieu* of the conventional packing fraction which is dimensionless.

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