What Causes The Mass To Be Deficit Inside A Nucleus?

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Abstract: *Deficit of mass is a change in the physical characteristics of an object. What corresponding changes, if any, in the nucleus represents the observed deficit in mass?*

A simple answer for the question is binding energy inside the nucleus. Apart from this well known explanation, is there any other physical aspect of the nucleus we can attribute as the cause for the deficit?

Mass of two objects causes the gravity between them. So the mass deficit can also be described as the deficit in gravity between objects. Because the association between the mass and gravity, lets ignore the notion of binding energy for a while and explore the deficit in respect to the gravity.

According to the standard theory, the mass of an object is resistance to change in motion and also it is a fixed amount for a given object. Each gram of an element will have a fixed number of atoms. Any two objects with same amount of mass and made from same material will measure equal gravity; hence the mass can be compared using the balance scale. According to shell theorem, size of the objects is irrelevant for the amount of gravity they exert on earth if the objects are in spherical shape. It means, even if we compress an object to a point size, the amount of mass it measures will remain same.

Formation of neutron star

A Neon atom contains ten of each basic particles; protons, neutrons and electrons. An atom of calcium contains double the amount of particles, means 20 of each individual particles. A mole of Neon measures 20.1791 grams and a half mole of Calcium measures (40.078/2) = 20.039 grams. Each of these two entities has same number of basic particles.

Now, let's consider the following two scenarios. A Neon cloud with *X* moles of atoms collapsed to form a neutron star and another cloud of Calcium dust with *X/2* moles of atoms collapsed to form another neutron star. What is the mass of these two individual neutron stars? Will that be different than the original mass or remains same as original?

When a cloud collapses to form a neutron star, all the matter inside the object converts to neutrons. Protons and electrons merge to form the neutrons. A neutron star is a compact form of the collapsed neutrons. After the star is formed, there wouldn't be any trace of elements from which it was formed. If we are given two neutron stars with same amount of neutrons, it is not possible to identify the initial composition of the cloud from which these two stars were formed. Because the atomic weights of original elements were different, it requires how many moles of each element were there in the beginning to determine the original mass. With the same set of particles, we can create number of combinations with different elements. Each combination yields a different mass to the original cloud of matter. Therefore, we can conclude that the neutron star doesn’t retain the original mass of the cloud from which it was formed.

In the above case, both the neon cloud and calcium dust yields the neutron stars same in all aspects because the total number of neutrons are same in those two objects. Therefore the mass of the two neutron stars should be same. Moreover, the mass of the newly formed neutron star could be higher than any of the material from which it formed.

According to the standard theory, they should retain the original mass of the objects from which they were formed because the mass doesn't depend on the size of the object. Even if we compress the object to a point size, the mass should not change. But in reality, it appears that the mass of an object does change with the volume or size of the object as seen in the formation of neutron star. It is a clear violation of the conclusions of shell theorem. There are huge implications for physics if the shell theorem turns out to be false. The derivation of inverse square law also depends upon the size factor of the object which assumes the sun as point mass object.

Relation between the baryons and the deficit of mass

As seen earlier, the mass or gravity of an object will change if the volume of the object decreases. Is there any similar phenomenon at the atomic level?

Let's assume four different atoms with different number of protons and neutrons but the total number of baryons (protons + neutrons) as 40. The structure and the mass of the four atoms are given in the Table 1. Combined mass of proton (p) and electron (e) is almost equal to the mass of the neutron (n).

Particles within the atom	Number of baryons	Combined mass of particles (grams)	Atomic mass (grams)
Atom 1: 20p,20e,20n	40	X	Y
Atom 2: 19p,19e,21n	40	X + n – p – e = X (because n = p + e)	Y ± a
Atom 3: 18p,18e,22n	40	X + 2n – 2p – 2e = X	Y ± b
Atom 4: 17p,17e,23n	40	X + 3n – 3p – 3e = X	Y ± c

Table 1: Atomic mass in different atoms with number of baryons as 40

As seen above, as long as we keep the number of baryons same within the atom, the total mass of all particles remains the same. But the actual measured atomic mass will always be less than the total mass of the particles. The difference between them is what called the mass deficit. There is no pattern in the change in mass deficit from one atom to another. Any one of those atoms could be having more deficit in mass compared to all other three. And any one of them could be a candidate to have less deficit in mass when compared to other atoms. Even though the number of baryons and the total mass of particles is same in all four of the atoms, what makes each of the atoms to exert different gravity to the earth?

As seen in the case of neutron star, a compact form of particles exerts more gravity than when they are part of an atom. It means, the way the particles are grouped together influences the amount of gravity they exert. The only possibility here is that the atom in which the baryons are packed together in a smaller volume will have less deficit in mass compared to the atom in which the particles occupy more space in the nucleus. Therefore the physical representation and the cause of the mass deficit is the volume in which the particles are packed together.

Mass deficit at the object level

In any object, the total mass of all particles will be equal to the measured mass of the object plus the mass deficit.

Total mass of an object = measured mass + mass deficit

We are simply aligning the mass of an object with gravity and measuring it using the balance scale and ignoring the deficit part of the object. When a set of particles occupy certain amount of volume, like particles in an atom, there will be a mass deficit. Again there will be further deficit of mass, when a set of atoms form as a molecule, in addition to the deficit in each of the individual atoms. This additional mass deficit will exist even if atoms of same element were grouped together like two atoms of iron. As more and more molecules and atoms occupy more space, the combined deficit will further increase. Eventually, an object of one centimeter cube will have more percentage of deficit of mass compared to a single atom. Deficit of mass will increase as the object grows bigger in size. A cloud of gas or dust will have even more deficit in mass. It is similar to the decrease in resultant force as the angle between the individual forces increases. A ring kept around the earth will stay in place. Gravity of the ring will be zero hence it has zero resistance. All of its mass becomes deficit because each pair of particles on the opposite side of the ring are placed at 180^o apart and their combined gravity becomes zero. An object will have a zero deficit of mass; means the combined mass of all particles will be equal to the mass of the object when the object collapses to a point size.

Avogadro Constant

Concept of mole or Avogadro constant (N_A) gives us an impression that the number of atoms of an element inside an object will measure same amount of mass irrespective of the amount of space those atoms occupy.

The prevailing measurement for the N_A is as follows. Volume of a single unit cell will be determined using the x-ray crystallography and then the number of such cells will be calculated in one cubic centimeter volume. By applying the data for the density, molar mass and the number of atoms in a cell, the value for the Avogadro number is calculated.

Volume of a single unit cell of an element = v cm^3
Number of unit cells in one cubic centimeter = $1/v$
Number of atoms in a unit cell = n
Number of atoms in one cubic centimeter = $(1/v) * n = N$ *atoms/* cm^3
Molar volume = Molar mass/Density = V_m cm^3
Avogadro number, $N_A = (V_m * N)$ *atoms/g-mole*

Following are the characteristics of the Titanium used to derive the Avogadro number [1].

Unit cell volume for the Titanium = $(3.306 \times 10^{-8})^3$ cm^3
Number of atoms in a body centric unit cell = 2
Molar mass = 47.88 g
Density = 4.401 g/cm3

Therefore, by applying the above values, we get the value for N_A as 6.02×10^{23} atoms/g-mol. Instead of atoms/g-mol, it is appropriate to name the constant as the atoms/molar volume. We basically calculated the number of atoms in a given volume. Above derivation doesn't establish any relation between the grams and atoms.

The assumption of the mass of an object as the product of density and volume is the main issue in the above derivation. There is no proof for an object to have same mass irrespective of the size of the object. As the object grows bigger in size, it exhibits more deficit in mass compared to smaller objects. As a result, the density (mass/volume) of the bigger objects will be less than the density measured for small objects made from same material. Product of density (mass measured for one cm^3) and the volume doesn't provide the mass of the object. With the same number of atoms, an object exerts different amount of gravity depending upon its size.

Conclusion

Mass of an object measured using the balance scale will defer depending upon the volume of the object. The same object will measure more gravity if all the matter inside the object was compressed to a smaller volume. Mass measured using the balance scale has no relation to the amount of atoms in that object. Different objects made of same material like iron with measuring same amount of gravity but in different shapes and sizes will have different amount of atoms.

Along with the number of particles and the atoms they form within, volume of the object is also an important factor in determining the gravity of an object [2], which was completely ignored in the definition and the measurement of mass. Kilogram, a gravity based measurement of mass, has no relation to the number of atoms inside the object. The notion of molar mass of an ideal element containing a fixed number of atoms is a baseless proposition.

An object where the matter is occupied in more space will have more deficit in mass and if the same amount of matter occupies less space then that object will have less deficit and measures more gravity in the balance scale. Volume of the matter is the cause for the deficit in gravity.

References

1. Whitten D and Peck S, General Chemistry, College Publishing, 2000.
   (Part of the calculation is available at: http://iweb.tntech.edu/chem281-tf/avogadro.htm)
2. Marasakatla K, *Gravity from a New Angle,* 2009.