University Lowbrow Astronomers
Ann Arbor, Michigan

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University Lowbrow Astronomers

August 2012

Volume 36 Issue 8

August Lowbrow Calendar

- **Thursday, August 9, 2012**. Estabrook School, Ypsilanti 3:00 PM Elementary School Presentation (contact Charlie Nielsen, if you can attend).
- **Saturday, August 11, 2012.** May be cancelled if it's cloudy. (Starting at Sunset). Open House at Peach Mountain
- **Friday, August 17, 2012.** (7:30PM). Monthly Club Meeting.
- **Saturday, August 18, 2012.** May be cancelled if it's cloudy. (Starting at Sunset). Open House at Peach Mountain

Nucleosynthesis, Part 2

Dave Snyder

Nuclear Physics

In a previous article ("Nucleosynthesis" by Dave Snyder, *Reflections*, March 2012, henceforth called "part 1"), I outlined how stars and supernovae use the processes of fusion, beta decay and neutron absorption to create elements from helium to uranium. This creation of elements is called nucleosynthesis. However part 1 was not the complete story. To tell that story we need to dig deeper into nuclear physics.

Nuclear physics is the study of the nucleus of atoms. It is the key to understanding nucleosynthesis as well as energy production in stars, energy production in nuclear power plants, nuclear weapons and radioactivity.

Here are a few things we need to know before continuing.

1) A nuclide is a unique combination of protons and neutrons. "Nuclide" has roughly the same meaning as "isotope," but the word nuclide is a better choice in situations where you are talking about a variety of different chemical elements. It is conventional to consider the neutron as a nuclide with $Z=0$ and $N=1$.
2) A nucleon is a particle that might be either a proton or a neutron. Protons and neutrons have differences (the neutron is slightly heavier, the electric charge is different, etc.) but it is useful to think of them as different versions of the same underlying particle.
3) A nuclear transition is where one nuclide changes into a different nuclide. Example 1: carbon-14 atoms will occasionally change into nitrogen-14 atoms (an example of radioactive decay). Example 2: Two oxygen-16 atoms can fuse into a silicon-28 atom and a helium-4 atom (an example of a nuclear reaction).
4) Among other things part 1 defined three symbols A, N, Z. (N is the number of neutrons in a nucleus, Z is the number of protons and A is the number of nucleons. There is a relationship between these symbols, $A = N+Z$).
5) MeV is a unit of energy. The details aren't important, but you will see MeV in the text below.

In this article I will discuss two ideas, the Segrè chart and binding energy. These ideas create a foundation essential to understanding nucleosynthesis reactions as well as other topics in nuclear physics (such as radioactivity).

Segrè Charts

An important tool for understanding nuclear physics is the Segrè chart. On these charts, each nuclide is represented by a square placed in a specific location. Hydrogen-1 is placed in the lower left, other nuclides are placed so that Z increases from bottom to top and N increases from left to right. Segrè charts are typically color coded.

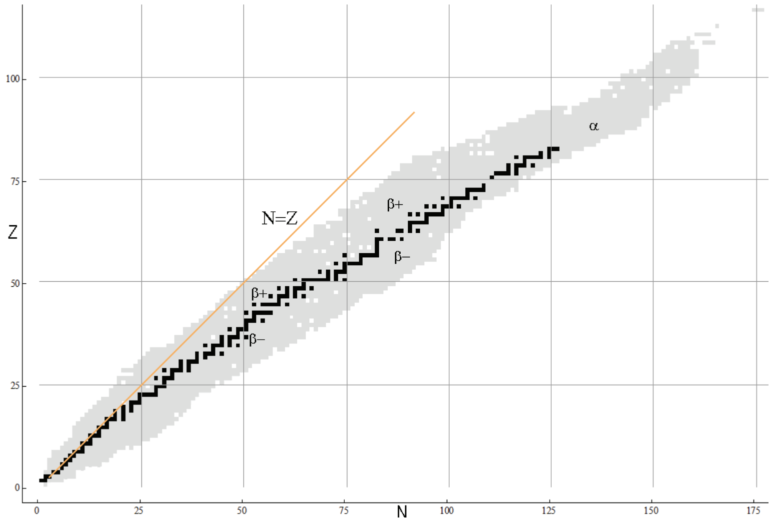


Figure 1

Among the hundreds of known nuclides, some are radioactive, others are stable. If you draw a Segrè chart with stable nuclides colored black and radioactive nuclides colored light gray, you get the chart in Figure 1

Notice the pattern The stable nuclides more or less follow a straight line (***N***=***Z***) from ***Z***=1 (hydrogen) to ***Z***=20 (calcium). For ***Z***>20, the line curves to the right. The line stops at ***Z***=82 (lead) and there are no heavier stable nuclides. (While there are gaps, you can imagine there is a continuous line from Z=1 to Z=82; this line is called the “beta stability line”)

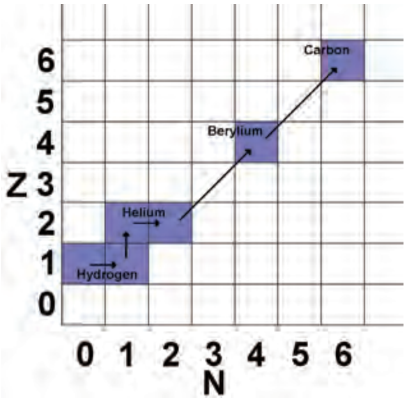


Figure 2

Segrè charts can also be used to follow nuclear transitions. For example, nucleosynthesis is a process that involves hundreds of transitions; it can be thought of a series of steps with nuclides moving from one square in a Segrè chart to the next. For example, the first few reactions of primary nucleosynthesis are shown in Figure 2 (which goes from hydrogen-1 to carbon-12).

Figure 2 could easily be extended to heavier atoms and it could be combined with Figure 1. However I need to go over another concept before we go into more nucleosynthesis reactions.

Binding Energy

All nuclides other than hydrogen-1 and the neutron consist of two or more nucleons bound together. Some are bound more tightly than others. Tightness leads a quantity called “binding energy.” A nuclide that is tightly bound is said to have high binding energy, and a nuclide that is loosely bound has low binding energy.

Binding energy is a useful tool. Typically physicists use the binding energy per nucleon (binding energy divided by ***A***) instead of the total binding energy. In the following discussion, BE is shorthand for binding energy per nucleon Hydrogen-1 and the neutron are defined to have BE=0. It is possible to measure the BE of the other nuclides, BE varies between 0 and 9 MeV. Nickel-62 has the maximum BE of 8.7945 MeV. It is often stated that iron-58 has the maximum BE, but that is incorrect (the maximum value matters as I will explain below).

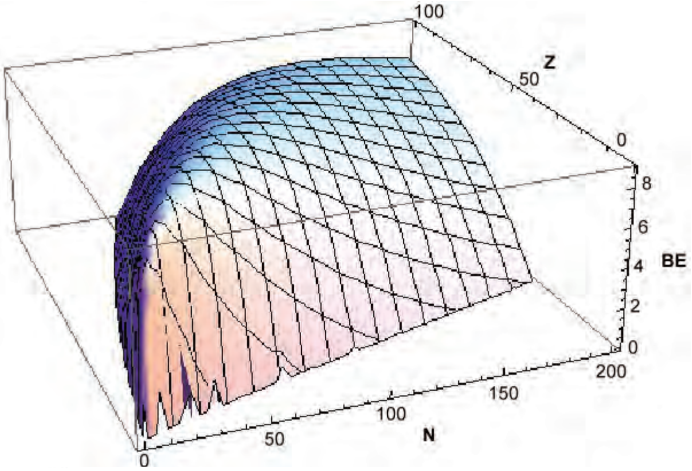


Figure 3

Figure 3 is plot of BE for all known nuclides. ***N*** and ***Z*** are on a horizontal axis, and BE is on the vertical axis. Instead of plotting the actual BE, I constructed a simple model for BE and plotted the model values instead. This model is slightly inaccurate, but has the advantage of producing a smooth curve. (If you plot actual BE values you get roughly the same shape, but with many irregularities added on. These irregularities make it harder to see the pattern).

Note this looks like a “mountain”, with a “summit” running along the top. Either side of the summit, BE drops from the maximum to low values.

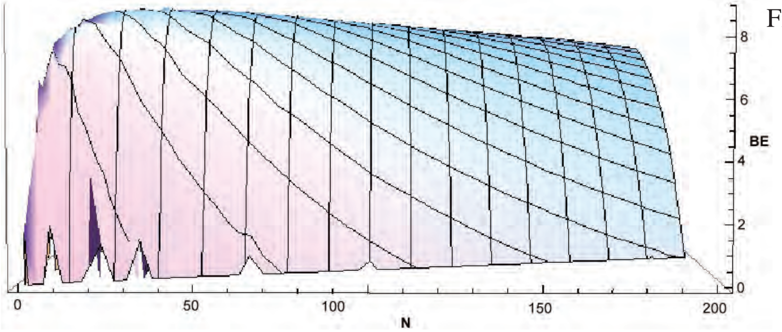


Figure 4

Figure 4 shows the same plot from a different vantage point. If you move along the summit from ***Z***=1, ***N***=1 to ***Z***=28, ***N***=34 (nickel-62), BE rapidly changes from the minimum BE=0 to the maximum BE=8.7945 MeV. For larger nuclides, BE slowly drops to smaller values.

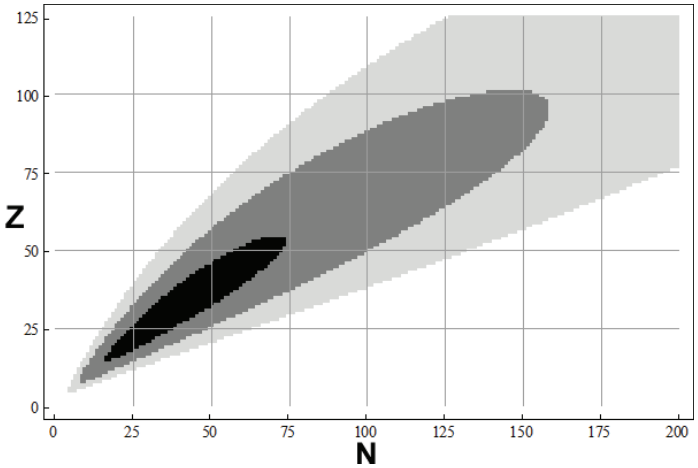


Figure 5

If we plot BE on a Segrè chart (BE>8 5 MeV black, BE>7.5 MeV gray, BE>6 MeV light gray, BE≤6 MeV white), the result is shown in Figure 5 (this is the BE mountain viewed from above). Note that the BE in Figure 5 curves to the right in a manner similar to the beta stability line in Figure 1.

It is not a coincidence; the resemblance can be understood by examining the process of radioactive decay. To start, experimental evidence gives us three rules:

1) For the most part nuclides with low BE are unstable (the exceptions all involve light weight nuclides with Z<6 such as hydrogen, but let's ignore them for the moment).
2) Radioactive decay always transforms unstable nuclides with lower BE to nuclides with higher BE.
3) Rule 2 can repeat itself as many times as necessary until a stable nuclide is reached.

Following these rules to their logical consequence, we might conclude that all nuclides will work their way up the binding energy mountain step by step until a nuclide with the maximum BE is reached (nickel-62). Nickel-62 has no nuclide to decay into (since it has the maximum BE). In other words only nickel-62 should be stable and everything else should be radioactive.

That isn't quite right. There are in fact hundreds of stable nuclides. There is a "stickiness" that prevents nuclides that are close to the top of mountain from going all the way to the top (and thus these nuclides are stable). A different "stickiness" prevents light atoms like hydrogen from decaying into heavier atoms. As a result, the stable nuclides occupy a region that roughly corresponds to a region of high BE. BE curves to the right and therefore the path of stable nuclides (the beta stability line) also curves to the right.

This stickiness can be explained by introducing additional rules (beyond the three mentioned above), but the details of these rules will have to wait for another article.

(Note the terms "BE mountain" and "summit" are not commonly used. The directions used are arbitrary, there is no reason BE couldn't be defined so that it goes from 0 to ***negative*** 9 MeV. That isn't the normal definition, but using negative BEs would turn the mountain upside-down and create a valley. You could think of nuclides falling down the valley to the bottom. This is an easier metaphor than climbing the mountain. The beta stability line becomes the "beta stability valley." The later is a commonly used phrase that only makes sense if you turn the mountain into a valley).

BE Model

The model used above is a simplification of the so-called “liquid drop model.” It has three parts: 1) each pair of protons pushes the nucleus apart, 2) there is attraction between each pair of nucleons, 3) nuclides “prefer” to have the same number of protons and neutrons. The balance between these three parts contributes to shape of the BE mountain described above. Note that part 1 isn’t quite balanced by part 2 (part 1 is based on the number of ***protons***, part 2 is based on the number of ***nucleons***), and this imbalance results in the “curve to the right.” Part 3 results in the falloff to the left and to the right of the summit. I created an equation that incorporates these three parts, and that equation was used to plot Figures 3, 4 and 5.

This model has the advantage that it’s easy to understand and generates a smooth curve, but the model BE differs from measured BE in several respects.

1) Real BE displays an even/odd pattern that the model BE does not have. Real BE values are higher when ***Z*** is even than when it is odd and are higher when ***N*** is even than when it is odd. If you look carefully at Figure 1, you may notice that stable nuclides are more likely to have even ***N*** or ***Z***; less likely to have odd ***N*** or ***Z***. That is a consequence of the even/odd BE pattern.
2) Real BE is higher when ***N*** or ***Z*** is one of a group of “magic numbers” (these include 8, 20, 28, 50, 82 and 126).
3) The model doesn’t work well for very light nuclides (A<10 or so).

There are other models that take some of these problems into account (they are of course more complicated). Unfortunately, perfect BE models do not exist.

In a future article I plan to continue to explore nucleosynthesis.

References

Audouze, J. 1986. *Nucleosynthesis and Chemical Evolution: Sixteenth Advanced Course of the Swiss Society of Astronomy and Astrophysics.* Sauverny-Versoix, Switzerland: Geneva Observatory.

Krane, Kenneth S. 1988. *Introductory Nuclear Physics.* Hoboken, New Jersey: John Wiley & Sons.

> While somewhat dated, it is still one of the better introductions to the topic. There is math, occasionally at the level of differential equations, but the emphasis is on physics, not math. It assumes some knowledge of quantum mechanics. A reader with a weak math background and/or a weak quantum mechanics background could probably skip or skim some sections and still understand most of the book.

Tayler, R. J. 1972. *The Origin of the Chemical Elements.* London and Winchester: Wykeham Publications (London) Ltd.

Wikipedia, `http://en.wikipedia.org/`

> These articles are most relevant: `Segre_chart`, `Nuclear_binding_energy` and `Semi-empirical_mass_formula`.

Tools Used

Wolfram Alpha (`http://www.wolframalpha.com`) was used a source for BE values.

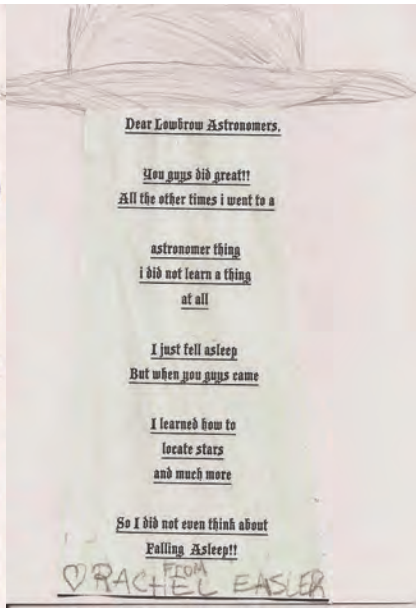
Figures 1, 3, 4 and 5 were produced by the author using Mathematica.

Thank You Lowbrows...

By Jack Brisbin

Those of you that have attended club meetings are well aware of the public outreach astronomy programs with the Ann Arbor Public Schools that we have been conducting. Recently, we developed a web site to go along with our astronomy programs: youngastronomer.org. Next time you are on the web, check it out. Some of the Ann Arbor Schools we presented at are: Bach, Haisley Emerson, and Lakewood, all elementary schools. This was discussed in the March 2012 Newsletter: “Lowbrow 2011 Year in Review”, written by Charlie Neilsen, President.

Last year some of the students from the 5th grade elementary schools sent us thank you cards after the Astronomy Telescope User’s event. The following is a selection of some of the thankyou cards we received. (More will appear in future issues of the newsletter.--ed.)



Dear Lowbrow Astronomers,

You guys did great!!
All the other times i went to a

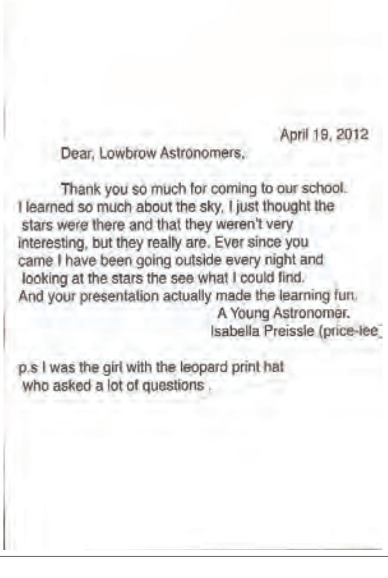
astronomer thing
i did not learn a thing
at all

I just fell asleep
But when you guys came

I learned how to
locate stars
and much more

So I did not even think about
Falling Asleep!!

♡ FROM RACHEL EASLER



April 19, 2012

Dear, Lowbrow Astronomers,

Thank you so much for coming to our school. I learned so much about the sky, I just thought the stars were there and that they weren't very interesting, but they really are. Ever since you came I have been going outside every night and looking at the stars the see what I could find. And your presentation actually made the learning fun.

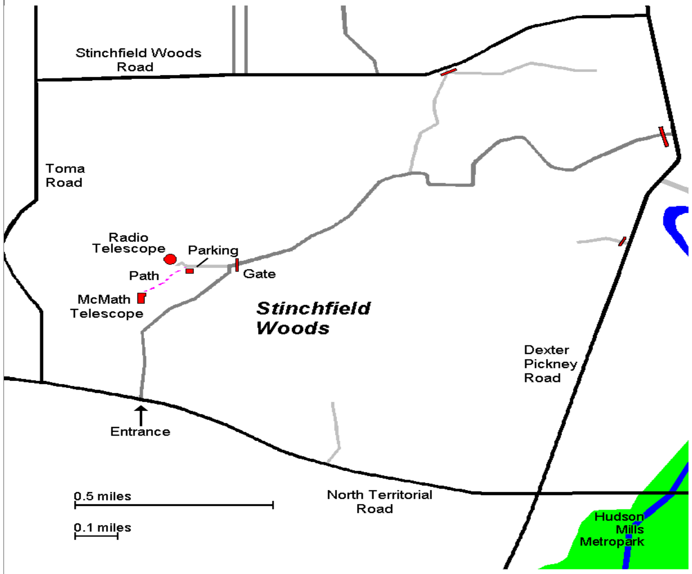
A Young Astronomer.
Isabella Preissle (price-lee

p.s I was the girl with the leopard print hat
who asked a lot of questions .

Places & Times

Dennison Hall, also known as The University of Michigan's Physics & Astronomy building, is the site of the monthly meeting of the University Lowbrow Astronomers. Dennison Hall can be found on Church Street about one block north of South University Avenue in Ann Arbor, MI. The meetings are usually held in room 130, and on the 3rd Friday of each month at 7:30 pm. During the summer months and when weather permits, a club observing session at the Peach Mountain Observatory will follow the meeting.

Peach Mountain Observatory is the home of the University of Michigan's 25 meter radio telescope as well as the University's McMath 24" telescope which is maintained and operated by the Lowbrows. The observatory is located northwest of Dexter, MI; the entrance is on North Territorial Rd. 1.1 miles west of Dexter-Pinckney Rd. A small maize & blue sign on the north side of the road marks the gate. Follow the gravel road to the top of the hill and a parking area near the radio telescopes, then walk along the path between the two fenced in areas (about 300 feet) to reach the McMath telescope building.



Public Open House / Star Parties

Public Open Houses / Star Parties are generally held on the Saturdays before and after the New Moon at the Peach Mountain observatory, but are usually cancelled if the sky is cloudy at sunset or the temperature is below 10 degrees F. For the most up to date info on the Open House / Star Party status call: (734)332-9132. Many members bring their telescope to share with the public and visitors are welcome to do the same. Peach Mountain is home to millions of hungry mosquitoes, so apply bug repellent, and it can get rather cold at night, please dress accordingly.

Membership

Membership dues in the University Lowbrow Astronomers are $20 per year for individuals or families, $12 per year for students and seniors (age 55+) and $5 if you live outside of the Lower Peninsula of Michigan.

This entitles you to the access to our monthly Newsletters on-line at our website and use of the 24" McMath telescope (after some training).

A hard copy of the Newsletter can be obtained with an additional $12 annual fee to cover printing and postage.
(See the website
http://www.umich.edu/~lowbrows/theclub/
for more information on joining the club).

Membership in the Lowbrows can also get you a discount on these magazine subscriptions:

Sky & Telescope - $32.95 / year

Astronomy - $34.00 / year or $60.00 for 2 years

For more information contact the club Treasurer.

Newsletter Contributions

Members and (non-members) are encouraged to write about any astronomy related topic of interest.

Lowbrow's Home Page

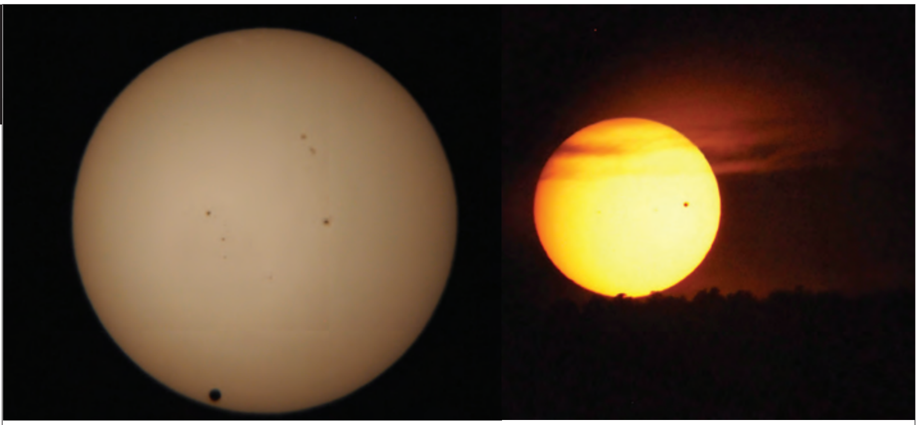
http://www.umich.edu/~lowbrows/

University Lowbrow Astronomers

Reflections & Refractions

Website

www.umich.edu/~lowbrows/



More Venus Transit: Paul Etzler in Utah

The weather was clear here, as usual. but very windy, 60 to 70 mile/hr. gusts. Even though I was in the lee of a building, the wind was at times vibrating the stubby Starblast. The telescope with it's Orion glass filter performed flawlessly. A great scope for this kind of event. Even at 75x, I could view the entire disc of the sun. The wind was particularly fierce between 1st and 2nd contact, making the observation difficult at times. Transit began at 2:05 MDWT (Mountain Daylight Watch Time) and was still happening at sunset. I did not see the black drop effect. Venus did seem to have a bright limb just before second contact (atmosphere?). There were some thin clouds in the west at sunset. The pictures were taken at 4:30 and 8:28 MDT.--Paul