AP Physics – Nuclear Physics

Lance furrowed his handsome, intelligent brow, and wiped glistening pearl-shaped beads of perspiration from his noble forehead as he examined the blinking data display of his plasmo Mark 22 magnetotronic force field sensor. His intelligent, hard yet sensitive eyes peered into the darkness of the impact crater that lay just in front of his all six wheel drive fusion powered terrain hoover-scout vehicle. Somewhere hidden in the Stygian blackness of that vast space was his arch enemy, Zuzandor the Fierce, and his cruel minions. Lieutenant Lance paused as he considered the dilemma he and his space companion, Ardella Lamont, now faced. The dreaded battle battalion of Bokonia had somehow caught up with Lance and Ardella in the backwater asteroid worlds of the Altair seven systems. Before the third moon of Casobo could set, Ardella and Lance might well be dead.

"Lance, how did Zuzander manage to find us?" Ardella asked. "I thought we would be free when we left Tachron seven via the quantum anti-muon drive of your star cruiser." She ran her strong, but delicate fingers through the long red locks of her ravishing curly hair and bit her full, heartshaped lips.

"Blast! They must have come up with a way to detect the Fermian field generated by our hyperspace warp drive! Zounds! I think we're in a hot spot."

"Lance, have I ever told you how much you mean to

Oops: Oh dear, there has been some kind of dreadful mistake. The Physics Kahuna apologizes for the previous stuff that you just read through. Apparently part of a file for his hugely popular, award winning soon-to-be-published third novel in the *Lieutenant Lance Lightning, Space Ranger* trilogy (a movie deal with Dreamworks in negotiations) got copied into this, a fine non-fiction educational work on AP Physics – that most important of subjects. How could this happen? Is it sheer incompetence displacing professional performance as it has so many times before? Well, frankly, the Physics Kahuna simply does not know. But this he promises, he will try to make sure it ***never happens again***!

Back to AP Physics! This is what you really want to read about, right?

Nuclear physics takes in a lot of territory and the range of things it effects is enormous – from saving the lives of cancer victims to use in weapons of mass destruction. There's a lot to love and hate in the nuke world.

Now another thing. This handout is like really thick and has lots of good stuff in it. Much of it you ***do not need to know*** for the AP Physics test. So why is the Physics Kahuna wasting your valuable time with this extraneous stuff? Well, because if only the stuff you needed to know was in here, then nuclear physics would not be complete, wouldn't make a whole lot of sense, and would be pretty confusing. Plus you would be shortchanged in a big-time way. The Physics Kahuna, because of his enormous respect for the Advanced Placement Student, refuses to do this to you. So, throughout, the document, the Physics Kahuna will make a notation on the stuff you need to know and also point out the stuff that you do not need to know. Is that fair or what?

Review of Atomic Theory Basics: ***(Here's important stuff you need to know.)*** Let's do a quick review about atoms. Nuclear physics deals with atoms, right? Anyway, the basic idea is that ordinary matter is made up of collections of atoms. There are around 90 different kinds of atoms that can be found on our beloved planet. Each of the different types is called an element. Elements are substances that cannot be broken down into other substances. There are 92 naturally occurring elements. So far this is nothing more than a basic chemistry review, ain't it? Well, it does get better. Wait and see.

Each atom has a ***nucleus***, which contains most of its mass. In this nucleus are the ***nucleons –protons*** and ***neutrons***. Surrounding the nucleus is the electron cloud – this is where the electrons go about their enormously busy little electron thing. There is one electron for every proton in an atom. When the number of electrons and protons is different, you don't have an atom anymore, you have gots you one of them ions. Remember them? Anyway, just what the electrons are doing in an atom is pretty complicated – we'll deal with them later when we get to quantum mechanics.

The ***atomic number*** is the number of protons in an atom. This information can be easily found from the periodic table (you will, no doubt, recall that elements are organized by atomic number in the periodic table). A periodic table is included at the end of this section of the text. You also have one available in your CCHS planner.

Z is the symbol for the atomic number.

The mass number is the number of nucleons in an atom – so it's like the number of protons plus the old number of your basic neutrons. Atoms are required to have a mass number because the number of neutrons can vary from one atom of a particular element to another. For example some atoms of carbon (atomic number 6) have 6 neutrons while others might have 8. Atoms that have different mass numbers are called ***isotopes***. Isotopes of an element behave pretty much the same way, chemically (at least) except that they have a very slightly, teeny difference in mass. So far as chemistry is concerned, isotopes behave the same. So a chemist doesn't really care about the thing.

A is the symbol for the mass number.

You won't find mass numbers on the periodic table. Instead they are supplied as part of the name of the isotope.

N is the number of neutrons.

Isotopes are identified by their mass numbers. There are several ways to do this. Let's take as our example an isotope of uranium. We could call it:

Uranium – 235	Here we give its mass number, 235.
U – 235	The chemical symbol for the element plus the mass number.
${}^{235}_{92}U$	Both the atomic number and the mass number are given.

The mass number and atomic number are supplied as follows:

Mass number → 235

Atomic number → 92

$${}^{235}_{92}U$$

Symbol for element → U

Using the atomic symbol and the mass number we can find the number of particles an isotope has.

$$A = Z + N$$

That is to say:

Mass number = atomic number + number of neutrons

- How many protons, electrons, and neutrons for ?

A = 92, so, this is by definition the number of protons.

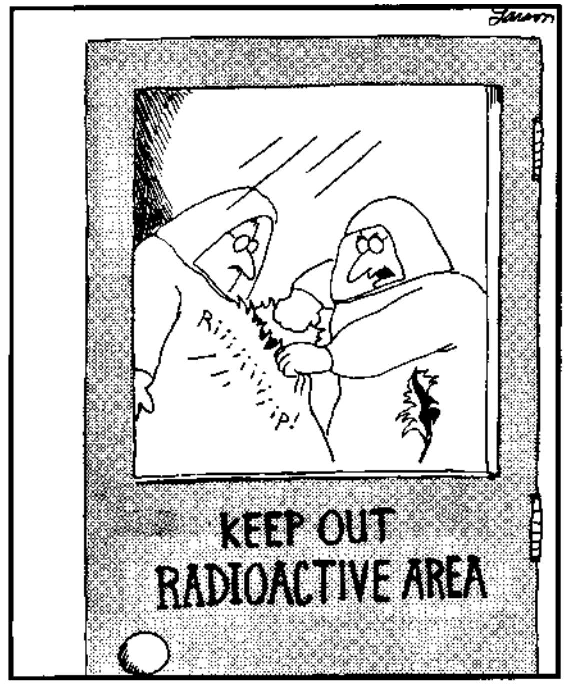
Number of electrons = 92, since the number of electrons = the number of protons.

Number of neutrons:

$$A = Z + N \quad N = A - Z \quad 238 - 92 \quad = \quad 146$$

Radioactivity: ***(You need to know this stuff.)*** Certain types of isotopes are not, for some reason, stable. The nuclei just up and break apart. Most disconcerting. We call such elements ***radioactive isotopes***. The whole general thing is called ***radioactivity***. Radioactivity has to do with the weak nuclear force and the combination of protons and neutrons. Turns out that some combinations are more stable than others.

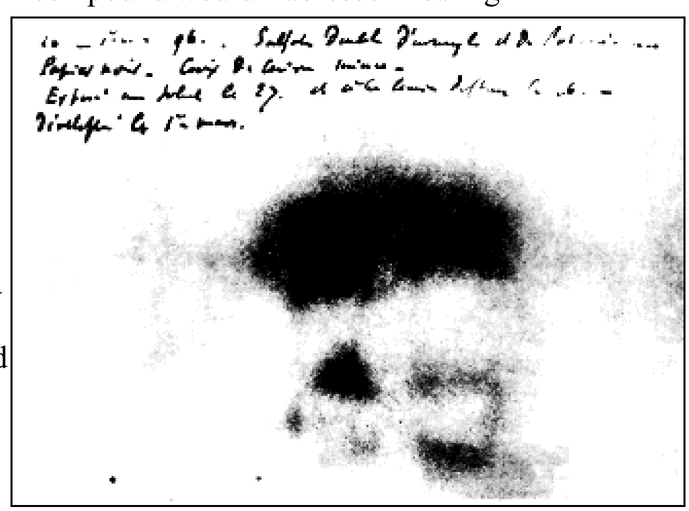
> ***Radioactivity*** ≡ spontaneous breakdown of an unstable atomic nucleus with emission of particles and rays.



"So, Foster! That's how you want it, huh?...Then take *this*!"

(Backkground info - you don't need to know this stuff.) Radioactivity was discovered in 1896 by Antoine-Henri Becquerel (1852 - 1908). It had been established that certain substances would fluoresce, giving off the newly discovered x-rays. Fluoresce means that the substance absorbs electromagnetic waves of some type (like light) and then emits electromagnetic waves later on. The emitted waves do not have to have the same wavelength as the absorbed waves. For example, we beamed UV light onto materials that would fluoresce with UV. They appeared to glow in the dark because the atoms were emitting visible light. The light causing them to do this was UV, and was "invisible" because we can't see that part of the electromagnetic spectrum.

Becquerel devised an elegant experiment to detect the x-rays. He wrapped a photographic plate with dark paper so no light could reach it. Then he placed a piece of potassium uranyl sulfate, a compound containing uranium, on the paper. His idea was that the uranium compound would fluoresce in sunlight – absorb light and then give off x-rays. The x-rays would go through the paper and fog the film. Sure enough, the plate was fogged when he developed it. Eureka! Unfortunately or maybe fortunately, he later placed some of the material, in a dark desk drawer on top of a wrapped up photographic plate, confident that nothing would happen without sunlight. Later, just for the heck of it, he developed the plate. To his amazement, he found that the plate was still fogged - even though it was in the dark and away from sunlight! Whatever had been emitted did not require sunlight and was not a fluorescence byproduct.


The Becquerel Plate

But what produced the emissions? A year later, a Polish born French chemist, Marie Skodowska Curie (1867-1934), found that it was the uranium, which was releasing the radiation. In 1898 she found that other substances such as thorium also gave off radiation. Working with her husband, Pierre, she discovered the element polonium (which she named for her native country, Poland) and radium. She coined the word "radioactivity" to describe the effect.

It turns out that all naturally occurring elements which have an atomic number greater than 83 (bismuth is the element with the honor of having atomic number 83) are radioactive. There are also quite a few isotopes with low atomic numbers that are radioactive, such as C-14 and Co-60.

Characteristics of radioactive isotopes:

1. Radioactive emissions affect photographic film.
2. Radiation ionizes air molecules surrounding them.
3. Radiation makes certain compounds fluoresce (give off electromagnetic radiation).
4. Radiation has physical effects on living organisms - it can kill or damage tissue.
5. Radiation destroys and alters the nucleus of the atom and produces a new element or elements from the old one.

Why Are Some Elements Radioactive? ***(Important stuff you need to know.)*** The mechanism of radioactivity is not really understood. It appears to be related to the interaction of protons and neutrons in the nucleus. The normal isotope of hydrogen has only one proton in its nucleus - no neutrons. Most helium atoms have two protons and two neutrons. The neutrons are required, in some way not fully understood, to "cement" the protons together to form a nucleus. The protons would normally repel each other because of their like charges, but this does not happen in the nucleus. As the number of protons increase, the number of neutrons increases. As the nucleus gets bigger, we soon find that the nuclei have more neutrons than protons. For some reason, certain combinations of neutrons and protons are more stable than others. For example, C-12 is stable, but C-14 is radioactive. The force that keeps the nucleus together, that acts between protons and neutrons is called the ***nuclear force***. Sometimes it is called the strong nuclear force. This force is many orders of magnitude greater than the electromagnetic force – it would have to be wouldn't it to keep the protons close together? We know that like electric charges repel each other, so the protons don't want to be close together. The strong force, much greater than the electromagnetic force binds them together. For this to happen, however, the protons must be very close together – about the radius of a proton or so. Then the strong force kicks in. To sum it up:

- The strong force is enormously stronger than the electromagnetic force.
- The strong force has a much smaller effective range than does the electromagnetic force.

Neutrons are required in the mix of protons for the strong force to work properly.

Half-life: ***(This is stuff you <u>do not need</u> to know.)*** Any sample of a radioactive element has atoms that undergo spontaneous radioactive decay. When it does this, the number of atoms of the radioactive isotope decreases as the nuclei break apart and form other elements. These new decay elements or products are called ***daughters***. The old, original radioactive element is called the ***parent***. Because of this decay, the amount of the parent decreases with time. The rate of decay is often described in terms of the ***half-life***.

Half-life ≡ the time for one half of a radioactive sample to decay.

For example, radium-226 has a half-life of 1620 years.

This is shown in the graph below. One kg of radium-226 begins the thing. After one half-life (1620years) only half of the sample remains – the other half has decayed into some other element. After two half-lives only one fourth would remain and so on.

Types of Radioactivity: ***(Important stuff you need to know.)***

There are three major types of radiation that the nuclear physicist is concerned with: ***alpha***, ***beta***, and ***gamma***. Alpha radiation consists of particles, alpha particles. The alpha particles are actually helium nuclei. Beta radiation is also made up of particles – electrons. Gamma radiation is made up of very short wavelength electromagnetic waves. The reason for the odd names is a simple one. The types of radiation were discovered before the particles were. So Ernest Rutherford discovered alpha particles before anyone knew anything about helium nuclei.

Here are some characteristics of the different types of radiation:

1. ***Alpha particles***. The symbol for the alpha particle is α.
    - α particles are helium nuclei. Each alpha consists of 2 protons and 2 neutrons.
    - α's have a positive charge (+2).
    - α's are only slightly deflected by a magnetic field (because of their large mass).
    - They are stopped easily by a sheet of paper.

2. ***Beta particles***. The symbol for the beta particle is β.
    - β's are electrons, so they have a have a negative charge (-1).
    - They can be greatly deflected by a magnetic field (because of their small mass and negative charge).
    - β's penetrate matter a greater distance than α particles, but they still aren't very penetrating. They can be stopped by a layer of metal foil.

3. ***Gamma rays***. The symbol for gamma rays is γ.

- γ 's are very short wavelength, high frequency photons.
- γ 's have no charge.
- They are not deflected by magnetic fields (again, they have no charge).
- They are the most penetrating form of radiation. Stopping γ 's requires great thicknesses of heavy materials such as lead or concrete.

Symbols Used For Particles In Nuclear Reactions:

Neutron

Proton

Electron

Alpha particle

Gamma ray

Beta particle

Nuclear Reactions: ***(Important stuff you need to know.)*** Nuclear reactions are somewhat different than chemical reactions. In chemical reactions, the equation is balanced when the number of each of the different elements on the reactant side equals the number of the different elements on the product side. In nuclear reactions, the atomic number and the mass number for each element must be balanced on both sides (in addition to the number of elements). We say that the mass number and atomic number must be ***conserved***. The effect of balancing the atomic number is to actually balance the charge of the reactant and product.

Types of Nuclear Reactions: *(Important stuff you need to know.)*

Alpha decay: In alpha decay, an unstable nucleus produces a daughter nucleus and releases an α particle.

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He$$

U-238 decays to produce Th-234 and an alpha particle. During alpha decay, the mass number decreases by 4 and the atomic number decreases by 2. The Th-234 is called a ***daughter*** or ***daughter product***.

Beta decay: In β decay a neutron in the nucleus of the unstable radioactive parent decays and becomes a proton as it emits a β particle (an electron).

$$^{234}_{90}Th \rightarrow \, ^{234}_{91}Pa + \, ^{0}_{-1}e$$

Here, Thorium-234 (produced by alpha decay above, say) has one of its neutrons become a proton - this increases the atomic number by one, but has no effect on the mass number since a neutron and a proton are both nucleons. A beta particle is also produced. Note that the atomic number on the left is equal to the total atomic number on the right.

During electron capture, the atomic number of the daughter decreases by one, there is no change to the mass number. Note that in this reaction, you are producing gold from mercury. Pretty cool thing.

Gamma Decay **:**Many nuclear reactions often produce γ rays. Alpha decay does this frequently.

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + {}^{0}_{0}\gamma$$

Other Nuclear Reactions: ***(Important stuff you need to know.)*** Beginning in the late 1930's, physicists would bombard atomic nuclei with high-speed particles and then see what happened. Originally the equipment that did the job was called an "atom smasher". These days we call the things "particle accelerators".

In 1932 James Chadwick (1891 - 1974), an English physicist, discovered the neutron. He did this by bombarding beryllium with alpha particles. The beryllium absorbed the alpha particle and became carbon. The process released a neutron, which Chadwick detected by the damage it wrought on a piece of paraffin. (Think about it, how do you detect a particle that has no charge?) Anyway, the neutron would plow into the paraffin and collide with hydrogen atoms and knock them about. The tracks of the hydrogen, which showed the path of the neutron, was what he could then observe. Here is the reaction:

$$^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + {}^{1}_{0}n + energy$$

The atomic number increased by 2 (the two protons in the α particle) and the mass number went up by 3 instead of 4, this is because a neutron was emitted.

- (a) State the type of reaction the following nuclear equation represents and (b) complete it:

$$^{15}_{8}O \rightarrow \underline{\quad\quad} + {}^{0}_{-1}e$$

(a) Okay, this is clearly beta decay. We know this because one of the products is an electron.

(b) Oxygen-15 loses a beta particle. The atomic number decreases by one so the oxygen becomes an element with an atomic number of seven, which is nitrogen. See the atomic number does this:

$$8 + (-1) = 7$$

There is no change to the mass number, so it stays at 15. Now we can fill everything in.

$$^{15}_{8}O \rightarrow {}^{15}_{7}N + {}^{0}_{-1}e$$

- Here is a nuclear reaction, see if you can balance the thing.

$$\underline{\quad\quad} + {}^{1}_{0}n \rightarrow {}^{7}_{3}Li + {}^{4}_{2}He$$

Here, the mass number on the right side totals up to be eleven. The atomic number total on the right side is five. On the left side we have a neutron, which has a mass number value of 1, so the mass number of the decaying nucleus must be ten. The neutron has no effect on the atomic number of the decaying nucleus, so it must be five (the total atomic number on the right side). So the decaying nucleus must be boron.

Now we can complete the reaction:

$$^{10}_{5}B \quad + \quad ^{1}_{0}n \quad \rightarrow \quad ^{7}_{3}Li \quad + \quad ^{4}_{2}He$$

Is Radiation All Bad? ***(Stuff you <u>do not need</u> to know.)*** The great teeming United States population is deathly afraid of radiation - any kind of radiation. Yet radiation is a natural thing. Radiation is all around us - even inside of us. We are exposed to it every second of our lives.

Mutations: Radiation causes mutations and this is a good thing. Doesn't sound like a good thing though, does it? Makes you think of those old black and white horror movies with the guy having the head of a fly or something, don't it?

But mutations are of great importance. They are one of the key factors in evolution. And, without evolution, we would not be here – well, we might be here, but in the form of a single cell happily living on a bit of sludge with no interest in physics whatsoever.

Medical Uses: Radiation is also used to treat cancers. Radiation in high doses is lethal to tissue. Turns out that cancer cells are slightly more vulnerable to radiation than healthy cells. A beam of radioactive particles (γ rays for example) are directed at the cancer tumor. To make sure that healthy tissue is not destroyed along with the malignant cells, the radiation source sweeps out an arc with the focus on the tumor. The tumor receives a lethal dose, but the surrounding tissue receives much less radiation and survives.

Insect Sterilization: Radiation is used to sterilize insects (usually the males) so that they can be released in the wild and mate without producing any offspring. The females will have satisfied their mating urges and will lay eggs that will never hatch. This is being done in Southern California to try and eradicate the Mediterranean fruit fly.

Gambling: Another strange use the Physics Kahuna recently ran across -- gambling casinos! A brochure from a casino states: "The games at Pharaoh's casino are based on true random numbers, generated by a Geiger-Müller Tube Detector, which uses the unpredictability of background radiation to generate genuinely random numbers."

Food Sterilization: Radiation is also used to sterilize food. Virtually all spices are treated with radiation.

Contamination of food with bacteria is quite common around the world, even in the good old US of A. Ground beef, eggs, and chicken are particularly vulnerable.

Our federal government estimates that 75 million Americans get some kind of stomach poisoning from nasty bacteria per anum, leading to 325,000 hospitalizations and 500 deaths every year.

Radiation can be used to truly sterilize food. This technique has been around for decades - the Physics Kahuna recalls reading about it in the good old *Weekly Reader* in the third grade. The process is very simple, the food is simply irradiated with high energy gamma rays. The gamma rays scream through the material, killing all the microorganisms in its path. Gamma rays are electromagnetic waves and leave no trace of themselves. The food is not made radioactive; merely rendered sterile. If the food is then sealed in a sterile container, it will keep indefinitely at room temperature without spoiling. (Actually, it is often irradiated after it is sealed. This makes sure that the contents are sterile.) Food has been irradiated for years in Europe, Africa, and Asia. The United States has not gotten on board – fear of radiation mainly.

Recently there have been some terrible outbreaks of food poisoning from several different bacteria strains (salmonella, *e. coli*, etc.) as well as some of the nastier parasites. Many people are seriously worried about eating hamburgers, eggs sunny side up, or drinking milk. Oprah has given up eating meat (at least hamburgers)! Using food irradiation, the problem would go away. The FDA recently approved the process for all foods (it had been previously authorized for use in pork). So far, however, none of the major food suppliers have come forward to take up the process. Irradiated food has to be labeled as such, and the big outfits fear that people would refuse to buy such products.

Biological Tracers: Radioactive isotopes can be added to systems and used as tracers. For example, radioactive iodine is often injected into a person's bloodstream. The isotope can be tracked as it circulates through the blood vessels, giving a doctor valuable information about how the individual's circulatory system is working.

Isotopes can be added to fertilizer before it is spread on a field. Later, by testing the plants, it can be determined how well they took up the fertilizer. Give you an idea how well the plants liked the stuff.

Smoke Detectors: A trace amount of americium-241 is used in smoke detectors. Am-241 is an α emitter. The α particles ionize the air inside a detector chamber causing the ionized air to conduct an electric current. Smoke particles interfere with the ionized air, the current flow stops and sets off the alarm.

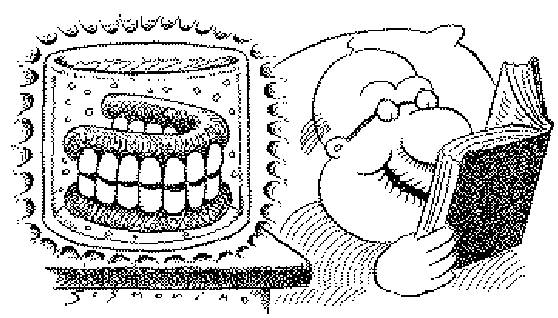
U.S. Mail Sterilization: (New! This just in!) Radiation is now being used to sterilize mail sent to the Senate and the House of Representatives to thwart any further anthrax attacks.

Radioactive Dating: Radioactive isotopes are used to accurately date archeological sites and the age of rocks and minerals on the earth (and also the ones brought back from the moon). The one you've probably heard about the most is carbon-14 dating. Carbon-14 is produced in the upper atmosphere by the collision of cosmic rays with nitrogen-14. Here is the nuclear reaction for its production:

$$^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{14}_{6}C + {}^{1}_{1}H$$

The carbon-14 is radioactive and decays over time – its half-life is 5730 years. The production rate is constant, so the percentage of carbon-14 in the atmosphere is also a constant. The isotope is taken up by plants and ends up in the entire food chain, so all living things have the same percent of carbon-14 in their tissues. Some of the carbon-14 will decay, but it is replaced. Once something dies, however, the decaying carbon-14 is no longer replaced and its concentration begins to diminish. Scientists can measure the amount of carbon-14 in the tissue and accurately determine the length of the time since the death of the organism. Because of the half-life, carbon-14 dating is good to only about 70 000 years ago.

Dear Cecil:
About 15 years ago I read an obscure government publication on the use of uranium in dental porcelain. It said uranium is added to dental porcelain for cosmetic reasons, to make the porcelain more luminous like natural teeth. It was estimated that this use of uranium causes about 2,000 cases of cancer per year.



Illustration/Slug Signorino

I've since mentioned this to many dentists, but none of them had ever heard of this. Cecil, I'm counting on you to find out what's going on here. Preferably before I need more dental work. And while you're at it, what is the safest dental material?
--Pearl E. White, Chicago

Cecil replies:
You read right, friend--in these days of crummy schools an accomplishment in itself. In one of those classic wacky moves, manufacturers once upon a time did put uranium in dental porcelain to give crowns and false teeth that certain glow.

Real teeth have natural fluorescence. If you shine a black light on your teeth they gleam a brilliant white. To give dental work the same glow, the use of uranium in dental porcelain was patented in 1942.

The timing of this was suspicious. You have to wonder if those Manhattan Project scientists, toiling over crucibles of hot uranium, got to thinking, hey, if this nuclear weapon thing, you know, bombs, we can always go into teeth.

I should point out that the glow imparted to false teeth by uranium was not in itself a consequence of radioactivity. Uranium merely happens to fluoresce in the presence of UV light. Fluorescence is harmless. Lots of compounds do it. Uranium's advantage was that it would survive the high heat of porcelain manufacture.

However, you did have the problem that uranium also emitted radioactivity. In the wake of Hiroshima and Nagasaki, it occurred to the dental-ceramics industry that a substance that had destroyed cities might have adverse health effects if used in the mouth. Manufacturers discussed the situation with the Atomic Energy Commission in the 1950s.

The debate proceeded along the following lines. On the one hand, putting uranium in people's mouths might possibly give them cancer and kill them. On the other hand, their teeth looked great.

It was an easy call. The industry was given a federal exemption to continue using uranium.

In the 1970s some began to wonder if this had been the world's smartest decision. The amount of uranium used in dental porcelain was small--0.05 percent by weight in the U.S., 0.1 percent in Germany.

Nonetheless the fake teeth bombarded the oral mucosa with radiation that was maybe eight times higher than normal background radiation. None of the research I came across mentioned a specific number of cancer deaths, but clearly this was not something you'd do for the health benefits.

Dear Dr. Science,
I've read that there's an antiproton shortage affecting anti-matter research. Where can we get more antiprotons, anyway?
----- Dave Berglund, Mishawaka, IN

Dr. Science responds:
You're in luck. They're on sale this week at Wal-Mart. Buy 'em by the sack and save, just like you used to be able to do at the five-and-dime but Woolworth's was another scarred era of my youth. Oh, your question? Of course, the main thing you want to do is keep them away from protons. Let an antiproton near one of those pesky protons and you've got a potential nuclear winter on your hands. Fortunately, most protons are huddled in proton globs deep beneath the arctic poles. But leave it to some National Geographic type to dig a hole in the ice, bring a bunch of protons home and then go shopping at Wal-Mart. I tell you, you can't win. Might as well stick your head in the target end of a linear accelerator some days.

Dear Doctor Science,
What's so bad about comparing apples to oranges?
----- Tim from Houston, TX

Dr. Science responds:
Apples and oranges are oppositely charged fruits. When compared, they cancel each other out, and become Polysorbate 60, a gummy substance used as filler in shampoos and food by-products. If you'd like to make your apples or oranges even zestier and full of life-giving energy, wrap them in tinfoil and place them in the microwave oven for a few minutes. That blue sparking you'll see around the edge is the energy being absorbed by the happy fruit. Don't leave them in there too long, or you'll end up with a broken microwave oven full of boiling fruit juice.

Neutrinos: ***(Important stuff you need to know.)*** Neutrinos are extremely tiny particles that have very little mass. The story of how they came to be discovered is interesting. In 1930 Wolfgang Pauli was studying beta decay. He caused the reaction to happen by bombarding an atomic nucleus with a high-energy particle. He predicted that the nuclear reaction should produce a certain amount of energy and of course, energy and momentum have to be conserved.

However after analyzing the motion of the particles after the reaction, he could not account for all the energy and momentum. He surmised that there had to be another particle that had the missing energy and momentum. So he theorized a new particle had to exist. Later it was given the name "neutrino" by Enrico Fermi. It wasn't until the mid 1950's that the neutrino was actually detected.

Here's an example of a reaction that produces a neutrino (this would be beta decay, right?):

$$ {}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + v $$

The symbol for the neutrino is ***v***.

Here are some characteristics of neutrinos:

- Neutrinos have zero charge
- They have an extremely small mass
- Very weak interaction with matter.

Essentially, neutrinos don't interact with matter at all. This made them very difficult to actually detect – if they don't interact with matter, how can you tell if you've got one? Actually they are very common in the universe, a huge flux of them is passing through your body as you read this thing.

Fission: ***(Important stuff you need to know.)*** Fission turns out to be a very important type of nuclear reaction. In fission, a nucleus splits apart to form two new elements (or daughter fission products). Let's look at two different reactions involving slow neutron bombardment. One causes fission and the other does not.

The first reaction is the bombardment of U-238 with a slow neutron. Here's the equation for the reaction:

$$ {}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U $$

U-239 is unstable and undergoes beta decay.

$$ {}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}e $$

Np-239 also undergoes beta decay.

$$ {}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}e $$

Pu – 239, the final product is also radioactive, but its rate of decay is much slower that the other products. It is fairly stable and will hang around for thousands of years before it all decays away. (Which is not to say that it is a safe material – it is extremely radioactive and very dangerous).

Now if you bombard U – 235 with the same slow neutrons, something very different happens – we get fission. There are actually a great number of possible reactions (which are all fairly similar). Here are three common, typical ones:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{132}_{50}Sn + ^{101}_{42}Mo + 3\,^{1}_{0}n$$

Note that we end up with two new elements. The other critical thing is the production of neutrons.

Pu-239, produced by the U-238, also undergoes fission when bombarded with neutrons. Here's an equation for the reaction.

$$^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{106}_{44}Ru + ^{131}_{50}Sn + 3\,^{1}_{0}n + energy$$

The fission process produces an enormous amount of energy (we will see how this happens shortly). For this reason fission is used to produce electricity in nuclear reactors. It is also used to make bombs.

The production of $\approx$ three neutrons is a critical thing. It can cause a ***chain reaction***. Do you see how this would work? A neutron causes a fission. The fissioning nucleus releases three neutrons and each of these neutrons causes another fission. So we get three fissions. Each of these produces three neutrons, so we get nine more fissions, which will give us 27 neutrons, and so on. The reaction increases and multiplies very quickly.

This reaction can have three states: it can be subcritical, critical, or supercritical. A subcritical reaction basically dies out. This will happen if you do not have a ***critical mass***. In a small amount of fissionable material, most of the neutrons leak out of the system and do not cause fissions. This causes the reaction to come to a halt.

If the system is critical, then each nucleus that fissions causes exactly one more nucleus to fission. The reaction takes place at a steady rate.

Nuclear power plants are designed to operate at a critical state. The reaction is controllable.

The system must have a critical mass for the chain reaction to take place. When the system is critical, you can see that we have excess neutrons produced and something has to be done with them. Some leak out of the system and the rest have to be absorbed by something. In a nuclear reactor control rods are inserted into the core (the place where the fuel is located) and absorbs some of the neutrons. By carefully positioning the rods, the reactor can be kept at a critical state.

Super critical is when each fissioning nucleus causes more than one other nucleus to fission. Atomic bomb explosions are super critical events. If a nuclear reactor were to go super critical, it would not cause an atomic explosion. Instead it would heat up, eventually melting the uranium fuel.

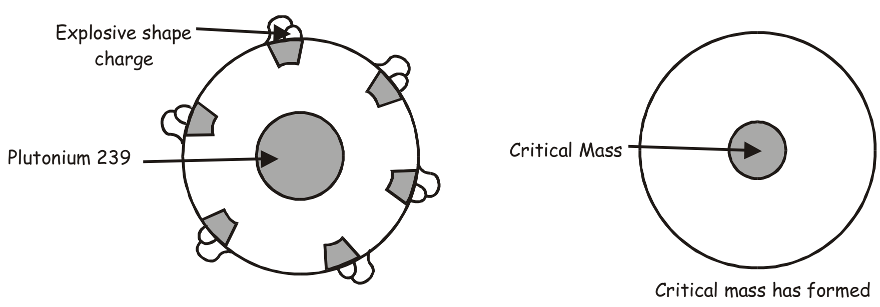
The United States built the first atomic bombs during WWII. The government set up a super secret program to build the bomb. The program was called the “Manhattan Project”.

Two bomb designs were conceived and built. One bomb used pure U-235. This was the "little boy" bomb. It used a gun type mechanism to achieve criticality. The uranium metal, highly enriched U-235, had to be kept out of a critical mass configuration (else it would go critical), so it was kept in two parts. A long tube separated two chunks of the metal.
When the weapon was set off, an explosive charge was detonated which drove the U-235 "bullet" down the tube and into the uranium mass at the end of the tube. Almost instantly the U-235 became a critical mass and went supercritical.

It takes 10^{-8} sec for a neutron (these are available because U 235 is naturally radioactive) to be absorbed and cause a nuclei to fission, which releases around 3 more neutrons. In 10^{-6} seconds (a millionth of a second) 100 reactions will have taken place and so on. The energy that is released is enormous - the first atomic bomb released around 4×10^{19} J.

The two chunks of uranium have to be put together into a critical mass almost instantly. Too slow and an explosion does not occur, instead the metal, while supercritical, would merely get very hot and melt.

The second bomb used plutonium and was called "fat man". It was basically a large metal sphere. The plutonium was formed an expanded sphere that was sort of spongy so that it would not be critical. Surrounding the plutonium sphere were explosive charges. The charges formed an explosive lens. When detonated a shock wave was formed that was focused towards the center. Anyway, once the charges were fired, the plutonium would almost instantly form a critical mass and at that point the plutonium would go supercritical and yield a nuclear explosion.
The first bomb actually exploded was a plutonium weapon that was test fired at Alamogordo, New



Plutonium "Fat boy" bomb

Mexico on 16 July 1945. One can say that a new age began with the test firing. The scientists expected a yield of around 5 000 ktons (a kton is the equivalent of 1 000 tons of TNT). Instead, the bomb produced 20 000 ktons.

Once the bomb was tested, a decision about its use had to be made. The war in Europe had ended, but the war in the Pacific raged on. There was a great deal of debate about how it should be best employed. Should the Japanese be warned that the US had the atom bomb? Should a bomb be set off as a demonstration? Well, you know what President Truman decided - use the thing. President Truman said that he never second guessed the decision. The main reasoning was that lives, both American and Japanese would be saved if the war could be ended without having to invade Japan. So the honor of being the first nation to use an atomic bomb belongs to the United States. The bomb was dropped on Hiroshima with devastating results, this was the little boy weapon, the uranium device. A few days later a second weapon - a plutonium bomb - was dropped on Nagasaki. There is still a huge controversy about the use of atomic weapons in this way. Many people think it stopped the war and saved millions of American (and Japanese) lives, - the invasion of Japan, seen as the only way to make the Japanese surrender, was sure to be a bloody affair (on both sides). Others believe that it was immoral and unjustified.

What do you think?

Nuclear Reactors: ***(Stuff you <u>do not need</u> to know.)*** Nuclear reactors, unlike bombs, are designed to release the energy stored in the atoms slowly and reasonably gently. Reactors do not require highly enriched uranium to operate. The fuel is typically 3 to 5 percent enriched. (Meaning that only 3 % to 5 % of the uranium is U-235.) A reactor must be able to sustain criticality (you don't want it to be supercritical!).

The core is flooded with water, which does two things: it cools the fuel rods, which are producing a huge amount of heat, and they moderate or slow down the neutrons. Controlling the neutron speed helps keep the reactor critical.

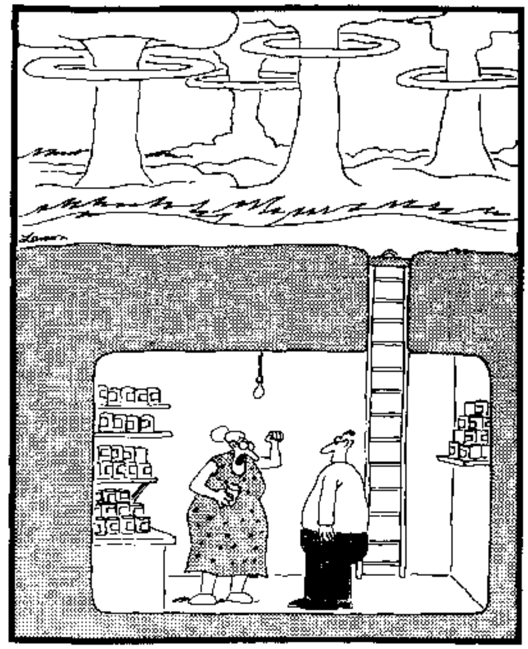
The coolant water is circulated through a heat exchanger where it gives up its heat to a second loop of cooling water called condensate. The condensate is converted to steam which can then drive a turbine. The turbine rotates an electric generator, generating electricity. The steam is condensed and returned to the heat exchanger.
The two loops do not mix, so that radioactivity is not released.

Nuclear Power Issues: ***(Stuff you <u>do not need</u> to know.)*** Nuclear power makes up 80 % of the electricity generated in France, yet the United States seems to be determined to get out of the nuclear power generating business. Today, only about 20 % of our electricity is generated by nuclear reactors. In fact there are presently no new reactors under construction and several that were being built have been abandoned. The primary reason for this is environmental concern. Many people fear that reactors are time bombs waiting to release deadly radiation that will poison the environment and cause terrible health damage to the populace. The other problem is that the spent fuel is highly radioactive and we have yet to work out a method of disposing of the nuclear wastes that makes everyone happy.

Nuclear disasters have taken place. The worst one was in Russia at a reactor located at Chernobyl. The Chernobyl reactor was a bad design to begin with, the people operating it were badly trained, and it was very poorly maintained. Due to an operator error, the reactor core melted which caused a chemical explosion. The reactor was not within an adequate containment vessel and huge amounts of radiation were released into the atmosphere and water system.

The worst reactor incident in the United States happened at the Three Mile Island reactor. Here, due to a faulty gauge and improper actions, the core also melted down. But the United States requires tremendous safety factors in nuclear reactors. There was no chemical explosion, the containment vessel was not breached, and there was no environmental impact. It was an awful expensive accident, however.

An important thing to remember is that nuclear reactors ***cannot*** undergo a nuclear explosion.



"How many times did I say it, Harold? How many times? 'Make sure that bomb shelter's got a can opener — ain't much good without a can opener,' I said."

Dear Cecil:

I know this is a sticky question, but I'll ask anyway: does [illegible] a Jesus of Nazareth actually lived? And what about the Shroud of Turin--have scientists concluded anything about it?
--Ben C., Chicago

Cecil replies:
Don't worry about getting me into hot water, Ben. About the only people this column has failed to offend already in its checkered history are left-handed Anabaptists--and just wait till they get a load of next week's blockbuster.

If what you're looking for is proof positive that Jesus Christ lived and breathed--e.g., library card, baby pictures, etc.--you're out of luck. The big guy left no written records, and no accounts of his life were written while he was still alive. The earliest Gospels date from maybe 70 AD, 40 years after his demise.

Still, barring an actual conspiracy, 40 years is too short a time for an entirely mythical Christ to have been fabricated out of (heh-heh) whole cloth. (See below.) Certainly the non-Christians who wrote about him in the years following his putative death did not doubt he had once lived. The Roman historian Tacitus, writing in his Annals around 110 AD, mentions one "Christ, whom the procurator Pontius Pilate had executed in the reign of Tiberius." The Jewish historian Josephus remarks on the stoning of "James, the brother of Jesus, who was called Christ." The Talmud, a collection of Jewish writings, also refers to Christ, although it says he was the illegitimate son of a Roman soldier called Panther. Doubts about the historicity of Christ did not surface until the 18th century. In short, whether or not JC was truly the Son of God, he was probably the son of somebody.

As for the Shroud of Turin--well, despite more than 100,000 hours of work by scientists involved in the Shroud of Turin Research Project (STURP), nobody can say for sure what it really is. However, we do have a pretty good idea what it isn't. But first a little background.

For those unfamiliar with it, the Shroud is one of the most famous Catholic artifacts, shall we say, in the world. It's a piece of ivory-colored linen about 14 feet long and 4 feet wide bearing the imprint of the front and back of a man's body. The image is straw-colored and very faint. The two sides of the figure are set head-to-head, suggesting that the man had been placed on the Shroud and that it was then folded over him. The figure has a beard, long hair, and imposing features, and looks much like traditional representations of Jesus.

There are bloodlike stains at the wrists, feet, and side, as though the figure had been crucified and stabbed. The back bears dozens of contusions characteristic of a type of Roman flail in common use during the time of Christ. Other apparent wounds at the shoulder and knees suggest that the man had been carrying a heavy object and had fallen one or more times. There are puncture wounds around the head, possibly inflicted by thorns. There is just one well-known religious figure who fits all these details, and it ain't Confucius.

The Shroud first turned up in 1357, when it was exhibited in a church that had been specially built for that purpose in Lirey, France, by one Geoffrey de Charny. In 1453 one of de Charny's descendants sold the Shroud to the Duke of Savoy, whose family later moved its headquarters, and the Shroud, to Turin. The cloth remained in the custody of the Savoys, who eventually became rulers of Italy, until 1983. The exiled King Umberto, the Shroud's last owner, died in that year, and it was subsequently turned over to the Vatican.

Some have conjectured that the Shroud is the Mandylion, another cloth bearing an imprint of Jesus that disappeared during the sack of Constantinople in 1204. From that point they trace it back to an early Christian town in Turkey and from thence to the Holy Sepulchre.
But there have always been skeptics. Only a short time after the Shroud was put on display in 1357 the local bishop ordered the exhibition stopped on the grounds that the thing was a forgery. The bishop's successor later claimed in a memo that his predecessor had found an artist who admitted to having painted the image. No independent corroboration of this has come to light, but it's not hard to imagine why people were skeptical--the number of "authentic" shrouds that have been displayed at one time or another totals about 40.

Having been exhibited periodically over the centuries, the Shroud was photographed for the first time in 1898. The negatives caused a sensation, and are largely responsible for the hold the Shroud has had on the public imagination ever since. While the image on the cloth is faint and difficult to make out, the image on the negatives is instantly recognizable as a man--basically because it looks like a positive print, with normal gradations of tone, i.e., the highlighted areas are white and the shadowed areas are dark. This implies that the image on the Shroud is a negative of sorts. If the image is the work of a forger, Shroud advocates say, it is hard to imagine why he would adopt such an odd technique.

Subsequent inquiries if anything deepened the conviction that the Shroud was, if not the real McCoy, at least not a fake. Researchers were initially puzzled that there were wounds at the wrist rather than the palm, since Jesus has traditionally been depicted as having been nailed to the cross through the latter. However, experiments in the 30s, some involving cadavers, demonstrated that a nail through the palm will not support the weight of a body, whereas a nail through the wrist will. In 1968 an archaeologist in Israel discovered the skeleton of a man who had been crucified through the wrists, lending credence to the notion that the Shroud is right and two thousand years' worth of paintings are wrong.

In 1976 a researcher at a U.S. government laboratory in New Mexico made an even more startling discovery. Using a computer, he found that the image had a peculiarly three-dimensional quality to it. When a photo of the Shroud was put through a computer analyzer that makes a sort of topographical relief map of an image, with brightness correlated to "height," a remarkable 3-D representation of a man's body resulted. Conventional paintings, and for that matter conventional photographs, don't work that way. Some take this as further proof that the image was not the work of an artist.

Which brings us to STURP. In 1978 a team of American scientists, most of them non-Catholics, was permitted to examine the Shroud round the clock for five days with sophisticated instruments. (One test they were not able to perform was a carbon-14 dating test, which might have resolved the issue right off the bat. Italian authorities feared, erroneously, that too much of the Shroud would have to be destroyed. However, there have been subsequent developments in this regard, which we shall discuss anon.) The STURP researchers concluded as follows:

(1) The image was the result of "dehydrative acid oxidation of the linen with the formation of a yellow carbonyl chromaphore." What this means in English is that the image is the result of an accelerated aging process: the underlying cloth dried out and yellowed. Some call it a scorch.

(2) The Shroud had some dried blood on it, certainly primate, probably human. This took some people by surprise; earlier forensic tests by Italian scientists had failed to find any indication of blood. The STURP conclusion was vigorously disputed by Walter McCrone, a distinguished microscopist, who thought the alleged blood was really iron oxide, a common pigment. More on this is a moment.

The blood did have some odd features about it. It was an unusual color, being a faint carmine rather than the brown one would expect. Moreover, it was difficult to see how it was conveyed from the body to the shroud. The drip pattern indicated that the blood initially flowed while the body was in a vertical position, with the arms stretched out from the sides, as though hanging from a cross. So far so good. The blood must then have been imprinted onto the sheet by direct physical contact. Yet the stains had not smeared as much as one would have expected, nor were there any traces of crusting. For that matter, no wound debris was discovered on the Shroud at all.

(3) The image was not painted by any known means. There were no brush strokes, and no sign of any known dye, pigment, or pigment carrier. Moreover, the image did not sink into the cloth at all, as it would have if borne by a liquid. (The blood, on the other hand, did soak through.)

This conclusion was flatly rejected by Walter McCrone, who told me he had no doubt the shroud was painted. He said water color painting on linen was a well known technique in the 14th century, when the Shroud first appeared.

(4) None of the explanations for the image proposed over the years was entirely satisfactory. Several early investigators, for instance, had suggested the image was caused by vapors rising off the body that resulted from a mixture of burial ointments and urea-laden sweat. Experiments showed that it was possible to produce such "vaporgraphs," but they were far more blurred and diffuse than the image on the Shroud.

Other scenarios were even more implausible, the STURP folks felt. Some true believers suggested that the image was made by "radiation scorch"--i.e., by a burst of energy at the moment of the Resurrection. The Shroud showed no significant amount of radioactivity, and researchers felt that speculating on the possibility of some sort of divine light was beyond the purview of science.

Skeptic Joe Nickell had suggested that the image was created by dusting a statue or body with rouge (finely ground ferric oxide) and then "pulling a print" with the linen cloth. This produces a detailed negative image, but the image consists of an applied substance, which the Shroud image does not. Nickell then suggested that if the ferric oxide "print" were moistened, it would cause the underlying cloth to discolor. The oxide might then be washed off, leaving a permanent image. STURP scientists conceded this was a possibility, but said there is no evidence to suggest that such a technique was ever used prior to the 19th century. (Nickell, on the other hand, claimed the technique dated back at least to the 12th century.)

S.F. Pellicori had proposed a "latent image theory," in which the Shroud was sensitized by contact with a corpse, with the image subsequently "developing" over a period of many years. Pellicori applied a mixture of myrrh, olive oil, and skin secretions to a piece of linen, which he then baked to produce rapid aging. This produced an image whose color and chemical properties are similar to those of the Shroud image. However, it did not have the Shroud image's three-dimensional shading. The STURP scientists acknowledged, however, that a way might be found to overcome this difficulty, and latent imaging remains a promising avenue of inquiry.

Many aspects of the Shroud remained unexplained. For one thing, it is unlike any other shroud of its era, most of which did not exceed eight feet in length. Moreover, it was not draped or wrapped around the body; there is no imprint of the figure's side. In fact, for the three-dimensional shading of the image to make sense, we have to assume that the Shroud was stretched out flat (more or less) above the body--a strange scenario, and one of the reasons some think the Shroud was purposely created, perhaps by some lost process of thermography.

For a while it appeared we'd have to leave it at that. Then in 1986 the Archbishop of Turin announced that the Pope had given his permission to perform carbon-14 tests on the shroud, which would answer the biggest remaining question: how old was the thing? A postage-stamp-size piece of the shroud was snipped off and samples sent to laboratories in three different countries. In 1988 the archbishop announced the results: the linen cloth had been made between 1260 and 1390 AD. Whatever it was, it was not the burial cloth of Jesus.

Not everybody bought this conclusion. Harvard University physicist Thomas Phillips, writing in the journal Nature, argued that if Christ had in fact been resurrected while wrapped in the shroud, a phenomenon known as "neutron flux" would have occurred, throwing off the results of the carbon-14 dating. But come on. If we start from the premise that a miracle occurred, you can arrive at any conclusion you want. Most people, and certainly most scientists, have accepted the idea that the shroud was made not long before it was first put on display in 1357. But how it was made we still have no clue.
--CECIL ADAMS

Other Uses of Nuclear Power: ***(Stuff you do not need to know.)*** Nuclear power is currently used to provide propulsion for submarines, missile cruisers, and aircraft carriers by the U.S. Navy. The Russians and British also have nuclear powered submarines. The old Soviet Union also operated nuclear powered ice breakers. In the 1950's, serious plans were developed for nuclear powered aircraft. A civilian merchant ship, the SS Savanah was also in service during the 1950s and 1960s.

Nuclear reactors are also used to power certain satellites and space probes.

Dear Dr. Science,
What is the odor, if any, of nuclear power?
Jenny, Gainesville, Florida

Dr. Science responds:
It's a smell that the nuclear power industry's house magazine, "Faulty Towers," describes as "chocolatey." This same publication refers to cosmic rays as giving off a "cinnamony" aroma and spent plutonium as "lemony fresh." This is an example of the power of corporations to inform and delight us about the exciting world Science has in store for all of us. So the next time you bite into an artificially flavored and colored food by-product, thank the nuclear power industry for exchanging our bland, real world for a zesty, imaginative one.

Dear Doctor Science,
I don't like to study and so I'm not doing very well in school. Is there any subject that I could concentrate on that would be fun and easy to master...you know, that wouldn't involve a bunch of tedious study?
-- Bernie Brown from St. Louis MO

Dr. Science responds:
Have you considered nuclear physics? It's even more unstructured than most art classes. You just do your own thing and see what happens. Since nobody really knows what the rules are, it's anything goes, and the burden of proof lies anywhere but on you. If you can't explain the results of your experiments, you just go ahead and invent another subatomic particle. Then, if somebody else agrees with you that the particle exists, they name it after you. You not only get away with murder, you get famous!

Units: ***(Important stuff you need to know.)*** Many units are used when dealing with the nucleus and subatomic particles.

Atomic mass unit**:** ***(Important stuff you need to know.)*** The mass of the atom is frequently measured in units called the atomic mass unit, which is abbreviated as u. One atomic mass unit is equal to one twelfth of the mass of a carbon-12 nucleus. So one atomic mass unit is about the mass of a proton or neutron. Protons have a slightly different mass than neutrons. Here is the value we will use.

$$1\,u = 1.66 \,x\, 10^{-27}\ kg$$

The electron volt: ***(Important stuff you need to know.)*** The electron volt, abbreviated as **eV** is a unit of energy that is used with subatomic particles. It is essentially the energy that an electron gains when accelerated through a potential difference of one volt.

$$1\,eV = 1.60\,x\,10^{-19}\,J$$

The electron volt is a small unit, so it is very common to use the MeV (mega-electron volt).

$$1\,MeV = 10^6\ eV$$

Mass Equivalence to Energy: ***(Important stuff you need to know.)*** The reason nuclear reactions (like fission) release tremendous amounts of energy is due to a discovery made by Albert Einstein, an overlooked German born physicist who nobody has ever heard of. It's sad how people so easily forget the poor scientists who spend their lives in obscurity trying to understand how the universe works. Anyway, to be specific, this would be an incidental part of his theory of special relativity – the idea that mass and energy are equivalent.

Perhaps you have seen the equation for this. It is certainly Einstein's most famous equation and is perhaps the most famous of all equations:

$$E_0 = mc^2$$

$\boldsymbol{E_0}$ is called the rest energy, ***m*** is the mass, and c is the speed of light.
On the AP Physics test the equation takes this form:

$$\Delta E = (\Delta m)c^2$$

Note, however, that it's really still essentially identical to the $E_0 = mc^2$ equation.

Here's another conversion value that you will have available for use on the AP Physics test:

$$1\,u = 931\,\frac{MeV}{c^2}$$

"Now you've done It!"

The c^2 part of it tells us it comes from the $E = mc^2$ equation. It has a really weird unit, don't you think? The Physics Kahuna puzzled over this thing for many a microsecond before he finally figured it out.

Mass is equivalent to energy via the old $\Delta E = (\Delta m)c^2$ equation, correctimundo?

So we take us this here equation and stick in $1\,u = 931\,\frac{MeV}{c^2}$ for the mass:

$$\Delta E = (\Delta m)c^2 \quad = \left(931\,\frac{MeV}{\cancel{c}^2}\right)\cancel{c}^2$$

The c^2 term cancels out, so we see that a mass of one atomic mass unit is equivalent to 993 MeV. So really, when you want to convert atomic mass units to MeV, you just use the conversion factor as:

$$1\,u = 931\,MeV$$

Meaning of Einstein's Equation: Ah, but what does Einstein's equation mean? Well, it doesn't say that matter and energy are the same thing. Indeed they are not – not even your basic close. No, young student of physics, what it does say is that mass and energy are ***equivalent***. This means that mass can be converted into energy and that energy can be converted into mass. This sounds pretty tame, but really, when you think about it, it is pretty revolutionary.

The effects of this are pretty insignificant in everyday life. No one notices that a car speeding down the interstate at 75 mph has a slightly greater mass than it had when it was at rest in a driveway (more energy means more mass).

This energy source cannot be tapped into ordinarily. We can't just raid the trashcan and convert some old coffee grounds into energy (as was done in the first *Back to the Future* movie with a Mr. Fusion device). This does not mean that it can't be done, however. Actually back in 1905 when Einstein published his theory, the response of the physics community was a sort of yawn type thing. The old boy network thought that the energy mass equivalence thing was interesting, but certainly nothing that would ever actually do anything.

There is no likelihood man can ever tap the power of the atom. The glib supposition of utilizing atomic energy when our coal has run out is a completely unscientific Utopian dream, a childish bug-a-boo. Nature has introduced a few fool-proof devices into the great majority of elements that constitute the bulk of the world, and they have no energy to give up in the process of disintegration.
-- Robert A. Millikan

...any one who expects a source of power from the transformation of these atoms is talking moonshine... -- Ernest Rutherford

Even Einstein was of this opinion:

There is not the slightest indication that nuclear energy will ever be obtainable. It would mean that the atom would have to be shattered at will. - Albert Einstein

Well, obviously, these guys, great physicists all, were mistaken. Hey! It can happen. Anyway, ways were found to the deed. One of the ways that we can tap into this energy/mass thing is during nuclear reactions. In fission, mass is converted into energy. This also happens in a process called ***fusion***. Fusion is when two nuclei are forced together to form a larger nuclei.

Fusion is the source of the sun's energy. Deep within the sun hydrogen fuses into helium. Huge amounts of energy are thus produced. Life exists on earth and we do what we do because of the energy we get from the sun.

Fusion is also used in hydrogen bombs (which fuse isotopes of hydrogen together to form helium).

We haven't been able to figure out a way to use fusion to produce power in reactor plants like we do fission. Maybe someday.

Dear Doctor Science,
In positron emission, a proton turns into a neutron and a positron, the positron and one of the electrons in the atom mutually destroy each other to keep the electrostatic charge of the atom balanced. My question is why does my nose itch when I think about chickens?
-- Eric Raxler from Chino, California

Dr. Science responds:
You may be allergic to chickens, and positron emission has nothing to do with it. Or, you might be one of those unfortunate few who have an electrostatic deficit, resulting in habitual negativity and a co-dependent relationship to most sub-atomic particles. If that's the case, you have to start setting limits and sticking to them. You can't be all things to all matter, even if you'd gladly twist yourself into a Mobius strip to do so. Once your level of self-loathing exceeds your sense of self worth, your nose begins to itch, chickens or no chickens.

Binding Energy -- Mass Defect: ***(Important stuff you need to know.)*** A weird thing happens when you put a nucleus together from its spare parts (protons and neutrons). The total mass of the new nucleus ends up being less than the combined mass of the individual particles that went into the thing. This means that the mass of the nucleus is less than the sum of the masses of its individual particles. This difference in mass is called the ***mass defect***. Since mass is equivalent to energy, the mass defect represents the energy that it takes to hold the nucleus together. This energy is called the ***binding energy***.

Now mass and energy are equivalent, so the mass defect and the binding energy equal each other.

For example, we can look at a helium nucleus, helium four. He – 4 has 2 protons and 2 neutrons. The mass of the nucleus is 4.001509 u, the mass of a single proton is 1.007276 u, and the mass of a single neutron is 1.008665 u. We can add up the mass of two protons and two neutrons and see what they total:

$$2\left(1.007276\ \mathrm{u}\right) = 2.014552\ \mathrm{u}$$
$$2\left(1.008665\ \mathrm{u}\right) = 2.017330\ \mathrm{u}$$
$$2.014552\ \mathrm{u} + 2.017330\ \mathrm{u} = 4.031882\ \mathrm{u}$$

Now we can compare this mass with the actual mass of a helium – 4 nucleus. This is the mass defect.

$$4.031882\ u - 4.001509\ u = 0.030373\ u$$

We can find the amount of energy that would be equivalent to it, which is the binding energy.

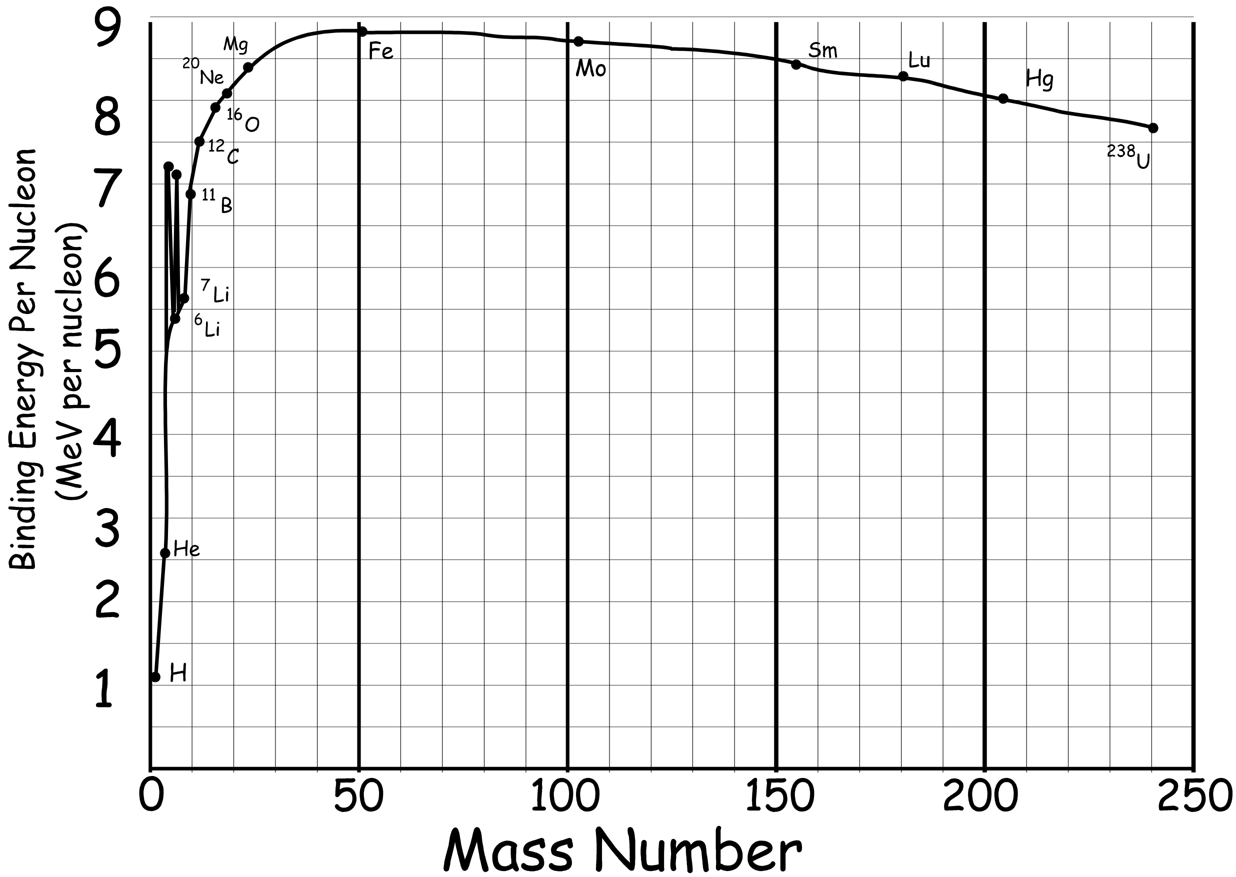
$$0.030373\ \cancel{u}\left(\frac{921.494\ MeV}{1\ \cancel{u}}\right) = 27.989\ MeV$$

28.0 MeV of energy is bound up in the He-4 nucleus.

The binding energy per nucleon is a critical factor in nuclear physics. Let's calculate it for the helium nucleus. The helium nucleus has four nucleons.

$$\frac{27.989\ MeV}{4} = 6.99\,725\ \frac{MeV}{nucleon}$$

If the binding energy per nucleon is plotted with mass number, we get the following graph:

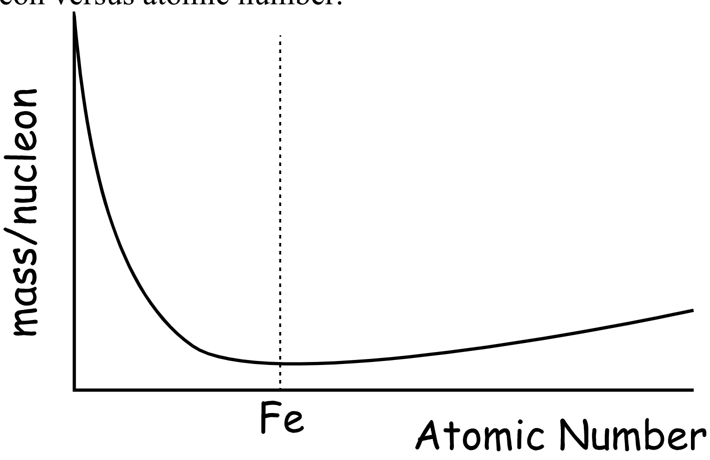


From the graph we can see that most elements have a binding energy per nucleon between eight and nine. The curves peaks around mass number 60, so isotopes that have a mass number around 60 tend to be the most stable. Their nucleons are the most tightly bound.

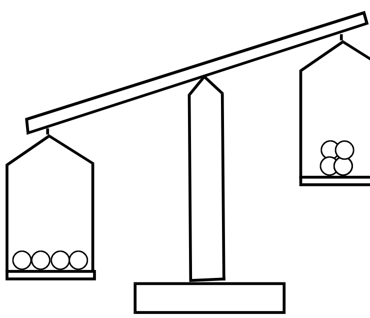
This curve turns out to be very important. We talked about how energy is released in the fission of isotopes like U-235 and Pu-239, but also how energy was also released in the fusion of hydrogen nuclei into helium nuclei. This curve explains how this can happen. For fission, we have elements with very large mass numbers. If the mass number decreases (i.e., fission takes place) we go from a low binding energy per nucleon to a higher binding energy per nucleon. This means that the nucleus changes from one where the nucleus is loosely bound to where the nuclei formed are more tightly bound. This means that energy can be released.

For small mass numbers, as the mass number increases the binding energy per nucleon also increases. This would be fusion, so in fusion, energy can also be released.

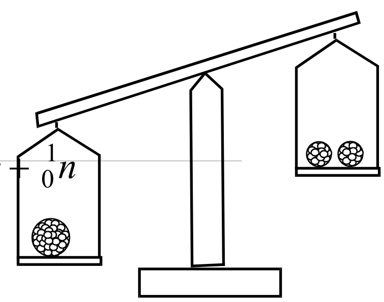
Another way to see the energy business a bit more clearly (in the opinion of the Physics Kahuna) is to plot mass per nucleon versus atomic number.



Here you can see that as the atomic number decreases for the low atomic number elements, the mass per nucleon decreases, the mass that is missing will have been converted into energy. Just the opposite happens for the higher atomic number elements – energy is released as the atomic number decreases.



In fusion, the mass of the new nucleus is less than the mass of the original nucleons.



In fission, the mass of the fission products is less than the mass of the original nucleus.

- In this nuclear reaction $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$ two deuterium nuclei combine in a fusion reaction to form Helium three and a neutron. The mass of a deuterium nuclei is 2.014 102 u. The mass of a helium-3 nuclei is 3.016 029 u. The mass of a solo neutron is 1.008 665 u. Calculate the following: (a) the mass defect for the production of a helium-3 nuclei in this reaction, (b) the energy release from a single fusion reaction in joules, (c) the energy release from a single fusion reaction in mega-electron volts, (d) A moderate sized city requires 2.0 x 10^9 J of energy in one year. Calculate the number of deuterium atoms that must be fused in order to produce this amount of energy.

(a) $$2\left(2.014\,102\,u\right) - 3.016\,029\,u - 1.008\,665\,u \quad = \quad 0.003\,249\,u$$

$$0.003\,249\ u\left(\frac{1.66\,x\,10^{-27}\,kg}{1\,u}\right) = 0.005393\,x\,10^{-27}\,kg \quad = \quad 5.393\,x\,10^{-30}\,kg$$

(b)

$$\Delta E = \left(\Delta m\right)c^2 \quad = 5.393\,x\,10^{-30}\,kg\left(3\,x\,10^{8}\,\frac{m}{s}\right)^2$$

$$\Delta E = 48.54 \; x \; 10^{-14} \; J \quad = \quad \boxed{4.85 \; x \; 10^{-13} \; J}$$

(c) $$\Delta E = (\Delta m)c^2 \quad = 0.003\,249 \; u \left(931 \frac{MeV}{c^2} \right) c^2 \quad = \quad \boxed{3.02 \; MeV}$$

Or (another way to do it).

$$4.85 \; x \; 10^{-13} \; J \left(\frac{1 \; eV}{1.60 \; x \; 10^{-19} \; J} \right) = 3.03 \; x \; 10^{6} \; eV \quad = \quad \boxed{3.03 \; MeV}$$

The answers are slightly different because the conversion factors are rounded off.

(d) $$2.0 \; x \; 10^{9} \; J \left(\frac{1 \; nuclei}{4.85 \; x \; 10^{-13} \; J} \right) = 0.41 \; x \; 10^{22} \; nuclei \quad = \quad \boxed{4.1 \; x \; 10^{21} \; nuclei}$$

Dear Cecil:

Why do nuclear explosions form a mushroom-shaped cloud? If you would tell me why frantic and furious fusion and fission have a fondness for the fungus form, I would certainly appreciate it.
--Paul Smith, Tampa, Florida

Cecil replies:
Shame on you, Paul. You know I cringe at F-words. You don't need an atom bomb to make a mushroom cloud, just convection. Mushroom clouds typically occur when an explosion produces a massive fireball. Since the fireball is very hot and thus less dense than the surrounding air, it rises rapidly, forming the cap of the mushroom cloud. In its wake the fireball leaves a column of heated air. This acts as a chimney, drawing in smoke and hot gases from ground fires. These form the stalk of the mushroom. Since the center is the hottest part of the mushroom cloud, it rises faster than the outer edges, giving the impression that the cap is curling down around the stalk. Thus the familiar fungal form.

Hydrogen bomb explosions are so huge the cloud may reach the tropopause, the boundary in the atmosphere where a fairly sharp rise in temperature starts. The cloud generally can't break through this and the top flattens out, producing an especially pronounced mushroom shape. (The tropopause also forms a ceiling for thunderheads, producing their anvil shape.)

Mushroom clouds aren't necessarily big. One of the Teeming Millions tells me he once set off a carbide noisemaker-type cannon with the igniter mechanism removed. Out of the hole where the igniter was supposed to go there issued a 10-inch mushroom cloud with a stem of fire and a cap of black smoke. And, we must suppose, a fabulously fierce FOOMP.
--CECIL ADAMS

Dear Doctor Science,
I've heard a lot about the element of Surprise, but I couldn't find it on my periodic table of the elements. What is the symbol for it? What is its atomic mass? Does it form compounds, like surprise oxide or surprise chloride? Does it have any unusual properties?
-- Greg Ellis from ?, ?

Dr. Science responds:
The element of surprise is represented by a simple question mark. Its atomic mass is the same as a neighboring element on the periodic table, Tedium. Being covalently needy and hungry for electrovalent stability, it forms neurotic bonds with any positively charged particle, including hydroxyl load-bearing ions, including the infamous Heisenberg Self Congratulatory Reflex, the cause of all emotional conflict. This is why you can't find these elements on most periodic tables, at least those sold to high school students.

- A polonium nucleus of atomic number 84 and mass number 210 decays to a nucleus of lead by the emission of an alpha particle of mass 4.0026 atomic mass units and kinetic energy 5.5 *MeV*.
  a. Determine each of the following.
     i. The atomic number of the lead nucleus

Atomic number is the number of Protons

$$84-2=\boxed{82}$$

     ii. The mass number of the lead nucleus

Number of Nucleons

$$210-4=\boxed{206}$$

  b. Determine the mass difference between the polonium nucleus and the lead nucleus, taking into account the kinetic energy of the alpha particle but ignoring the recoil energy of the lead nucleus.

The kinetic energy of the alpha particle is the mass difference of the two nuclei.

$$\Delta E=(\Delta m)c^2 \quad \Delta m=\frac{\Delta E}{c^2}$$

$$\Delta m=5.5\,M\cancel{e}V\left(\frac{1.66\,x\,10^{-27}\,kg}{1\,\cancel{u}}\right)\left(\frac{1\,\cancel{u}}{931\,\frac{M\cancel{e}V}{\cancel{c}^2}}\right)\frac{1}{\cancel{c}^2}$$

$$\Delta m = 0.0098\,x\,10^{-27}\,kg \quad = \quad \boxed{9.8\,x\,10^{-30}\,kg}$$

c. Determine the speed of the alpha particle.

$$K = 5.5\,MeV\left(\frac{1\,x\,10^{6}\,eV}{1\,MeV}\right)\left(\frac{1.60\,x\,10^{-19}\,J}{1\,eV}\right) \quad = \quad 8.8\,x\,10^{-13}\,J$$

$$K = \frac{1}{2}mv^2 \quad v = \sqrt{\frac{2K}{m}} \quad = \sqrt{\frac{2\left(8.8\,x\,10^{-13}\,\frac{kg \cdot m \cdot m}{s^2}\right)}{6.64\,x\,10^{-27}\,kg}} \quad = \quad \boxed{1.63\,x\,10^{7}\,\frac{m}{s}}$$

The alpha particle is scattered from a gold nucleus (atomic number 79) in a "headon" collision.

d. Write an equation that could be used to determine the distance of closest approach of the alpha particle to the gold nucleus. It is not necessary to actually solve this equation.

At closest approach the kinetic energy becomes zero and the electric potential is maximized and equal to the kinetic energy the particle began with. (Throw something up and the kinetic energy is zero while the potential energy is max. The kinetic energy becomes potential energy.)

$$K = U_E$$

$$\frac{1}{2}mv^2 = qV \quad V = \frac{1}{4\pi \in_0}\frac{q}{r} \quad so \quad \frac{1}{2}mv^2 = q\left(k\frac{q}{r}\right)$$

Thus

$$r = 2\left(\frac{1}{4\pi \in_0}\right)\frac{q^2}{mv^2}$$

Dear Cecil:
What's the difference between a hydrogen bomb and an atomic bomb?! How lethal are they?! please find out!!!
--Anonymous

Cecil responds:
I told you not to buy stuff at those Kiev flea markets. The original atomic bomb used nuclear fission, in which big atoms (uranium or plutonium) were split into littler ones in a chain reaction, releasing vast amounts of energy. The hydrogen bomb employs nuclear fusion, in which little atoms

(various forms of hydrogen) fuse together to make bigger ones (helium), essentially the same process that occurs in the sun.

Fusion bombs are a thousand times more powerful than fission bombs, which are a million times more powerful than chemical ones. Wouldn't you be just as happy with, say, a cherry bomb?
--CECIL ADAM

Official Kahuna Physics Institute

Periotic Table

1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potasium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yitrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.20	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Ti Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astitane (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium 226.03	89 Ac Actinium 227.03	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)									

58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.97	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)