Nuclear Radiation

The nucleus

- Although little was known about atomic theory in the time of Becquerel, he discovered that an energy was emitted from Uranium ore that cannot be explained.
- He called it radiation, and later after Rutherford’s Gold Foil experiment, it was discovered that the atoms contained a small, dense, positively charged particle called a nucleus.
- It was not long before a connection was made between this radiation and the atomic nucleus.

Isotopes

- The nucleus contains all of the protons and neutrons in the atom.
- These two particles give the atom its mass.
- The number of protons is a way to identify what element it is, but the number of neutrons can change.
- This is why a single element can have atoms of varying masses called isotopes.
- The actual atomic mass is an *average* of all of the possible atomic masses. That's why it's a decimal.

Calculating average atomic mass.

- We can't add up the mass of each individual isotope and divide by the number of particles because there are too many to count.
- What we can do is figure out percentage of each isotope in the sample and then calculate.
- (%A/100)(mass A) + (%B/100)(mass B) + …… = average atomic mass.
- Do that for each isotope regardless of how many you have.

Nuclear radiation

- 3 types of nuclear radiation were discovered along with their properties.
- Alpha Particles – helium nuclei – symbol is ${}^{4}_{2}He$ – or α. Large mass, low penetrating power.
- Beta Particles – electrons – symbol is ${}^{0}_{-1}e$ – or β. Small mass, high penetrating power.
- Gamma rays – pure energy – symbol is ${}^{0}_{0}\gamma$ – no mass, very high penetrating power.
- Notice that 2 of them are particles.
- Gamma rays are most dangerous.

Nuclear Decay

- Since the nucleus has a lot of protons, they repel and try to fly apart.
- Neutrons in the nucleus help to bring some stability, and the particles are held together with a strong force.
- Sometimes the force tearing the nucleus apart has a probability of overcoming the strong force and so the nucleus sheds particles and energy to attempt to become more stable.
- This is nuclear decay. The particles are alpha or beta, and the energy is gamma radiation.

Decay types

- If an isotope is considered an alpha emitter, it mean that many alpha particles are emitted with few beta particles and little gamma rays.
- Likewise, a beta emitter is a radioisotope that gives off mostly beta particles with few alpha and little gamma radiation.
- A gamma emitter gives off few particles but a lot of gamma rays.
- The gamma radiation is the excess kinetic energy that the nucleus has after emission, and once released helps the nucleus settle down.

Decay equations

- For the decay equations, you must get the atomic numbers and masses in the equation to match on both sides of the arrow.
- Ex. Einsteinium-252 decays by alpha emission:
- ${}^{252}_{99}Es \rightarrow {}^{4}_{2}He + ???$
- The rest must be ${}^{248}_{97}Bk$ since that will make the top and bottom equal on both sides of the arrow.

Decay series

- After a decay, the nucleus may not be stable yet, so it will decay again.
- For large, unstable atoms, decay series may be more than 10 steps long before the nucleus is stable.
- In addition, since it is based on probability, some isotopes can undergo either alpha or beta decay.
- Most heavy elements complete their decay series at Pb.

Half-Lives

- The amount of time it takes half of a sample of a radioactive isotope to decay is the half life.
- Since decay is a probability, the half-lives of substances vary greatly.
- Half-lives can never change, so once you know the half life, it always takes that same amount of time to remove half of the sample.
- Samples can only decay away, so amounts always decrease when you look in the future, and increase when you go back into the past.

Length of decay

- Since there are so many atoms of each isotope, then essentially there will always be some amount of the isotope left.
- Since the probability of decay is the same, and the half life is the same, then the amount of decay slows down as more particles decay away.
- This is why you always divide your previous amount by 2. The sample size then keeps getting smaller, but at a slower and slower rate.

Transmutation

- Another type of nuclear reaction (also developed by Rutherford) is a nuclear transmutation.
- This is where two particles are forced together and create new particles.
- This is how new elements and isotopes are created.
- This also opened the door for advanced power generation methods.
- Still balance the top and bottom numbers on both sides of the reaction just like in decay reactions.

Nuclear Fission

- Fission is a special type of transmutation reaction.
- If you have a large unstable nucleus and hit it with a particle, it can cause the nucleus to tear into pieces.
- When the nucleus comes apart, less strong force is needed to hold it together.
- Einstein said $E=mc^2$ which means that energy and mass are related.
- The loss of strong force is measured as a change in mass, but that means a large amount of energy is released.

Fission reactions

- U -235 is one of the only fissionable radioisotopes the exists naturally.
- If U-235 is hit by a neutron, it splits into two other nuclei and several more neutrons.
- These other neutrons can go and fission other nuclei creating a chain reaction.
- An amount of U-235 called the critical mass is necessary to ensure that a chain reaction will occur and be self-sustaining.
- This is the amount needed for a nuclear bomb and a nuclear power plant.

Bomb vs. Power plants

- In an atomic bomb, 90% or more of the material needed to be U-235.
- In a power plant, the amount of U-235 is only 3% so a power plant can never explode like a bomb.
- If a reaction runs out of control in a power plant, it releases too much heat and melts the core. This is called a meltdown.
- It is dangerous because not the material is harder to control and can melt out of the containment building and get into the atmosphere.

Power plants

- Nuclear plants have control rods which absorb neutrons to control the rate of reaction.
- Plants also need a moderator to slow down the neutrons in order to fission other nuclei.
- The U.S. uses water, so if the core overheats, the moderator boils away and the reaction stops.
- This makes our plants safer.
- Russian plants use graphite as a moderator so that when the core overheats, the moderator melts and continues to keep the reaction going.

Nuclear Fusion

- Fusion is another type of transmutation reaction.
- In fusion, two small nuclei are combined to make a larger nucleus.
- This causes more mass to be lost, and therefore creates more energy.
- The small nuclei are hydrogen isotopes.
  - Hydrogen-2 is naturally occurring and called deuterium.
  - Hydrogen-3 is man-made and radioactive and called tritium.
- Fusion powers the sun, but can only be created on Earth in labs.

Protect against radiation

- Shielding – put something between you and the source.
- Time – don't be near the source very often.
- Distance – the farther away you are the less radiation you will experience.
- Radiation causes genetic mutations in adults which causes cancer.
- In fetuses this can cause birth defects.
- In all cases, high doses of radiation kill healthy cells and cause radiation sickness.