EXPERIMENT 0

Nuclear Chemistry

A. Goal

The goal of this laboratory experiment is to measure the radioactivity of a set of chips and to test the effect of the use of a shield and distance.

B. Materials

- ☐ ST360 radiation counter
- ☐ set of chips
- ☐ set of shields

C. Background

Radiation, particles & radioisotopes

Light elements have normally stable nuclei. Differently, heavier elements with atomic numbers larger than 20 tend to often have several isotopes–remember these are atoms of the element with a different number of neutrons–that have unstable nuclei. For these unstable isotopes, the forces that keep the nucleus together are not strong enough to stabilize the nuclei. An unstable nucleus is radioactive, which means that it will spontaneously emit radiation in the form of small particles. Not all radioactivity is the same and there exist different types of radiation, which we will address in the following. Table **??** reports common nuclear symbols.

alpha radiation

Alpha radiation–referred to as α–is a type of radiation that contains alpha particles. These particles are indeed helium nuclei, with 2 protons, 2 neutrons, and a (2+) positive charge. Alpha particles are often represented as α or $^{4}_{2}He$.

beta radiation

Beta radiation–referred to as β–is a type of radiation that contains beta particles. These particles are indeed high-energy electrons with $(-)$ negative charge. Beta particles are often represented as β or $^{0}_{-1}e$.

gamma radiation

Gamma radiation–referred to as γ–is a type of radiation that contains high-energy photons. These particles are indeed photons with no mass or charge. Gamma particles are often represented as γ or $^{0}_{0}\gamma$.

protons

Protons in this chapter are often referred to as p or $^{1}_{1}H^{+}$. These are positive charges.

positrons

Positrons are the electron antiparticle, often referred to as β^{+} or $^{0}_{+1}e$. They do have a positive charge.

neutrons

Neutrons are nuclear particles with no charge, often referred to as n or ${}^{1}_{0}\mathrm{n}$.

Radioisotope notation

Radioisotopes–atomic isotopes that produce radiation–are written as ${}^{A}_{Z}\mathrm{X}$. For example, ${}^{14}_{6}\mathrm{C}$ is referred to as carbon-14. The number on the top is the mass number A, that is represented the total number of neutrons and protons in the isotope. The number on the bottom refers to the atomic number Z, that is, the total number of electrons in the atom. For example, the mass number of ${}^{14}_{6}\mathrm{C}$ is 14 whereas its atomic number is 6. ${}^{14}_{6}\mathrm{C}$ has 14 neutrons and protons and 6 electrons.

Sample Problem 1

Name or give the symbols for the following nuclear particles: beta particle, β^{+}, p and ${}^{0}_{0}\gamma$.

SOLUTION

Beta particles are represented by β or ${}^{0}_{-1}\mathrm{e}$. These particles are indeed simply electrons ejected during a nuclear decay. β^{+} represents a positron, an anti-electron. p stands for protons, a nuclear particle with positive charge. Finally, ${}^{0}_{0}\gamma$ represents gamma radiation.

STUDY CHECK

Name or give the symbols for the following nuclear particles: n, α and ${}^{1}_{1}\mathrm{H}^{+}$.

Table ?? Nuclear symbols

Particle Name		Symbol	Charge	Identity	Penetrating power	Discovery
Alpha	(α)	${}^{4}_{2}\mathrm{He}$	$2+$	Helium nucleus	Minimal	1899
Beta	(β)	${}^{0}_{-1}\mathrm{e}$	-1	Electrons	Short	1899
Gamma	(γ)	${}^{0}_{0}\gamma$	0	Electromagnetic radiation	Deep	1900
Neutrons	(n)	${}^{1}_{0}\mathrm{n}$	0	nuclear particle	Maximal	1932
Proton	(p)	${}^{1}_{1}\mathrm{H}^{+}$	$+1$	nuclear particle		1919
Positrons	(β^{+})	${}^{0}_{+1}\mathrm{e}$	$+1$	antiparticle		1932

Nuclear reactions

Isotopes–called emitters–spontaneously decompose producing new isotopes in a process called radioactive decay. In this decay, radiation is also emitted.

$$\text{Emitter} \longrightarrow \text{radiation} + \text{New isotope}$$

In the following, we will discuss the most important type of radioactive decay.

alpha decay

Some isotopes produce alpha radiation, that is, they produce α particles on its decay. A nuclear reaction that produces an α particle (${}^{4}_{2}\mathrm{He}$) is called alpha decay. In alpha decay, the emitter decreases its mass number A four units and its atomic number Z two units.

$$\text{Emitter} \longrightarrow {}^{4}_{2}\mathrm{He} + \text{New isotope}$$

beta decay

Other isotopes produce beta radiation, that is, they produce β particles on its decay. A nuclear reaction that produces a β particle (${}^{0}_{-1}\mathrm{e}$) is called beta decay. In beta decay, the emitter has the same mass number A as the product isotope. However, its atomic number Z decreases by one unit.

$$\text{Emitter} \longrightarrow {}_{-1}^{0}\text{e} + \text{New isotope}$$

positron emission

Certain isotopes decay by producing a positron, that is, they produce ${}_{+1}^{0}\text{e}$ particles on its decay. A nuclear reaction that produces ${}_{+1}^{0}\text{e}$ is called positron emission. In a positron emission, the emitter has the same mass number A as the product isotope. However, its atomic number Z increases by one unit.

$$\text{Emitter} \longrightarrow {}_{+1}^{0}\text{e} + \text{New isotope}$$

gamma decay

Some other isotopes produce gamma radiation in the form of γ particles on its decay. A nuclear reaction that produces a γ particle (${}_{0}^{0}\gamma$) is called gamma decay. In this type of decay, no new isotope is produced. Gamma emitters are normally excited, that is they have higher energy than normal; we denote this with a * symbol. Exited particles tend to lose energy to become more stable. In gamma decay, the emitter and the product isotope, both have the same mass and atomic number.

$$\text{Emitter}^* \longrightarrow {}_{0}^{0}\gamma + \text{Emitter}^*$$

Sample Problem 2

Label the following nuclear reactions as: α, β or γ decay, or positron emission:

(a) ${}_{92}^{238}\text{U} \longrightarrow {}_{90}^{234}\text{Th} + {}_{2}^{4}\text{He}$

(b) ${}_{13}^{24}\text{Al} \longrightarrow {}_{12}^{24}\text{Mg} + {}_{+1}^{0}\text{e}$

(c) ${}_{6}^{14}\text{C} \longrightarrow {}_{7}^{14}\text{N} + {}_{-1}^{0}\text{e}$

(d) ${}_{43}^{99}\text{Tc}^* \longrightarrow {}_{43}^{99}\text{Tc} + {}_{0}^{0}\gamma$

SOLUTION

(a) This process produces ${}_{2}^{4}\text{He}$ and therefore is alpha emission. (b) This process generates ${}_{+1}^{0}\text{e}$ and therefore is positron emission. (c) This process produces ${}_{-1}^{0}\text{e}$ and therefore is beta emission. (d) This process produces ${}_{0}^{0}\gamma$ and therefore is gamma emission.

STUDY CHECK

Label the following nuclear reactions as: α, β or γ decay, or positron emission:

(a) ${}_{55}^{127}\text{Cs} \longrightarrow {}_{54}^{127}\text{Xe} + {}_{+1}^{0}\text{e}$

(b) ${}_{13}^{27}\text{Al}^* \longrightarrow {}_{13}^{27}\text{Al} + {}_{0}^{0}\gamma$

(c) ${}_{85}^{218}\text{At} \longrightarrow {}_{83}^{214}\text{Bi} + {}_{2}^{4}\text{He}$

Radiation protection

Radioactivity results from the emission of very energetic and small particles. It can be extremely harmful when no proper protection is used. Therefore, all hospital personnel working with radioactive isotopes–radiologists, doctors, and nurses–need to be protected against radiation. Table **??** reports some useful information regarding radiation protection.

alpha particles

Alpha radiation is made of very heavy particles (He nuclei) that can only travel between 2-4cm in the air before disappearing Inside your body they can penetrate only 0.05mm. A simple piece of thin clothing, a lab coat, gloves, or even our skin can protect us against alpha particles.

beta particles

Beta radiation is made of lighter particles (electrons) that move much faster than alpha particles. Beta particles travel between 200-300cm in the air and between 4-5mm in body tissue. Heavy clothing such as lab coats or gloves is needed to protect you against this radiation.

gamma particles

Gamma radiation can pass through many materials including body tissues. Gamma rays travel around 500 m in the air and more than 50cm in tissue. Only very dense shielding, such as lead or concrete, will protect you from this radiation.

D. Procedure

0. Instructions for the use of ST360 radiation counter

Step 1: – Turn on the radiation counter (red button on the back).

Step 2: – Use display select to select *time*. Set the time to 60 seconds by pressing the display Up or Down.

Step 3: – Use display select until the light cursor is next to *high voltage*. Set the voltage to 900V by pressing the display Up or Down.

Step 4: – Use display select until the light cursor is next to counts.

Step 5: – Place a radioactive chip on the chip support and measure. In case of using a shield, place it between the counter and the chip.

Step 6: – Press Count and wait until the stop button sign lights up, as the machine stops automatically when the 60s is up.

Step 7: – Right down the unit of the reading as count per minute (cpm).

1. Background radiation The air has a certain radioactivity called background radioactivity. This is a very small activity but still affect the radioactive measurements and hence it should be taken into account. In this experiment you will measure the background radiation by means of a Geiger counter. You will have to repeat the measurement several times and average the radiation measured in order to obtain a reliable number.

Step 1: – Do not use any of the chips and make sure they are in the secured protecting box.

Step 2: – Start the Geiger counter. Set up the measurement time to 60 seconds and the measuring voltage according to your professor's instructions. Mind to select a voltage of 900V for all measurements (Press Display/High Voltage/Up/Down until you reach 900V). Press measure (press Display until the light cursor is next to count; then press Count until the stop button lights up.) and write down the background radioactivity in counts per minute in the table below.

Step 3: – Repeat the measurement two more times and calculate the average by adding the three measurements and dividing by three. Make sure the measurements are consistent with each other.

2. Radioactive chips In this section you will calculate the radioactivity of a set of different radioactive chops. You will still use the Geiger counter and after measuring the number of counts per minutes you will have to subtract the background radiation to your measurement.

Step 1: – Select three of the radioactive chips.

Step 2: – Place one of the chips 5cm away from the counter by means of the plastic stand.

Step 3: – Start the Geiger counter. Set up the measurement time to 60 seconds and the measuring voltage according to your professor's instructions. Press measure and write down the background radioactivity in counts per minute in the table below.

Step 4: – Repeat the measurement for the other two chips.

Step 5: – Repeat the measurement for other materials such as tea, instant coffee, potassium chloride or dry seaweed.

Step 6: – Now subtract the background radiation measured in the previous section to teach of the measurements.

3. Radioactivity protection In this section you will only use one of the chips from the previous experiment. For this one chip you will use different barriers to shield radiation and estimate the shielding impact.

Step 1: – Select radioactive chip from the previous experiment that gave you the highest counts per minute.

Step 2: – Place the chips at a 10cm distance from the counter by means of the plastic stand.

Step 3: – Select three of the shielding and place one of these in between the counter and the chip.

Step 4: – Measure the number of counts per minute and subtract the background radiation.

Step 5: – Write down the measurement in the table below. Compute the activity taking into account the background radiation. These results can potentially be a negative value.

Step 6: – Repeat the procedure for the other two shielding.

4. Effect of distance on radioactivity In this section you will only use one of the chips from the previous experiment, again the stronger one. You will place this chip at different distances from the counter and measure the impact of distance on radioactivity.

Step 1: – Place the chips at five different distances from the counter by means of the plastic stand. The distances are indicated in the table below.

Step 2: – Measure the number of counts per minute for each distance and subtract the background radiation.

Step 3: – Write down the measurement in the table below.

Step 4: – Plot activity without the background (right column, vertical axis) vs distance (horizontal axis) connecting the points with a line in the graph below.

STUDENT INFO	
Name: ______________________	Date: ______

Pre-lab Questions

Nuclear Chemistry

---

1. Classify the following decays as α, β, γ or positron emission:

   (a)
   $$^{235}_{92}U \longrightarrow ^{231}_{90}Th + ^{4}_{2}He$$

   (b)
   $$^{235}_{92}U \longrightarrow ^{235}_{92}Np + ^{0}_{0}\gamma$$

   (c)
   $$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e$$

   (d)
   $$^{222}_{88}Ra \longrightarrow ^{4}_{2}He + ^{226}_{88}Ra$$

2. Iodine-131 is used to treat certain types of thyroid cancer and some rarer types of cancer. Given that its half-life is 8days, calculate the amount of iodine of a 4g sample that remains after 10 days.

3. Strontium-89 is used to treat some types of secondary bone cancer. Given that its half-life is 50days, calculate the time needed to reduce a 4g sample into 2g.

4. Iron-59 is used in studies of iron metabolism in the spleen. A Iron-59 sample has an activity of 20cpm and 10cpm 46 days after the first measurement. Calculate the half life of the isotope.

STUDENT INFO

Name: ______________________ Date: ______

Results
EXPERIMENT

Nuclear Chemistry

---

1. Background radiation

Measurement 1 (cpm)	Measurement 2 (cpm)	Measurement 3 (cpm)	Average Radiation (cpm)

2. Radioactive chips

Isotope name	Activity (cpm)	Activity - Background (cpm)

3. Radioactivity protection

Isotope name=____________________________

Shielding name	Activity (cpm)	Activity - Background (cpm)

5. Effect of distance on radioactivity

Isotope name=____________________________

Distance (cm)	Activity (cpm)	Activity - Background (cpm)
1cm		
2cm		
3cm		
4cm		
5cm		

Isotope Name=______________________________

STUDENT INFO

Name: ______________________ Date: ______

Post-lab Questions

Nuclear Chemistry

---

1. From the radioactive chips you studied indicate the nature of the radiation (written on the chip) produced by the strongest chip.

2. From the common materials, you tested for radiation (tea, seaweed, coffee, and KCl), which one gave you the highest radioactive measurement?

3. From the different shielding you studied indicate the nature of the one that protected the most from radiation.

4. From the graph you made estimate the number of counts per minute at 3.5cm from the counter.