# Hoofdstuk; Radioactivity

## 3 Atheneum TTO Physics

Maarten Becx (STMBC)

Mencia de Mendoza Lyceum, Breda

April - May

# General Information

## Contact STMBC

- Email: mbecx@mencia.nl
- Webmail: info@becxlibrary.nl
- Teams: Maarten Becx
- Workspace: C1.08

## Structure

- Website: www.becxlibrary.nl
- Website info: This contains all the files you need for my lessons. **If something is missing or incorrect, please let me know as soon as possible via one of the contact options. Thanks in advance!**

## Don't forget!

The universe is not obligated to make sense to you! So always ask your questions!

# Important Information

## Materials List

- Pen (Writing)
- Pencil (Drawing)
- Set square *(Optional: Extra ruler)*
- Basic calculator *(Non-graphical and/or programmable)*
- Laptop (Simulations)
- Book; Science School (Online method: Radioactivity)

## Tips

- Use these slides for structure!
- You are always allowed to write and highlight on the test. You will hand it in, but it will not be graded!
- Always work carefully and in a structured way.
- You can always ask me for help! So make sure you do :)

# Introduction: Chemistry Recap

## Objects

Every object has mass and consists of molecules. Molecules are made up of atoms, which themselves consist of even smaller particles. These smaller particles are part of modern Physics.

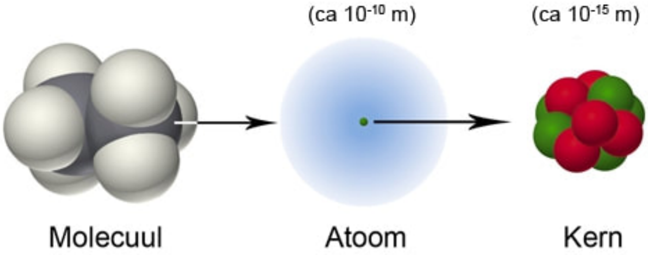


Figure: Familiar knowledge from Chemistry

# Introduction: Objects in the Universe

## Models

The Bohr atomic model used in Chemistry is central to this chapter. An atom consists of a nucleus with positively charged protons and neutrally charged neutrons. Negatively charged electrons orbit the nucleus in shells, and there can be multiple shells.

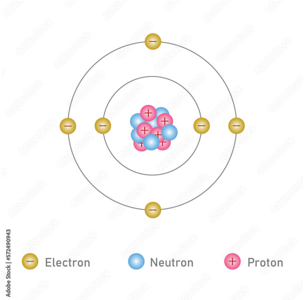


Figure: Bohr's Atomic Model

# Introduction: Radioactivity

Figure: Nuclear Power Plant

# Introduction: Radioactivity

## Personal Opinion

- Write down your personal opinion on nuclear energy in your own words.
- After watching two videos presenting both the positive and negative perspectives, you may adjust your opinion if it has changed.
- Keep your opinion safe. We will come back to it later.

## Why is your own opinion important?

- Later, when you start voting at age 18, it's important to understand nuclear energy. It's a major topic in political party programs — often a clear distinction between left and right.
- Nuclear energy is one of the ways a country can produce electricity in a green way with less waste. Nuclear energy could be a solution to the climate crisis. Should we invest in it?
- It is always important to form your own opinion on important topics so that you are able to stand up for yourself and look at the world from different perspectives.

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# Introduction: Misconceptions in (Scientific) Terms

## Radiation

When the nucleus of an element spontaneously breaks apart (at high speed), it releases **radiation**. The element is decaying because a particle “falls” out of the nucleus — sometimes more than one.

## Radioactivity

The amount of radiation released per second. When an element decays, it is said to be **radioactive**.

Figure: Symbol for radioactivity/radiation

# Radioactivity: Radiation

## Nuclear Decay

When an atomic nucleus decays, radiation is released, which is radioactive. This radiation can be classified into three different types. This process is also called the decay of the nucleus, or more specifically: **nuclear decay**.

## 3 Types of Radiation

- $\alpha$ - Radiation: Helium nuclei are released
- $\beta$ - Radiation: Electrons are released
- $\gamma$ - Radiation: No protons or neutrons are released, but photons are. These are energy packets that make up light

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# Radioactivity: Alpha ($\alpha$) Radiation

## Important!

- Definition: Radiation in which helium nuclei are released
- Notation: ${}^{4}_{2}\mathrm{He}$
- Name: Alpha particle
- Rule: $\alpha$-radiation can never occur simultaneously with $\beta$-radiation, but it can with $\gamma$-radiation. $\alpha$ and $\beta$ radiation can occur from the same isotope, just not at the same time.

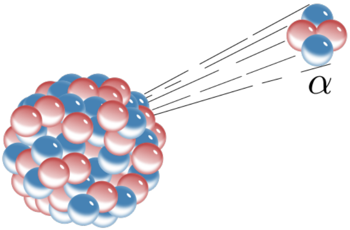


Figure: Alpha radiation with the "alpha particle"

# Radioactivity: Beta ($\beta$) Radiation

## Important!

- Definition: Radiation in which electrons are released
- Notation: ${}_{-1}^{0}\mathrm{e}$
- Name: Beta particle
- Rule: $\alpha$-radiation can never occur simultaneously with $\beta$-radiation, but it can with $\gamma$-radiation. $\alpha$ and $\beta$ radiation can occur from the same isotope, just not at the same time.

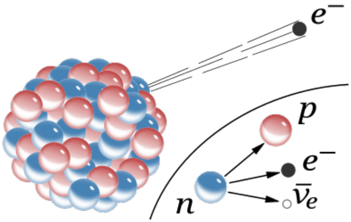


Figure: Beta radiation with the "beta particle"

# Radioactivity: Gamma ($\gamma$) Radiation

**Important!**

- Definition: Radiation in which no protons or neutrons are released, but photons are. These are energy packets that make up light
- Notation: ${}^{0}_{0}\gamma$
- Name: Gamma particle or photon
- Rule: $\gamma$-radiation can occur simultaneously with both $\alpha$ and $\beta$ radiation

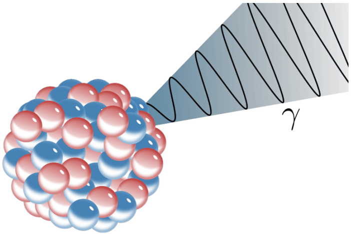


Figure: Gamma radiation with the "gamma particle" or photon

# Nuclear Decay: Decay Equations

## Nuclear Decay (recap)

When an atomic nucleus decays, radiation is released, which is radioactive. This radiation can be expressed in three types. This process is also known as the decay of the nucleus, or: **nuclear decay**.

## Isotope

All elements in the periodic table are stable, with a neutral (0) charge. If an element has a different number of neutrons, it is called an **isotope**. It is an isotope of the standard element. These isotopes can be found in the table you received during the lesson.

## Example

**Polonium-214** is an alpha emitter. This means a helium nucleus is ejected from the polonium nucleus. The "214" means that the atom has a different number of neutrons than standard polonium. The nucleus is unstable and is therefore called an isotope.

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# Nuclear Decay: Example Decay Equation

## Polonium-214

- What do we know? **Polonium-214** has **214 protons and neutrons**. The symbol for Polonium is $\mathrm{Po}$ and it has **atomic number 84**. It is written as: $^{214}_{84}\mathrm{Po}$
- The table shows that **Polonium-214** is an $(\alpha)$ alpha emitter.

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| | | | | | | |
|---|---|---|---|---|---|---|
| 84 | Po | 209 | 208,98240 | | 102 y | α 4,09 |
| | | 210 | 209,98286 | | 138 d | α 5,4, γ |
| | | 211 | 210,98666 | | 0,5 s | α 7,434 |
| | | 212 | 211,98887 | | $3 \cdot 10^{-7}$ s | α 8,776 |
| | | 213 | 212,99283 | | $3{,}2 \cdot 10^{-6}$ s | α 8,3 |
| | | 214 | 213,99519 | | $1{,}6 \cdot 10^{-4}$ s | α 7,68 |
| | | 215 | 214,99942 | | $1{,}83 \cdot 10^{-3}$ s | α 7,365 |
| | | 216 | 216,00190 | | 0,158 s | α 6,774, $\beta^-$ |
| | | 218 | 218,00893 | | 3,05 min | α 5,998, $\beta^-$ |

Figure: Lookup in the BiNaS isotope table

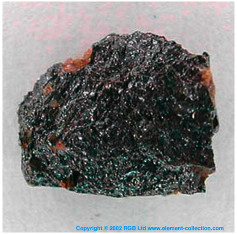


Figure: The element Polonium

# Nuclear Decay: Decay Equation Polonium-214

## Known

- Notation: $^{214}_{84}\mathrm{Po}$
- Radiation: $\alpha$ radiation
- Decay: A helium nucleus: $^{4}_{2}\mathrm{He}$

## Decay Equation Polonium-214

$$^{214}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{210}_{82}\mathrm{Pb}$$

## Attention!

The same atomic nucleus transforms into a new isotope of another element — in this case, **Lead-210**. Make sure the total number of protons and neutrons is always equal on both sides of the arrow! A nuclear reaction has taken place.

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# Nuclear Decay: Decay Series

## Important Distinction

A **decay equation** describes a single decay event of a nucleus. If this happens multiple times, it becomes a **decay series**. *On tests and assignments, it will be indicated which one to use.*

## Assignment

1. Write the decay equation of Lead-210
2. Write the 2 possible decay equations of the newly formed isotope
3. Explain what stands out about these two decay equations

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# Nuclear Decay: Polonium-214 Decay Series – Assignment 1

## Assignment 1 Solution

- Known: Lead-210 is a $\beta$ and $\gamma$ emitter. So electrons and photons are emitted
- Result: Bismuth-210 is formed
- Decay Equation: ${}^{210}_{82}\mathrm{Pb} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\gamma + {}^{210}_{83}\mathrm{Bi}$

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# Nuclear Decay: Polonium-214 Decay Series – Assignment 2

## Assignment 2 Solution

- Known: Bismuth-210 is an $\alpha$, $\beta$, and $\gamma$ emitter. So helium nuclei, electrons, and photons may be emitted. Note that alpha and beta cannot occur simultaneously.
- Result: Alpha decay forms Thallium-206; beta decay forms Polonium-210
- Decay Equation for $\alpha$ radiation: ${}^{210}_{83}\mathrm{Bi} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma + {}^{206}_{81}\mathrm{Tl}$
- Decay Equation for $\beta$ radiation: ${}^{210}_{83}\mathrm{Bi} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\gamma + {}^{210}_{84}\mathrm{Po}$

# Nuclear Decay: Polonium-214 Decay Series – Assignment 2

## Assignment 2 Solution

- Known: Bismuth-210 is an $\alpha$, $\beta$, and $\gamma$ emitter. So helium nuclei, electrons, and photons may be emitted. Note that alpha and beta cannot occur simultaneously.
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# Nuclear Decay: Repeat Assignment

## Assignment

Write the full decay series of Polonium-214, including the final two decay equations — both the $\alpha$ and $\beta$ decay equations of Bismuth-210.

# Nuclear Decay: Example Decay Series of Polonium-214

## Worked-Out Polonium-214 Decay Series

- $^{214}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{210}_{82}\mathrm{Pb}$
- $^{210}_{82}\mathrm{Pb} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\gamma + {}^{210}_{83}\mathrm{Bi}$
- 1. $^{210}_{83}\mathrm{Bi} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma + {}^{206}_{81}\mathrm{Tl}\ (\alpha)$
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## Conclusion

You can observe that $\alpha$ decay results in a different isotope than $\beta$ decay. That's why $\alpha$ and $\beta$ radiation can never occur at the same time.

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# WELKOM

Kom rustig binnen en ga zitten

Leg je spullen voor deze les op tafel

# Radioactivity: Learning Goals for Today

## Learning Goals

- I can calculate and apply the half-life of an isotope
- I can explain why half-life is related to the radioactivity of an element
- I can distinguish misconceptions from reality
- I can explain how to handle radioactive radiation as safely as possible
- I can explain what ionizing and penetrating power is, and how to handle it safely

# Half-Life: Definition

## Definition

Every isotope has its own half-life. The half-life indicates how long it takes for half of the total number of atomic nuclei of the isotope to decay.

## Example in Percentages

$100\% \rightarrow 50\% \rightarrow 25\% \rightarrow 12.5\% \rightarrow ...\%$. Half-life literally means dividing by 2

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# Half-Life: In Graph Form

## Prior Knowledge So Far

An element can be radioactive. This means that the number of neutrons is different compared to when the element is stable. This isotope has its own half-life. The atomic nucleus of an isotope is called a radioactive particle. After one half-life, the number of radioactive particles decreases by half — in other words, the number of radioactive isotopes decreases. You can look this up in the isotope table.

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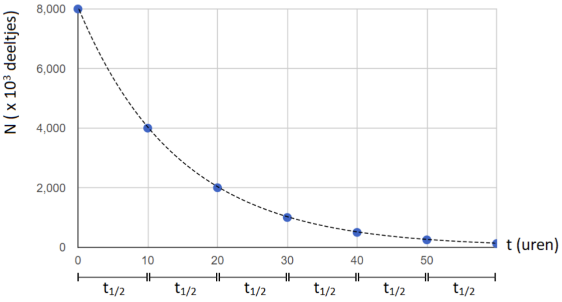


Figure: Half-life of radioactive particles

# Half-Life: Formula for Half-Life

## Important

It is important to look at how long it takes for the total number of atomic nuclei in a radioactive isotope to be halved, and how many times this can occur over time.

$$t = t_{1/2} * n \tag{1}$$

## Where:

- $t$ is the time needed for the number of halvings (in seconds)
- $t_{1/2}$ is the half-life of the isotope (in seconds)
- $n$ is the number of halvings

# Radiation Risk and Medical Applications

## Clarifying Misconceptions

- There are many misconceptions about radioactivity. Radioactive substances are often seen as dangerous and scary. While this is partly true, it's not always as frightening as portrayed in movies.
- It's important that when someone makes a claim about radiation or radioactivity, you always do your own research.

## Which of these three statements are true?

- The new 5G network for Wi-Fi emits radiation that causes COVID-19.
- Radiation can damage reproductive organs. This may reduce the potency of sperm cells and eggs.
- Radiation exposure can be harmful to unborn babies if the mother comes into contact with radioactive sources.

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# Radiation Risk

## Dangerous?

You are exposed to radiation and radioactive sources daily. Your body is used to small amounts. However, long-term exposure to a strong radioactive source can be harmful. These effects can also take time to appear.

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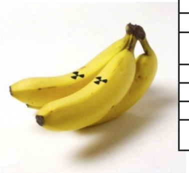
You are exposed to radiation and radioactive sources daily. Your body is used to small amounts. However, long-term exposure to a strong radioactive source can be harmful. These effects can also take time to appear.

### Banana Equivalent Dose

Bananas are a natural source of radioactive isotopes.

Eating one banana = 1 BED = 0.1 μSv = 0.01 mrem



| Number of bananas | Equivalent exposure |
|---|---|
| 100,000,000 | Fatal dose (death within 2 weeks) |
| 20,000,000 | Typical targeted dose used in radiotherapy (one session) |
| 70,000 | Chest CT scan |
| 20,000 | Mammogram (single exposure) |
| 200 - 1000 | Chest X-ray |
| 700 | Living in a stone, brick or concrete building for one year |
| 400 | Flight from London to New York |
| 100 | Average daily background dose |
| 50 | Dental X-ray |
| 1 - 100 | Yearly dose from living near a nuclear power station |

Figure: Radioactivity of a banana compared to ...

# Radiation Risk

## Background Radiation

This is the radiation you are exposed to every day. It passes through your body almost constantly. The largest source of daily background radiation is concrete.

## Geiger-Müller Counter

This device can measure the number of radioactive particles, and therefore the radioactivity of a source. It works for all types of radiation.

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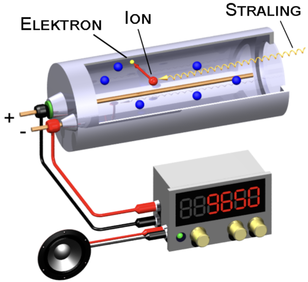

# Radiation Risk: Ionizing Power

## Ionization

When radiation with enough **kinetic energy** exits an atomic nucleus, it can **ionize** other atoms — meaning electrons are pulled out of the atom. The extent to which this happens is called **ionizing power**. The higher the ionizing power, the more dangerous it is.

## Possible Effects

- If electrons leave the atom, protons may also leave the nucleus, changing the atom into a different element.
- It can damage DNA, which may lead to tumor growth.

## 2 Forms of Contact

- **Irradiation**: Radiation from a source outside the body. You can move away from the source, making it less harmful.
- **Contamination**: Radiation from a source inside the body. You cannot escape from it, so it is more dangerous than irradiation.

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# Radiation Risk: Penetrating Power

## Definition of Penetrating Power

The extent to which radiation can pass through objects.

## On a Scale

- $\alpha$-radiation has the **lowest** penetrating power and is therefore the most dangerous if inside the body.
- $\beta$-radiation has **moderate** penetrating power and sits in the middle of the danger scale.
- $\gamma$-radiation has the **highest** penetrating power and is the least dangerous externally — but can still be harmful.

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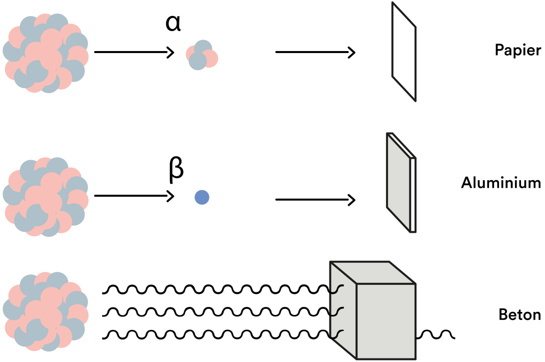


Figure: Penetrating power of different radiation types

# Radiation Risk: Check Questions

## Questions

- Why is half-life related to the radioactivity of an element?
- How can I recognize and investigate misconceptions?
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