

Evidence and Effects of Ionizing Radiation

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Everybody is constantly exposed to small amounts of radioactive, and thus ionizing radiation. Some energy-rich radiation reaches Earth from space, slowed down by the atmosphere, but naturally radioactive substances exist here as well. In the world of medicine, radiation is used in many forms of therapy, such as X-ray exams at the dentist's office, a suspected broken bone or mammography.



Here you will find the first section of the article concerning [Ionizing Radiation and Radioactivity](#).

Mass-energy equivalence

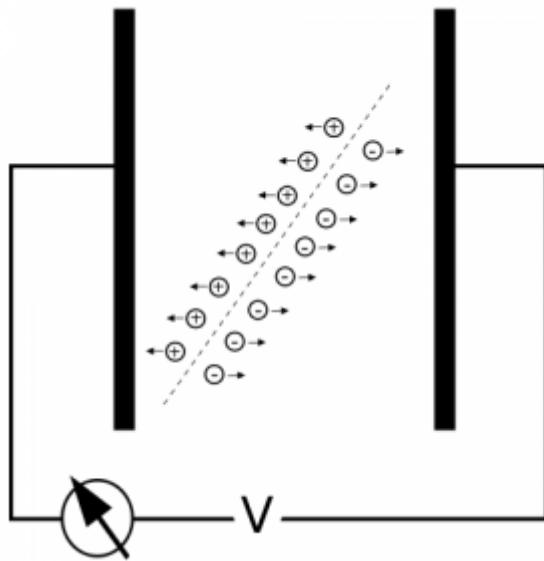
As early as 1905, long before the discovery of nuclear energy, the German physicist Albert Einstein proposed his theory of relativity demonstrating that **mass and energy are 2 manifestations of the same phenomenon**. According to his formula $E = m \cdot c^2$, the energy of 24 billion kilowatt-hours accounts for a mass of 1 kilogram. This massive energy is stored in atomic nuclei.

The acquisition of atomic energy is thus nothing more than converting some of the mass within the nuclei into energy. This simple logic formed the foundation of radiation.

Evidence of radiation

Radioactivity can be recognized by its diverse effects. For instance, radiation emitted by radioactive substances **blackens a light-sensitive photographic plate**. Radiation causes **flashes of light** in fluorescent materials, which is only visible with a **spinhariscope** in complete darkness.

Verification devices



[Image](#): Ionization chamber (sketch). By Michael Schönlitzer, [License](#): CC BY 2.5

Ionization chambers: The ions created between the 2 electrodes via impact ionization are accelerated by potential, which then enters the inner filament where a current pulse is visible. However, a measurable current pulse only occurs as a result of multiple incidental alpha particles or correspondingly high radiation.

The Geiger-Müller counter: The Geiger-Müller counter is an ionization chamber that operates at very high voltage levels. Any incidental particle induces a measurable current pulse. The charge carriers created by impact ionization are heavily accelerated by the strong electrical field and release an avalanche of additional charge carriers.

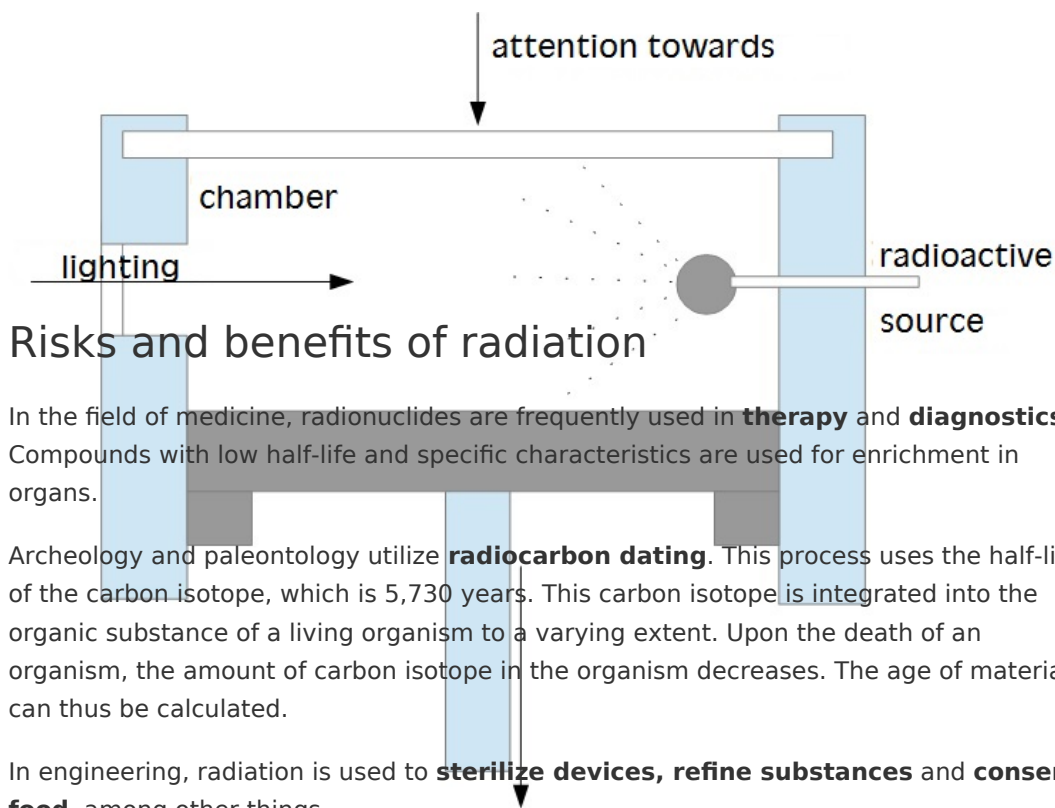
The impinging particles lead to a brief discharge pulse that can be enhanced and measured. These pulses are also audible in the form of crackling.

Pulse rate = Number of pulses / time

The pulse rate depends on the **radioactivity**, the **distance between the source of radiation and the counter** and the **design of the counter**.

The scintillation counter: The impinging radiation in a scintillation counter triggers the emission of light flashes by specific luminescent materials. These flashes are observed and counted upon magnification. The electrons emitted are then enhanced in secondary electron multipliers. This method uses the most sensitive and efficient radiation measurement device to detect radioactive materials.

The Wilson chamber: In a Wilson chamber, the air is oversaturated with water vapor. The ions created to serve as condensation nuclei upon which water condenses. The resulting condenser streaks reveal the process of radiation or the particle trajectory.



Risks and benefits of radiation

In the field of medicine, radionuclides are frequently used in **therapy** and **diagnostics**. Compounds with low half-life and specific characteristics are used for enrichment in organs.

Archeology and paleontology utilize **radiocarbon dating**. This process uses the half-life of the carbon isotope, which is 5,730 years. This carbon isotope is integrated into the organic substance of a living organism to a varying extent. Upon the death of an organism, the amount of carbon isotope in the organism decreases. The age of materials can thus be calculated.

In engineering, radiation is used to **sterilize devices**, **refine substances** and **conserve food**, among other things.

The human body is influenced by **transient exposure to higher and continuously decreasing radiation**. **Internal radiation** is defined as the radiation emitted by radioactive substances that enter the body via food intake and respiration. Radioactive materials are distributed throughout the body or are stored in specific organs. Iodine, for example, is stored in the thyroid gland, strontium in the bone and radon in the lungs.

External radiation is defined as the penetration of radiation into the body. Both internal and external radiation is harmful, as ionization leads to **chemical alterations** in living cells, and thus triggering potential **changes in the genetic makeup** of the cells.

The effects of ionizing radiation on humans **depend** on the **type, energy, duration** and **temporal distribution of the radiation** as well as the **radiosensitivity** of the specific organ.

Heavy exposure to radiation leads to **radiation sickness** and direct **death from radiation**. Weak exposure to radiation results in long-term damage such as **cancer**. Deformities and miscarriage may also occur.

Because of the great danger of ionizing radiation of any sort, guidelines have been set by legislation. The maximum permitted biological doses are set:

- **For individuals occupationally exposed to radiation**, the maximum permitted the biological dose is 0.5 sievert/year.
- **For individuals who only occasionally come into contact with ionizing radiation**, 1/10 of the value.

Decay chains

A radioactive nucleus usually forms again upon the decay of another radioactive nucleus. Natural decay chains form because the **decay products are similarly radioactive**. These decay chains lead to **stable lead isotopes** that do not decay further. In addition to decay chains, many other forms of natural radioactive decay exist.

Example of a naturally occurring decay chain: Uranium-radium chain

- Starting nucleus: ${}_{92}^{238}\text{U}$
- Stable end nucleus: ${}_{82}^{206}\text{Pb}$

Origin of natural radioactivity

A low level of radiation emitted by radioactive substances is ubiquitous in nature. This is referred to as the so-called **null effect**, which is based on 2 types of constant radiation:

1. **Cosmic radiation**: radiation from space
2. **Terrestrial radiation**: radiation from rock and construction materials

Biological dose

The biological dose is a **measure of the biological effect** of a form of radiation with equal energy dose.

$$\text{Biological dose} = \text{energy dose} * \text{factor of movement}$$

Sievert is the unit of biological dose. One sievert is equal to 1 joule per kilogram.

Factors affecting movement q in Sv/Gy:

γ -radiation: 1

β - and X-ray radiation: 1

α -radiation: 10

Neutrons: 5 to 8

Rapid protons: 10

Artificial radioactivity

Based on the model of natural radioactivity, scientists have always attempted to convert an atom of 1 specific element into an atom of a different element by bombarding the nucleus with light particles, such as protons, deuterons, neutrons, and helium nuclei. However, the nucleus is difficult to hit and the forces holding the nucleus together are very strong.

In 1919, the English physicist Rutherford successfully converted individual nitrogen atoms into oxygen atoms by bombarding with alpha rays in the **Wilson chamber**.

If the trails of the alpha particles in the Wilson chamber are smooth and have no kinks, then no nitrogen nucleus has been struck. If the alpha particle strikes a nucleus, the trail of the alpha particle forks off, which occurs only once in every 45,000 trails.

When branching off, the short **thick trail** shows the **path of the newly formed oxygen nucleus**, and the **long trail** indicates the **path of the ejected proton**.

Rutherford converted another 12 elements using similar experiments. The energy of alpha particles is not sufficient to break down heavy nuclei. To do so, particles, such as protons and deuterons are needed to raise to another level of energy by **particle accelerators**.

The law of absorption

Nearly all applications, except for analytics, are based on various types of radiation absorption.

The degree of absorption is conveyed by radiographic film or suitable detectors. Factors underlying the absorption of radiation, especially for radioactive rays, include:

- Diameter D of the screened layers
- Texture of the layers
- Extent of the radiation energy
- Type of radiation.

Attenuation of radiation, especially X-ray radiation, occurs via **ionization** (photo effect) or scattering processes.

N.B. The Law of Absorption states that gamma radiation is exponentially weakened via absorption by a material placed between the radioactive source and the recipient.

Safety measures for X-ray equipment in medicine

The most important safety measure for lowering patients' exposure to radiation during X-ray treatment is **keeping them at a greater distance** from the source of radiation. This precaution not only applies to the focusing distance of the tubes but also the distance from the useful beam field in the air and the patient's volume in the useful beam, which emits intense stray radiation.

The decrease in intensity with increased distance is explained by the **more frequent interaction between the photons in the air**. The resulting weakening, however, is generally insignificant and only amounts to 5% of the useful radiation in the air for 100 kV tube voltage and 2 mm Al total filtration, for example.

The law of distance: The loss of radiation intensity from a roughly point-shaped source is inversely correlated with the square of the distance from the emitting source, as the emitted radioactive particles are distributed homogeneously onto a surface at an increasing distance.

Lead equivalent

The lead equivalent of a substance is the **thickness of a lead layer that has the same attenuating effect** as the observed material in the actual thickness.

Example: A 100 kV of X-ray radiation weakens a 12-cm-thick brick wall as much as it weakens 1 mm of lead. This brick wall thus has a lead equivalent of 1 mm.

Lead rubber is also frequently used to protect against radiation. The protective effect depends on the lead equivalent and radiation quality (useful or stray radiation, tube voltage, filtration). Lead rubber attenuates X-ray radiation down to a few percents.

Effect of ionizing radiation

Ionizing radiation has an effect on cells affected by radiation. The respective effect can vary greatly and may also be fatal in some individuals depending on the intensity and type of radiation.

The following parameters must be defined in advance to describe the effect of ionizing radiation.

Energy dose

The energy dose describes a **quantity of energy absorbed by an object** (e.g., tissue) exposed to radiation. It is primarily dependent on the radiation intensity of the ionizing radiation and tissue absorption. The unit of the energy dose is the **gray [Gy]**.

Ion dose

The ion dose is defined as the amount that provides radiation strength. It is defined by the following formula:

$$\text{Ion dose} = \frac{\text{released charge}}{\text{mass of the radiated substance}}$$

The ion dose is expressed in Coulomb/kilogram [C/kg]. (See article: [Physics for Medical Students - Ionizing Radiation and Radioactivity](#))

Equivalent dose

The equivalent dose **defines the strength or intensity of the biological effect** of a specific dose of radiation. The equivalent dose is expressed in **sieverts [Sv]**.

Biological effect

Molecules are destroyed by ionizing radiation. However, the damage caused solely by momentary radiation and destruction is relatively low. The damage caused by the subsequent chemical reactions in the body is much greater.

The various forms of biological effect are:

- **Short-term exposure:**

From 0.2 to 1 Sv: Exposure to 0.2 to 1 Sv may result in so-called **radiation sickness**. The symptoms vary and may cause minor long-term damage or even death. The process depends on the dose of radiation.

From 4 Sv onward: In 50% of the cases, exposure to a dose of 4 Sv leads to death.

From 7 Sv onward: Exposure to a dosage of 7 Sv is always fatal, due to weakened immune system, burns, changes in DNA or even mutations.

- **Intermediate equivalent doses:**

Mid-term equivalent doses equate to approx. 0.1 Sv, which is the dose that a person aged 76 years has received through cosmic/natural radiation.

- **Lower equivalent doses:**

Lower doses include cosmic and terrestrial radiation (natural radiation).

The most dangerous type of radiation is **alpha radiation**. Its typically very short-range ensures that the risk of harm is very low, and exposure to alpha radiation can be screened using a simple sheet of paper. Direct tissue contact with an object emitting alpha rays, for instance, via inhalation of radioactive dust or swallowing such objects is dangerous.

References

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