All radioactive particles and waves, from the entire electromagnetic spectrum, to alpha, beta, and gamma particles, possess the ability to eject electrons from atoms and molecules to create ions.

**Introduction**

There are many types of radiation, but the two most common are electromagnetic radiation and ionizing radiation. Ionizing radiation refers to radioactive particles, such as alpha and beta particles, or electromagnetic waves, such as gamma or ultraviolet rays, which have sufficient energy to detach electrons off of atoms to create ions, hence the name “ionizing radiations.” Electromagnetic radiation, which sometimes can be placed as a subcategory of ionizing radiation, deals with waves or photons from the electromagnetic spectrum. Unlike ionizing radiation, electromagnetic radiation deals with electric and magnetic field oscillations such as with X-rays, radio waves, or gamma rays.

Radioactive decay of atoms creates three radioactive particles, alpha, beta, and gamma. Of the three, alpha particles are known to have the most “ionizing power,” a term describing the number of ion pairs produced per centimeter through a material, followed by beta, then gamma. However, a common misconception is that the higher ionizing power a particle has, the more damaging it is to matter. Electromagnetic waves can also ionize, hence the reason electromagnetic radiation is often placed as part of ionizing radiation.

**Primary Electrons and Secondary Ionization**

The main effect radiation has on matter is its ability to ionize atoms to become ions, a phenomenon known as ionization, which is very similar to the photoelectric effect. Radioactive particles or electromagnetic waves with sufficient energy collide with electrons on the atom to knock electrons off the atom. The electron ejected off the atom is called the primary electron. When the primary electrons hold energy, a particle ejecting the primary electron may cause it to eject another electron, either on their own atom or on another atom. This is known as secondary ionization.

However, ionization does not have to completely eject an electron off the atom. It can raise the energy of the electron instead, raising the electron energy to a higher energy state. When the electron reverts to its normal energy level, it emits energy in the form of radiation, usually in the forms of ultraviolet rays or radio waves.

**Production of X-Rays and Electromagnetic Radiation**

Radiation can be both natural and synthetic. Artificially induced radioactivity utilizes primary and secondary ionizations in order to emit X-rays. Most X-ray emission is due to the bombardment of electrons on a metal target. If the electrons have sufficient energy, the inner shell electrons of the atom fall out, and higher-leveled electrons fill in the hole left by the previous electrons. By doing so, packets of energy are released in the forms of X-ray photons. Other forms of ionizing radiation can produce UV and gamma rays in a similar manner. This type of radiation is known as “ionizing radiations.”

All charged particles and rays have the ability to be radioactive; however, not all rays and particles have the energy per photon to ionize atoms. This is known as “non-ionizing radiation.” Non-ionizing radiation has enough energy to excite electrons to move to a higher state, releasing photons of electromagnetic radiation such as visible light, near ultraviolet,
Radio waves, microwaves, and neutron radiation (an important application in fission and fusion) all fall under non-ionizing radiation, as their respective energies are too low to ionize atoms.

Penetration and Radiation

Radiation, besides having the ability to ionize matter, can also penetrate through matter. How far they penetrate is dependent on the different types of radiation and their ionizing power. Since alpha particles are high in ionizing power, it is difficult for them to penetrate matter thoroughly. This is because alpha particles are likely to ionize the first thing they come into contact with; thus, they hold a small range of penetrating power. The inverse relation between ionizing power and penetrating power can be applied to beta and gamma rays as well. Alpha particles can be stopped with a sheet of paper or a layer of clothing, while beta particles can penetrate up to a fraction of an inch in solids and liquids and several feet in air. Gamma rays, which are electrically neutral and have small ionizing power, are not slowed by collisions with materials and can only be stopped with heavy metals such as lead.

Effects of Radiation on Living Matter

Prolonged exposure to radiation often has detrimental effects on living matter. This is due to radiation’s ionizing ability, which can damage the internal functioning of cells. Radiation either ionizes or excites atoms or molecules in living cells, leading to the dissociation of molecules within an organism. The most destructive effect radiation has on living matter is ionizing radiation on DNA. Damage to DNA can cause cellular death, mutagenesis (the process by which genetic information is modified by radiation or chemicals), and genetic transformation. Effects from exposure to radiation include
leukemia, birth defects, and many forms of cancer.

Most external radiation is absorbed by the environment; for example, most ultraviolet radiation is absorbed by the ozone layer, preventing deadly levels of ultraviolet radiation to come in contact with the surface of the earth. Sunburn is an effect of UV radiation damaging skin cells, and prolonged exposure to UV radiation can cause genetic information in skin cells to mutate, leading to skin cancer.

Alpha, beta, and gamma rays also cause damage to living matter, in varying degrees. Alpha particles have a very small absorption range, and thus are usually not harmful to life, unless ingested, due to its high ionizing power. Beta particles are also damaging to DNA, and therefore are often used in radiation therapy to mutate and kill cancer cells. Gamma rays are often considered the most dangerous type of radiation to living matter. Unlike alpha and beta particles, which are charged particles, gamma rays are instead forms of energy. They have large penetrating range and can diffuse through many cells before dissipating, causing widespread damage such as radiation sickness. Because gamma rays have such high penetrating power and can damage living cells to a great extent, they are often used in irradiation, a process used to kill living organisms.

**Radiation Dosage and Decay**

There are several methods to measure radiation; hence, there are several radiation units based on different radiation factors. Radiation units can measure radioactive decay, absorbed dosage, and human absorbed doses. Bq and Ci measure radioactive decay, while Gy and Rad measures absorbed doses. Sv and Rem measure absorbed doses in Gy and Rad equivalents. Rem takes into account different radiation types and the speed of particles. Below is a chart to help organize the different units:

### Units for Radioactive Decay

<table>
<thead>
<tr>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Becquerel, Bq</td>
<td>Measured in s⁻¹, as disintegration per second</td>
</tr>
<tr>
<td>Curie, Ci</td>
<td>Measured as amount of decay at the same rate as 1 gram of radium</td>
</tr>
<tr>
<td></td>
<td>1 Ci = 3.70⋅10^{10} Bq</td>
</tr>
</tbody>
</table>

### Units for Absorbed Dose

<table>
<thead>
<tr>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray, Gy</td>
<td>1 Gy deposits 1 Joule of energy per kilogram of matter</td>
</tr>
<tr>
<td>Rad</td>
<td>1 rad = 0.01 Gy</td>
</tr>
</tbody>
</table>

### Equivalent Doses

<table>
<thead>
<tr>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sievert, Sv</td>
<td>1Sv= 100 rem</td>
</tr>
<tr>
<td>Rem</td>
<td>1 rem = 1 rad-Q</td>
</tr>
</tbody>
</table>
The most commonly used unit is the "rad," which stands for "radiation absorbed dose," and the "rem," which stands for "radiation equivalent for man." One rad corresponds to the absorption of 0.01 Joules of energy per kilogram of matter. Rem is the rad multiplied by the relative biological effectiveness, which is most often expressed as the variable "Q." The factor Q is used to take into account the different effects caused by different radiation.

### Concept Review Questions

1. Classify the following interactions that occur as either primary ionization, secondary ionization, or electron excitement.
   a. Photons are ejected from the atom.
   b. An electron from a nearby atom is ejected, knocking out an electron from a neighboring atom.
   c. Electrons are ejected from the atom.
2. Describe the difference between ionizing and non-ionizing radiation.
3. Explain why radiation has such a harmful effect on living matter.
4. Consider modern microwave oven used in kitchens. Are the microwaves ejected to heat water and food harmful to the human body?
5. What is the Q in the calculation or REM?

### Answers

1. a. Electron excitement. An electron is excited to a higher energy level. When it falls, it releases a packet of energy in the form of a photon.
   b. Secondary ionization. The ejection of the second electron was caused by another electron, as opposed to another charged particle or radiating ray.
   c. Primary ionization. The electron was ejected by a charged particle or ray.
2. Ionizing radiation describes atoms becoming ionized to ions. During ionizing radiation, an electron is ejected off the atom, causing the atom to lose an electron and become ionized. Non-ionizing radiation is generally caused by excitation of electrons. When a particle or electromagnetic ray does not have sufficient energy to completely knock an electron off an atom, it can instead excite the electron to go to a higher energy level. When the electron falls, it emits photons of energy.
3. Radiation can ionize atoms, but it can also mutant molecules by ionizing atoms. It can affect the structure of a cell by debilitating organelles or other cellular functions, but its most damaging effect is on DNA. Radiation mutates DNA by ionizing base sequences, or by altering the backbone of DNA. DNA mutations arising from irradiation can cause cancer, or otherwise kill the cell.
4. Although there are many myths concerning microwave radiation, microwaves fall under "non-ionizing" radiation and hence does not cause any of the effects that ionizing radiation causes, such as cancer. A microwave oven is also designed to minimise microwaves escaping outside of the oven by using metal to absorb the microwaves. This is why the door of the microwave oven is not transparent; it is lined with strategically placed metal atoms for maximum absorbing efficiency.

5. Q is the constant that is used depending on what radioactive particle you are calculating. It is based on the type of particle and its effect on matter.

References


Contributions

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